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Introduction

Purpose of this report

This report documents the mathematical formulation, database description, and programming guide for the International Natural Gas Model (INGM). The documentation conforms to EIA standards manual 2002-26. The report lists and describes the modeling assumptions, computational methodology, and source code. This document serves multiple purposes. First, it is a reference document providing a detailed description for model analysts, users, and the public. Second, this report meets the legal requirement of the Energy Information Administration (EIA) to provide adequate documentation in support of its models (Public Law 93-275, section 57.b.1). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake model enhancements, data updates, and parameter refinements as future projects.

Model summary

The INGM is a tool that estimates natural gas production, demand, and international trade for 61 regions covering the globe. It combines estimates of natural gas reserves, natural gas resources and resource extraction costs, energy demand, and processing and transportation costs and capacity, and it uses these data to estimate future production, consumption, and prices of natural gas.

Model archival citation

This documentation refers to the International Natural Gas Model as archived for the International Energy Outlook 2011 (IEO 2011).

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Organization of this report

This document provides the mathematical formulation, database description, and programming guide for the International Natural Gas Model (INGM). The documentation conforms to EIA standards manual 2002-26.

The report is organized into this introduction, three additional chapters and five appendicies. Chapter 2 focuses on the model purpose including key objectives and model inputs and outputs. Chapter 3 discusses the model rationale including the theoretical approach and the fundamental assumptions used for the Annual Energy Outlook (AEO) 2011 and IEO 2011 model runs. Chapter 4 provides more detail into the model structure including the mathematical formulation of the linear program (LP) used to solve for the market equilibrium and key algorithms used to determine the model coefficients.

Appendix A provides the model cost and efficiency assumptions and Appendix B provides assumptions used for asset capacities including near term and longer term capacity constraints. Appendix C contains a description of the database used to store the input assumptions and output results including names of variables used in the mathematical descriptions. Appendix D provides a programmer's guide for the Visual Basic for Applications (VBA) code used to implement the model in Microsoft Access. Appendix E provides the list of references used in this documentation.

Model Purpose

Model objectives

Natural gas represents over twenty percent of global primary energy consumption and one of the fastest growing energy sources globally. As such, global production, consumption, and international trade of natural gas are key components of any forecast of national or international energy markets.

EIA developed the INGM to provide the following:

- A reasonably detailed outlook for global natural gas production including:
  - Detail by production source (conventional or unconventional)
  - Regional detail where it is critical to understanding international trade and constraints on production, consumption, or trade
- Detailed estimates of natural gas consumption and competing uses of natural gas including data by demand sector and for key regions
- Detailed estimates of international trade and regional prices including imports and exports of LNG to/from the U.S.

Model input and output

Inputs

The primary inputs to INGM include:

- Data describing natural gas resources
  - Primary data including
    - Reserves
    - Convnetional undiscovered/undeveloped resources, including
      - Field sizes
      - Well depths
      - Water depths
      - Onshore/Offshore
    - Unconventional in-place resource estimates
    - Resource extraction costs including drilling costs, facility costs, fixed and variable operation maintenance (O&M) costs
  - Secondary data
    - Resource supply curves based on the primary data
- Demand estimates
  - U.S. estimates from the National Energy Modelling System (NEMS)
  - Other estimates from the World Energy Projection System Plus (WEPS+)
  - Includes estimates of energy consumption for 5 demand sectors and 6 energy sources
  - Price elasticities by demand sector
- Transportation, processing, and energy conversion asset specifications including
  - Data for gas processing plants, liquefaction plants, regasification plants, LNG tankers, gas-to-liquid (GTL) plants, and pipelines

- o Existing asset capacities
- o Constraints on asset capacities in the near term and long term
- o Asset investment and O&M costs
- o Asset efficiencies including pipeline fuel use, energy losses in gas processing, liquefaction, regasification, and gas-to-liquid (GTL) plants

- LNG tanker routes including
    - o Length of round trips
    - o Time at port for loading and unloading

Outputs

The primary outputs of INGM include projections of:

- Natural gas production for five resource categories, by year and for 61 geographic aggregations covering the globe, henceforth referred to *as nodes*.
- Natural gas demand for seven demand sectors, 61 nodes, and three seasons: Winter, Summer, and Spring/Fall.
- Asset capacities for gas processing, liquefaction, regasification, GTLs, pipelines and tankers
- Asset utilization for gas processing, liquefaction, regasification, GTLs, pipelines and tankers
- Annual and seasonal wholesale natural gas prices by node and year

The natural gas production resource estimates are broken out into the following categories:

- Conventional onshore
- Conventional offshore
- Tight gas
- Shale gas
- Coal bed methane

The demand sectors include:

- Residential
- Commercial
- Industrial Feedstocks
- Industrial Cogeneration
- Other Industrial (does not include energy use in LNG plants)
- Transportation (not including pipeline fuel use)
- Electric Power Generation

Relationship of the INGM to other EIA models

The INGM uses information from EIA's World Energy Projections Plus (WEPS+) model and from the National Energy Modelling System (NEMS); it also provides information to WEPS+ and to the Natural Gas Transmission and Distribution Module (NGTDM) of NEMS.

The interface between the INGM and WEPS+ is in both directions with the INGM providing natural gas supply curves to WEPS+ and using demand estimates developed by WEPS+ in an iterative process. For a more detailed description of the interaction, the reader is referred to the WEPS+ Overview Documentation.

The INGM uses regional demand estimates from NEMS for the U.S., replacing the aggregated WEPS+ estimates. Additionally, the INGM provides NGTDM with estimates of LNG available to North America from the Atlantic and Pacific basins.

Model Rationale

Theoretical approach

The basic assumption behind the model structure is that future natural gas and LNG markets will behave competitively including among producers, energy transportation providers, consumers, providers of alternatives to natural gas (such as coal in the power generation sector) and converters of natural gas (such as to methanol or GTLs).

The model assumes that while contracts with pricing formulas related to crude oil or fuel oil prices will dominate LNG trade and pipeline supply from Russia to Europe, marginal supply and demand decisions will reflect the marginal costs based on supply, demand, and transport fundamentals as reflected in short-term nodal and seasonal market prices. In addition, while LNG contracts may constrain trade in the near term, the long term trends will predominantly reflect flexible markets where the LNG will flow to the demand locations that value the LNG the most. The model does not account for the impact of contractual flows or pricing.

Regions that currently show non-competitive characteristics or have internal constraints that will impact future markets are captured through min/max constraints on future key asset capacities for domestic use and possibly international trade. Max constraints on asset capacity provides hard limits on a region's ability to produce and export natural gas or LNG, while forcing in assets with min constraints makes these assets available for utilization at variable O&M costs.

Saudi Arabia, for example, is not permitted in INGM to build LNG or natural gas export facilities so as to reflect political decisions to keep the natural gas for domestic uses and economic growth.

The INGM uses a linear program (LP) to simulate the competitive global natural gas and LNG markets. The LP combines multiple activities at different locations and optimizes them to determine the market equilibrium for each year of the simulation.

The objective function is the variable optimized within the LP. General equilibrium theory predicts that gas prices will converge in each geographic node and year to those price values that maximize the cumulative discounted sum of producer and consumer surplus. This theory is the basic assumption of the INGM. In this model, we approximate this sum with the net discounted values below:

- Producer profits are represented as the marginal nodal price times resource quantity developed minus supply development and production cost. The producer costs used in the calculation of profits has in it a similar cost of capital as used in the discounting in the INGM but also includes government take. This means that the overall producer surplus is underestimated by the amount of the government take.
- Consumer profits are represented as the difference between the prices consumers are willing to pay minus the marginal nodal gas price, times the volume of gas the consumers are willing to consume at this price. These values are summed across all from the demand curves which are derived from the WEPS+ demand estimates using the WEPS+ prices and price elasticities by sector.

- Asset operator profits represent the discounted value of the output of the assets (e.g., LNG for liquefaction facility and dry gas delivered for a pipeline) minus the investment and operating costs including the cost of the gas input to the LNG facility or pipeline.

The model looks at the global natural gas market from production to consumption in 61 nodes, simulating activities for three seasons. The model includes endogenous decisions on capacity expansion and capacity utilization within capacity expansion constraints provided by the user. The specific activities modeled include:

- Finding and development of undiscovered gas resources
- Production of natural gas
- Gas processing
- Liquefaction
- Regasification
- Gas-to-Liquids conversion
- Pipeline transport of natural gas
- Tanker transport of LNG

The LP contains energy balance constraints for each fuel at each node and each year and season. The "duals" from the LP solution define the wholesale market prices reported by the INGM. Duals in this LP represent the marginal cost of the constraint and in this case define the instantaneous value of the energy in the season at the node.

The simulation can use either full perfect foresight or a rolling optimization. For a rolling optimization, the INGM will start in the first year (e.g., 2008) and provide a detailed annual simulation for a number of years (typically 11) and then group years after that with the simulation going out twenty-five or thirty years. After this optimization, the capacity decisions for the first five years are constrained to the solution value and the optimization is restarted five years later with detailed annual simulation for the same number of years as before and grouped after that.

For a run with full perfect foresight, the INGM will typically be run using single years through the end of the desired forecast range (2035) and then run using three year increments past the end of the desired forecast range for approximately 20 years in order to reduce any impact of end-of-forecast conditions that would otherwise lead to over or under building of capacity.

Fundamental assumptions

This section provides the assumptions and data sources used for different input parameters and constraints for capacity expansion in version 16zb of the INGM model. The section is organized by sector or area of the natural gas supply chain as defined in the model structure. The following sectors are included:

- Processing Assets
  a. Liquefaction
  b. Regasification
  c. GTL Plants
  d. Gas Processing

- LNG Shipping
  a. Tankers
  b. Ports
- Gas Pipelines
- Gas Storage
- Natural Gas Demand
- Natural Gas Supply
- Common Economic Parameters

There are two main types of input required for infrastructure assets (processing, shipping, pipelines and storage): capacity and costs. The capacity for each type of asset includes the operational capacity as of the base year (2008) and the minimum and maximum limits on possible capacity expansion for the remaining time period. For the near-term forecast (2008-2015), the minimum and maximum limits are arrived at by summing up capacities of projects already under construction and those judged to have a high likelihood of becoming operational. Most of these projects are in advanced stages of construction or planning. For the mid-term (2016-2018), maximum limits are computed by summing up capacities of proposed projects that could reasonably become operational within this time period. For the mid-term, minimums are generally not set, reflecting the uncertain nature of proposed projects, and giving the model the ability to determine the optimum capacity expansion within the maximum limits set. For most nodes, the limits on expansion after 2018 are relaxed so that the model can determine the optimum capacity expansion based on investment decisions. The costs include investment required to build new facilities and operating and maintenance costs for existing as well as future facilities. All costs in the model are in real 2006 dollars.

Common data structure

Some common elements in the cost structure and the capacity expansion are applicable to all types of assets. Please note that gas volume inputs to the model are measured in petajoules per day (PJ/day) of output. Fixed costs are measured in millions of dollars ($MM) or millions of dollars per year ($MM/y), while variable costs are measured in dollars per gigajoule ($/GJ). 1 Bcf/d is equivalent to 1.083 PJ/d and $1/Mcf is equivalent to 0.923 $/GJ for processed gas with an energy content of 1.025 mmbtu/mcf.

Common Cost Structure: The common elements for the cost structure are as follows:

1. **Capacity Increment**: This defines the unit size of expansion. For example, the capacity increment for gas pipelines is 1.083 PJ/d (1 Bcf/d). The investment costs provided relate directly to the facility expansion for 1 Bcf/d pipelines, i.e., the capacity increment.
2. **Number of years required for planning and approvals (Num_Yrs_PlnAppr):** This is the number of years between project announcement and start of construction. It includes time for planning, permitting and feasibility studies. Pipelines and regasification plants are assumed to require 3 years for planning and approval. Gas processing plants, GTL plants, liquefaction plants and gas storage assets are assumed to require 3 years for planning and approval.
3. **Annual Planning and Approval costs (PlanAppr_Cst):** This is the total amount of money required for the planning and approval stage of the project divided by the number of years required for approval. The units are millions of dollars per year. In the model, this is assumed to be $500,000/ year for most assets.

4. **Number of years required for construction (Num_Yrs_Inv):** This is the number of years required for construction. In the model, the default assumption for this category is 3 years. The exceptions are small LNG carriers (2 years).
5. **Investment cost in year (Investment_Cost):** This is the total amount of investment required for construction divided by the number of years required for construction. The units are million dollars per year.
6. **Maximum operating life of asset (Maximum_Life):** The physical life of an asset before retirement. The current version of the model assumes that all assets have 100 years of physical life. This means that assets will not retire during the model time frame.
7. **Annual fixed operating and maintenance costs (Fixed_OaM_Cost):** This is the fixed annual operating cost of an asset including taxes, insurance, labor costs etc. This does not include the capital recovery or depreciation cost, which is accounted for separately by the model using the discount rates. The units are millions of dollars per year for an asset of the size specified by the capacity increment.
8. **Variable Operating and Maintenance Cost (Variable_OaM_Cost):** This is the variable operating and maintenance cost of running an asset and is specified in dollars per gigajoule. It primarily consists of the non-fuel costs associated with operations since fuel costs are captured as part of the fuel use for asset (e.g., pipelines and storage) or in the input and output energy specifications (e.g., processing assets). In one case, tankers, this number includes the cost of the fuel used to run the tankers.
9. **Cost of retiring the asset (Retirement_Cost):** This represents the cost of retiring an asset and is specified in millions of dollars for an asset of the size specified by the capacity increment. The default assumption used in the model is 0.1 $MM.

Common structure for the asset capacity specification: Once the capacity in the base year is specified, lower and upper bounds on the capacity for the future years are computed by adding the minimum and maximum volume of capacity expansion that can occur. As explained earlier, projects already under construction or in advanced stages of planning are assumed to definitely become operational and their capacities are used as the minimum capacity expansion for that node. The minimum capacity limits are usually set for projects becoming operational in the 2008-2015 timeframe. Once an expansion is announced, the asset will go through the planning and construction phases based on the number of years specified (Num_Yrs_PlnAppr, Num_Yrs_Inv). The capacity expansion from year 2008 (base year) till 2015 is constrained based on the announcements already made in the media. From 2016 onwards, the minimum capacity expansion is generally set at zero. From 2016 to 2018 maximum capacity expansions are set based on proposed projects, and beyond 2018 the maximums are set at 99999 PJ/d (except where we have limited it to keep the model from building capacities to unrealistic levels), an artificially high number that indicates that the model can build new capacity as required based on investment decisions. The following are elements of the common structure used to specify asset capacities in the model:

1. **Node Name (NodeId):** Node for which the capacity is specified.
2. **Asset Id (AssetId):** The asset within the node for which the capacity is specified (e.g. GTL Plant, Liquefaction facility etc.)

3. **Start Year (SYear):** First year that following data apply for (e.g., 2008)
4. **Last Year (EYear):** Last year that following data apply for (e.g., 2008)
5. **Minimum Capacity (Min_Capacity):** Minimum capacity expansion allowed in the region. The units are PJ/day output of primary fuel.
6. **Maximum Capacity (Max_Capacity):** Maximum capacity expansion allowed in the region. The units are PJ/day output of primary fuel.

The next section gives the numeric values for the cost and capacity parameters used in the model and the underlying assumptions/sources.

Model Assumptions for Individual Asset Categories

1. Processing assets

Asset capacity

The capacity assumptions for all liquefaction, regasification, and GTL plants are provided in Appendix B, Table B.1. The gas processing capacity is assumed to be unconstrained.

Asset Costs and Energy Conversion Specifications

Table A.1 and Table A.2 in Appendix A provides the specifications for the different processing [1, 2, 3], liquefaction [4, 5, 6], regasification [4, 5, 7], and GTL plants [8, 9].

Note that industry estimates put the overall energy efficiency for the GTL process at about 60% (i.e., for 100 Btu of natural gas in, you get about 60 Btu of hydrocarbon product out) [10]. In newer plants, it appears to require about 10 MMBtu of gas to produce one barrel of GTL product. Energy efficiency is more consistently cited at about 65%, .i.e., the energy content of the GTL product represents only 65% of what was contained in the input gas [11].

2. LNG shipping

Tanker capacity

Table B.2 in Appendix B provides the assumed LNG shipping capacity. A database of existing LNG carriers and those on order was built using the data available on the Maritime Business Strategies, LLC website [12]. Existing ships have a capacity of about 135,000 cu.m with a few ships below the 100,000 cu.m size. The ships that are on order range from 135,000 cu.m to 270,000 cu.m (ordered by RasGas, Qatar) in capacity. Based on the data, four ship categories were defined: Small (<100,000 cu. m. LNG), Medium (100,000-160,000), Large (160,000-200,000) and Ultra-Large (>200,000). Next, the delivery date for each ship was used to determine if the ship was an existing ship, or an ordered ship. Since the model base year is 2008, all ships delivered after 2008 have been moved to the "ordered" category which is essentially the number of LNG ships forecasted. The forecast is limited to 2008-2010 because that is the extent of the Colton database. For 2008 to 2010, ICF forecasted for each year the number of ships in each size class added to the LNG fleet. Between 2008 and 2010, ICF assumed no growth in the number of ships beyond those listed as ordered in the Maritime Business Strategies, LLC database. After 2010, ICF allowed the model to decide on new ship construction based on requirements. The short term forecast was validated by comparing against predictions by other sources. One such source was the website of Mitsui O.S.K. Lines that owns nearly one-quarter of the world LNG shipping fleet [13]. As of 12/1/2006, the website indicated that there will be a total of 344 LNG ships by 2010. This compares well with the 335 ships that we have in the INGM database based on data from Maritime Business Strategies, LLC.

The majority of ships that are on order fall into the medium capacity category of 100,000-160,000 cu. m. LNG. Some ships that are scheduled to be delivered after 2006 will have very large capacities not seen in the existing fleet.

Tanker costs

The tanker cost and other specifications are provided in Table A.3 of Appendix A.

The Maritime Business Strategies, LLC database also has values for the construction cost of most ships on order and we estimated the tanker costs using this data. The medium and large tanker costs are set consistent with the average costs for ships of that size and costs for the small and ultra-large tankers are estimated using a linear extrapolation from these values[1] .

Average ship speed

Based on the fleet data, the design speed for new LNG carriers is approximately 19.5 knots. The average ship speed on port to port voyages was assumed to be 80% of the design speed to account for slow speeds due to port manoeuvring and bad weather. Other related data sources for LNG carriers are [15, 5, 12].

Ports and routes

Each node was assigned a port city that was used to calculate distances between ports. Port cities were selected based on existing, planned or proposed LNG infrastructure or based on ICF assessment of the most logical LNG port for a given node.

Each node was assigned one port to be used in estimating distance between nodes. Port distances were taken from a distance calculator 'Sea Distances - Voyage Calculator' [16]. For links where the distance could be reduced by using the Suez Canal, it was assumed that the ship would pass through it, and the reduced distance was estimated. The number of days required by tankers to complete a one-way journey on each link was estimated by dividing the total distance by an average tanker speed of 80% of 19.5 knots for all tanker categories.

ICF assessed a matrix of exporting and importing nodes to determine the most likely routes for LNG trade. ICF used knowledge of LNG market supply and demand to populate the model with likely LNG trade routes rather than all possible node to node connections.

The utilization of either the Panama or Suez Canal was determined by the *Sea Distance and Voyage Calculator*. A ship that travels through one of these canals incurs tolls not paid by other LNG ships. Therefore, on any route through a canal an additional cost had to be calculated and applied to the total shipping cost for that route.[2]

The Suez Canal cost was calculated using the *Suez* Toll Calculator [17], which requires inputs to determine the tolls for an LNG tanker. The following LNG tanker assumptions were made to calculate the total canal charge: capacity- 160,000 cubic meters, Suez specific tonnage- 105,000 dwt, gross laden part and ballast legs of the trip and added together to determine a total roundtrip canal cost. LNG tankers going through the Suez Canal receive a 35% rebate, which was applied to the total cost. The final total cost after the rebate was divided by the volume of gas aboard the ship to arrive at the cost in $/GJ.

The Panama Canal did not have a toll calculator similar to the Suez toll calculator. To estimate cost, actual 2005 Panama Canal traffic data was used [18]. As for the Suez tolls, both laden and ballast tolls were calculated. The total number of laden trips through the canal was divided by the total tolls

[1] LNG carrier Cost data was obtained from [12]. GDP Deflator was estimated from Bureau of Economic Analysis data Current-Dollar and "Real" Gross Domestic Product [14].
[2] The canal tolls have not yet been implemented.

collected to calculate an average toll per ship. The same was done for ballast trips. Average laden ship tolls were added to average ballast ship tolls for a total Panama Canal toll cost. The final total cost was divided by the volume of gas aboard the ship to arrive at the cost in $/GJ.

3. Gas pipelines

Pipeline capacity

Appendix B, Table B.3 shows the pipeline capacity constraints assumed for the INGM.

ICF forecasted worldwide pipeline capacity based on numerous sources of data. The 2008 base year data for North American capacity as well as other international pipeline capacity was supplied by EIA databases. Each pipeline record in the EIA databases had the following properties listed: start point, end point, pipeline name, status, start year, and capacity.

EIA assigned each pipeline in their database a status: operating, under construction, firm, planned, and potential. All five of these statuses were included in the INGM pipeline database. The status represents the likelihood that the pipeline will at some point be completed and additional capacity added. The pipelines with a status of operating were included in the base capacity estimate. The scale for likelihood of completion went from “under construction” (the most likely) to “potential” (the least likely).

Existing gas pipeline capacity data were collected for the U.S.A [19], Europe [20], Russia [21], as well as for other regions [22]. Capacity expansion data was obtained from EIA [23, 24] and ICF’s internal data sources.

Pipeline costs and specifications

Appendix A, Table A.4 shows the assumptions for the pipeline asset costs. The standard unit of pipeline expansion (capacity increment) was assumed to be 1 Bcf/d. The cost of expansion between different nodes is estimated using the distance between two representative locations in those nodes. Pipeline investment costs were calculated using data from an Oil & Gas Journal survey, which reported the actual total costs and distances for fifteen pipelines built in the United States in 2005. ICF used pipeline diameter to calculate the daily pipeline flow rate. ICF then divided the total reported cost by the flow rate to calculate the average dollars per mile per Bcf of gas flow per day for the fifteen pipelines in the survey. This average, $2.8 million per mile per Bcf/d[3] , was applied to each pipeline link represented in the INGM to calculate total investment costs based on distance. Because the number of years for investment (3 years) and the unit of expansion (1 Bcf/d) are constants, total pipeline investment cost for different links varies based solely on distance.

Variable operating and maintenance pipeline costs are based on fuel use and gas price consistent with [25, 26]. ICF used fuel use data for an upcoming pipeline being built from the Rocky Mountains to Ohio as the default for all pipeline links. The ‘Rockies Express’ pipeline project fuel usage percentage is equivalent to 2.59% per 1000 miles of pipeline length. Variable O&M costs were then calculated by multiplying the fuel use by an ICF assumed gas price of $5/GJ.

[3] The exception to this rule are the pipelines originating in the Russia Arctic node. Due to the inhospitable construction and operating environment, the unit capital cost was doubled for pipelines connecting Russia Arctic to Russia West and Russia East.

Pipelines from the 'Russia Arctic' nodes.

The nodes in the Russian Arctic region (above the Arctic Circle) contain some of the largest Russian gas resources. The resources in this node were discovered nearly two decades ago and are counted as reserves; however there is no current production as political decisions have regularly delayed investment in production facilities. The Russian state natural gas company, Gazprom indicates that the resources in these nodes will be home to the biggest new production developments that will constitute most of the expected increase in Russia's natural gas supply over the next three decades. The key developments include Shtokman and the Yamal Peninsula (onshore and offshore) which have been in the news for many years and are currently expected to start producing in the next 10 to 20 years.

Due to the special nature of this supply reserve, production from it cannot be predicted based on economics alone. The pipeline capacity and marine LNG links that will take gas out of this region are used to model the above-ground constraints on supply. The pipelines connecting to the Russian arctic nodes have artificial capacity constraints which have been applied to approximate the production schedule as per official announcements and analyst judgement.

4. Gas storage

Gas storage in the INGM only covers underground storage facilities that can be used for seasonal storage of natural gas. Small gas storage facilities at LNG plants or other facilities that are used for operational smoothing are not included in this category. The list of existing gas storage facilities is taken from the CEDIGAZ Underground Gas Storage in the World 2006 report.

Gas storage capacity constraints

Appendix B, Table B.4 contains the assumed constraints for gas storage capacity. The primary source of data on existing working gas storage capacity was obtained from a CEDIGAZ publication [27] that lists underground natural gas storage capacity in the world, by country, as of January 2006.

ICF used data from the EIA [28] to allocate the United States capacity as reported by CEDIGAZ to the various United States INGM regions.

Outside the U.S., EIA made the following assumptions regarding countries with storage capacity that have more than one node:

- All existing Canadian capacity is in the Canada East node
- All Australia capacity is in the Australia and NZ Demand node
- All Russia capacity is in the Russia West node
- All China capacity is in the Northeast China node

Gas storage asset assumptions

Appendix A, Table A.5 shows the assumptions used for the gas storage asset build and operation costs. The unit costs for new builds are based on a UNECE study [29] and additional data from [30, 31].

Natural gas demand

Natural gas demand baseline estimates are based on model results provided from the EIA NEMS and WEPS+ models for the following sectors:

- Residential
- Commercial
- Transportation (not including pipeline fuel or tanker fuel)
- Industrial
- Electric Power Generation

An additional sector for natural gas used for reinjection to support crude oil production was also included in the INGM with estimates developed from a number of sources.

Energy used in gas processing, liquefaction, regasification, and GTL production are accounted for separately in the model.

Price elasticity of demand

When making the final model run, in order to match the input demands from the WEPS+ model as closely as possible, the INGM is run with very low demand elasticities. In earlier model runs used to iterate with the WEPS+ model higher demand elasticities are used in INGM. Appendix A, Table A.6 shows both sets of assumed demand price elasticities used in INGM.

Nodal and sectoral allocation of demand

WEPS+ model demand output for the sixteen WEPS+ regions was used as the basis to allocate demand to the 61 INGM nodes. Each INGM node was mapped to a single WEPS+ region as shown in Appendix A, Table A.7. IEA data for years 2003 and 2004 was used to allocate the WEPS+ regional demands to the nodes within each region. The IEA data was available by individual country and within the country by sector. The average demand for 2003 and 2004 was calculated by sector and country. The averages for each individual country and sector were summed up in the respective INGM nodes. Each INGM node was then rolled in to the appropriate WEPS+ region and the percentage of sector demand for each INGM node within each WEPS+ region was calculated. The resulting shares of demand were used to allocate WEPS+ regional forecast demand to INGM nodes. For nodes that contained only part of a single country, the allocations are further explained below.

In many cases, the future trends for each node within a WEPS+ region may vary considerably especially due to the large variance in factors such as political systems and energy resource endowment which will not be captured by fixed allocations through 2035. For some nodes, we revised the allocations to reflect short term information on growth in demand at the node which may be different then the overall growth of the WEPS+ region. For example, the power demand for natural gas grows faster in Qatar than for the remaining nodes within the WEPS+ Middle East region.

The allocations by sector are based on historical IEA energy balance data. The 2004 edition of IEA energy balance was used, which included time series data for all countries through 2002. Table 1 details how energy flows in the IEA data were classified into sectors for the model and coefficients assigned to the flows for the purpose of aggregating them into the INGM sectors.

Table 1. Classification of IEA energy flows to INGM sectors

IEA Flow	INGM Sector	Coefficient
International Marine Bunkers	Transportation	-1
Public Electricity Plants	Electric Power	-1
Autoproducer Electricity Plants	Electric Power	-1
Public CHP Plants	Electric Power	-1
Autoproducer CHP Plants	Industrial Cogen	-1
Public Heat Plants	Commercial	-1
Autoproducer Heat Plants	Industrial Heat/fuel Usage	-1
Petroleum Refineries	Industrial Feedstock	0
Coal Transformation	Industrial Feedstock	0
Other Transformation	Industrial Feedstock	0
Own Use	Own Use/Lease and Plant Fuel	-1
Distribution Losses	Residential	0
Iron and Steel	Industrial Heat/Fuel Usage	1
Chemical and Petrochemical	Industrial Heat/Fuel Usage	1
Memo: Feedstock Use in Petchem. Industry	Industrial Feedstock	1
Non-ferrous Metals	Industrial Heat/Fuel Usage	1
Non-Metallic Minerals	Industrial Heat/Fuel Usage	1
Transpoort Equipment	Industrial Heat/Fuel Usage	1
Machinery	Industrial Heat/Fuel Usage	1
Mining and Quarrying	Industrial Heat/Fuel Usage	1
Food and Tobacco	Industrial Heat/Fuel Usage	1
Paper, Pulp and Printing	Industrial Heat/Fuel Usage	1
Wood and Wood Products	Industrial Heat/Fuel Usage	1
Construction	Industrial Heat/Fuel Usage	1
Textile and Leather	Industrial Heat/Fuel Usage	1
Non-specified Industry	Industrial Heat/Fuel Usage	1
International Civil Aviation	Transportation	1
Domestic Air Transport	Transportation	1
Road	Transportation	1
Rail	Transportation	1

Table 1. Classification of IEA energy flows to INGM sectors (cont.)

IEA Flow	INGM Sector	Coefficient
Pipeline Transport	Pipeline Fuel	1
Internal Navigation	Transportation	1
Non-specified Transport	Transportation	1
Agriculture	Industrial Heat/Fuel Usage	1
Commercial and Public Services	Commercial	1
Residential	Residential	1
Non-specified Other	Commercial	1
Non-Energy Use Ind/Transf/Energy	Industrial Feedstock	1
Non-Energy Use in Transport	Transportation	1
Non-Energy Use in Other Sectors	Industrial Feedstock	1
TPES Minus TFC	Transformation	1

The following combinations of fuels and flows have coefficients of zero, superseding those listed above:

- Electricity: All three types autoproducer plants, all three types public plants
- Heat: All three types autoproducer plants, all three types public plants
- Crude, NGL and Feedstocks: Other Transformation

The "Chemical and Petrochemical" values used are derived by subtracting "Memo: Feedstock Use In Petchem. Industry" values from the IEA data values for "Chemical and Petrochemical."

Countries that came into existence during the period covered by the IEA time series necessitated two assumptions for the purpose of generating continuous time series:

- For former Soviet republics: 1971-1991 demand data for each of the 15 member republics were computed as a percentage of the "Former USSR" totals. A separate percentage was computed for each fuel and sector combination using 1992 numbers.
- For the former Yugoslavia: Since all the current states of the former Yugoslavia are in the same INGM node, demand data for "Former Yugoslavia" was retained instead of computing estimates for each of the current states for the period prior to the dissolution.

Sub-country allocation

There are six countries that each comprises two or more INGM nodes, thus requiring national-level consumption figures to be allocated to the nodes. Similar but not identical methodologies were used for the allocation based on relevant information that was available. In general, subnational proportions were calculated and applied to all previous years of historical data.

United States: The United States demand projections for the nine census divisions were allocated to INGM nodes based on EIA's state-level natural gas consumption data for 2003 through 2007 [32].

Canada: Canada's national-level demand was allocated to INGM nodes based on the sum of 2002 Statistics Canada data for direct sales and utility sales, as follows [33]:

Canada East - 43.8%
Canada West - 56.2%

Mexico: Mexico's national-level demand was allocated to INGM nodes as follows [34]:

Mexico Northwest - 5.2%
Mexico Northeast - 25.7%
Mexico South - 69.1%

India: India's national-level demand was allocated to INGM nodes by population, as follows [35]:

India - North - 48%
India – Southeast - 29%
India - Southwest - 23%

China: China's national-level demand was allocated to INGM nodes as follows [36]:

China - West - 28%
China - Northeast - 31%
China - South - 41%

Russia: Russia's national-level demand was allocated to INGM nodes as follows [37]:

Russia West - 90%
Russia East - 10%

This allocation is based on a Gazprom report stating that 34% of 2006 domestic consumption took place in the Central Federal District, 14% in the Southern Federal District, and 32% in the Volga Federal District. All the consumption for these three districts is included in the Russia West node, as well as for two of the four remaining districts. The remaining 20% of consumption is allocated to the remaining four federal districts by population.

Australia: Australia's national-level demand was allocated to INGM nodes consistent with the historic demand in Western Australia verses that in Eastern Australia and New Zealand as follows:

Australia and New Zealand - Demand - 70.3%
Australia and New Zealand - NW Shelf - 29.7%

Seasonal multipliers by sector

Seasonal multipliers were calculated for INGM nodes and sectors. These multipliers are applied to annual base demand numbers to model seasonal variation in natural gas demand by sector. The following two sections describe how seasonal multipliers were calculated for the 61 INGM nodes.

United States: Monthly data from 2001-2005 for each sector [38] was used to calculate average monthly consumption on an MMcf/d basis for the United States as a whole. The months were then broken down in to seasons as follows: December, January and February constitute Winter; June, July, August constitute Summer; and March, April, May, September, October, November constitute Spring/Fall. The average seasonal consumption on an MMcf/d basis was calculated for each season. The seasonal multipliers were then calculated by dividing the average seasonal consumption by the average annual consumption.

Japan: The electric power sector accounts for nearly two-thirds of the annual gas consumption in Japan. Seasonal multipliers for the Japanese electric power sector were derived from monthly "Electricity Generated and Purchased" bulletins from the Federation of Electric Power Companies of Japan [39]. These bulletins list the monthly gas purchase and consumption for electricity generation.

The seasonal demand pattern for the other sectors in Japan was estimated using the same method as for "Other Nodes" given below.

South Korea: Monthly gas consumption statistics for South Korea were obtained from the Korea Energy Economics Institute [40]. The data from this website was used to develop seasonal allocation factors for the Electric, Residential/Commercial and Industrial sectors.

Europe: Monthly gas consumption statistics for European countries was obtained from the Eurostat database [41]. The data for the individual countries was aggregated to IEO regions (OECD Europe and Non-OECD Europe). The monthly statistics were available for two broad categories in each region: Power Generation Sector and Gross Inland Consumption. The seasonal multipliers derived from Eurostat's power generation sector were applied to the Power Generation Sector of INGM for OECD Europe and Non-OECD Europe regions respectively, and multipliers derived from gross inland consumption were applied to all other sectors in OECD Europe, and Non-OECD Europe.

Other Nodes: A different method was used for regions for which monthly or quarterly data were unavailable. The other regions that have seasonal differences in demand are: Arabian Producers, Australia and New Zealand, Brazil, Canada, Chile, China, FSU Central Asia, India, Iran, Latin America – Southern Cone, Qatar, Russia, and Saudi Arabia. The four sectors that may have seasonal differences are: Residential, Commercial, Industry, and Power Generation. Not all nodes have seasonal variation in all sectors. For instance, Saudi Arabia only has seasonal differences only in the power generation sector.

To estimate the seasonal variation in these regions and sectors, ICF matched the regions with U.S. regions based on weather data. ICF used a climate database with heating degree day (HDD) and cooling degree day (CDD) data for weather stations all over the world. For each region, a weather station was chosen that was as close as possible to a primary demand center in that region based on longitude and latitude coordinates. The average HDD and CDD were calculated for that weather station. ICF then performed an analysis of U.S. weather stations to examine which U.S. weather stations have a similar weather pattern to the foreign region station based on HDD and CDD. For each region, two U.S. weather stations were chosen that exhibited very similar HDD and CDD data. The corresponding EIA monthly state and sector-level data [38] for each U.S. weather station was used to calculate the seasonality for each region as described in the U.S. methodology above.

For the remaining regions, ICF assumed no seasonality in demand, based on knowledge of the climate and natural gas demand.

Nodal allocation of wholesale prices

WEPS+ model wholesale prices for the 16 WEPS+ regions was used as the basis to allocate prices to the 61 INGM nodes. Each INGM node was mapped to a single WEPS+ region as shown in Appendix A, Table A.7. The WEPS+ regional wholesale price was allocated to component nodes based on nodal prices from the previous INGM run.

Natural gas resources and extraction

This section provides an overview of the data sources used to estimate natural gas resources and extraction and details how the resource estimates are used to produce resource extraction curves for use in the INGM.

Conventional gas resources: The primary data source was the United States Geological Survey (USGS), which provides data on gas resources for the United States [42, 43] and the world [44].

The USGS data include the following:

- Resource data by assessment units (AU) (306 globally)
- A field size distribution for the remaining resources in each AU,
- Mean resources for each AU,
- Minimum, median, and maximum well depths for each AU,
- Minimum, median, and maximum water depths for each AU.
- The portion of resources that are onshore and offshore

Canada conventional gas resources

The 2000 USGS assessment only covered some areas of Canada. In order to include a comprehensive assessment of the remaining Canadian potential, ICF developed an analysis that combines the recent USGS assessment of the Mackenzie –Beaufort region and a previous analysis carried out in 2003 by the National Petroleum Council, an industry sponsored forecasting analysis of North American gas markets which includes detailed oil and gas resource base characterization of the U.S., Canada, and Mexico [45]. This new analysis includes the Western Canadian Sedimentary Basin, the East Coast onshore and offshore, and various frontier regions of Canada. For each area, a field size distribution was specified, as was the mix of crude oil, natural gas, and NGLs. ICF also included estimates of onshore drilling depth and offshore water depth for each area. Proved reserves in Canada are provided in [46].

China conventional gas resources

The 2000 USGS assessment covered the undiscovered resources and field size distribution of major future potential areas for China. More recent data on oil and gas reserves were also available [47, 48]. For the INGM, it was necessary to re-allocate the USGS resources in China to the three INGM nodes for China. ICF evaluated the map distribution of the USGS basin assessments to assign resources to specific nodes.

Conventional gas reserves growth

The 2000 USGS assessment also provides AU level data on the growth of gas volume from the non-U.S. gas and oil fields. This data is used in INGM to estimate reserves growth (RG) for each AU. The AU level reserve growth is calculated based on AU level growth volumes, reserves, and estimated ultimate recovery (EUR), and is scaled up to meet the world growth target (excluding U.S.) of 3,305 Tcf. The following is the procedure for calculating an AU-level reserves growth factor:

1. Start with USGS growth volumes by AU
2. Scale up the growth volume to reach the world growth target (excluding US) of 3,305 Tcf subject to:

    a. Minimum growth of 30% of AU reserves

    b. Maximum growth of 75% of AU estimated ultimate recovery (EUR)

3. Calculate RG factor:

    AU RG Factor = ([AU Resources] + [AU Growth]) / [AU Resources]

Since basin level growth data is not available for the United States, a constant RG percentage is assumed for U.S. regions. Values of 1.9157 and 1.72 are used for U.S. onshore and offshore regions, respectively.

Unconventional gas resources

Multiple data sources and documents were used to estimate unconventional gas resources [49, 50, 51, 52, 53].

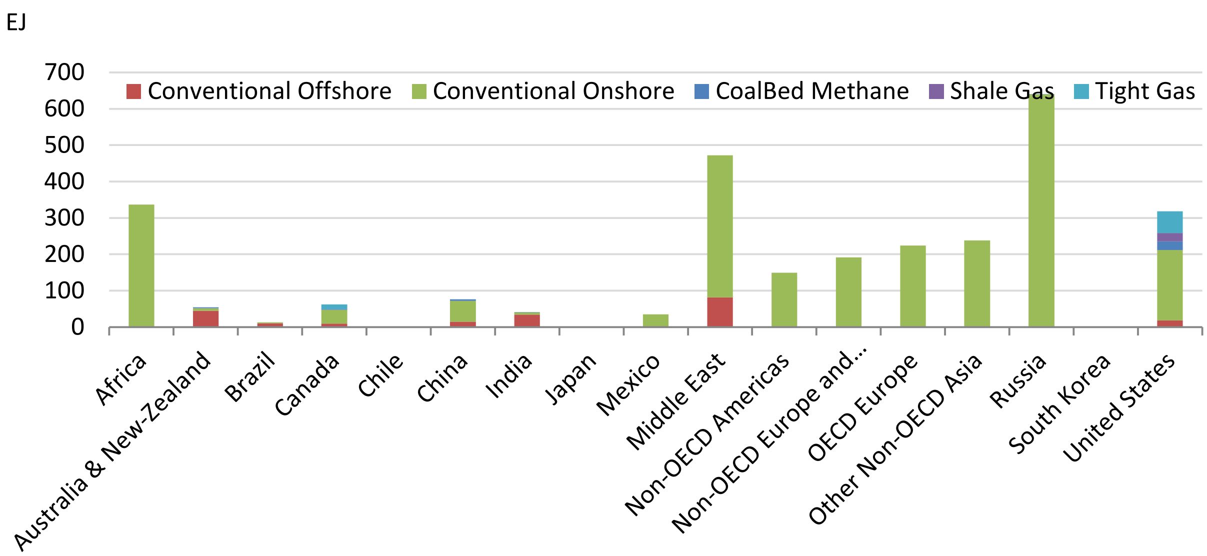
[49] provides worldwide estimates of gas-in-place for coalbed methane, shale gas, and tight-sand gas resources (Table 2). The article further mentions that the volume of undiscovered resources is around 10% of the total gas-in-place for the United States. But more recent estimates of recoverable reserves suggest a ratio of closer to 19% which we used to estimate the economically and technically recoverable resources for tight gas, shale gas and coal bed methane (CBM).

Table 2. Total undiscovered unconventional in-place gas resources[4]

Region	Coalbed Methane Tcf	Shale Gas Tcf	Tight-Sand Gas Tcf	Total Tcf
North America	3,017	3,840	1,370	8,228
Latin America	39	2,116	1,293	3,448
Western Europe	157	509	353	1,019
Central and Eastern Europe	118	39	78	235
Former Soviet Union	3,957	627	901	5,485
Middle East and North Africa	0	2,547	823	3,370
Sub-Saharan Africa	39	274	784	1,097
Centrally planned Asia and China	1,215	3,526	353	5,094
Pacific OECD	470	2,312	705	3,487
Other Asia Pacific	0	313	549	862
South Asia	39	0	196	235
World	**9,051**	**16,103**	**7,406**	**32,560**

The regional estimates of reserves and undiscovered resources are presented in Figure and Figure below. The allocation of natural gas between reserves and undiscovered resources differs from the allocation based on USGS data, due to the reallocation in regions with P/R ratios less than 0.04. In this case, some of the reserves are modelled as very low cost undiscovered resources. The regional allocation also reflects modifications to reserves and resources in Canada and China.

Figure 1. Reserves in the INGM [5]



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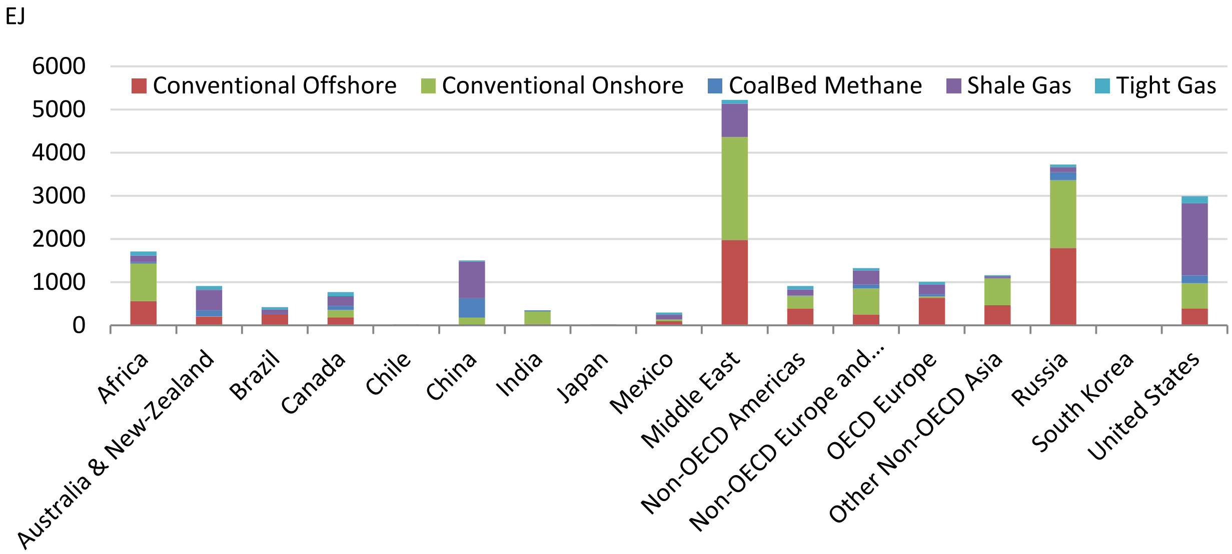
[4] [49, 50]

[5] Existing reserves of unconventional gas may be classified as conventional where no separate data exists.

Figure 2. Undiscovered Resources in the INGM



Resource extraction cost curves

In order to develop resource extraction cost curves, ICF used average nodal field size distributions and well depths from USGS conventional resources.

The aforementioned data sources provide resource estimates but do not provide the cost of developing and producing the resources with one exception, the MMS source for offshore federal resources in the United States. ICF then integrated these estimates within a simplified development/production cost model to develop resource extraction curves.

The resource cost curves were developed as follows:

- Allocate resources to resource steps based on field size classes, well depths, and water depths
- Determine the number of wells for each resource step based on the field size
- Determine the production to reserves ratio based on field size
- Determine development and operating costs for the resource step
- Estimate minimum acceptable supply price for the resource step
- Convert the field size class resource step into a risk-based drilling step using the field find rate matrix which was developed from ICF's World Assessment Unit (WAU) model

Resource steps: The allocation of undiscovered resources to the resource step first involves allocating the resources to field size categories based on the field size distribution. In many cases, the sum of the fields in each field size category times the average resources in the field size category do not add to the estimated mean resources. The number of fields is then scaled to achieve this.

Number of wells per field: The number of wells per field is determined by the following formula that was derived from a more detailed production model (ICF's North American Natural Gas Analysis System – NANGAS) for the United States and constrained to reflect the much larger fields in the Middle East, and Russia.

$$NWells_{rs} = Min[EXP(NWI + NWRes * \log(Res_{rs}) + UnWlA_{rs}) * 5, MAX\left(\frac{\mathrm{RES_{rs}}}{\mathrm{MnWell_{rs}}}, \mathrm{EXP(NWI + NWRes * \log(Res_{rs}) + UnW1A_{rs})}\right)]$$

$NWells_{rs}$ = MIN(EXP(NWI+NWRes*Log(Res_{rs})+$UnWlA_{rs}$) *5,

MAX(Res_{rs} /$MnWell_{rs}$),EXP(NWI+NWRes*Log(Res_{rs})+$UnWlA_{rs}$))

where,

- $NWells_{rs}$ is the number of wells estimated for each field in the field size class
- Res_{rs} is the average size of the field size class (Bcf)
- $MnWell_{rs}$ is the minimum number of wells needed to develop the field size class. The values of 6.5 for conventional and 3.5 for unconventional resources are utilized based on regression analysis of U.S. resources using NANGAS model
- NWI and NWRes are regression coefficients derived from the same regression above which take the values 1.446804 and 0.417948 respectively
- $UnWlA_{rs}$ is an adjustment for unconventional resources which take the value 1.157944 for coalbed methane and shale gas, and 0.628118 for tight gas and is derived from the same regression above

PR ratio: The production to reserves ratio is then estimated. The first step is to estimate the present value of production for the field size class based on the following equation:

$$PVPrd_{rs} = EXP(-0.57965 + 0.965089 * \log(Res_{rs}))$$

where,

- $PVPrd_{rs}$ is the present value of production from the field (BCF), and
- the two coefficients are estimated using regression analysis of NANGAS results on multiple fields in the United States. This estimate of present value of production assumes a real discount rate of 12%.

The PR ratio is then estimated from the reserves in the field and the present value of reserves as follows:

$$PR_{rs} = \left(\frac{PVPrd_{rs}}{Res_{rs}}\right) * (1 - 0.9)/(1 - \left(\frac{PVPrd_{rs}}{Res_{rs}}\right) * 0.9)$$

where,

- PR_{rs} is the production to reserves ratio (fraction).

Drilling costs : The next step is to estimate drilling costs using the equation below:

$$DDCst_{rs} = 1.1542 * \left((dc1 + dc2 * DD_{rs} + dc3 * DD_{rs}^{2} + dc4 * DD_{rs}^{3}) * 1.1 + (0.000079863 * DD_{rs} * WD_{rs})\right) * \left(\frac{NWells_{rs}}{DSucRate} - 1\right) * DCostS_{rs}$$

$$EDCst_{rs} = 1.1542 * \left((dc1 + dc2 * DD_{rs} + dc3 * DD_{rs}^{2} + dc4 * DD_{rs}^{3}) * 1.1 * dc5 + (0.000079863 * DD_{rs} * WD_{rs})\right) * NWells_{rs} * DCostS_{rs})/ESucRate$$

where,

- $DDCst_{rs}$ is the development drilling costs ($000) for the field
- $EDCst_{rs}$ is the exploration drilling costs ($000) for the field
- 1.1542 is inflation adjustment and 1.1 is a drilling cost adjustment,
- DD_{rs} is the drilling depth (ft),
- WD_{rs} is the water depth (ft),
- dc1, dc2, dc3, dc4, and dc5 take the values below

dc1	dc2	dc3	dc4	dc5
203.7943063	0.025909	9.23E-07	5.45E-10	1.324375

- DSucRate is development drilling success rate (fraction) and is set to 0.9
- ESucRate is exploration drilling success rate (fraction) and is set to 0.2
- $DCostS_{rs}$ is set to 1.0 for conventional resources and 1.75 for unconventional resources.

Fixed operating costs: The fixed operating costs are estimated as a function of the number of wells and well depth for onshore resources and as a function of the number of wells for offshore resources as follows:

$Foc_{rs} = 2.37 * NWells_{rs} * DD_{rs}$ if the resource is onshore and

$FOC_{rs} = 289423.7 * NWells_{rs}$ otherwise

where,

- FOC_{rs} is the fixed operating costs ($000 per year)

Well workover costs: ICF assumes one workover per well during the production life (10th year) with the following cost structure:

$$WWC_{rs} = \frac{25000 + 3 * DD_{rs} + WWAdder_{rs}}{1000} * Nwells_{rs}$$

where,

- WWC_{rs} is the well workover costs ($000), and
- $WWAdder_{rs}$ is a cost adder which is zero for conventional resources and $43,750 for unconventional resources.

Facilities costs: The facilities costs are estimated as a function of well depth and the number of wells as follows:

$$FC_{rs} = \frac{17{,}327.32 + 1.44 * DD_{rs}}{1000} * NWells_{rs}$$

where,

- FC_{rs} is the facilities costs for the field ($000)

Compression: The cost of compression facilities is estimated by calculating initial flow rate from the wells which is used to determine the size of the compressor and the overall cost.

$$IPR_{rs} = Re_{rs} * \frac{PR_{rs}}{365} * 10^6$$

$$CC_{rs} = 22 * \frac{\frac{IPR_{rs}}{500}}{1000} * 1400$$

where,

- IPR_{rs} is the initial production rate (mcf/day),
- CC_{rs} is the compression cost for the field ($000),
- 22 is a conversion coefficient (BHP*day/mcf/psia),
- 500 is the wellhead pressure (psia), and$1400 is the compressor cost $/BHP)[6]

Other costs: Other costs include geological and geophysical (G&G) costs and variable production costs. The G&G costs are defined as a function of exploratory drilling costs:

$$GGC_{rs} = 0.05 * EDCst_{rs}$$

[6] For single stage compressor, BHP stands for Brake Horsepower

where,

- GGC_{rs} is the G&G costs ($000)

The variable production costs are set to $0.20/mcf.

Minimum acceptable supply price

The minimum acceptable supply price is defined as the cumulative discounted present value of costs divided by the cumulative discounted present value of production. All investment costs are assumed to occur in the first year of production. The fixed operating costs occur annually and the variable operating costs are scaled by production. The well workover costs are assumed to occur in the 10th year of production.

Common economic parameters

Prices for diesel fuel from Gas-to-Liquids facilities are set to a Btu equivalent of crude oil prices.

Risk-based drilling resource steps

In order to account for the risks associated in finding different size fields within the assessment unit, a field find rate is applied to the resource cost curves. ICF's World Assessment Unit (WAU) model is used to construct a matrix of field find rates by field size class (FSC) and by drilling step as shown in Table 3. The matrix is used to convert the original FSC-based resource steps into risk-based drilling steps where a higher probability of finding is given to the larger fields and vice versa.

Table 3. Field find rate matrix

FSC	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
MMBOE	0.75	1.5	3	6	12	24	48	96	192	384	768	1536	3072	6144	12288	24576	49152
Drilling Step									**Incremental of Fields Found (fraction)**								
1	0.0068	0.0096	0.0139	0.0204	0.0302	0.0448	0.0665	0.0985	0.1449	0.2107	0.3009	0.4184	0.5599	0.7116	0.8480	0.9424	0.9868
2	0.0076	0.0107	0.0154	0.0225	0.0329	0.0480	0.0696	0.0993	0.1382	0.1846	0.2320	0.2657	0.2655	0.2173	0.1338	0.0552	0.0131
3	0.0084	0.0119	0.0171	0.0246	0.0356	0.0511	0.0720	0.0986	0.1287	0.1564	0.1701	0.1567	0.1128	0.0563	0.0165	0.0022	0.0001
4	0.0093	0.0131	0.0187	0.0268	0.0383	0.0538	0.0735	0.0960	0.1169	0.1276	0.1181	0.0853	0.0425	0.0122	0.0016	0.0001	0.0000
5	0.0103	0.0145	0.0205	0.0291	0.0408	0.0561	0.0741	0.0919	0.1033	0.1001	0.0773	0.0425	0.0141	0.0022	0.0001	0.0000	0.0000
6	0.0114	0.0159	0.0223	0.0313	0.0432	0.0579	0.0736	0.0861	0.0887	0.0752	0.0475	0.0193	0.0040	0.0003	0.0000	0.0000	0.0000
7	0.0125	0.0173	0.0242	0.0335	0.0454	0.0591	0.0720	0.0790	0.0737	0.0539	0.0273	0.0079	0.0010	0.0000	0.0000	0.0000	-
8	0.0137	0.0188	0.0260	0.0356	0.0473	0.0596	0.0693	0.0708	0.0593	0.0368	0.0145	0.0029	0.0002	0.0000	0.0000	0.0000	-
9	0.0149	0.0204	0.0279	0.0376	0.0488	0.0595	0.0656	0.0618	0.0459	0.0238	0.0071	0.0009	0.0000	0.0000	0.0000	-	-
10	0.0162	0.0220	0.0298	0.0395	0.0500	0.0586	0.0609	0.0526	0.0342	0.0145	0.0032	0.0003	0.0000	0.0000	0.0000	-	-
11	0.0176	0.0237	0.0317	0.0411	0.0506	0.0569	0.0555	0.0435	0.0244	0.0083	0.0013	0.0001	0.0000	0.0000	0.0000	-	-
12	0.0190	0.0254	0.0334	0.0426	0.0508	0.0545	0.0495	0.0348	0.0166	0.0044	0.0005	0.0000	0.0000	0.0000	-	-	-
13	0.0204	0.0270	0.0351	0.0437	0.0504	0.0514	0.0431	0.0270	0.0108	0.0022	0.0002	0.0000	0.0000	0.0000	-	-	-
14	0.0219	0.0287	0.0366	0.0445	0.0494	0.0476	0.0367	0.0201	0.0066	0.0010	0.0000	0.0000	0.0000	0.0000	-	-	-
15	0.0234	0.0303	0.0380	0.0449	0.0479	0.0433	0.0304	0.0145	0.0038	0.0004	0.0000	0.0000	0.0000	-	-	-	-
16	0.0249	0.0318	0.0392	0.0449	0.0457	0.0386	0.0244	0.0099	0.0021	0.0002	0.0000	0.0000	0.0000	-	-	-	-

Table 3. Field find rate matrix (cont.)

Drilling Step	Incremental of Fields Found (Fraction)																
17	0.0264	0.0332	0.0400	0.0445	0.0431	0.0338	0.0191	0.0065	0.0010	0.0001	0.0000	0.0000	0.0000	-	-	-	-
18	0.0279	0.0345	0.0407	0.0435	0.0400	0.0288	0.0144	0.0041	0.0005	0.0000	0.0000	0.0000	-	-	-	-	-
19	0.0293	0.0357	0.0409	0.0421	0.0365	0.0240	0.0104	0.0024	0.0002	0.0000	0.0000	0.0000	-	-	-	-	-
20	0.0307	0.0367	0.0409	0.0403	0.0327	0.0195	0.0073	0.0013	0.0001	0.0000	0.0000	0.0000	-	-	-	-	-
21	0.0319	0.0374	0.0404	0.0380	0.0287	0.0154	0.0049	0.0007	0.0000	0.0000	0.0000	-	-	-	-	-	-
22	0.0331	0.0379	0.0396	0.0354	0.0247	0.0118	0.0031	0.0003	0.0000	0.0000	0.0000	-	-	-	-	-	-
23	0.0341	0.0381	0.0383	0.0324	0.0208	0.0087	0.0019	0.0002	0.0000	0.0000	0.0000	-	-	-	-	-	-
24	0.0349	0.0380	0.0367	0.0292	0.0171	0.0062	0.0011	0.0001	0.0000	0.0000	0.0000	-	-	-	-	-	-
25	0.5137	0.3874	0.2526	0.1321	0.0494	0.0111	0.0012	0.0000	0.0000	0.0000	0.0000	-	-	-	-	-	-
SUM	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Resource availability constraints

The resource cost curves resulting from the above described methods include significant volumes of relatively low cost tight, shale and coalbed methane resources. Timing of the development and production of these resources, however, is dependent on more than just their cost relative to other resources in the region. To prevent the model from developing and producing these resources before it is realistically possible, the portion of the total resources available for development in any one year are limited. Appendix B, Table B.5 contains the assumed constraints for resource availability by node, year and resource type. Conventional onshore and offshore resources have an availability of 1.00 in the base year. This means that 100 percent of the remaining resource is available for development in the base year and all subsequent years. The percent of tight, shale and coalbed methane resources available for development in any given year is limited based on the regulatory environment and existing gas infrastructure for the region and to what extent there has been leasing or drilling activity in the region for each resource type. Various sources were consulted in developing these constraints including [54] for shale gas and [55] for tight, shale and coalbed methane.

Model Structure

Structural overview

The INGM includes a number of key components including:

- Spreadsheet used to combine the input natural gas resource data and develop supply curves for the INGM
- Spreadsheet used to reformat the energy consumption estimates from WEPS+ and NEMS and allocate the consumption and wholesale prices to 61 nodes from the 16 regions in WEPS+ and the 9 census divisions in NEMS.
- Input database tables which include all cost, efficiency, and capacity specifications for a run and how these are combined to create scenarios
- Output database tables including the model results by scenario
- Code to develop the LP used to represent the competitive natural gas markets
- A commercial LP solver used to solve the LP
- Code to extract the LP results and store them in the output database tables

The algorithms used in the two input spreadsheets are described under the fundamental assumptions in the previous section. The input and output database tables are described in Appendix C. The detailed mathematical representation used in the LP is described below.

Key computations and equations

This section provides detailed mathematical formulation of the LP used to solve for production, transmission, and demand in the model.

Indices used in mathematical formulation

The indices used in the definition of coefficients, columns/activities, and rows/constraints in the LP are as follows:

- *a* – processing asset id
- *c* – supply category
- *f* – fuel type
- *g* – storage asset
- *i* – demand price step
- *j* – supply minor price step for supply category
- *k* – demand sector
- *l* – port-to-port link id
- *m* – major price step for supply category
- *n* – node
- *p* – pipeline asset id
- *r* – region
- *s* – season
- *sy* – starting year (e.g., 2006)
- *t* – tanker id
- *x* – investment year of asset

- *y* – year or marker[7] year

Coefficients

The following table, Table 4, defines the coefficients and intermediate values used in the LP. These definitions include references to data from the database whose definitions can be found in the database section of this document.

[7] The marker year is a single year within a time group used to identify the time group.

Table 4. Coefficients and intermediate values for the LP

Coefficient Name	Coefficient	Description	Units	Source
AssetId	a	Unique ID number for the Asset		tInp_ProcessingAsset, tInp_ProcessingAsset_Fuel, tInp_ProcessingAsset_RegCnstr
AvgLife	ALfk or Alf(k)	Average life of energy consuming capital in sector k	Number of years	tInp_DmdSector
Atl_Flag	atlf(n)	Flag set to true if the node is on the Atlantic in North America		tInp_Node
PS_Type	b	Asset type (Pipeline, Production, ProcAsset, Storage, or Tanker)	0 for production, 1 for pipeline, 2 for processing asset, 3 for tanker, and 4 for storage	tInp_PScalar
BaseDmd	$BDmd_{n,f,k,y}$	Base demand in year for node, fuel, and sector. Note that if data are not specified for a year then a value is interpolated between years where it is specified. If there are no values past some year then the last specified value is assumed	PJ	tInp_DmdBase
BaseEff	$BEff_{n,f,k,y}$	Base efficiency for demand sector for node, sector, fuel, and year	Fraction	tInp_DmdBase
BasePrc_Orig	$BPrc\_Orig_{n,f,k,y}$	Base price for demand estimate initially from the WEPS+ model and before adjustment to nodal values.	$/GJ	tInp_DmdBase
BasePrc	$BPrc_{n,f,k,y}$	Base price for demand estimate. Note that if the value is not specified for a year then the value is interpolated between years where it is specified. If there are no values past some year then the last specified value is assumed	$/GJ	tInp_DmdBase
BYrRsv	$BRsv_{n,c}$	Base year reserves	EJ	tInp_SupplyBase
BYrURes	$BURs_{n,c}$	Base year undeveloped resources	EJ	tInp_SupplyBase

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
SupCatId	*c*	Unique Id for the supply category – Note set to "All" now		tInp_SupplyBase, tInp_SupplyCat, tInp_SupplyCatAsgn, tInp_SupplyCatCnst
Capacity_Increment	CapIa	Capacity increments required for investment	PJ/day of primary output fuel	tInp_ProcessingAsset
Capacity_Increment	CapIg	Capacity increments required for investment	EJ of working capacity	tInp_StorageAsset
Capacity_Increment	CapIp	Capacity increment for capacity increases	PJ/day	tInp_PipelineAsset
Capacity_Increment	CapIt	Capacity increment for capacity increases – adjusted for expected utilization	Pj per ship	tInp_TankerAsset
CarContent	CarCf	CO2 content of the fuel	Tonne CO2/GJ	tInp_Fuel
Availability	$CCnst_{n,c,y}$	Share of reserves and undiscovered resources by node and by supply category that is available to be developed in specified year. Note that if data are not specified for a year then a value is interpolated between years where it is specified. If there are no values past some year then the last specified value is assumed	Fraction	tInp_SupplyCatCnst

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
Asset Construction Flag	$CF_{a,x,y}$	Flag if capacity from asset type a, started in year x, is under construction in year y		1.0 if $x+NYP_a \le y < x+NYP_a+NYC_a$ and 0.0 otherwise
Pipeline Construction Flag	$CF_{p,x,y}$	Flag if capacity from pipeline p, started in year x, is under construction in year y		1.0 if $x+NYP_p \le y < x+NYP_p+NYC_p$ and 0.0 otherwise
Tanker Construction Flag	$CF_{t,x,y}$	Flag if capacity from tanker t, started in year x, is under construction in year y		1.0 if $x+NYP_t \le y < x+NYP_t+NYC_t$ and 0.0 otherwise
Storage Construction Flag	$CF_{g,x,y}$	Flag if capacity from storage g, started in year x, is under construction in year y		1.0 if $x+NYP_g \le y < x+NYP_g+NYC_g$ and 0.0 otherwise
Number of years in year group	CG(y), GC_y	Number of years in the time group with marker year y, a time group is a group of years that are combined in the LP to reduce processing time		
CTax_Scen	$CTax\_Scenn_{,y}$	Tax on CO_2 used in the INGM scenario	$2006/tonne CO2e	tInp_CTax
CTax	$CTax_{n,y}$	Tax on CO_2 assumed in the WEPS+ model and used to estimate the base demand	$2006/tonne CO2e	tInp_CTax
SeasAllocFac	$DmdS_{n,k,s}$	Allocation factor for seasonal demand. Sum over seasons of SeasAllocFac*NDs/365 must equal 1.0	Fraction	tInp_DmdSeasAlloc
Dst_NodeId	dn(l)	NodeId of the other end of the link		tInp_PorttoPort
Dst_NodeId	dn(p)	NodeId of the node at the end of the pipeline		tInp_PipelineAsset

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
Fuel index for processed natural gas	DNG	Fuel index for processed natural gas		
PriceElas	DPE_k or DPE(k)	Price elasticity for demand in demand sector k	Ratio	tInp_DmdSector
DRate	DRate	Global discount rate	Fraction (.12 is 12%)	tInp_Scenario
DRate	DR_r	Discount rate for the region	fraction	tInp_Region_Scn
Dry gas flag	Dry_f	Set to 1 if f = DNG and 0 otherwist		
Demand scaling factor	DSFn,k,i,y	Scaling factor for demand in region r for sector k in year y and for price step i	Fraction	See section Calculation of DSF Values below
DistMar	$DstMar_{n,f,k,y}$	Distribution Margin	$/GJ	tInp_DmdBase
MinCntrrFlag	$EI\_Cnst_{r,y}$	Flag if export/import constraint is annual and not seasonal	True/False	tInp_ImpExp_Cnstr
ExpCnstr	$ExpLmt_{r,f,y}$	Annual limit on exports from the region and only used if FuelId is null	EJ	tInp_ImpExp_Cnstr
End_Year	EYear	Last year of optimization	Year	tInp_Scenario
LYear	$EY_{n,a,sy}$	Last year that following data apply for (e.g., 2010) – inclusive	Year	tInp_ProcessingAsset_RegCnstr
LYear	$EY_{n,g,sy}$	Last year that following data apply for (e.g., 2010) – inclusive	Year	tInp_StorageAsset_RegCnstr
LYear	$EY_{p,sy}$	Last year that following data apply for (e.g., 2010) – inclusive	Year	tInp_PipelineAsset_Cnstr

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
LYear	$EY_{t,sy}$	Last year that following data apply for (e.g., 2010) – inclusive	Year	tInp_TankerAsset_Cnstr
FuelId	*f*	Unique ID for the fuel type		tInp_DmdBase, tInp_Fuel, tInp_Fuel_Scn, tInp_OthDmd, tInp_ProcessingAsset_Fuel
FuelId	*f(a)*	Id of primary output fuel (capacity is measure on output of this fuel)		tInp_ProcessingAsset
FuelId	*f(g)*	Id of fuel type storded		tInp_StorageAsset
FuelId	*f(p)*	ID of fuel type that the pipeline transports		tInp_PipelineAsset
Fixed_OaM_Cost	FOaMCa	Annual fixed operating and maintenance cost per year	$mil per year per capacity increment	tInp_ProcessingAsset
Fixed_OaM_Cost	FOaMCg	Annual fixed operating and maintenance cost	$mil per year	tInp_StorageAsset
Fixed_OaM_Cost	FOaMCp	Annual fixed operating and maintenance cost per year	$mil per year per capacity increment	tInp_PipelineAsset
Fixed_OaM_Cost	FOaMCt	Annual fixed operating and maintenance cost	$mil per year per ship	tInp_TankerAsset
FuelId	$fp_{(r)}$	Unique ID for the fuel type used to index the minimum price on		tInp_ImpExp_Cnstr
Fuel use	FU_g	Fuel use from the injection and withdrawal and including losses applied on injections	Fraction as a percentage of injections	tInp_StorageAsset
Fuel_Use	FU_p	Pipeline fuel use	fraction	tInp_PipelineAsset

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
StorageId	*g*	Unique ID number for the Asset		tInp_StorageAsset, tInp_StorageAsset_RegCnstr
GovtTake	$Govt_n$	The government share of the natural gas sales price	Fraction	tInp_Node_Scn
Investment_Cost	ICs_{ta}	Investment cost per year	$mil per year per capacity increment	tInp_ProcessingAsset
Investment_Cost	ICstg	Investment cost per year	$mil per year	tInp_StorageAsset
Investment_Cost	$ICst_p$	Investment cost per year	$mil per year per capacity increment	tInp_PipelineAsset
Investment_Cost	$ICst_t$	Investment cost per year	$mil per year per ship	tInp_TankerAsset
ImpCnstr	$ImpLmt_{r,f,y}$	Annual limit on imports to the region and only used if FuelId is null	EJ	tInp_ImpExp_Cnstr
Inp_FuelId	Inpf(t)	Id of input fuel to tanker		tInp_TankerFuel
InvCnstr	$InvC_{r,y}$	Investment costraint for the region and only used if FuelId is null	Million $	tInp_ImpExp_Cnstr
DmdSectorId	*k*	Unique Id for the demand sector		tInp_DmdBase, tInp_DmdSeasAlloc, tInp_DmdSector
PorttoPortId	*l*	Id of Port-to-port link		tInp_PorttoPort
Loading Time	LdTt	The number of days required to load the ship	Days	tInp_TankerAsset
Last year in time horizon	*LY*	The last year in the time horizon	Year	
SMPrcStep	*m*	Major price step for supply category (0, 1, 2, …)		tInp_SupplyBase, tInp_SupplyCatAsgn

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
	m(n,c,i)	Major price step that the minor price step is part of		tInp_SupplyBase
Min_Capacity	$MnCap_{n,a,sy}$	Minimum capacity addition allowed in the node	PJ/day output of primary fuel	tInp_ProcessingAsset_RegCnstr
Min_Capacity	$MnCap_{n,g,sy}$	Minimum capacity addition allowed in the node	PJ working gas	tInp_StorageAsset_RegCnstr
Min_Capacity	$MnCap_{p,sy}$	Minimum capacity addition allowed for the pipeline	PJ/day of input fuel to pipeline	tInp_PipelineAsset_Cnstr
Min_Capacity	$MnCap_{t,sy}$	Minimum capacity addition allowed for the tanker type	Number of ships	tInp_TankerAsset_Cnstr
MnCapAn,g,sy	$MnCapA_{n,g,sy}$	Minimum capacity for storage adjusted for storage fraction	PJ	MnCapn,g,sy * StorFrac
MxCapAn,g,sy	$MxCapA_{n,g,sy}$	Maximum capacity for storage adjusted for storage fraction	PJ	MxCapn,g,sy * StorFrac
MinFlow_Flag	mnfflg(l)	Flag if minimum flow is to be assigned to the port-to-port link and is used to control prices for the NGTDM interface. The minimum flow 1e-7 PJ tanker capacity	Yes/No	tInp_PorttoPort
MnPrc	$MnP_{n,c,m}$	Minimum development costs at which reserves come online	$/GJ	tInp_SupplyBase
MinPrc_Fac	$MnPrcF_r$	Factor for minimum price equation to be multiplied for price for specified fuel. Note that it is specified for only one year but applies to all	Ratio	tInp_ImpExp_Cnstr
MinPrc_Int	$MnPrcI_r$	Intercept for minimum price equation. Note that it is specified for only one year but applies to all	$/GJ	tInp_ImpExp_Cnstr
Max_Capacity	$MxCap_{n,a,sy}$	Maximum capacity addition allowed in the node	PJ/day output of primary fuel	tInp_ProcessingAsset_RegCnstr

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
Max_Capacity	$MxCap_{n,g,sy}$	Maximum capacity addition allowed in the node	PJ working gas	tInp_StorageAsset_RegCnstr
Max_Capacity	$MxCap_{p,sy}$	Maximum capacity addition allowed for the pipeline	PJ/day of input fuel to pipeline	tInp_PipelineAsset_Cnstr
Max_Capacity	$MxCap_{t,sy}$	Maximum capacity addition allowed for the tanker type	Number of ships	tInp_TankerAsset_Cnstr
Maximum_Life	MxL_a	Maximum operating life of asset (e.g., 30 years)	Number Years	tInp_ProcessingAsset
Maximum_Life	MxL_g	Maximum operating life of asset (e.g., 30 years)	Number Years	tInp_StorageAsset
Maximum_Life	MxL_p	Maximum operating life of asset (e.g., 30 years)	Number Years	tInp_PipelineAsset
Maximum_Life	MxL_t	Maximum operating life of asset (e.g., 30 years)	Number Years	tInp_TankerAsset
MxPrc	$MxP_{n,c,m}$	Maximum development costs at which reserves come online	$/GJ	tInp_SupplyBase
NodeId	*n*	Unique id for node		tInp_CTax, tInp_DmdBase, tInp_DmdSeasAlloc, tInp_Node, tInp_Node_Scn, tInp_ProcessingAsset_RegCnstr, tInp_StorageAsset_RegCnstr, tInp_SupplyBase, tInp_SupplyCatAsgn, tInp_SupplyCatCnst, tInp_TankerPort
NA_Flag	naf(n)	Flag set to true if the node is in North America		tInp_Node

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
NA_Flag	naf(r)	Flag set to true if the region is in North America		tlnp_Region
NumDays	ND_s	Number of days in the season	Days	tlnp_Season_Scn
NFCstgs	$NFCsts_{n,f,k,y}$	Non-fuel costs in using fuel	$/GJ	tlnp_DmdBase
NGL Flag	NGL_f	Set to 1 if the fuel f is NGLs		
NGL_Frac	$NGLF_{n,c,m}$	Fraction of wet gas that is NGLs	Fraction	tlnp_SupplyBase
Num_MinPrcStp	$NPS_{n,c,m}$	Number of minor price steps within major price step	number	tlnp_SupplyBase
Num_Yrs_Inv	NYC_a	Number of years required for construction	Number Years	tlnp_ProcessingAsset
Num_Yrs_Inv	NYC_g	Number of years required for construction	Number Years	tlnp_StorageAsset
Num_Yrs_Inv	NYC_p	Number of years required for construction	Number Years	tlnp_PipelineAsset
Num_Yrs_Inv	NYC_t	Number of years required for construction	Number Years	tlnp_TankerAsset
Num_Yrs_PlnAppr	NYP_a	Number of years required for planning and approvals	Number Years	tlnp_ProcessingAsset
Num_Yrs_PlnAppr	NYP_g	Number of years required for planning and approvals	Number Years	tlnp_StorageAsset
Num_Yrs_PlnAppr	NYP_p	Number of years required for planning and approvals	Number Years	tlnp_PipelineAsset
Num_Yrs_PlnAppr	NYP_t	Number of years required for planning and approvals	Number Years	tlnp_TankerAsset
Asset Operational Flag	$OF_{a,x,y}$	Flag if capacity from asset type a, started in year x, is operational in year y		1.0 if $x+NYP_a+NYC_a \le y < x+NYP_a+NYC_a+MxL_a$ and 0.0 otherwise

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
Pipeline Operation Flag	$OF_{p,x,y}$	Flag if capacity from pipeline p, started in year x, is operational in year y		1.0 if $x+NYP_p+NYC_p \le y < x+NYP_p+NYC_p+MxL_p$ and 0.0 otherwise
Tanker Operational Flag	$OF_{t,x,y}$	Flag if capacity from tanker t, started in year x, is operational in year y		1.0 if x+NYPt+NYCt ≤ y <x+NYPt+NYCt+MxLt and 0.0 otherwise\
Storage Operational Flag	$OF_{g,x,y}$	Flag if capacity from storage g, started in year x, is operational in year y		1.0 if $x+NYP_g+NYC_g \le y < x+NYP_g+NYC_g+MxL_g$ and 0.0 otherwise\
Org_NodeId	*on(l)*	NodeId of one end of the link		tInp_PorttoPort
Org_NodeId	*on(p)*	NodeId of the node at the start of the pipeline		tInp_PipelineAsset
ODPrc	$OPrc_{f,y}$	Price of fuel in the market (applies only to NGLs, GTLs, and reinjected gas)	$/GJ	tInp_OthDmd
OthFU	$OthFU_n$	Fraction of secondary demand used for internal pipelines and distribution and not captured in the specified pipelines	Fraction	tInp_Node_Scn
Out_FuelId	*Outf(t)*	Id of output fuel to tanker corresponding to input fuel		tInp_TankerFuel

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
PipelineId	p	Unique ID for the pipeline		tInp_PipelineAsset, tInp_PipelineAsset_Cnstr
PlanAppr_Cst	$PACst_a$	Annual Planning and Approval costs	$mil per year per capacity increment	tInp_ProcessingAsset
PlanAppr_Cst	$PACst_g$	Annual Planning and Approval costs	$mil per year	tInp_StorageAsset
PlanAppr_Cst	$PACst_p$	Annual Planning and Approval costs	$mil per year per capacity increment	tInp_PipelineAsset
PlanAppr_Cst	$PACst_t$	Annual Planning and Approval costs	$mil per year per ship	tInp_TankerAsset
ProdIEffBase	$PEffB_n$	Base Value for production inefficiency for node – reduces the share of economic resources that can be developed	Fraction	tInp_Node_Scn
ProdIEffImp	$PEffI_n$	Annual improvement in production inefficiency value with total share capped at 1.0	Fraction/Year	tInp_Node_Scn
Asset Planning Flag	$PF_{a,x,y}$	Flag if capacity from asset type a, started in year x, is in planning in year y		1.0 if $x \le y < x+NYP_a$ and 0.0 otherwise
Pipeline Planning Flag	$PF_{p,x,y}$	Flag if capacity from pipeline p, started in year x, is in planning in year y		1.0 if $x \le y < x+NYP_p$ and 0.0 otherwise
Tanker Planning Flag	$PF_{t,x,y}$	Flag if capacity from tanker t, started in year x, is in planning in year y		1.0 if $x \le y < x+NYP_t$ and 0.0 otherwise
Storage Planning Flag	$PF_{g,x,y}$	Flag if capacity from storage g, started in year x, is in planning in year y		1.0 if $x \le y < x+NYP_g$ and 0.0 otherwise

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
Production factor for previous years reserves	$PFac1_{n,c,m,y}$	Used to apply against the beginning of year reserves for the year group. This equation sums up the PR ratios times the remaining reserves within the year group and averages	Ratio	$(1- PRB_{n,c,m,y}{}^{CG(y)})/CG_y * 1000/365 = \sum_{y', g(y')=y} PRB_{n,c,m,y} * (1-PRB_{n,c,m,y})^{(y'-y)}/CG_y * 1000/365$
Production factor reserve adds	$PFac2_{n,c,m,y}$	Used to apply against the total reserve additions for the year group. It simulates an equal fraction of the reserves added in each year and reserve depletion over the remaining years in the year group.	Ratio	$1000/365 * (CG_y - (1-PRB_{n,c,m,y}{}^{CG(y)})/(1-PRB_{n,c,m,y}) * PRB_{n,c,m,y})/CG_y^2$
Factor for adjusting supply costs	PFac3n,c,m,y	This factor adjusts the costs of the reserve additions to account for only production within the time horizon. It equals the sum of production that starts in each year of the time group that contains the marker year y.	Ratio	$\sum x=SYG(y)$ to $LY\{(PrA_{n,c,m}/CG_y) * (1- PRB_{n,c,m}(x-SYG(y)))/(1-PRB_{n,c,m})\}$
Adjusted P/R ratio	$PRE_{n,c,m}$	P/R ratio for node and supply category but adjusted to work against end or year reserves	Ratio	$PR_{n,c,m} / (1- PR_{n,c,m})$
Production Factor Beta	$PRB_{n,c,m}$	1 minus P/R ratio for node and supply category but adjusted to work against end of year reserves	Ratio	$(1-PRE_{n,c,m})$
Port_Capacity	$PortC_n$	The maximum number of ships in the port at any one time for loading or unloading – not currently used	Number ships per day	tInp_Node_Scn
PrcSub	$PrcSub_{n,f,k,y}$	Price subsidy assumed for the input demand assumptions for the wholesale price on average for the region.	$/GJ	tInp_DmdBase

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
PrcSub_Scn	$PrcSubS_{n,f,k,y}$	Price subsidy used to estimate demand for demand assumptions for the wholesale price on average for the region.	$/GJ	tInp_DmdBase
PR_Ratio	$PR_{n,c,m}$	Maximum production to reserves ratio	ratio	tInp_SupplyBase
PScalar	$PScalar_{b,y}$	Cost scalar reflecting both increases in asset/production costs and technological improvement	Ratio	tInp_PScalar
Qty	$Qty_{a,f}$	Quantity input (negative) or output (positive) for capacity increment	PJ/day	tInp_ProcessingAsset_Fuel
RegionId	*r*	RegionId of region that the constraint applies to		tInp_ImpExp_Cnstr, tInp_Region, tInp_Region_Scn
RegionId	*r(n)*	RegionId of region in which node n is located		tInp_Node_Scn
CmbImpExp_RegionId	*rc(r)*	Id of Region used as aggregate region for combined import/export constraint		tInp_Region_Scn
Retirement_Cost	$RCst_a$	Cost of retiring the asset	$mil per year per capacity increment	tInp_ProcessingAsset
Retirement_Cost	$RCst_g$	Cost of retiring the asset	$mil	tInp_StorageAsset
Retirement_Cost	$RCst_p$	Cost of retiring the asset	$mil per year per capacity increment	tInp_PipelineAsset
Retirement_Cost	$RCst_t$	Cost of retiring the asset	$mil per year per capacity increment	tInp_TankerAsset
Asset Decommission Flag	$RF_{a,x,y}$	Flag if capacity from asset type a, started in year x, is being decomissioned in year y		1.0 if $y = x+NYP_a+NYC_a+MxL_a$ and 0.0 otherwise

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
Pipeline Decommission Flag	$RF_{p,x,y}$	Flag if capacity from pipeline p, started in year x, is being decomissioned in year y		1.0 if y = x+NYPp+NYCp+MxLp and 0.0 otherwise
Tanker Decommission Flag	$RF_{t,x,y}$	Flag if capacity from tanker t, started in year x, is being decomissioned in year y		1.0 if y = x+NYPt+NYCt+MxLt and 0.0 otherwise
Storage Decommission Flag	$RF_{g,x,y}$	Flag if capacity from storage g, started in year x, is being decomissioned in year y		1.0 if y = x+NYP_g+NYC_g+MxL_g and 0.0 otherwise
Regas_Cap	RGF_t	Flag is True if tanker has regasification capability built onboard	True/False	tInp_TankerAsset
Reinjected gas point	RIG	Index to fuel which is reinjected gas to get value of the gas for other purposes		
Resource qty at cumulative price step	RRQn,c,j	Remaining reserves at price step j (including lower prices)	EJ	$BURs_{n,c,m}$ * [($SPrc_{n,c,j}$ – $MnP_{n,c,m}$)/ [($MxP_{n,c,m}$ – $MnP_{n,c,m}$)] $\alpha_{(n,c,m)}$ $RRQ_{n,c,0}$ is set to the value 0 where 1 is the first step
RsvShr	$RsvS_{n,c,m}$	Share of economic/undeveloped resources that can be developed in the year	Fraction	tInp_SupplyBase
SeasonId	*s*	Unique id for season		tInp_DmdSeasAlloc, tInp_Season, tInp_Season_Scn

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
SeasonId	*s*	Unique ID number for the season		tlnp_Season, tlnp_Season_Scn
SeasonId	*s*	Unique ID number for the season		tlnp_Season_Scn
Scale_Flag	ScaleFlag	Flag set to true if demand is to be based on another baseline demand option scaled and false otherwise		tlnp_AA_Dmd_Spec
	$S_{n,c,j}$	The incremental order of the minor price step within the major price step. For example if 16 is the first minor price step for major price step 4 and 20 is the last minor price step for price step 4 then s(n,c,16) is 1 and s(n,c,20) is 5.		tlnp_SupplyBase
Non-variable costs of supply in minor price step	$SPrc_{n,c,j,y}$	Non-variable costs of supply in minor price step set equal to point between minimum and maximum supply price for the major price step	$/GJ	$MnP_{n,c,m(n,c,j)}$ + ($MxP_{n,c,m(n,c,j)}$ - $MnP_{n,c,m(n,c,j))}$/ $NPS_{n,c,m(n,c,j)}$
ScnPrc	$SPrc_{n,f,k,y}$	Scenario price for scenario estimation	$/GJ	tlnp_DmdBase
Adjusted price for resource additions reflecting regional price constraints	$SPrcA_{n,c,j,y}$	Adjusted price for supply step reflecting regional price constraints. Some differentiation allowed for prices below minimum regional price.	$/GJ	Max{$SPrcB_{n,c,j}$, $SPrc_{n,c,j}{}^{0.05}$ * (MnPrcIr + MnPrcFr * $OPrc_{f\ fp(r),y}$}$^{0.95}$}
Adjusted price for resource additions reflecting production through end of the time period	$SPrcB_{n,c,j,y}$	Adjusted price for resource additions reflecting production through end of the time period and regional price constraints.	$/GJ	Min{$SPrc_{n,c,j}$,y*Pscalar0,y/(1-Govtn), SPrcn,c,j,y*Pscalar0, + Govtn * 4.0) * PFac3n,c,m,y*1000
Storage_Fraction	StorFrac	Fraction of storage working gas that can be effectively used	Fraction	Tlnp_Scenario

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
FYear	sy	First year that following data apply for (e.g., 2006)	Year	tInp_PipelineAsset_Cnstr, tInp_ProcessingAsset_RegCnstr, tInp_StorageAsset_RegCnstr, tInp_TankerAsset_Cnstr
Start_Year	SYear	First year of optimization	Year	tInp_Scenario
Start year of year group	SYG(y)	Start year of time group with marker year y		
TankerId	t	Unique ID for the tanker type		tInp_TankerAsset, tInp_TankerAsset_Cnstr, tInp_TankerFuel, tInp_TankerPort
Tanker_Port_Flag	$TPF_{t,n}$	Flag set to true if tanker allowed in port and false (or not specified) otherwise	True/False	tInp_TankerPort
TripDuration	$TrpD_l$	Duration of trip	Days	tInp_PorttoPort
Time_Step	TStep	Number of years between optimizations	Years	tInp_Scenario
Unloading Time	$UnLdT_t$	The number of days required to unload the ship	Days	tInp_TankerAsset
Share	$URShr_{n,c,m}$	Share of reserves and undiscovered resources by node and major price step represented by supply category.	Fraction	tInp_SupplyCatAsgn
US_Flag	usf(n)	Flag set to true if node is in the U.S.		tInp_Node
US_Flag	usf(r)	Flag set to true if region is in the U.S.		tInp_Region
Variable_OaM_Cost	$VOaMC_a$	Variable Operating and Maintenance Cost	$/GJ	tInp_ProcessingAsset
Variable_OaM_Cost	$VOaMC_g$	Variable Operating and Maintenance Cost	$/GJ	tInp_StorageAsset

Table 4. Coefficients and intermediate values for the LP (cont.)

Coefficient Name	Coefficient	Description	Units	Source
Variable_OaM_Cost	$VOaMC_p$	Variable Operating and Maintenance Cost	$/GJ	tInp_PipelineAsset
Variable_OaM_Cost	$VOaMC_t$	Variable Operating and Maintenance Cost	$ per GJ per day	tInp_TankerAsset
VrPrdCosts	$VPC_{n,c,m}$	Variable production costs	$/GJ	tInp_SupplyBase
Variable cost for accelerated production	VPCAn,c,m			Min{$VPC_{n,c,m}$ + ($MnP_{n,c,m}$ + $MnP_{n,c,m}$)/2* $PrAC_{n,c,m}$ * CG_y * ND_s/(1- $Govt_n$)*Pscalar0,y , $VPC_{n,c,m}$ + ($MnP_{n,c,m}$ + $MnP_{n,c,m}$)/2* $PrAC_{n,c,m}$ * CG_y * ND_s*$Pscalar_{0,y}$ + $Govt_n$*4.2
Unprocessed Natural Gas Flag	WNGf	Set to 1 if the fuel f is unprocessed natural gas		
	x	x is an index representing a year where FYear < x < LYear	Year	tInp_PipelineAsset_Cnstr, tInp_ProcessingAsset_RegCnstr, tInp_StorageAsset_RegCnstr, tInp_TankerAsset_Cnstr
Year	y	Year of the demand specification	Year	tInp_CTax, tInp_DmdBase, tInp_ImpExp_Cnstr, tInp_OthDmd, tInp_PScalar, tInp_SupplyCatCnst
Point to market year for year group	YG(y’)	Market year of year y’ in time group		
Point to market year for previous year group	YGP(y’)	Previous Market year of year y’ in time group		
SPVFac	$\alpha_{n,c,m}$	Supply curve price/volume factor		tInp_SupplyBase

Determination of supply price steps

The input to the INGM includes the Baseline Supply (tInp_SupplyBase and tInp_SupplyCatAsgn) which defines supply curves for each node. The supply curve specifications disaggregate the reserves and available resources available at the node into a series of categories (major price steps) defined by the cost of developing and producing the resources. The specification for each major price step includes the following:

- Identification data such as the node identifier and price step identifier
- The minimum price required for the resources to be economic
- The maximum price needed for all of the resources to be economic
- A shape variable which is used to define the resources available at prices between the minimum and maximum price
- The NGL (e.g., lease condensate only) fraction which defines the amount of lease condensate production that would occur concurrent with the wet gas production
- The share of the resources that can be developed in any year
- The production to reserves (PR) ratio
- The wet gas reserves (1st step only) available at the beginning of the first simulation year
- The wet gas resources available for development
- The number of minor price steps to use with the major price step

The INGM also uses the concept of minor price steps which are used to provide additional resolution to the development and production costs while reducing the storage of the price curves in the INGM database and reducing the need for some of the LP constraints and variables. The resources from the major price steps are disaggregated into additional price steps (see definition of coefficients RRQ and SPrc, above) used for tracking the resource development in the INGM LP and the overall costs of development and production in the objective function, but tracking of reserves and production is performed only at the major price step level.

The development of the supply curves and major price steps is performed through a pre-processor to the INGM which combines a number of data sources to produce the supply curves as described in the section *Fundamental Assumptions, Natural Gas Resources and Extraction*, earlier in this document.

Calculation of demand scaling factor (DSF) values

The calculation of the DSF values assumes that the demand behavior is best simulated through a logit formulation:

$$ES_{n,k,f,y} = ES_{n,k,f,y-1} * \left(1 - \frac{1}{\beta_k}\right) + A_{n,k,y} * C^{\alpha}_{n,k,f,y}$$

where

- $ES_{n,k,f,y}$ is the energy service requirements for the node, sector, fuel and year (PJ/year)
- β_k is the average useful life of the energy capital (years)

- $A_{n,k,y}$ is a regional intercept for the node, sector and year (PJ/Year/$/GJ)
- $C_{n,k,f,y}$ is the cost of providing the energy service for the node, sector, fuel, and year ($/GJ)
- α is the price elasticity (fraction)

$$Dmd_{n,k,f,y} = ES_{n,k,f,y}/Eff_{n,k,f,y}$$

where

- $Dmd_{n,k,f,y}$ is the energy demand for the node, sector, fuel and year (PJ/year)
- $Eff_{n,k,f,y}$ is the relative energy efficiency of the demand sector for the node, sector, fuel, and year (fraction)

$$C_{n,k,f,y} = \frac{P_{n,k,f,y} + PrcSub_{n,k,f,y} + CTax_{n,y} * CarC_f + DistMar_{n,k,f,y}}{Eff_{n,k,f,y}} + NFCsts_{n,k,f,y} + AdfF_{n,k,f,y}$$

where

- $P_{n,f,y}$ is the energy price for the node, fuel, and year ($/GJ) and the input value $Prc_{n,f,k,y}$ is used in the initial estimation of the $AdjF_{n,k,f,y}$ but the value $SPrc_{n,f,k,y}$ is used in the actual modeling
- $PrcSub_{n,k,f,y}$ is the price subsidy applied in the node for the sector, fuel, and year ($/GJ)
- $CTax_{n,y}$ is the CO_2 tax for the node and year ($/tonne CO_2)
- $CarC_f$ is the CO_2 content of the fuel (tonne CO_2/GJ)
- $DistMar_{n,k,f,y}$ is the distribution margin for the node, sector,fuel and year ($/GJ)
- $NFCsts_{n,k,f,y}$ are the non-fuel costs of converting the fuel to energy service ($/GJ)
- $AdjF_{n,k,f,y}$ is an availability adjustment factor for the node, sector, fuel, and year which also includes non-fuel costs ($/GJ)

$$ESI_{n,k,f,y} = A_{n,k,y} * C_{n,k,f,y}^{\alpha}$$

where

- $ESI_{n,k,f,y}$ is the annual incremental energy service requirements for the node, sector, fuel and year (PJ/year)

$$Shr_{n,k,f,y} = \frac{A_{n,k,y} * C_{n,k,f,y}^{\alpha}}{} = \frac{C_{n,k,f,y}^{\alpha}}{\sum_f C_{n,k,f,y}^{\alpha}}$$

where $Shr_{n,k,f,y}$ is the share of the incremental energy service requirement for node, sector and year satisfied with the fuel f (fraction)

The first step is to adjust the price subsidy so that the resulting price is no less than $0.75/GJ. We then estimate the annual incremental energy service requirement as follows:

- When y is the start year:

$$ESI_{n,k,f,y} = Dmd_{n,k,f,y} * Eff_{n,k,f,y}$$

Otherwise

$$ESI_{n,k,f,y} = Dmd_{n,k,f,y} * Eff_{n,k,f,y} - Dmd_{n,k,f,y-1} * Eff_{n,k,f,y-1} * (1 - 1/\beta_k)$$

We calculate the efficiency of the incremental energy service as follows:

- When y is the start year:

$$EFFI_{n,k,f,y} = ESI_{n,k,f,y}/(Dmd_{n,k,f,y})$$

- Otherwise

$$EFFI_{n,k,f,y} = ESI_{n,k,f,y}/(Dmd_{n,k,f,y} - Dmd_{n,k,f,y-1} * (1 - \frac{1}{\beta_k}))$$

We then calculate the estimated share for each fuel type as:

$$Shr_{n,k,f,y} = \frac{ESI_{n,k,f,y}}{\sum_{f'} ESI_{n,k,f',y}}$$

The next step is to calculate the values of C and $AdjF_{n,k,f,y}$ where

$$C =$$

and for all f

$$AdjF_{n,k,f,y} = \max\{0, (Shr_{n,k,f,y} * C)^{\left(\frac{1}{a}\right)} - \frac{P_{n,f,y}}{Eff_{n,k,f,y}}\}$$

The value of $A_{n,k,y}$ is then calculated for the fuel, *f,* natural gas as:

$$A_{n,k,y} = ESI_{n,k,f,y}/C^{\alpha}_{n,k,f,y}$$

where :

$$C_{n,k,f,y} = \frac{P_{n,f,y} + PrcSub_{n,k,f,y} + CTax_{n,y} * CarC_f + DistMar_{n,k,f,y}}{Eff_{n,k,f,y}} + NFCsts_{n,k,f,y} + AdfF_{n,k,f,y}$$

The natural gas demand can then be estimated for different natural gas prices by applying these equations:

$$TSF_{n,k,i,y} = (A_{n,k,f,y} * (\frac{DPrc_{n,k,i,y} + PrcSubS_{n,k,f,y} + CTax_{Scen_{n,y}} * CarC_f + DistMar_{n,k,f,y}}{DEff_{n,k,f,y}} + NFCsts_{n,k,f,y} + AdjF_{n,k,f,y})$$

and

$$DSF_{n,k,i,y} = TSF_{n,k,i,y} - TSF_{n,k,i-1,y}$$

Where

- $DPrc_{n,k,i,y}$ is the modeled price for natural gas for the node *n*, sector *k*, step *i*, and year *y*
- $PrcSubS_{n,k,f,y}$ is the subsidy used to estimate demand for demand assumptions for the wholesale price on average for the region (\$/GJ).
- $CTax\_Scen_{n,y}$ is the CO_2 tax used for the INGM run for the node and year (\$/tonne CO_2)

Scaling

The INGM allows for the base demand to be scaled. When this option is used (*ScaleFlag = True)* then the base demand for select regions are scaled based on the input scaling factors provided for the scenario.

Columns/activities

The following table, Table 5, defines the columns in the LP and provides units, lower bounds and upper bounds.

Table 5. Columns in the LP

Column Name	Description	Lower Bound	Upper Bound	Units
$DRs_{n,c,j,y}$	Quantity of resources converted to reserves in node n for supply category c and minor price step j in year y	0	$Min\{ 1.0, \sum_{y',g(y')}) = y$ $RsvS_{n,c,m}(_{n,c,j}))$ *	EJ
$Exp_{r,y,s}$	Exports from region r for fuel f in year y and season s	0	If $EI\_Cnst_{r,y}$ then None, otherwise$ExpLmt_{r,f,y}$ /365*1000	PJ/day
$Imp_{r,y,s}$	Imports to region r for fuel f in year y and season s	0	If $EI\_Cnst_{r,y}$ then None, otherwise$ImpLmt_{r,f,y}$ /365*1000	PJ/day
$NCI_{r,y,d}$	Net costs from asset investments and operations for region r and year y when d is 1 and takes the value 0 when d is 0	0	None	$mil
$NCO_{r,y,d}$	Net costs minus revenues from all but asset investments for region r and year y – if costs are greater than revenues then $NCO_{r,y,1}$ is positive and is the net costs and $NCO_{r,y,0}$ takes the value 0 otherwise $NCO_{r,y,1}$ takes the value 0 and $NCO_{r,y,0}$ takes the net revenues minus costs	0	None	$mil
$OD_{n,f,y,s}$	Other demand at node n for fuel f in year y and season s	0	None	PJ/day
$PLCpE_{p,x}$	Pipeline capacity investment started for pipeline p in year x.	0	None	PJ/day
$PlCpU_{p,y,s}$	Pipeline capacity utilization for pipeline p, for year y, and for season s. Only where capacity data for p,x exists where $x + NYP_{p,x} + NYC_{p,x} \leq y < x + NYP_{p,x} + NYC_{p,x} + MxL_{p,x}$	0	None	PJ/day
$PrCpE_{n,a,x}$	Processing capacity investment started for asset a, at node n, in year x.	0	None	PJ/Day measured as output of primary output fuel
$PrCpU_{n,a,y,s}$	Processing capacity utilization for asset a, at node n, for year y, and for season s. Only where regional capacity data for n,a,x exists where $x + NYP_{n,a,x} + NYC_{n,a,x} \leq y < x + NYP_{n,a,x} + NYC_{n,a,x} + MxL_{n,a,x}$	0	None	PJ/day
$PrA_{n,c,m,y,s}$	Accelerated production for supply category c in node n, for major price step m, in year y and season s	0	None	PJ/Day
$Prd_{n,c,m,y,s}$	Production for supply category c in node n, for major price step m, in year y and season s	0	None	PJ/Day

Table 5. Columns in the LP (cont.)

Column Name	Description	Lower Bound	Upper Bound	Units
$RIJ_{n,c,m=0,y,s}$	Reinjection of gas (to supply step 0) for supply category c in node n, for major price step m=0, in year y and season s	0	None	PJ/Day
$RR_{n,c,j,y}$	Remaining resources in node n for supply category c at end of year y	0 except when y is the start year minus 1 then $RRQ_{n,c,i}$ equals $RRQ_{n,c,j-1}$ when i is the first step of a major price step and $RRQ_{n,c,j}$ – $RRQ_{n,c,j-1}$ otherwise	None except when y is the start year minus 1 then $RRQ_{n,c,j}$ equals $RRQ_{n,c,j-1}$ when i is the first step of a major price step and $RRQ_{n,c,j}$ – $RRQ_{n,c,j-1}$ otherwise,$_{c,j-1}$	EJ
$Rsv_{n,c,m,y}$	End-of-year reserves for supply category c, node n, major price step m, and year y	0 except when y is the start year minus 1 then $BR_{svn,c}$	None except when y is the start year minus 1 then $BR_{svn,c}$	EJ
$SCpE_{n,g,x}$	Storage capacity investment started for asset g, at node n, in year x.	0	None	PJ working gas
$SCpI_{n,g,y,s}$	Storage injections as share of capacity increment for asset g, at node n, for year y, and for season s. Only where regional capacity data for n,g,x exists where x + NYPn,g,x + NYCn,g,x ≤ y < x + NYPn,g,x + NYCn,g,x + MxLn,g,x	0	None	PJ/Day
SCpWn,g,y,s	Storage withdrawals as share of capacity increment for asset g, at node n, for year y, and for season s. Only where regional capacity data for n,g,x exists where x + $NYP_{n,g,x}$ + $NYC_{n,g,x}$ ≤ y < x + $NYP_{n,g,x}$ + $NYC_{n,g,x}$ + $MxL_{n,g,x}$	0	None	PJ/Day

Table 5. Columns in the LP (cont.)

Column Name	Description	Lower Bound	Upper Bound	Units
$TCpE_{r,t,x}$	Tanker capacity investment started for tanker t in year x for region r.	0	None	PJ tanker capacity
$TCpU_{t,fi,l,y,s}$	Tanker utilization for tanker t, using input fuel fi, for port-to-port link l, for year y, and for season s. Only where regional capacity data for t,x exists where x + NYPt,x + NYCt,x ≤ y < x + NYPt,x + NYCt,x + MxLt,x. Also, no t,l combinations allowed if TPFlt,on(l) or TPFLt,dn(l) are false.	0. if mnfflg(l) is false and 1e-7 otherwise	None	PJ tanker capacity
$TD_{n,k,y}$	Average daily demand for natural gas in node n for sector k in year y	0 if y > Syear and BDmdn,f=DNG,k,y otherwise	None if Y > Syear and BDmdn,f=DNG,k,y otherwise	PJ/day
$TDS_{n,k,i,y}$	Average daily demand for natural gas in node n for sector k in year y for price step i	0	∑YGP(y)<y'<y(DSFn,k,i,y' * (1-1/Alfk)(y-y')	PJ/day

Constraints

The following sections define the constraints in the LP. Each description includes the set of indices that the constraint applies to (e.g., all nodes), the units of the constraint, the name of the constraint, the sense of the constraint (e.g., less than or equal to), the right hand side of the constraint, and the coefficients for each column.

Objective (Obj)

- Units: $mil discounted
- Name: obj

$$\sum_{r,y}\left(-NCI_{r,y,0}+NCI_{r,y,1}-NCO_{r,y,0}+NCO_{r,y,1}\right)*\sum_{yg(y')=y}DRate^{(y'-SYear)}/CG_{y}$$

The net cash flows are accounted separately for operations and investments as $NCO_{r,y,d}$ and $NCI_{r,y,d}$, respectively, so their sum represents producer net cash flows. The variables used to store these quantities are constrained to be non-negative, so a subscript *d* is introduced to denote the sign where d=0 is the positive value and d=1 is the negative value and $NCI_{r,y,0}-NCI_{r,y,1}$ represents the net investment for the region and year while and $NCO_{r,y,0}-NCO_{r,y,1}$ represents the net operating and maintenance costs for the region and year. The second sum represents the discount factor for year y. Finally, we desire to minimize the Objective Function, so we construct the negative of the discounted net cash flows.

Energy Balance Constraint (MB)

This constraint forces the energy output to equal energy input for each node, fuel, year, and season.

- for all *n, f, y*, and *s*
- Units: PJ/day
- Constraint: $MB_{n,f,y,s}$

In order, the equation includes the following:

- Input to the node (if Qty_{af} is positive) or output to the node (otherwise) from gas processing by taking the utilization of the gas processing times the ratio of the input/output flow specifcation (Qty_{af}) divided by the capacity assumed in the flow specification ($CapI_{p}$) which is the unit flow of the fuel per PJ/day of utilization
- Input to node from the pipeline transport of the fuel to the node less fuel use during transport
- Output from the node from pipeline transport
- Input to the node from LNG transport minus fuel use during transport which is set to the tanker utilization divided by the number of days required for the round trip including loading and unloading time, all times one mines the fuel use fraction
- Output from the node from LNG transport which is set to the tanker utilization divided by the number of days required for the round trip including loading and unloading time
- Output to demand which is the average hourly demand allocated to the season and scaled up to reflect pipeline fuel use not captured by the node to node pipelines

- Input from the production of wet gas from the field (times WNG_f which is zero for all fuels except for wet gas)
- Input from the accelerated production of wet gas from the field (times WNG_f which is zero for all fuels except for wet gas)
- Input of NGLs from the production of wet gas which equals the wet gas production times the ration of NGL production to wet gas production ($NGLF_{n,c,m}$) times the flag NGL_f which is set to one for NGLs and zero for all other fuels
- Input of NGLs from the accelerated production of wet gas which equals the wet gas production times the ration of NGL production to wet gas production ($NGLF_{n,c,m}$) times the flag NGL_f which is set to one for NGLs and zero for all other fuels
- Output representing other demand for the fuel at the node (note applicable for wet gas, dry gas, or LNG)
- Output representing storage injections at the node in the year and season
- Input representing storage withdrawals at the node in the year and season
- Output representings the reinjection of dry gas at the node for the year and season

$$\begin{aligned}\sum_{\boldsymbol{a}} PrCpU_{n,a,y,s} * \frac{Qty_{af}}{CapI_p} + \sum_a PICpU_{p,y,s,dn(p)=n,f(p)=f} * (1 - FU_p) \\ - \sum_a PICpU_{p,y,s,on(p)=n,f(p)=f} + \sum_{fi,fo,(t,fi)=f,i} TCpU_{t,fi,;,s,y,dn(t)=n} / (2 * TrpD_l \\ + UnLdt_t + LdT_t) * (1 - FU_{t^7} * TrpD_l) - \frac{\sum_1 TCpU_{t,f,l,y,s,on(t)=n}}{2 * TrpD_l + UnLdT_t + LdT_t} \\ - \sum_k TD_{n,k,y} * DmdS_{n.k.s} * (1 + OthFU_n) + \sum_{c,m} WNG_f * Prd_{n,c,m,y,s} \\ + \sum_{c,m} WNG_f * PrA_{n,c,m,y,s} + \sum_{c,m} NGL_f * NGLF_{n,c,m} * Prd_{n,c,m,y,s} \\ + \sum_{c,m} NGL_f * NGLF_{n,c,m} * PrA_{n,c,m,y,s} - OD_{n,f,y,s} - \sum_g SCpI_{n,g,y,s} \\ + \sum_g SCpW_{n,g,y,s} - Dry_f * RIJ_{n,c,m=0,y,s} = 0\end{aligned}$$

Export/Import Constraint (EI)

The constraint limits energy imports and exports for a region, year, and season based on the input data

- for all *r, y*, and *s* where constraint specified
- Units: PJ/day
- Constraint: $EI_{r,y,s}$

This equation takes sum of all pipeline flows to the region from outside the region (minus fuel use) minus the pipeline flows from the region to outside the region plus tanker flow of LNG to the region from outside the region minus fuel use in the transport plus tanker flows from the region to outside the region plus exports minus imports must equal zero. Note that if imports and exports are constrained in the next equation.

$$\sum\nolimits_{\boldsymbol{p},\boldsymbol{rc}(\boldsymbol{dn}(\boldsymbol{p}))=\boldsymbol{r},\boldsymbol{rc}(\boldsymbol{on}(\boldsymbol{p}))\neq \boldsymbol{r}} PICpU_{p,y,s} * (\mathbf{1} - FU_p) - \sum\nolimits_{\boldsymbol{p},\boldsymbol{rc}(\boldsymbol{n}(\boldsymbol{p}))=\boldsymbol{r},\boldsymbol{rc}(\boldsymbol{dn}(\boldsymbol{p}))\neq \boldsymbol{r}} PICpU_{p,y,s} + \frac{\sum_{fi,fo(t,fi)=f,1,rc(dn(1))=r,rc(on(1))\neq r,f} TCpU_{t,fi,l,y,s}}{2 * TrpD_l + UnLdT_t + LdT_t} * (1 - FU_t * TrpD_l) - \frac{\sum_{fi,fo(t,fi)=f,1,rc(on(1))=r,rc(dn(1))\neq r,f} TCpU_{t,f,l,y,s,on,11=n,f}}{2 * TrpD_l + UnLdT_t + LdT_t} + Exp_{r,y,s} - Imp_{r,y,s} = 0$$

Export/Import Annual Constraint (EJ)

The constraint limits Energy imports and exports for a region and year for all *r* and *y* where constraint specified and constraint is annual (i.e., *$EI\_Cnst_{r,y}$ is true)*

- Units: EJ
- Constraint: $EJ_{r,y}$

This constraint sums over all season, the daily exports times the number of days in the season minus the daily imports times the number of days in the season, all divided by 1000 which much match in net export constraint (export limit minus import limit) for the year in exajoules.

$$\sum_s Exp_{r,y,s} * \frac{ND_s}{1000} - Imp_{r,y,s} * \frac{ND_s}{1000} = (ExpLmt_{r,f=Null,y} - ImpLmt_{r,f=Null,y})$$

Investment Constraint – Regional (CC)

This constraint limits asset investments for each region and year based upon the exogenous limits set by the user (current not set)

- for all *r* and *y*
- Units: $mil
- Constraint:$CC_{r,y}$

Planning, approval, construction, fixed O&M, and variable O&M costs ($NCI_{r,y,0}$) must be less than the investment constraint ($InvC_{r,y}$). Note that $NCI_{r,y,1}$ will always be zero.

$$NCI_{r,y,0} - NCI_{r,y,1} \leq InvC_{r,y}$$

Net Investment and O&M Costs – Regional (CI)

This constraint is used to calculate the net investment costs for each region and year

- for all *r* and *y*
- Units: $mil
- Constraint:$CI_{r,y}$

This constraint sums up costs minus revenues for each year *y* as follows:

- Adds up the planning and approval costs, construction costs, fixed operating and mainternace costs, and retirement costs for generic assets
- Adds the sum of asset planning and approval costs for assets started in previous year *x* that will have planning and approval costs in year *y* as follows:
  - $PF_{a,x,y}$ is 1 only if investments that start in year *x* for asset *a* has planning and approval costs in year *y*
  - times $PrCpE_{n,a,x}$ which is the modelled capacity additions (PJ/day)
  - times $PACst_a$ which is the annual planning and approval cost for the capacity for a capacity increment of $CapI_a$ ($mil/(PJ/day))
  - divided by the capacity increment (PJ/day)
  - times the cost scalar ($PScalar_{2,y}$)
- Adds the sum of asset construction costs for assets started in previous year *x* that will have construction costs in year *y* as follows:
  - $CF_{a,x,y}$ is 1 only if investments that start in year *x* for asset *a* has construction costs in year *y*
  - times $PrCpE_{n,a,x}$ which is the modelled capacity additions (PJ/day)
  - times $ICst_a$ which is the annual planning and approval cost for the capacity for a capacity increment of $CapI_a$ ($mil/(PJ/day))
  - divided by the capacity increment (PJ/day)
  - times the cost scalar ($PScalar_{2,y}$)
- Adds the sum of asset fixed O&M costs for assets started in previous year *x* that will have construction costs in year *y* as follows:
  - $OF_{a,x,y}$ is 1 only if investments that start in year *x* for asset *a* is operational in year *y*
  - times $PrCpE_{n,a,x}$ which is the modelled capacity additions (PJ/day)
  - times $FOaMC_a$ which is the annual fixed O&M cost for the capacity for a capacity increment of $CapI_a$ ($mil/(PJ/day))
  - divided by the capacity increment (PJ/day)
  - times the cost scalar ($PScalar_{2,y}$)
- Adds the sum of asset retirement costs for assets started in previous year *x* that will have retire in year *y* as follows:
  - $RF_{a,x,y}$ is 1 only if investments that start in year *x* for asset *a* retires in year *y*
  - times $PrCpE_{n,a,x}$ which is the modelled capacity additions (PJ/day)
  - times $RCst_a$ which is the retirement cost for the capacity for a capacity increment of $CapI_a$ ($mil/(PJ/day))
  - divided by the capacity increment (PJ/day)
  - times the cost scalar ($PScalar_{2,y}$)

- Adds the sum of variable O&M costs for assets that will operate in year *y* as follows:
  - $PrCpU_{n,a,y,s}$ which is the modelled capacity utilization of the asset type at the node in the specified year and seasson (PJ/day)
  - times $VOaMC_a$ which is the variable operating cost for the ($/GJ output of primary product)
  - times $Qty_{a,f(a)}$ which is the output fo the primary product (PJ/Day per CapIa of capacity)
  - divided by $CapI_a$ which is the input capacity used for costs and flows (PJ/day)
  - times the number of days in the seas ($ND_{s)}$
  - times CG_y which is the number of years in the year grouping
  - times the cost scalar ($PScalar_{2,y}$)
- Adds up the planning and approval costs, construction costs, fixed operating and mainternace costs, and retirement costs for pipelines like above but
  - Using the pipeline capacity expansion starting planning approval in year *x* ($PlCpE_{p,x}$)
  - Using the pipeline utilization ($PlCpU_{p,y,s}$)
  - Time flags for the pipeline ($PF_{p,x,y,\ldots}$)
  - Simplifying the O&M costs calcualtions which do not need the flow ($Qty_{a,f(a)}$ and $CapI_a$), and
  - Using the price scalar for pipeline costs ($PScalar_{1,y}$)
- Adds up the planning and approval costs, construction costs, fixed operating and mainternace costs, and retirement costs for tankers like above but
  - Using the tanker capacity expansion starting planning approval in year *x* ($TCpE_{r,t,,x}$)
  - Using the tanker utilization ($TCpU_{t,f,l,y,s}$)
  - Time flags for the tanker ($PF_{t,x,y,\ldots}$)
  - Simplifying the O&M costs calcualtions which do not need the flow ($Qty_{a,f(a)}$ and $CapI_a$), and
  - Using the price scalar for tanker costs ($PScalar_{3,y}$)
- Adds up the planning and approval costs, construction costs, fixed operating and mainternace costs, and retirement costs for seasonal storage like above but
  - Using the storage capacity expansion starting planning approval in year *x* ($SCpE_{n,g,x}$)
  - Using the storage injections ($SCpI_{n,g,y,s}$) for the variable operating costs
  - Time flags for the storage ($PF_{g,x,y,\ldots}$)
  - Simplifying the O&M costs calcualtions which do not need the flow ($Qty_{a,f(a)}$ and $CapI_a$), and
  - Using the price scalar for storage costs ($PScalar_{4,y}$)
- Subtracts the net cost variable ($NCI_{r,y,1}$), and
- Constrains the total to zero

$$\sum_{ar(n)=r,x} PF_{a,x,y} * PrCpE_{n,a,x} * \frac{PACst_a}{CapI_a} * Pscalar_{2,y} + \sum_{a,r(n)=r,x} CF_{a.x.y} * PrCpE_{n,a,x} * \frac{ICst_a}{CapI_a} * Pscalar_{2,y} + \sum_{ar(n)=r,x} OF_{a,x,y} * PrCpE_{n,a,x} * \frac{FOaMC_a}{CapI_a} * Pscalar_{2,y} + \sum_{ar(n)=r,x} RF_{a,x,y} * PrCpE_{n,a,x} * \frac{RCst_a}{CapI_a} * Pscalar_{2,y} + \sum_{ar(n)=r,s} PrCpU_{n,a,y,s} * VOaMC_a * Qty_{a,f(a)} \frac{ND_s * CG_y}{CapI_a} * Pscalar_{2,y} + \sum_{pr(on(p))=r,x} PF_{p,x,y} * PlCpE_{p,x} * \frac{PACst_p}{CapI_p} * Pscalar_{1,y} + \sum_{pr(on(p))=r,x} CF_{p,x,y} * PlCpE_{p,x} * \frac{ICCst_p}{CapI_p} * Pscalar_{1,y} + \sum_{pr(on(p))=r,x} OF_{p,x,y} * PlCpE_{p,x} * \frac{FOaMC_p}{CapI_p} * Pscalar_{1,y} + \sum_{pr(on(p))=r,x} RF_{p,x,y} * PlCpE_{p,x} * \frac{RCst_p}{CapI_p} * Pscalar_{1,y} + \sum_{pr(on(p))=r,s} PICpU_{p,y,s} * VOaMC_p * ND_s * CG_y * Pscalar_{1,y} + \sum_{t,x} PF_{t,x,y} * TcpE_{r,t,x} * \frac{PACst_t}{CapI_t} * PScalar_{3,y} + \sum_{t,x} CF_{t,x,y} * TcpE_{r,t,x} * \frac{ICst_t}{CapI_t} * PScalar_{3,y} + \sum_{t,x} OF_{t,x,y} * TcpE_{r,t,x} * \frac{FoaMCt_t}{CapI_t} * PScalar_{3,y} + \sum_{t,x} RF_{t,x,y} * TcpE_{r,t,x} * \frac{RCst_t}{CapI_t} * PScalar_{3,y} + \sum_{t,f,;,y(on(1))=r} TCpU_{t,f,l,y,s} * VOaMC_t * ND_s * CG_y * PScalar_{3,y} + \sum_{a\_r(n)=r,x} PF_{g,x,y} * SCpE_{n,g,x} \frac{PACst_g}{CapI_g} * Pscalar_{4,y} + \sum_{a\_r(n)=r,x} CF_{g,x,y} * SCpE_{n,g,x} \frac{ICCst_g}{CapI_g} * Pscalar_{4,y} + \sum_{a\_r(n)=r,x} OF_{g,x,y} * SCpE_{n,g,x} \frac{FOamC_g}{CapI_g} * Pscalar_{4,y} + \sum_{a\_r(n)=r,x} RF_{g,x,y} * SCpE_{n,g,x} \frac{RCst_g}{CapI_g} * Pscalar_{4,y} + \sum_{a\_r(n)=r,s} SCpI_{n,g,y,s} * VoaMC_g * ND_s * CG_y Pscalar_{4,y} - NCI_{r,y,l} + NCI_{r,y,0} = 0$$

Capital constraint for other costs – regional (CO)

This constraint is used to calculate the net operating costs for each region and year

- for all *r* and *y*
- Units: $mil
- Constraint:$CO_{r,y}$

This constraint is as follows

- The negative of the incremental daily demand scheduled from the demand curve price step ($TDS_{n,k,i,y}$) is multiplied by the price of the step ($DPrc_{k,i}$) and number of years in the time group and converted to an annual cost. For this version ALf_k is set to one, so the autoregressive component is one.

- Reserve adds ($DRs_{n,c,j,y}$) times the adjusted resource extraction cost added.
- Seasonal daily production ($Prd_{n,c,m,y,s}$) is multiplied by the minimum of variable production costs times the number of years in the time group, times the number of days in the season, and adjusted for government take but with the government take constrained to the government take percentage time $0.20/GJ, also with the prices scaled
- The revenue from other seasonal daily demand ($OD_{n,f,y,s}$) times the price for the fuel and the number of days in the season and the number of years in time group I subtracted
- Plus the seasonal daily reinjected volumes times the reinjection cost times the number of days in the season and years in the time group, also times the operational cost price scalar
- Minus the variable for positive operational costs plus the variable for negative operational costs

$$-\sum_{n,k,i,r(n)=r} TDS_{n,k,i,y} * DPrc_{k,i} * 365.* CG_y \sum_{y' \geq y, YG(y')=y'} [(1-\frac{1}{ALf_k})^{(y'-y)}$$
$$* \sum_{y'',g(y'')=y'} DRate^{(y''-Syear)}] \frac{}{\sum_{y',g(y')=y'} DRate^{(y'-SYear)}}$$
$$+ \sum_{n,c,j,m(n,c,j)=m,r(n)=r} DRs_{n,c,j,y} * SPrcA_{n,c,j,y} + \sum_{n,c,m,r(n)=r} Prd_{n,c,m,y,s}$$
$$* min\left\{VPC_{n,c,m} * CG_y * \frac{ND_s}{1-Govt_n}\right.$$
$$\left.* Pscalar_{0,y,} \left(VPC_{n,c,.m} * CG_y * ND_s + Govt_n * 0.2\right) * Pscalaro_{,y}\right\}$$
$$-\sum_{n,f,s,r(n)=r} OD_{n,f,y,s} * \sum_{yg(y)=y'} OPrcf_{f'} * ND_s + RIJ_{n,c,m=0,y,s}$$
$$* \frac{CGy * \sum_{y'SYG(y')=y} \quad \left(0.075 - OP_{rcf=RIG,y}\right) ND_s}{1000} * PScalar_{0,y} - NCO_{r,y,1}$$
$$+ NCO_{r,y,o} = 0$$

Average daily demand (ADD)

This constraint sets the the natural gas demand quantity to be equal to the demand from the previous stock plus new demand using a autoregressive function of demand. Note that for now the variable ALf_k is set to 1.

- for all n,k,y
- Units: PJ/day
- Constraint: $ADD_{n,k,y}$

In the constraint the demand for the specified node, sector, and year is set to the demand in the previous time group YGP(y) times the reduction in demand due to the autoregressive coefficient (which for now is zero) plus the sum of the additional demand for the node, sector, and year by demand step.

$$TD_{n,k,y} = TD_{n,k,YGP(y)} * (1-\frac{1}{ALf_k})^{(y-YGP(y))} + \sum_i TDS_{n,k,i,y}$$

Annual resource constraint (ARC)

This constraint guarantees that the reserve additions in any year for any node, supply category, and supply step do not exceep the remaining resources for the step adjusted by the resources efficiency for the node.

- for all n,c,j,
- Units: EJ
- Constraint: $ARC_{n,c,j}$

In the constraint, the sum of the reserve additions over all modelled years for the node, supply category, and supply step must be less than the resoures in that group.

$$\sum\nolimits_{y',g(y')=y} \boldsymbol{DRs_{n,cj,y}} \quad \leq \boldsymbol{RR_{n,c,j,SYear-1}}$$

Remaining undeveloped resources - end-of year (RUR)

- for all n,c,j,y
- Units: EJ
- Constraint: $RUR_{n,c,j,y}$

$$\boldsymbol{RR_{n,c,j,y} = RR_{n,c,j,y-1} - DRs_{n,c,j,y}}$$

Reserves (RSV)

This constraint calculates the reserves for each node, supply catetgory, major price step, and year.

- for all n,c,m,y
- Units: EJ
- Constraint: $RSV_{n,c,m,y}$

The reserves in year *y* are set equal to reserves in year *y-1* plus the sum or all reserve additions for each minor step within the majort step for the year minus annual production from the supply category and price step times the number of years in the year group.

$$\boldsymbol{Rsv_{n,c,m,y} = Rsv_{n,c,m,y-1} + \sum\nolimits_{j,m(n,c,j)=m} DRs_{n,c,j,y} - Prd_{n,c,m,y} * CG_y * \frac{ND_s}{1000}}$$

Production (PRD)

This constraint makes sure that the seasonal production from a supply category and major price step at a node is less than the last years end of year reserves (e.g. beginning of year reserves) plus the reserve addtions times the adjusted production to reserves ratio.

- for all n,c,m,y,s
- Units: PJ/day
- Constraint: $PRD_{n,c,m,y,s}$

The constraint has the production less than or equal to the beginning of year reserves for the year group time PFac1 plus the total reserve additions for the year group times PFac2. Note that PFac1 accounts for the reserve depletion of the beginning of year reserves over all years in the year group using the PR ration and PFac2 accounts for the reserve additions being equally distributed to each year in the year group and reserve depletion for the reserve additions for all but the last year in the year group.

$$\boldsymbol{Prd_{n,c,m,y,s} \leq Rsv_{n,c,m,y-1} * PFac1_{n,c,m,s} + \sum_{j,m(n,c,j)=m} DRs_{n,c,j,y} * PFAC2_{n,c,m,y}}$$

Pipeline asset capacity utilization (PCU)

This constraint guarantees that the seasonal utilization of pipeline capacity in each year is less than or equal to the capacity existing or built as part of the optimization

- for all *p*, *y,* and *s* where $sy+NYP_p+NYC_p \leq y < EY_{p,sy}+NYP_p+NYC_p+MxL_p$ where there is a pipeline constraint at *p,sy*
- Units: PJ/Day
- Constraint: $PCU_{p,y,s}$

The sum of the capacity builds ($PLCpE_{p,x}$) for the capacity investment years x where the capacity would be available for operation in year y (e.g., $OF_{p,x,y}$ = 1 and not 0) minus the pipeline utilization for the year and season must be greater than or equal to zero.

$$\boldsymbol{\sum_{x} OF_{p,x,y} * PLCpE_{p,x} - PICpU_{p,y,s} \geq 0}$$

Pipeline capacity build constraints (PCG, PCL)

These constraints limit the pipeline capacity additions to the range allowed by input data

- for all *p* and *sy* from pipeline asset constraints
- Units: PJ/Day
- Constraint: $PCG_{p,sy}$

For each pipeline and capacity constraint identified by the start year of the constraint (*sy*), the sum of the capacity additions for year groups within the year range of the constraint must be greater than or equal to the minimum value allowed.

$$\sum_{sy \leq x \leq EYp,sy} \boldsymbol{PLCpE_{p,x}} \geq \boldsymbol{MnCap_{p,sy}}$$

- Constraint: $PCL_{p,sy}$

For each pipeline and capacity constraint identified by the start year of the constraint (*sy*), the sum of the capacity additions for year groups within the year range of the constraint must be less than or equal to the maximum value allowed.

$$\sum_{sy \leq x \leq EYp,sy} \boldsymbol{PLCpE_{p,x}} \leq \boldsymbol{MxCap_{p,sy}}$$

Processing asset capacity utilization (ACU)

This constraint guarantees that the seasonal utilization of processing asset capacity in each year is less than or equal to the capacity existing or built as part of the optimization

- for all *n, a, y,* and *s* where $sy+NYP_a+NYC_a \leq y < EY_{n,a,sy}+NYP_a+NYC_a+MxL_a$ where there is an asset constraint for n,a,sy
- Units: PJ/Day
- Constraint $ACU_{n,a,y,s}$

The sum of the capacity builds ($PrCpE_{n,a,x}$) for the capacity investment years x where the capacity would be available for operation in year y (e.g., $OF_{a,x,y}$ = 1 and not 0) minus the processing asset utilization for the year and season must be greater than or equal to zero.

$$\sum_{x} \boldsymbol{OF_{a,x,y}} * \boldsymbol{PrCpE_{n,a,x}} - \boldsymbol{PrCpU_{n,a,y,s}} \geq \boldsymbol{0}$$

Processing asset capacity regional constraints (ACG, ACL)

These constraints limit the processing capacity additions to the range allowed by input data

- for all *n, a,* and *sy* from processing asset regional constraints
- Units: PJ/day
- Constraint $AGG_{n,a,y,s}$

For each processing asset, node, and capacity constraint identified by the start year of the constraint (*sy*), the sum of the capacity additions for year groups within the year range of the constraint must be greater than or equal to the minimum value allowed.

$$\sum_{sy \leq x \leq EYn,a,sy} \boldsymbol{PrCpE_{n,ax}} \geq \boldsymbol{MnCap_{n,a,sy}}$$

Constraint $AGL_{n,a,y,s}$

For each processing asset, node, and capacity constraint identified by the start year of the constraint (*sy*), the sum of the capacity additions for year groups within the year range of the constraint must be less than or equal to the maximum value allowed.

$$\sum_{sy \le x \le EYn,a,sy} PrCpE_{n,a,x} \ge MxCap_{n,a,sy}$$

Tanker asset capacity utilization (TCU)

This constraint guarantees that the seasonal utilization of tanker asset capacity in each year is less than or equal to the capacity existing or built as part of the optimization

- for all *r, t, y,* and *s* where $SY_{t,sy}+NYP_t+NYC_t \le y \le EY_{t,sy}+NYP_t+NYC_t+MxL_t$
- Units: PJ Tanker Capacity
- Constraint $TCU_{r,t,y,s}$

The sum of the capacity builds ($TcpE_{r,t,x}$) for the capacity investment years x where the capacity would be available for operation in year y (e.g., $OF_{t,x,y}$ = 1 and not 0) minus the tanker asset utilization for the year and season must be greater than or equal to zero.

$$\sum_{x} OF_{t,x,y} * TCpE_{r,t,x} - \sum_{fi,1,r(on(1))=r} TCpU_{t,fi,1,y,s} \ge 0$$

Tanker capacity constraints (TCG, TCL)

These constraints limit the tanker capacity additions to the range allowed by input data

- for all *t* and *sy* from tanker capacity constraints
- Units: PJ/Day
- Constraint $TCG_{t,sy}$

For each tanker asset and capacity constraint identified by the start year of the constraint (*sy*), the sum of the capacity additions for year groups within the year range of the constraint must be greater than or equal to the minimum value allowed.

$$\sum_{r,sy \le x \le EYt,sy} TCpE_{r,t,x} \ge MnCap_{t,sy} * CapI_t$$

Constraint $TCL_{t,sy}$

For each tanker asset and capacity constraint identified by the start year of the constraint (*sy*), the sum of the capacity additions for year groups within the year range of the constraint must be less than or equal to the maximum value allowed.

$$\sum_{r,sy \le x \le EYt,sy} \boldsymbol{TcpE_{r,t,x}} \le \boldsymbol{MxCap_{t,sy}} * \boldsymbol{CapI_t}$$

Storage asset capacity utilization (SCU)

This constraint guarantees that the seasonal utilization of storage asset capacity in each year is less than or equal to the capacity existing or built as part of the optimization

- for all n, g, and sy from storage asset regional constraints, and y where

$$sy + NYP_g \le y < EY_{n,g,sy} + NYP_g + NYC_g + MxL_g$$

- Units: EJ
- Constraint $SCU_{n,g,y}$

The sum of the capacity builds ($SCpE_{n,a,x}$) for the capacity investment years x where the capacity would be available for operation in year y (e.g., $OF_{g,x,y}$ = 1 and not 0) minus the storage asset injection volumes for the year and season must be greater than or equal to zero.

$$\sum_{x} OF_{g,x,y} * SCpE_{n,g,x} - \sum_{s} SCpI_{n,g,y,s} * ND_s \ge 0$$

Storage asset capacity regional constraints (SCG, SCL)

These constraints limit the storage asset capacity additions to the range allowed by input data

- for all *n, g,* and *sy* from processing asset regional constraints
- Units: EJ

Constraint $SCG_{n,g,y,s}$

For each storage asset and capacity constraint identified by the start year of the constraint (*sy*), the sum of the capacity additions for year groups within the year range of the constraint must be greater than or equal to the minimum value allowed.

$$\sum_{sy \le x \le EY_{g,sy}} SCpE_{n,g,x} \ge MnCapA_{n,g,sy}$$

Constraint $SCL_{n,g,y,s}$

For each storage asset and capacity constraint identified by the start year of the constraint (*sy*), the sum of the capacity additions for year groups within the year range of the constraint must be less than or equal to the maximum value allowed.

$$\sum_{sy \le x \le EY_{g,sy}} SCpE_{n,g,x} \le MxCapA_{n,g,sy}$$

Storage asset volume balance (SCB)

This constraint guarantees that the injection and withdrawal volumes match for each year

. for all *n, a*, *sy* from storage asset regional constraints, and *y* where

$$sy + NYP_g + NYC_g \le y \le EY_{n,a,sy} + NYP_g + NYC_g + MxL_g$$

- Units: EJ
- Constraint $ACU_{n,g,y,s}$

The sum of the seasonal daily injection volumes times the number of days in the season times one minus the fuel use fraction, all minus the sum of the seasonal daily withdrawal volumes times the number of days in the season must equal to 0.

$$\sum_{s} SCpI_{n,g,y,s} * ND_s * (1 - FU_g) - \sum_{s} SCpW_{n,g,y,s} * ND_s = 0$$

Appendix A. Model Cost and Efficiency Assumptions

A.1 Processing, liquefaction, regasification, and GTL asset specifications

Asset Name	Capacity Increment	FuelId	Num Yrs PlnAppr	PlanAppr Cst	Num Yrs Investment	Investment Cost	Maximum Life	Fixed O&M Cost	Variable O&M Cost	Retirement Cost
	PJ/Day		Years	2006 $MM/yr	Years	2006 $MM/yr	Years	2006 $MM/yr	2006 $/GJ	2006 $MM
Liquefaction Plant	1.0834	Processed LNG	3	102.2	3	2044	100	183.96	0.015	0
Small Regas Plant	0.5417	Processed Natural Gas	3	11.4975	3	229.95	100	20.6955	0.123648	0
Large Regas Plant	1.0834	Processed Natural Gas	3	19.1625	3	383.25	100	34.4925	0.123648	0
Large GTL Plant	0.37	Diesel (GTL)	3	20.64411	3	688.137	100	0	0.976	0
Small GTL Plant	0.184	Diesel (GTL)	3	16.09024	3	536.3413	100	0	0.976	0
Gas Processing Plant	0.4334	Processed Natural Gas	3	1.3332	3	44.44	100	0	0.461	0

A.2 Plant efficiencies (output energy divided by input energy)

Asset Type	Plant Efficiency
Gas Processing Plant	99.4%
Large GTL Plant	50.0%
Large Regas Plant	96.0%
Liquefaction Plant	92.0%
Small GTL Plant	50.0%
Small Regas Plant	96.0%

A.3 LNG tanker asset specifications

Tanker Name	Capacity Increment	Years Planning and Approval	PlanAppr Cst	Years Investment	Investment Cost	Maximum Life	Fixed O&M Cost	Variable O&M Cost	Retirement Cost	ReGas Cap	Loading Time	Unloading Time
	PJ/Ship		2006 $MM/year		2006 $MM/year		2006 $MM/year	2006 $/GJ/day	2006$MM		days	days
Small NoRegas	1.864	1	0.05	2	67.2535	40	0	0.038	0.05	Yes	1.85	1.85
Medium No Regas	2.984	1	0.05	3	56.5023	40	0	0.029	0.05	Yes	1.94	1.94
Large NoReGas	3.736	1	0.05	3	68.169	40	0	0.028	0.05	Yes	2.06	2.06
UltraLarge NoRegas	4.664	1	0.05	3	79.835	40	0	0.026	0.05	Yes	2.19	2.19

A.4 Pipeline specifications

Origin Node	Dest. Node	Capacity Incre-ment (PJ/day)	Years Planning and Approval	Planning and Approval Cost ($MM/yr)	Years Invest-ment	Investment Cost (2006$MM/yr)	Max Life (years)	Fixed O&M Costs (2006 $MM/yr)	Variable O&M Cost (2006 $MM/yr)	Fuel Use (%)	Retire-ment Cost (2006 $MM)
Africa - North	Africa - Rest	1.08	3	0.5	3	2978	100	0	0.412	8.25%	0.5
Africa - North	Europe- South	1.08	3	0.5	3	1415	100	0	0.112	2.24%	0.5
Africa - North	Europe- South West	1.08	3	0.5	3	1357	100	0	0.088	1.77%	0.5
Africa - North	Rest of Middle East	1.08	3	0.5	3	1778	100	0	0.246	4.92%	0.5
Africa - Rest	Africa - South	1.08	3	0.5	3	178	100	0	0.025	0.49%	0.5
Africa - West	Africa - North	1.08	3	0.5	3	1257	100	0	0.174	3.48%	0.5
Africa - West	Africa - Rest	1.08	3	0.5	3	2258	100	0	0.313	6.25%	0.5
Asia - Northwest	India - North	1.08	3	0.5	3	276	100	0	0.038	0.76%	0.5
Asia - Other Developing SE	China - West	1.08	3	0.5	3	1352	100	0	0.187	3.74%	0.5
Asia - Other Developing SE	India - Southeast	1.08	3	0.5	3	610	100	0	0.084	1.69%	0.5
Asia - Producers	Asia - Other Developed	1.08	3	0.5	3	523	100	0	0.072	1.45%	0.5
Australia and NZ - NW Shelf	Australia and NZ - Demand	1.08	3	0.5	3	2062	100	0	0.286	5.71%	0.5
Brazil	Latin America - Northern Producers	1.08	3	0.5	3	2692	100	0	0.373	7.46%	0.5
Canada East	US - East North Central	1.08	3	0.5	3	603	100	0	0.084	1.67%	0.5
Canada East	US - Middle Atlantic	1.08	3	0.5	3	315	100	0	0.044	0.87%	0.5
Canada East	US - New England	1.08	3	0.5	3	294	100	0	0.041	0.81%	0.5
Canada East	US - West North Central	1.08	3	0.5	3	874	100	0	0.121	2.42%	0.5
Canada West	Canada East	1.08	3	0.5	3	1650	100	0	0.229	4.57%	0.5
Canada West	US - Mountain	1.08	3	0.5	3	967	100	0	0.134	2.68%	0.5
Canada West	US - Pacific Northwest	1.08	3	0.5	3	645	100	0	0.089	1.79%	0.5

A.4 Pipeline specifications (cont.)

Origin Node	Dest. Node	Capacity Increment (PJ/day)	Years Planning and Approval	Planning and Approval Cost ($MM/yr)	Years Invest-ment	Investment Cost (2006$MM/yr)	Max Life (years)	Fixed O&M Costs (2006 $MM/yr)	Variable O&M Cost (2006 $MM/yr)	Fuel Use (%)	Retire-ment Cost (2006 $MM)
Canada West	US - West North Central	1.08	3	0.5	3	1154	100	0	0.16	3.20%	0.5
China - Northeast	China - South	1.08	3	0.5	3	1100	100	0	0.152	3.05%	0.5
China - Northeast	South Korea	1.08	3	0.5	3	554	100	0	0.077	1.54%	0.5
China - South	Asia - Other Developed	1.08	3	0.5	3	554	100	0	0.077	1.54%	0.5
China - South	China - Northeast	1.08	3	0.5	3	1100	100	0	0.152	3.05%	0.5
China - South	China - West	1.08	3	0.5	3	762	100	0	0.106	2.11%	0.5
China - West	Asia - Northwest	1.08	3	0.5	3	1977	100	0	0.274	5.48%	0.5
China - West	China - South	1.08	3	0.5	3	762	100	0	0.106	2.11%	0.5
Europe- East	Europe- North	1.08	3	0.5	3	966	100	0	0.134	2.68%	0.5
Europe- East	Europe- South	1.08	3	0.5	3	981	100	0	0.136	2.72%	0.5
Europe- East	Europe- Turkey	1.08	3	0.5	3	937	100	0	0.13	2.59%	0.5
Europe- East	Russia West	1.08	3	0.5	3	1064	100	0	0.147	2.95%	0.5
Europe- North	Europe- East	1.08	3	0.5	3	966	100	0	0.134	2.68%	0.5
Europe- North	Europe- South	1.08	3	0.5	3	551	100	0	0.076	1.53%	0.5
Europe- North	Europe- South West	1.08	3	0.5	3	771	100	0	0.107	2.14%	0.5
Europe- South	Europe- East	1.08	3	0.5	3	981	100	0	0.136	2.72%	0.5
Europe- South	Europe- North	1.08	3	0.5	3	551	100	0	0.076	1.53%	0.5
Europe- South West	Europe- North	1.08	3	0.5	3	771	100	0	0.107	2.14%	0.5
Europe- Turkey	Europe- East	1.08	3	0.5	3	937	100	0	0.13	2.59%	0.5
Europe- Turkey	Europe- South	1.08	3	0.5	3	1137	100	0	0.157	3.15%	0.5
Europe- Turkey	Rest of Middle East	1.08	3	0.5	3	388	100	0	0.054	1.07%	0.5
FSU Central Asia	Asia - Northwest	1.08	3	0.5	3	740	100	0	0.102	2.05%	0.5
FSU Central Asia	China - West	1.08	3	0.5	3	2348	100	0	0.325	6.50%	0.5
FSU Central Asia	Europe- East	1.08	3	0.5	3	1838	100	0	0.255	5.09%	0.5
FSU Central Asia	Europe- Turkey	1.08	3	0.5	3	1526	100	0	0.211	4.23%	0.5

A.4 Pipeline specifications (cont.)

Origin Node	Dest. Node	Capacity Incre-ment (PJ/day)	Years Planning and Approval	Planning and Approval Cost ($MM/yr)	Years Invest-ment	Investment Cost (2006$MM/yr)	Max Life (years)	Fixed O&M Costs (2006 $MM/yr)	Variable O&M Cost (2006 $MM/yr)	Fuel Use (%)	Retire-ment Cost (2006 $MM)
FSU Central Asia	Iran	1.08	3	0.5	3	918	100	0	0.127	2.54%	0.5
FSU Central Asia	Russia Caspian Sea	1.08	3	0.5	3	1102	100	0	0.153	3.05%	0.5
FSU Central Asia	Russia West	1.08	3	0.5	3	1627	100	0	0.225	4.51%	0.5
India - Southeast	India - Southwest	1.08	3	0.5	3	279	100	0	0.072	1.44%	0.5
India - Southwest	India - North	1.08	3	0.5	3	521	100	0	0.072	1.44%	0.5
Iran	Europe- Turkey	1.08	3	0.5	3	1606	100	0	0.222	4.45%	0.5
Iran	FSU Central Asia	1.08	3	0.5	3	918	100	0	0.127	2.54%	0.5
Iraq	Arabian Producers	1.08	3	0.5	3	45	100	0	0.065	15.00%	0.2
Iraq	Europe- Turkey	1.08	3	0.5	3	842	100	0	0.117	2.33%	0.5
Iraq	Rest of Middle East	1.08	3	0.5	3	187	100	0	0.026	0.52%	0.5
Latin America - Andean	Brazil	1.08	3	0.5	3	2297	100	0	0.318	6.36%	0.5
Latin America - Andean	Latin America - Southern Cone	1.08	3	0.5	3	1829	100	0	0.253	5.07%	0.5
Latin America - Central America	US - Florida	1.08	3	0.5	3	975	100	0	0.135	2.70%	0.5
Latin America - Northern Producers	Brazil	1.08	3	0.5	3	2692	100	0	0.373	7.46%	0.5
Latin America - Northern Producers	Latin America - Central America	1.08	3	0.5	3	1063	100	0	0.147	2.95%	0.5
Latin America - Southern Cone	Brazil	1.08	3	0.5	3	1276	100	0	0.177	3.53%	0.5
Latin America - Southern Cone	Chile	1.08	3	0.5	3	717	100	0	0.099	1.99%	0.5
Mexico Northeast	US - West South Central	1.08	3	0.5	3	499	100	0	0.069	1.38%	0.5
Mexico Northwest	Mexico Northeast	1.08	3	0.5	3	648	100	0	0.09	1.80%	0.5
Mexico Northwest	US - AZNM	1.08	3	0.5	3	289	100	0	0.04	0.80%	0.5
Mexico Northwest	US - California	1.08	3	0.5	3	501	100	0	0.069	1.39%	0.5
Mexico South	Mexico Northeast	1.08	3	0.5	3	413	100	0	0.057	1.14%	0.5

A.4 Pipeline specifications (cont.)

Origin Node	Dest. Node	Capacity Incre-ment (PJ/day)	Years Planning and Approval	Planning and Approval Cost ($MM/yr)	Years Invest-ment	Investment Cost (2006$MM/yr)	Max Life (years)	Fixed O&M Costs (2006 $MM/yr)	Variable O&M Cost (2006 $MM/yr)	Fuel Use (%)	Retire-ment Cost (2006 $MM)
Mexico Southwest LNG	Mexico South	1.08	3	0.5	3	292	100	0	0.04	0.81%	0.5
Qatar	Arabian Producers	1.08	3	0.5	3	557	100	0	0.077	1.54%	0.5
Rest of Middle East	Europe- Turkey	1.08	3	0.5	3	388	100	0	0.054	1.07%	0.5
Russia Caspian Sea	Europe- Turkey	1.08	3	0.5	3	548	100	0	0.076	1.52%	0.5
Russia Caspian Sea	FSU Central Asia	1.08	3	0.5	3	1102	100	0	0.153	3.05%	0.5
Russia Caspian Sea	Russia West	1.08	3	0.5	3	1102	100	0	0.153	3.05%	0.5
Russia East	China - Northeast	1.08	3	0.5	3	999	100	0	0.138	2.77%	0.5
Russia East	China - West	1.08	3	0.5	3	2874	100	0	0.398	7.96%	0.5
Russia East	Russia Sakhalin	1.08	3	0.5	3	2874	100	0	0.398	7.96%	0.5
Russia East	Russia West	1.08	3	0.5	3	2874	100	0	0.398	7.96%	0.5
Russia Sakhalin	China - Northeast	1.08	3	0.5	3	999	100	0	0.138	2.77%	0.5
Russia Sakhalin	Russia East	1.08	3	0.5	3	647	100	0	0.09	1.79%	0.5
Russia Shtokman	Russia West	1.08	3	0.5	3	635	100	0	0.088	1.76%	0.5
Russia West	China - West	1.08	3	0.5	3	1726	100	0	0.398	7.96%	0.5
Russia West	Europe- East	1.08	3	0.5	3	1064	100	0	0.147	2.95%	0.5
Russia West	Europe- North	1.08	3	0.5	3	1864	100	0	0.258	5.16%	0.5
Russia West	Russia Caspian Sea	1.08	3	0.5	3	1102	100	0	0.153	3.05%	0.5
Russia West	Russia East	1.08	3	0.5	3	2874	100	0	0.398	7.96%	0.5
Russia Yamal	Russia West	1.08	3	0.5	3	575	100	0	0.08	1.59%	0.5
US - Arctic	Canada West	1.08	3	0.5	3	1476	100	0	0.204	4.09%	0.5
US - AZNM	Mexico Northwest	1.08	3	0.5	3	289	100	0	0.04	0.80%	0.5
US - AZNM	US - California	1.08	3	0.5	3	330	100	0	0.046	0.92%	0.5
US - AZNM	US - Mountain	1.08	3	0.5	3	548	100	0	0.076	1.52%	0.5
US - AZNM	US - West South Central	1.08	3	0.5	3	828	100	0	0.115	2.29%	0.5

A.4 Pipeline specifications (cont.)

Origin Node	Dest. Node	Capacity Incre-ment (PJ/day)	Years Planning and Approval	Planning and Approval Cost ($MM/yr)	Years Invest-ment	Investment Cost (2006$MM/yr)	Max Life (years)	Fixed O&M Costs (2006 $MM/yr)	Variable O&M Cost (2006 $MM/yr)	Fuel Use (%)	Retire-ment Cost (2006 $MM)
US - California	Mexico Northwest	1.08	3	0.5	3	501	100	0	0.069	1.39%	0.5
US - California	US - AZNM	1.08	3	0.5	3	330	100	0	0.046	0.92%	0.5
US - California	US - Mountain	1.08	3	0.5	3	784	100	0	0.109	2.17%	0.5
US - East North Central	Canada East	1.08	3	0.5	3	603	100	0	0.084	1.67%	0.5
US - East North Central	US - East South Central	1.08	3	0.5	3	631	100	0	0.087	1.75%	0.5
US - East North Central	US - Middle Atlantic	1.08	3	0.5	3	666	100	0	0.092	1.84%	0.5
US - East North Central	US - South Atlantic	1.08	3	0.5	3	551	100	0	0.076	1.53%	0.5
US - East North Central	US - West North Central	1.08	3	0.5	3	290	100	0	0.04	0.80%	0.5
US - East South Central	US - East North Central	1.08	3	0.5	3	631	100	0	0.087	1.75%	0.5
US - East South Central	US - Florida	1.08	3	0.5	3	640	100	0	0.089	1.77%	0.5
US - East South Central	US - South Atlantic	1.08	3	0.5	3	328	100	0	0.045	0.91%	0.5
US - East South Central	US - West South Central	1.08	3	0.5	3	361	100	0	0.05	1.00%	0.5
US - Middle Atlantic	Canada East	1.08	3	0.5	3	315	100	0	0.044	0.87%	0.5
US - Middle Atlantic	US - East North Central	1.08	3	0.5	3	666	100	0	0.092	1.84%	0.5
US - Middle Atlantic	US - New England	1.08	3	0.5	3	178	100	0	0.025	0.49%	0.5
US - Middle Atlantic	US - South Atlantic	1.08	3	0.5	3	699	100	0	0.097	1.93%	0.5
US - Mountain	Canada West	1.08	3	0.5	3	967	100	0	0.134	2.68%	0.5
US - Mountain	US - AZNM	1.08	3	0.5	3	548	100	0	0.076	1.52%	0.5
US - Mountain	US - California	1.08	3	0.5	3	784	100	0	0.109	2.17%	0.5
US - Mountain	US - Pacific Northwest	1.08	3	0.5	3	918	100	0	0.127	2.54%	0.5
US - Mountain	US - West North Central	1.08	3	0.5	3	570	100	0	0.079	1.58%	0.5

A.4 Pipeline specifications (cont.)

Origin Node	Dest. Node	Capacity Incre-ment (PJ/day)	Years Planning and Approval	Planning and Approval Cost ($MM/yr)	Years Invest-ment	Investment Cost (2006$MM/yr)	Max Life (years)	Fixed O&M Costs (2006 $MM/yr)	Variable O&M Cost (2006 $MM/yr)	Fuel Use (%)	Retire-ment Cost (2006 $MM)
US - Mountain	US - West South Central	1.08	3	0.5	3	620	100	0	0.086	1.72%	0.5
US - New England	Canada East	1.08	3	0.5	3	294	100	0	0.041	0.81%	0.5
US - New England	US - Middle Atlantic	1.08	3	0.5	3	178	100	0	0.025	0.49%	0.5
US - Pacific Northwest	Canada West	1.08	3	0.5	3	645	100	0	0.089	1.79%	0.5
US - Pacific Northwest	US - California	1.08	3	0.5	3	792	100	0	0.11	2.19%	0.5
US - Pacific Northwest	US - Mountain	1.08	3	0.5	3	918	100	0	0.127	2.54%	0.5
US – South Atlantic	US – East North Central	1.083485	3	0.5	3	551	100	0	0.076365	1.53%	0.5
US – South Atlantic	US – East South Central	1.083485	3	0.5	3	328	100	0	0.045454	0.91%	0.5
US – South Atlantic	US – Florida	1.083485	3	0.5	3	509	100	0	0.070429	1.41%	0.5
US – South Atlantic	US – Middle Atlantic	1.083485	3	0.5	3	699	100	0	0.096731	1.93%	0.5
US – West North Central	Canada East	1.083485	3	0.5	3	874	100	0	0.121078	2.42%	0.5
US – West North Central	US – East North Central	1.083485	3	0.5	3	290	100	0	0.040102	0.80%	0.5
US – West North Central	US – Moiuntain	1.083485	3	0.5	3	570	100	0	0.078985	1.58%	0.5
US – West North Central	US – West South Central	1.083485	3	0.5	3	593	100	0	0.082102	1.64%	0.5
US – West South Central	Mexico Northeast	1.083485	3	0.5	3	499	100	0	0.069116	1.38%	0.5
US – West South Central	US - AZNM	1.083485	3	0.5	3	828	100	0	0.114632	2.29%	0.5
US – West South Central	US – East South Central	1.083485	3	0.5	3	361	100	0	0.049961	1.00%	0.5
US – West South Central	US – Mountain	1.083485	3	0.5	3	620	100	0	0.085842	1.72%	0.5
US – West South Central	US –West North Central	1.083485	3	0.5	3	593	100	0	0.082102	1.64%	0.5

A.5 Storage asset specifications

Capacity Increment (EJ of Working Gas)	Years Planning and Approval	Planning and Approval Cost ($MM/yr)	Years Invest-ment	Investment Cost (2006$MM/yr)	Max Life (years)	Fixed O&M Costs (2006 $MM/yr)	Variable O&M Cost (2006 $MM/yr)	Fuel Use (%)	Fuel Use (%)
230.4171	2	12.81	3	426.95	100	0	0.185	0.1	5.00%

A.6 Demand sector price elasticities

	tInp_DmdSector	
DmdSector Name	Price Elasticity for Iterative Runs	Price Elasticity for Final Fun
Residential	-0.87971	-0.031
Commercial	-0.9	-0.032
Transportation	-1	-0.033
Industrial Cogen	-1	-0.05
Industrial Feedstock	-0.92017	-0.05
Other Industrial	-0.6646	-0.05
Power Generation	-1	-0.055
Reinjection	-0.0001	-0.0001

A.7 Mapping from INGM nodes to WEPS+regions

tInp_Node_Scn

NodeId	RegionId
Africa - North	Africa
Africa - Rest	Africa
Africa - South	Africa
Africa - West	Africa
Arabian Producers	Middle East
Asia - Northwest	Other Asia
Asia - Other Developed	Other Asia
Asia - Other Developing SE	Other Asia
Asia - Producers	Other Asia
Australia and NZ - Demand	Australia & New-Zealand
Australia and NZ - NW Shelf	Australia & New-Zealand
Brazil	Brazil
Canada East	Canada
Canada West	Canada
Chile	Chile
China - Northeast	China
China - South	China
China - West	China
Europe- East	Non-OECD Europe and Eurasia
Europe- North	OECD Europe
Europe- South	OECD Europe
Europe- South West	OECD Europe
Europe- Turkey	OECD Europe
FSU Central Asia	Non-OECD Europe and Eurasia
India - North	India
India - Southeast	India
India - Southwest	India
Iran	Middle East
Iraq	Middle East
Japan	Japan
Latin America - Andean	Non-OECD Americas
Latin America - Central America	Non-OECD Americas
Latin America - Northern Producers	Non-OECD Americas

A.7 Mapping from INGM nodes to WEPS+regions (cont.)

tInp_Node_Scn

NodeId	RegionId
Latin America - Southern Cone	Non-OECD Americas
Mexico Northeast	Mexico
Mexico Northwest	Mexico
Mexico South	Mexico
Mexico Southwest LNG	Mexico
Qatar	Middle East
Rest of Middle East	Middle East
Russia Caspian Sea	Russia
Russia East	Russia
Russia Sakhalin	Russia
Russia Shtokman	Russia
Russia West	Russia
Russia Yamal	Russia
Saudi Arabia	Middle East
South Korea	South Korea
US - Arctic	United States
US - AZNM	United States
US - California	United States
US - East North Central	United States
US - East South Central	United States
US - Florida	United States
US - Middle Atlantic	United States
US - Mountain	United States
US - New England	United States
US - Pacific Northwest	United States
US - South Atlantic	United States
US - West North Central	United States
US - West South Central	United States

Appendix B Capacity Assumptions for Processing, Conversion, and Transporation Assets

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Africa - North	Gas Processing Plant	2006	2006	16.203	999999
Africa - North	Gas Processing Plant	2007	2060	0	999999
Africa - North	Liquefaction Plant	2006	2006	4.334628	4.334628
Africa - North	Liquefaction Plant	2012	2013	0.645943	0.98953
Africa - North	Liquefaction Plant	2014	2015	0.645943	1.126965
Africa - North	Liquefaction Plant	2016	2060	0	999999
Africa - Rest	Gas Processing Plant	2006	2060	0	999999
Africa - Rest	Liquefaction Plant	2016	2060	0	999999
Africa - South	Gas Processing Plant	2006	2060	0	999999
Africa - South	Small GTL Plant	2007	2007	0.276	0.276
Africa - South	Small GTL Plant	2012	2012	0.0138	0.0138
Africa - South	Small GTL Plant	2013	2013	0.01449	0.01449
Africa - South	Small GTL Plant	2014	2014	0.015215	0.015215
Africa - South	Small GTL Plant	2015	2015	0.009585	0.009585
Africa - South	Small GTL Plant	2016	2020	0.00831	0.00831
Africa - South	Small GTL Plant	2021	2025	0.00852	0.00852
Africa - South	Small GTL Plant	2026	2030	0.008735	0.008735
Africa - South	Small GTL Plant	2031	2035	0.008955	0.008955
Africa - South	Small GTL Plant	2036	2040	0.008955	0.008955
Africa - South	Small Regas Plant	2016	2060	0	999999
Africa - West	Gas Processing Plant	2006	2006	2.54	999999
Africa - West	Gas Processing Plant	2007	2060	0	999999
Africa - West	Liquefaction Plant	2008	2008	2.241171	2.241171
Africa - West	Liquefaction Plant	2010	2010	0.518324	0.518324
Africa - West	Liquefaction Plant	2011	2011	0.518324	0.518324
Africa - West	Liquefaction Plant	2012	2012	0.35733	0.35733
Africa - West	Liquefaction Plant	2013	2013	0.35733	0.35733
Africa - West	Liquefaction Plant	2016	2060	0	999999
Africa - West	Small GTL Plant	2013	2013	0.1045	0.1045
Africa - West	Small GTL Plant	2014	2014	0.1045	0.1045

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Arabian Producers	Gas Processing Plant	2006	2006	4.688	999999
Arabian Producers	Gas Processing Plant	2007	2060	0	999999
Arabian Producers	Liquefaction Plant	2006	2006	1.553013	1.553013
Arabian Producers	Liquefaction Plant	2009	2009	0.460406	0.460406
Arabian Producers	Liquefaction Plant	2010	2010	0.460406	0.460406
Arabian Producers	Liquefaction Plant	2116	2160	0	999999
Arabian Producers	Small Regas Plant	2009	2009	0.180229	0.180229
Arabian Producers	Small Regas Plant	2010	2010	0.765974	0.765974
Arabian Producers	Small Regas Plant	2011	2011	0.135172	0.135172
Arabian Producers	Small Regas Plant	2015	2060	0	999999
Asia - Northwest	Gas Processing Plant	2006	2006	1.298	999999
Asia - Northwest	Gas Processing Plant	2007	2060	0	999999
Asia - Northwest	Small Regas Plant	2012	2013	0	0.481022
Asia - Northwest	Small Regas Plant	2014	2015	0	0.481022
Asia - Northwest	Small Regas Plant	2016	2060	0	1032289
Asia - Other Developed	Gas Processing Plant	2006	2060	0	999999
Asia - Other Developed	Small Regas Plant	2006	2006	1.085735	1.085735
Asia - Other Developed	Small Regas Plant	2008	2008	0.206152	0.206152
Asia - Other Developed	Small Regas Plant	2009	2009	0.206152	0.206152
Asia - Other Developed	Small Regas Plant	2012	2014	0	0.412304
Asia - Other Developed	Small Regas Plant	2015	2060	0	999999
Asia - Other Developing SE	Gas Processing Plant	2006	2006	1.503	999999
Asia - Other Developing SE	Gas Processing Plant	2007	2060	0	999999
Asia - Other Developing SE	Liquefaction Plant	2012	2013	0.233639	0.371074
Asia - Other Developing SE	Liquefaction Plant	2014	2015	0	1.965317
Asia - Other Developing SE	Liquefaction Plant	2016	2060	0	999999
Asia - Other Developing SE	Small Regas Plant	2012	2014	0	0.687174
Asia - Other Developing SE	Small Regas Plant	2015	2060	0	999999

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Asia - Producers	Gas Processing Plant	2006	2006	13.963	999999
Asia - Producers	Gas Processing Plant	2007	2060	0	999999
Asia - Producers	Liquefaction Plant	2006	2006	7.160351	7.160351
Asia - Producers	Liquefaction Plant	2008	2008	0.522252	0.522252
Asia - Producers	Liquefaction Plant	2009	2009	0.522252	0.522252
Asia - Producers	Liquefaction Plant	2010	2010	0	0.137435
Asia - Producers	Liquefaction Plant	2011	2015	0	0.824609
Asia - Producers	Liquefaction Plant	2016	2060	0	999999
Asia - Producers	Small GTL Plant	2001	2001	0.09	0.09
Asia - Producers	Small Regas Plant	2012	2014	0.206152	0.412304
Asia - Producers	Small Regas Plant	2015	2060	0	999999
Australia and NZ - Demand	Gas Processing Plant	2006	2060	0	999999
Australia and NZ - Demand	Liquefaction Plant	2015	2015	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2016	2016	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2017	2017	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2018	2018	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2019	2019	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2020	2020	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2021	2021	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2022	2022	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2023	2023	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2024	2024	0	0.470115
Australia and NZ - Demand	Liquefaction Plant	2025	2025	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2026	2026	0	0.183246

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Australia and NZ - Demand	Liquefaction Plant	2027	2027	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2028	2028	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2029	2029	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2030	2030	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2031	2031	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2032	2032	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2033	2033	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2034	2034	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2035	2035	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2036	2036	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2037	2037	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2038	2038	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2039	2039	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2040	2040	0	0.183246
Australia and NZ - Demand	Liquefaction Plant	2041	2041	0	0.183246
Australia and NZ - Demand	Small Regas Plant	2012	2014	0	0.412304
Australia and NZ - Demand	Small Regas Plant	2015	2060	0	999999
Australia and NZ - NW Shelf	Gas Processing Plant	2006	2006	4.763	999999
Australia and NZ - NW Shelf	Gas Processing Plant	2007	2060	0	999999
Australia and NZ - NW Shelf	Liquefaction Plant	2006	2006	1.889728	1.889728
Australia and NZ - NW Shelf	Liquefaction Plant	2007	2007	0.240511	0.240511
Australia and NZ - NW Shelf	Liquefaction Plant	2008	2008	0.201571	0.201571

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Australia and NZ - NW Shelf	Liquefaction Plant	2009	2009	0.403142	0.403142
Australia and NZ - NW Shelf	Liquefaction Plant	2010	2010	0	0
Australia and NZ - NW Shelf	Liquefaction Plant	2011	2011	0.439791	0.439791
Australia and NZ - NW Shelf	Liquefaction Plant	2012	2012	0.219896	0.219896
Australia and NZ - NW Shelf	Liquefaction Plant	2013	2013	0	0
Australia and NZ - NW Shelf	Liquefaction Plant	2014	2014	0.229058	0.229058
Australia and NZ - NW Shelf	Liquefaction Plant	2015	2015	0.687174	0.687174
Australia and NZ - NW Shelf	Liquefaction Plant	2016	2016	0.687174	0.687174
Australia and NZ - NW Shelf	Liquefaction Plant	2017	2017	0.458116	1.787797
Australia and NZ - NW Shelf	Liquefaction Plant	2018	2060	0	999999
Brazil	Gas Processing Plant	2006	2006	1.177	999999
Brazil	Gas Processing Plant	2007	2060	0	999999
Brazil	Liquefaction Plant	2025	2027	0	0.1649
Brazil	Liquefaction Plant	2028	2030	0	0.1649
Brazil	Liquefaction Plant	2031	2033	0	0.1649
Brazil	Liquefaction Plant	2034	2036	0	0.1649
Brazil	Liquefaction Plant	2037	2039	0	0.1649
Brazil	Liquefaction Plant	2040	2042	0	0.1649
Brazil	Liquefaction Plant	2043	2045	0	0.1649
Brazil	Liquefaction Plant	2046	2048	0	0.1649
Brazil	Liquefaction Plant	2049	2051	0	0.1649
Brazil	Liquefaction Plant	2052	2054	0	0.1649
Brazil	Small Regas Plant	2009	2009	0.886454	0.886454
Brazil	Small Regas Plant	2010	2010	0.364202	0.364202
Brazil	Small Regas Plant	2011	2014	0.522252	1.250656
Brazil	Small Regas Plant	2015	2060	0	999999
Canada East	Gas Processing Plant	2006	2006	0.652	999999
Canada East	Gas Processing Plant	2007	2060	0	999999

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Canada East	Small Regas Plant	2009	2009	0.542867	0.542867
Canada East	Small Regas Plant	2010	2010	0.542867	0.542867
Canada East	Small Regas Plant	2014	2015	0	0.549739
Canada East	Small Regas Plant	2016	2060	0	999999
Canada West	Gas Processing Plant	2006	2006	56.38	999999
Canada West	Gas Processing Plant	2007	2060	0	999999
Canada West	Liquefaction Plant	2013	2014	0	0.068717
Canada West	Liquefaction Plant	2015	2017	0	0.687174
Canada West	Liquefaction Plant	2018	2060	0	999999
Canada West	Small Regas Plant	2012	2014	0	0.687174
Canada West	Small Regas Plant	2015	2060	0	999999
Chile	Gas Processing Plant	2006	2006	0.518143	0.518143
Chile	Gas Processing Plant	2007	2060	0	999999
Chile	Small Regas Plant	2009	2009	0.351833	0.351833
Chile	Small Regas Plant	2010	2010	0.350459	0.350459
Chile	Small Regas Plant	2016	2060	0	999999
China - Northeast	Gas Processing Plant	2006	2060	0	999999
China - Northeast	Small Regas Plant	2012	2012	0	0.412304
China - Northeast	Small Regas Plant	2013	2013	0	0.412304
China - Northeast	Small Regas Plant	2014	2014	0	0.412304
China - Northeast	Small Regas Plant	2015	2060	0	999999
China - South	Gas Processing Plant	2006	2060	0	999999
China - South	Small Regas Plant	2006	2006	0.254254	0.254254
China - South	Small Regas Plant	2007	2007	0.254254	0.254254
China - South	Small Regas Plant	2009	2009	0.384817	0.384817
China - South	Small Regas Plant	2010	2010	0.384817	0.384817
China - South	Small Regas Plant	2011	2011	0	0.412304
China - South	Small Regas Plant	2012	2012	0	0.412304
China - South	Small Regas Plant	2013	2013	0	0.412304
China - South	Small Regas Plant	2014	2014	0	0.412304
China - South	Small Regas Plant	2015	2060	0	999999
China - West	Gas Processing Plant	2006	2060	0	999999

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Europe- East	Gas Processing Plant	2006	2006	0.047	999999
Europe- East	Gas Processing Plant	2007	2060	0	999999
Europe- East	Small Regas Plant	2013	2015	0	1.099478
Europe- East	Small Regas Plant	2016	2060	0	999999
Europe- North	Gas Processing Plant	2006	2006	22.177	999999
Europe- North	Gas Processing Plant	2007	2060	0	999999
Europe- North	Liquefaction Plant	2007	2007	0.085897	0.085897
Europe- North	Liquefaction Plant	2008	2008	0.296584	0.296584
Europe- North	Liquefaction Plant	2009	2009	0.194745	0.194745
Europe- North	Liquefaction Plant	2016	2060	0	999999
Europe- North	Small Regas Plant	2006	2006	2.789926	2.789926
Europe- North	Small Regas Plant	2008	2008	0.865839	0.865839
Europe- North	Small Regas Plant	2009	2009	2.226443	2.226443
Europe- North	Small Regas Plant	2010	2010	0	0.824609
Europe- North	Small Regas Plant	2011	2011	0.872711	0.872711
Europe- North	Small Regas Plant	2012	2012	0.27487	1.649217
Europe- North	Small Regas Plant	2013	2014	0	0.824609
Europe- North	Small Regas Plant	2015	2060	0	999999
Europe- South	Gas Processing Plant	2006	2006	5.621	999999
Europe- South	Gas Processing Plant	2007	2060	0	999999
Europe- South	Small Regas Plant	2006	2006	0.563483	0.563483
Europe- South	Small Regas Plant	2009	2009	0.412304	0.412304
Europe- South	Small Regas Plant	2010	2010	0.824609	0.824609
Europe- South	Small Regas Plant	2011	2012	0	1.374348
Europe- South	Small Regas Plant	2013	2014	0	2.748695
Europe- South	Small Regas Plant	2015	2060	0	999999
Europe- South West	Gas Processing Plant	2006	2060	0	999999
Europe- South West	Small Regas Plant	2006	2006	5.328346	5.328346
Europe- South West	Small Regas Plant	2007	2007	0.261126	0.261126
Europe- South West	Small Regas Plant	2008	2008	0.109948	0.109948
Europe- South West	Small Regas Plant	2009	2009	0.137435	0.137435
Europe- South West	Small Regas Plant	2010	2010	0.408181	0.559208
Europe- South West	Small Regas Plant	2011	2011	0.365576	0.50084

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Europe- South West	Small Regas Plant	2012	2014	0.732527	1.632725
Europe- South West	Small Regas Plant	2015	2060	0	999999
Europe- Turkey	Gas Processing Plant	2006	2060	0	999999
Europe- Turkey	Small Regas Plant	2006	2006	1.260277	1.260277
Europe- Turkey	Small Regas Plant	2015	2060	0	999999
FSU Central Asia	Gas Processing Plant	2006	2006	0.168	999999
FSU Central Asia	Gas Processing Plant	2007	2060	0	999999
India - North	Gas Processing Plant	2006	2006	3.857	999999
India - North	Gas Processing Plant	2007	2060	0	999999
India - Southeast	Gas Processing Plant	2006	2060	0	999999
India - Southeast	Small Regas Plant	2015	2060	0	999999
India - Southwest	Gas Processing Plant	2006	2006	0.154	999999
India - Southwest	Gas Processing Plant	2007	2060	0	999999
India - Southwest	Small Regas Plant	2006	2006	1.236913	1.236913
India - Southwest	Small Regas Plant	2009	2009	0.492016	0.492016
India - Southwest	Small Regas Plant	2010	2010	0.652815	0.652815
India - Southwest	Small Regas Plant	2012	2012	0.744896	0.744896
India - Southwest	Small Regas Plant	2013	2013	0.171793	0.171793
India - Southwest	Small Regas Plant	2015	2060	0	999999
Iran	Gas Processing Plant	2006	2006	6.373	999999
Iran	Gas Processing Plant	2007	2060	0	999999
Iran	Liquefaction Plant	2016	2018	0	1.374348
Iran	Liquefaction Plant	2019	2020	0	0.687174
Iran	Liquefaction Plant	2021	2022	0	0.687174
Iran	Liquefaction Plant	2023	2024	0	0.687174
Iran	Liquefaction Plant	2025	2026	0	0.687174
Iran	Liquefaction Plant	2027	2028	0	0.687174
Iran	Liquefaction Plant	2029	2030	0	0.687174
Iran	Liquefaction Plant	2031	2032	0	0.687174
Iran	Liquefaction Plant	2033	2034	0	0.687174

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Iran	Liquefaction Plant	2035	2036	0	0.687174
Iran	Liquefaction Plant	2037	2042	0	1.374348
Iran	Liquefaction Plant	2043	2048	0	1.374348
Iran	Liquefaction Plant	2053	2058	0	1.374348
Iran	Liquefaction Plant	2059	2060	0	0.687174
Iraq	Gas Processing Plant	2006	2006	4.085	999999
Iraq	Gas Processing Plant	2007	2060	0	999999
Iraq	Liquefaction Plant	2025	2027	0	0.1649
Iraq	Liquefaction Plant	2028	2030	0	0.1649
Iraq	Liquefaction Plant	2031	2033	0	0.1649
Iraq	Liquefaction Plant	2034	2036	0	0.1649
Iraq	Liquefaction Plant	2037	2039	0	0.1649
Iraq	Liquefaction Plant	2040	2042	0	0.1649
Iraq	Liquefaction Plant	2043	2045	0	0.1649
Iraq	Liquefaction Plant	2046	2048	0	0.1649
Iraq	Liquefaction Plant	2049	2051	0	0.1649
Iraq	Liquefaction Plant	2052	2054	0	0.1649
Japan	Gas Processing Plant	2006	2060	0	999999
Japan	Small Regas Plant	2006	2006	24.3878	24.3878
Japan	Small Regas Plant	2015	2060	0	999999
Latin America - Andean	Gas Processing Plant	2006	2006	1.596249	1.596249
Latin America - Andean	Gas Processing Plant	2007	2060	0	999999
Latin America - Andean	Liquefaction Plant	2010	2010	0.19928	0.19928
Latin America - Andean	Liquefaction Plant	2011	2011	0.412304	0.412304
Latin America - Andean	Liquefaction Plant	2016	2060	0	999999
Latin America - Central America	Gas Processing Plant	2006	2060	0	999999
Latin America - Central America	Small Regas Plant	2006	2006	0.371074	0.371074
Latin America - Central America	Small Regas Plant	2010	2011	0	0.412304
Latin America - Central America	Small Regas Plant	2012	2013	0	0.412304
Latin America - Central America	Small Regas Plant	2014	2060	0	999999

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Iran	Liquefaction Plant	2035	2036	0	0.687174
Iran	Liquefaction Plant	2037	2042	0	1.374348
Iran	Liquefaction Plant	2043	2048	0	1.374348
Iran	Liquefaction Plant	2053	2058	0	1.374348
Iran	Liquefaction Plant	2059	2060	0	0.687174
Iraq	Gas Processing Plant	2006	2006	4.085	999999
Iraq	Gas Processing Plant	2007	2060	0	999999
Iraq	Liquefaction Plant	2025	2027	0	0.1649
Iraq	Liquefaction Plant	2028	2030	0	0.1649
Iraq	Liquefaction Plant	2031	2033	0	0.1649
Iraq	Liquefaction Plant	2034	2036	0	0.1649
Iraq	Liquefaction Plant	2037	2039	0	0.1649
Iraq	Liquefaction Plant	2040	2042	0	0.1649
Iraq	Liquefaction Plant	2043	2045	0	0.1649
Iraq	Liquefaction Plant	2046	2048	0	0.1649
Iraq	Liquefaction Plant	2049	2051	0	0.1649
Iraq	Liquefaction Plant	2052	2054	0	0.1649
Japan	Gas Processing Plant	2006	2060	0	999999
Japan	Small Regas Plant	2006	2006	24.3878	24.3878
Japan	Small Regas Plant	2015	2060	0	999999
Latin America - Andean	Gas Processing Plant	2006	2006	1.596249	1.596249
Latin America - Andean	Gas Processing Plant	2007	2060	0	999999
Latin America - Andean	Liquefaction Plant	2010	2010	0.19928	0.19928
Latin America - Andean	Liquefaction Plant	2011	2011	0.412304	0.412304
Latin America - Andean	Liquefaction Plant	2016	2060	0	999999
Latin America - Central America	Gas Processing Plant	2006	2060	0	999999
Latin America - Central America	Small Regas Plant	2006	2006	0.371074	0.371074
Latin America - Central America	Small Regas Plant	2010	2011	0	0.412304
Latin America - Central America	Small Regas Plant	2012	2013	0	0.412304
Latin America - Central America	Small Regas Plant	2014	2060	0	999999

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Latin America - Northern Producers	Gas Processing Plant	2006	2006	6.138418	6.138418
Latin America - Northern Producers	Gas Processing Plant	2007	2060	0	999999
Latin America - Northern Producers	Liquefaction Plant	2008	2008	1.841217	1.841217
Latin America - Northern Producers	Liquefaction Plant	2009	2009	0.295763	0.295763
Latin America - Northern Producers	Liquefaction Plant	2015	2016	0	0.645943
Latin America - Northern Producers	Liquefaction Plant	2017	2018	0	1.291887
Latin America - Northern Producers	Liquefaction Plant	2019	2020	0	0.687174
Latin America - Northern Producers	Liquefaction Plant	2021	2022	0	0.687174
Latin America - Northern Producers	Liquefaction Plant	2023	2060	0	999999
Latin America - Southern Cone	Gas Processing Plant	2006	2006	5.306674	5.306674
Latin America - Southern Cone	Gas Processing Plant	2007	2060	0	999999
Latin America - Southern Cone	Small Regas Plant	2008	2008	0.25288	0.25288
Latin America - Southern Cone	Small Regas Plant	2014	2015	0	0.824609
Latin America - Southern Cone	Small Regas Plant	2016	2060	0	999999
Mexico Northeast	Gas Processing Plant	2006	2006	2.483	999999
Mexico Northeast	Gas Processing Plant	2007	2060	0	999999
Mexico Northeast	Small Regas Plant	2016	2060	0	999999
Mexico Northwest	Gas Processing Plant	2006	2006	0.276	999999
Mexico Northwest	Gas Processing Plant	2007	2060	0	999999
Mexico Northwest	Small Regas Plant	2008	2008	0.541493	0.541493
Mexico Northwest	Small Regas Plant	2009	2009	0.541493	0.541493
Mexico Northwest	Small Regas Plant	2012	2015	0	1.649217
Mexico Northwest	Small Regas Plant	2016	2060	0	999999
Mexico South	Gas Processing Plant	2006	2006	2.759	999999
Mexico South	Gas Processing Plant	2007	2060	0	999999

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Mexico South	Small Regas Plant	2006	2006	0.081087	0.081087
Mexico South	Small Regas Plant	2007	2007	0.460406	0.460406
Mexico South	Small Regas Plant	2012	2015	0	0.549739
Mexico South	Small Regas Plant	2016	2060	0	999999
Mexico Southwest LNG	Gas Processing Plant	2006	2060	0	999999
Mexico Southwest LNG	Small Regas Plant	2011	2011	0.522252	0.522252
Mexico Southwest LNG	Small Regas Plant	2013	2015	0	0.522252
Mexico Southwest LNG	Small Regas Plant	2016	2060	0	999999
Qatar	Gas Processing Plant	2006	2006	1.097	999999
Qatar	Gas Processing Plant	2007	2060	0	999999
Qatar	Liquefaction Plant	2006	2006	3.62278	3.62278
Qatar	Liquefaction Plant	2008	2008	0.492704	0.492704
Qatar	Liquefaction Plant	2009	2009	1.593556	1.593556
Qatar	Liquefaction Plant	2010	2010	3.215973	3.215973
Qatar	Liquefaction Plant	2011	2011	1.071991	1.071991
Qatar	Liquefaction Plant	2012	2012	0.714661	0.714661
Qatar	Liquefaction Plant	2016	2017	0	0.25
Qatar	Liquefaction Plant	2018	2019	0	0.25
Qatar	Liquefaction Plant	2020	2021	0	0.25
Qatar	Liquefaction Plant	2022	2023	0	0.25
Qatar	Liquefaction Plant	2024	2025	0	0.25
Qatar	Liquefaction Plant	2026	2027	0	0.25
Qatar	Liquefaction Plant	2028	2029	0	0.25
Qatar	Liquefaction Plant	2030	2031	0	0.25
Qatar	Liquefaction Plant	2032	2033	0	0.25
Qatar	Liquefaction Plant	2034	2035	0	0.25
Qatar	Liquefaction Plant	2036	2060	0	999999
Qatar	Small GTL Plant	2006	2006	0.030667	0.030667
Qatar	Small GTL Plant	2009	2009	0.019222	0.019222
Qatar	Small GTL Plant	2011	2011	0.318918	0.318918
Qatar	Small GTL Plant	2012	2012	0.214667	0.214667
Qatar	Small GTL Plant	2013	2013	0.143111	0.143111
Qatar	Small GTL Plant	2014	2014	0.143111	0.143111
Qatar	Small GTL Plant	2015	2015	0.143111	0.143111
Qatar	Small GTL Plant	2016	2017	0.120892	0.120892

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
Qatar	Small GTL Plant	2018	2019	0.120892	0.120892
Qatar	Small GTL Plant	2020	2021	0.120892	0.120892
Qatar	Small GTL Plant	2022	2023	0.120892	0.120892
Rest of Middle East	Gas Processing Plant	2006	2006	0.489	999999
Rest of Middle East	Gas Processing Plant	2007	2060	0	999999
Russia Caspian Sea	Gas Processing Plant	2006	2060	0	999999
Russia East	Gas Processing Plant	2006	2060	0	999999
Russia Sakhalin	Gas Processing Plant	2006	2060	0	999999
Russia Sakhalin	Liquefaction Plant	2009	2009	0.494765	0.494765
Russia Sakhalin	Liquefaction Plant	2010	2010	0.824609	0.824609
Russia Sakhalin	Liquefaction Plant	2011	2013	0	0.219896
Russia Sakhalin	Liquefaction Plant	2014	2016	0	1.319374
Russia Sakhalin	Liquefaction Plant	2017	2060	0	999999
Russia Shtokman	Gas Processing Plant	2006	2060	0	999999
Russia Shtokman	Liquefaction Plant	2023	2060	0	999999
Russia West	Gas Processing Plant	2006	2006	1.527	999999
Russia West	Gas Processing Plant	2007	2060	0	999999
Russia Yamal	Gas Processing Plant	2006	2060	0	999999
Russia Yamal	Liquefaction Plant	2018	2018	0	0.470115
Russia Yamal	Liquefaction Plant	2019	2019	0	0.470115
Russia Yamal	Liquefaction Plant	2020	2020	0	0.470115
Russia Yamal	Liquefaction Plant	2021	2021	0	0.470115
Russia Yamal	Liquefaction Plant	2022	2022	0	0.470115
Russia Yamal	Liquefaction Plant	2023	2023	0	0.470115
Russia Yamal	Liquefaction Plant	2024	2024	0	0.470115
Russia Yamal	Liquefaction Plant	2025	2060	0	999999
Saudi Arabia	Gas Processing Plant	2006	2006	10.906	999999
Saudi Arabia	Gas Processing Plant	2007	2060	0	999999
South Korea	Gas Processing Plant	2006	2060	0	999999
South Korea	Small Regas Plant	2006	2006	6.899225	6.899225

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
South Korea	Small Regas Plant	2009	2014	0	0.27487
South Korea	Small Regas Plant	2015	2060	0	999999
US - Arctic	Gas Processing Plant	2006	2006	10.347	999999
US - Arctic	Gas Processing Plant	2007	2060	0	999999
US - Arctic	Liquefaction Plant	2006	2006	0.178665	0.178665
US - Arctic	Liquefaction Plant	2116	2160	0	999999
US - AZNM	Gas Processing Plant	2006	2006	3.58	999999
US - AZNM	Gas Processing Plant	2007	2060	0	999999
US - California	Gas Processing Plant	2006	2006	1.609	999999
US - California	Gas Processing Plant	2007	2060	0	999999
US - California	Small Regas Plant	2013	2015	0	2.061521
US - California	Small Regas Plant	2016	2060	0	999999
US - East North Central	Gas Processing Plant	2006	2006	3.991	999999
US - East North Central	Gas Processing Plant	2007	2060	0	999999
US - East South Central	Gas Processing Plant	2006	2006	3.052	999999
US - East South Central	Gas Processing Plant	2007	2060	0	999999
US - East South Central	Small Regas Plant	2012	2012	1.408706	1.408706
US - East South Central	Small Regas Plant	2014	2015	0	1.374348
US - East South Central	Small Regas Plant	2016	2060	0	999999
US - Florida	Gas Processing Plant	2006	2006	0.091	999999
US - Florida	Gas Processing Plant	2007	2060	0	999999
US - Florida	Small Regas Plant	2013	2015	0	0.412304
US - Florida	Small Regas Plant	2016	2060	0	999999
US - Middle Atlantic	Gas Processing Plant	2006	2006	0.047	999999
US - Middle Atlantic	Gas Processing Plant	2007	2060	0	999999
US - Middle Atlantic	Small Regas Plant	2013	2015	0	2.061521
US - Middle Atlantic	Small Regas Plant	2016	2060	0	999999
US - Mountain	Gas Processing Plant	2006	2006	7.986	999999
US - Mountain	Gas Processing Plant	2007	2060	0	999999
US - New England	Gas Processing Plant	2006	2060	0	999999
US - New England	Small Regas Plant	2006	2006	0.742148	0.742148
US - New England	Small Regas Plant	2008	2008	0.412304	0.412304
US - New England	Small Regas Plant	2010	2010	0.412304	0.412304
US - New England	Small Regas Plant	2013	2014	0	0.522252
US - New England	Small Regas Plant	2015	2060	0	999999
US - Pacific Northwest	Gas Processing Plant	2006	2060	0	999999

B.1 Processing, liquefaction, regasification, and gtl asset nodal constraints (cont.)

Node	Asset	First Year Available	Last Year Available	Minimum Capacity Build	Maximum Capacity Build
US - Pacific Northwest	Small Regas Plant	2013	2015	0	3.435869
US - Pacific Northwest	Small Regas Plant	2016	2060	0	999999
US - South Atlantic	Gas Processing Plant	2006	2006	0.635	999999
US - South Atlantic	Gas Processing Plant	2007	2060	0	999999
US - South Atlantic	Small Regas Plant	2006	2006	1.456808	1.456808
US - South Atlantic	Small Regas Plant	2007	2007	0.302356	0.302356
US - South Atlantic	Small Regas Plant	2009	2009	0.566918	0.566918
US - South Atlantic	Small Regas Plant	2010	2010	0.429484	0.429484
US - South Atlantic	Small Regas Plant	2011	2011	0.240511	0.240511
US - South Atlantic	Small Regas Plant	2013	2015	0	2.061521
US - South Atlantic	Small Regas Plant	2016	2060	0	999999
US - West North Central	Gas Processing Plant	2006	2006	3.498	999999
US - West North Central	Gas Processing Plant	2007	2060	0	999999
US - West South Central	Gas Processing Plant	2006	2006	41.825	999999
US - West South Central	Gas Processing Plant	2007	2060	0	999999
US - West South Central	Small Regas Plant	2006	2006	1.649217	1.649217
US - West South Central	Small Regas Plant	2007	2007	0.604713	0.604713
US - West South Central	Small Regas Plant	2008	2008	1.044504	1.044504
US - West South Central	Small Regas Plant	2009	2009	4.870688	4.870688
US - West South Central	Small Regas Plant	2010	2010	3.952624	3.952624
US - West South Central	Small Regas Plant	2011	2011	1.030761	1.030761
US - West South Central	Small Regas Plant	2012	2015	0	11.44832
US - West South Central	Small Regas Plant	2016	2060	0	999999

B2. Tanker capacity

Tankerid	First Year	Last Year	Minimum Capacity Number of ships that can be added in the period	Maximum Capacity Number of ships that can be added in the period
Small NoRegas	1980	2003	32	32
Small NoRegas	2007	2007	2	2
Small NoRegas	2008	2008	1	1
Small NoRegas	2009	2100	0	250
Medium No Regas	1980	2003	96	96
Medium No Regas	2006	2006	86	86
Medium No Regas	2007	2007	24	24
Medium No Regas	2008	2008	43	43
Medium No Regas	2009	2009	13	13
Medium No Regas	2010	2014	0	200
Medium No Regas	2015	2019	0	200
Medium No Regas	2020	2024	0	200
Medium No Regas	2025	2029	0	200
Medium No Regas	2030	2100	2	9999
Large NoReGas	2009	2009	2	2
Large NoReGas	2010	2014	0	200
Large NoReGas	2015	2019	0	200
Large NoReGas	2020	2024	0	200
Large NoReGas	2025	2029	0	200
Large NoReGas	2030	2100	0	9999
UltraLarge NoRegas	2007	2007	4	4
UltraLarge NoRegas	2008	2008	19	19
UltraLarge NoRegas	2009	2009	13	13
UltraLarge NoRegas	2010	2014	0	150
UltraLarge NoRegas	2015	2019	0	150
UltraLarge NoRegas	2020	2024	0	150
UltraLarge NoRegas	2025	2029	0	150
UltraLarge NoRegas	2030	2100	0	9999

B.3 Pipeline capacity

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
Africa - North to Africa - Rest	2013	2060	0	999999
Africa - North to Europe- South	1983	1983	0.982762	0.982762
Africa - North to Europe- South	1991	1991	0.982762	0.982762
Africa - North to Europe- South	2005	2005	1.007331	1.007331
Africa - North to Europe- South	2007	2007	0.286639	0.286639
Africa - North to Europe- South	2008	2008	0.245691	0.245691
Africa - North to Europe- South	2010	2010	0.30964	0.30964
Africa - North to Europe- South	2012	2012	0.30964	0.30964
Africa - North to Europe- South	2013	2013	0.30964	0.30964
Africa - North to Europe- South	2014	2014	0.30964	0.30964
Africa - North to Europe- South	2015	2015	0.30964	0.30964
Africa - North to Europe- South	2016	2060	0	999999
Africa - North to Europe- South West	2006	2006	0.865248	0.865248
Africa - North to Europe- South West	2011	2011	0.255913	0.255913
Africa - North to Europe- South West	2012	2012	0.255913	0.255913
Africa - North to Europe- South West	2013	2013	0.255913	0.255913
Africa - North to Europe- South West	2014	2014	0.255913	0.255913
Africa - North to Europe- South West	2015	2015	0.255913	0.255913
Africa - North to Europe- South West	2016	2060	0	999999
Africa - North to Rest of Middle East	2003	2003	0.374184	0.374184
Africa - North to Rest of Middle East	2004	2004	0.374184	0.374184
Africa - North to Rest of Middle East	2008	2008	0.138049	0.138049
Africa - North to Rest of Middle East	2009	2009	0.138049	0.138049
Africa - North to Rest of Middle East	2012	2012	0.112686	0.112686
Africa - North to Rest of Middle East	2013	2013	0.112686	0.112686
Africa - North to Rest of Middle East	2014	2014	0.112686	0.112686
Africa - North to Rest of Middle East	2015	2015	0.112686	0.112686
Africa - North to Rest of Middle East	2016	2060	0	999999
Africa - Rest to Africa - South	2004	2004	0.313875	0.313875
Africa - West to Africa - North	2030	2060	0	999999
Africa - West to Africa - Rest	2008	2008	0.020925	0.020925
Africa - West to Africa - Rest	2011	2011	0.156937	0.156937
Africa - West to Africa - Rest	2013	2060	0	999999
Asia - Northwest to India - North	2120	2120	0	1.472

B.3 Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
Asia - Northwest to India - North	2121	2160	0	999999
Asia - Other Developing SE to China - West	2014	2014	0.62775	0.62775
Asia - Other Developing SE to China - West	2015	2015	0.62775	0.62775
Asia - Other Developing SE to China - West	2016	2060	0	999999
Asia - Producers to Asia - Other Developed	2006	2006	0.736	0.736
Asia - Producers to Asia - Other Developed	2113	2160	0	999999
Australia and NZ - NW Shelf to Australia and NZ - Demand	2006	2006	0.679	0.679
Australia and NZ - NW Shelf to Australia and NZ - Demand	2013	2060	0	999999
Brazil to Latin America - Northern Producers	2113	2160	0	999999
Canada East to US - East North Central	2008	2008	1.616456	1.616456
Canada East to US - East North Central	2013	2060	0	999999
Canada East to US - Middle Atlantic	2008	2008	3.481919	3.481919
Canada East to US - Middle Atlantic	2011	2011	0.540911	0.540911
Canada East to US - Middle Atlantic	2013	2060	0	999999
Canada East to US - New England	2008	2008	1.235621	1.235621
Canada East to US - New England	2013	2060	0	999999
Canada East to US - West North Central	2008	2008	5.34215	5.34215
Canada East to US - West North Central	2013	2060	0	999999
Canada West to Canada East	2006	2006	8.476	8.476
Canada West to Canada East	2013	2060	0	999999
Canada West to US - Mountain	2008	2008	0.166354	0.166354
Canada West to US - Mountain	2013	2060	0	999999
Canada West to US - Pacific Northwest	2008	2008	5.189398	5.189398
Canada West to US - Pacific Northwest	2013	2060	0	999999
Canada West to US - West North Central	2008	2008	2.56645	2.56645
Canada West to US - West North Central	2013	2060	0	999999
China - Northeast to China - South	2013	2060	0	999999
China - Northeast to South Korea	2023	2060	0	999999
China - South to Asia - Other Developed	2006	2006	0.4185	0.4185
China - South to China - Northeast	1997	1997	0.20925	0.20925
China - South to China - Northeast	2005	2005	0.156937	0.156937
China - South to China - Northeast	2006	2006	0.156937	0.156937

B.3. Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
China - South to China - Northeast	2011	2011	0.313875	0.313875
China - South to China - Northeast	2012	2060	0	999999
China - West to Asia - Northwest	2113	2160	0	999999
China - West to China - South	1997	1997	0.20925	0.20925
China - West to China - South	2005	2005	1.726312	1.726312
China - West to China - South	2006	2006	0.287719	0.287719
China - West to China - South	2007	2007	0.183094	0.183094
China - West to China - South	2010	2010	0.4185	0.4185
China - West to China - South	2011	2011	1.04625	1.04625
China - West to China - South	2012	2012	1.569374	1.569374
China - West to China - South	2013	2013	1.569374	1.569374
China - West to China - South	2014	2060	0	999999
Europe- East to Europe- North	2006	2006	14.662	14.662
Europe- East to Europe- North	2013	2060	0	999999
Europe- East to Europe- South	2006	2006	0.507	0.507
Europe- East to Europe- South	2013	2060	0	999999
Europe- East to Europe- Turkey	1988	1988	1.464749	1.464749
Europe- East to Europe- Turkey	2013	2060	0	999999
Europe- East to Russia West	2006	2006	0.258	0.258
Europe- East to Russia West	2013	2060	0	999999
Europe- North to Europe- East	2006	2006	0.884	0.884
Europe- North to Europe- East	2013	2060	0	999999
Europe- North to Europe- South	2006	2006	5.885	5.885
Europe- North to Europe- South	2007	2007	0.946	0.946
Europe- North to Europe- South	2008	2008	0.336	0.336
Europe- North to Europe- South	2009	2009	0.357	0.357
Europe- North to Europe- South	2013	2060	0	999999
Europe- North to Europe- South West	2006	2006	0.304	0.304
Europe- North to Europe- South West	2010	2010	0.096	0.096
Europe- North to Europe- South West	2013	2060	0	999999
Europe- South to Europe- East	2006	2006	0.157	0.157
Europe- South to Europe- East	2013	2060	0	999999
Europe- South to Europe- North	2006	2006	0.516	0.516
Europe- South to Europe- North	2013	2060	0	999999

B.3. Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
Europe- South West to Europe- North	2006	2006	0.0181	0.0181
Europe- South West to Europe- North	2013	2013	0.19115	0.19115
Europe- South West to Europe- North	2015	2015	0.575437	0.575437
Europe- South West to Europe- North	2016	2060	0	999999
Europe- Turkey to Europe- East	2016	2017	0	3.138749
Europe- Turkey to Europe- East	2018	2060	0	999999
Europe- Turkey to Europe- South	2007	2007	0.575437	0.575437
Europe- Turkey to Europe- South	2008	2008	0.575437	0.575437
Europe- Turkey to Europe- South	2013	2060	0	999999
Europe- Turkey to Rest of Middle East	2011	2011	0.104625	0.104625
Europe- Turkey to Rest of Middle East	2013	2060	0	999999
FSU Central Asia to Asia - Northwest	2113	2160	0	999999
FSU Central Asia to China - West	2010	2010	0.523125	0.523125
FSU Central Asia to China - West	2012	2012	3.661873	3.661873
FSU Central Asia to China - West	2013	2060	0	999999
FSU Central Asia to Europe- East	2113	2160	0	999999
FSU Central Asia to Europe- Turkey	2007	2007	0.690525	0.690525
FSU Central Asia to Europe- Turkey	2017	2017	1.401974	1.401974
FSU Central Asia to Europe- Turkey	2018	2060	0	999999
FSU Central Asia to Iran	2006	2006	0.841	0.841
FSU Central Asia to Iran	2010	2010	0.104625	0.104625
FSU Central Asia to Iran	2012	2012	0.523125	0.523125
FSU Central Asia to Iran	2013	2060	0	999999
FSU Central Asia to Russia Caspian Sea	2010	2010	0.523125	0.523125
FSU Central Asia to Russia Caspian Sea	2013	2060	0	999999
FSU Central Asia to Russia West	2005	2005	4.831888	4.831888
FSU Central Asia to Russia West	2006	2006	0	0
FSU Central Asia to Russia West	2013	2060	0	999999
India - Southeast to India - Southwest	2010	2011	0	0.767
India - Southeast to India - Southwest	2012	2013	0	0.767
India - Southeast to India - Southwest	2036	2060	0	999999
India - Southwest to India - North	2006	2006	1.304	1.304
India - Southwest to India - North	2009	2010	0	0.767

B.3. Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
India - Southwest to India - North	2011	2012	0	0.767
India - Southwest to India - North	2013	2060	0	999999
Iran to Europe- Turkey	2006	2006	0.62775	0.62775
Iran to Europe- Turkey	2010	2010	0.104625	0.104625
Iran to Europe- Turkey	2011	2011	0.104625	0.104625
Iran to Europe- Turkey	2012	2012	0.20925	0.20925
Iran to Europe- Turkey	2013	2013	0.20925	0.20925
Iran to Europe- Turkey	2014	2014	0.20925	0.20925
Iran to Europe- Turkey	2018	2021	0	1
Iran to Europe- Turkey	2022	2026	0	1
Iran to Europe- Turkey	2027	2030	0	1
Iran to Europe- Turkey	2031	2060	0	999999
Iran to FSU Central Asia	2006	2006	0.076376	0.076376
Iran to FSU Central Asia	2011	2013	0.076376	0.076376
Iran to FSU Central Asia	2014	2160	0	0.087885
Iraq to Arabian Producers	2025	2060	0	0.428962
Iraq to Europe- Turkey	2030	2034	0	0.366831
Iraq to Europe- Turkey	2036	2038	0	0.3154
Iraq to Europe- Turkey	2039	2041	0	0.3154
Iraq to Europe- Turkey	2042	2044	0	0.3154
Iraq to Europe- Turkey	2045	2047	0	0.3154
Iraq to Europe- Turkey	2048	2050	0	0.3154
Iraq to Europe- Turkey	2051	2053	0	0.3154
Iraq to Europe- Turkey	2054	2056	0	0.3154
Iraq to Rest of Middle East	2025	2060	0	0.220099
Latin America - Andean to Brazil	2001	2001	1.148782	1.148782
Latin America - Andean to Brazil	2003	2003	0.09207	0.09207
Latin America - Andean to Brazil	2013	2060	0	999999
Latin America - Andean to Latin America - Southern Cone	2006	2006	0.29295	0.29295
Latin America - Andean to Latin America - Southern Cone	2013	2060	0	999999
Latin America - Central America to US - Florida	2109	2109	0.915	0.915
Latin America - Central America to US - Florida	2113	2160	0	999999

B.3. Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
Latin America - Northern Producers to Brazil	2113	2160	0	999999
Latin America - Northern Producers to Latin America - Central America	2113	2160	0	999999
Latin America - Southern Cone to Brazil	2001	2001	0.104625	0.104625
Latin America - Southern Cone to Brazil	2013	2060	0	999999
Latin America - Southern Cone to Chile	1996	1996	0.076376	0.076376
Latin America - Southern Cone to Chile	1998	1998	0.363049	0.363049
Latin America - Southern Cone to Chile	1999	1999	0.183094	0.183094
Latin America - Southern Cone to Chile	2000	2000	0.959411	0.959411
Latin America - Southern Cone to Chile	2013	2060	0	999999
Mexico Northeast to US - West South Central	2008	2008	0.935347	0.935347
Mexico Northeast to US - West South Central	2013	2060	0	999999
Mexico Northwest to Mexico Northeast	2013	2060	0	999999
Mexico Northwest to US - AZNM	2013	2060	0	999999
Mexico Northwest to US - California	2008	2008	0.664368	0.664368
Mexico Northwest to US - California	2009	2009	0.087885	0.087885
Mexico Northwest to US - California	2013	2060	0	999999
Mexico South to Mexico Northeast	2006	2006	0.272	0.272
Mexico Southwest LNG to Mexico South	2008	2008	0.815	0.815
Mexico Southwest LNG to Mexico South	2013	2060	0	999999
Qatar to Arabian Producers	2007	2007	2.162598	2.162598
Qatar to Arabian Producers	2015	2060	1.297349	1.297349
Rest of Middle East to Europe- Turkey	2011	2011	0.104625	0.104625
Rest of Middle East to Europe- Turkey	2014	2060	0	999999
Russia Caspian Sea to Europe- Turkey	2006	2006	1.673999	1.673999
Russia Caspian Sea to Europe- Turkey	2015	2030	0	1.63
Russia Caspian Sea to FSU Central Asia	2005	2005	0.20925	0.20925
Russia Caspian Sea to FSU Central Asia	2115	2130	0	999999
Russia Caspian Sea to Russia West	2006	2006	4.184998	4.184998
Russia Caspian Sea to Russia West	2013	2060	0	999999
Russia East to Russia Sakhalin	2023	2060	0	999999
Russia East to Russia West	2013	2060	0	999999
Russia Sakhalin to China - Northeast	2023	2060	0	999999
Russia Sakhalin to Russia East	2006	2006	0.434	0.434
Russia Sakhalin to Russia East	2013	2060	0	999999

B.3. Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
Russia Shtokman to Russia West	2025	2025	0	0.657
Russia Shtokman to Russia West	2026	2026	0	0.657
Russia Shtokman to Russia West	2027	2027	0	0.657
Russia Shtokman to Russia West	2028	2028	0	0.657
Russia Shtokman to Russia West	2029	2029	0	0.657
Russia Shtokman to Russia West	2030	2030	0	0.657
Russia Shtokman to Russia West	2031	2031	0	0.657
Russia Shtokman to Russia West	2032	2032	0	0.657
Russia Shtokman to Russia West	2033	2060	0	999999
Russia West to China - West	2018	2060	0	999999
Russia West to Europe- East	2006	2006	26.18	26.18
Russia West to Europe- East	2013	2060	0	999999
Russia West to Europe- North	2006	2006	0.737	0.737
Russia West to Europe- North	2012	2012	1.438593	1.438593
Russia West to Europe- North	2013	2013	1.438593	1.438593
Russia West to Europe- North	2015	2015	1.438593	1.438593
Russia West to Europe- North	2016	2016	1.438593	1.438593
Russia West to Europe- North	2017	2060	0	999999
Russia West to Russia Caspian Sea	2006	2006	4.184998	4.184998
Russia West to Russia Caspian Sea	2013	2060	0	999999
Russia West to Russia East	2013	2060	0	999999
Russia Yamal to Russia West	2014	2014	0	0.935
Russia Yamal to Russia West	2015	2015	0	0.935
Russia Yamal to Russia West	2016	2016	0	0.935
Russia Yamal to Russia West	2017	2017	0	0.935
Russia Yamal to Russia West	2018	2018	0	0.935
Russia Yamal to Russia West	2019	2019	0	0.935
Russia Yamal to Russia West	2020	2020	0	0.935
Russia Yamal to Russia West	2021	2021	0	0.935
Russia Yamal to Russia West	2022	2022	0	0.935
Russia Yamal to Russia West	2023	2023	0	0.935
Russia Yamal to Russia West	2024	2024	0	0.935
Russia Yamal to Russia West	2025	2025	0	0.935

B.3. Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
Russia Yamal to Russia West	2026	2026	0	0.935
Russia Yamal to Russia West	2027	2027	0	0.935
Russia Yamal to Russia West	2028	2028	0	0.935
Russia Yamal to Russia West	2029	2029	0	0.935
Russia Yamal to Russia West	2030	2030	0	0.935
Russia Yamal to Russia West	2031	2031	0	0.935
Russia Yamal to Russia West	2032	2032	0	0.935
Russia Yamal to Russia West	2033	2033	0	0.935
Russia Yamal to Russia West	2034	2034	0	0.935
Russia Yamal to Russia West	2035	2035	0	0.935
Russia Yamal to Russia West	2036	2060	0	999999
US - Arctic to Canada West	2036	2040	0	4.217
US - Arctic to Canada West	2041	2060	0	999999
US - AZNM to Mexico Northwest	2006	2006	0.284	0.284
US - AZNM to Mexico Northwest	2013	2060	0	999999
US - AZNM to US - California	2008	2008	6.149855	6.149855
US - AZNM to US - California	2013	2060	0	999999
US - AZNM to US - Mountain	2008	2008	0.587992	0.587992
US - AZNM to US - Mountain	2013	2060	0	999999
US - AZNM to US - West South Central	2008	2008	3.613746	3.613746
US - AZNM to US - West South Central	2010	2010	0.107764	0.107764
US - AZNM to US - West South Central	2011	2011	0.037665	0.037665
US - AZNM to US - West South Central	2012	2012	0.899775	1.0044
US - AZNM to US - West South Central	2013	2060	0	999999
US - California to Mexico Northwest	2008	2008	0.892451	0.892451
US - California to Mexico Northwest	2010	2010	0.216574	0.216574
US - California to Mexico Northwest	2013	2060	0	999999
US - California to US - AZNM	2008	2008	0.664368	0.664368
US - California to US - AZNM	2013	2060	0	999999
US - California to US - Mountain	2006	2006	0.176	0.176
US - California to US - Mountain	2013	2060	0	999999
US - East North Central to Canada East	2008	2008	4.277068	4.277068
US - East North Central to Canada East	2011	2011	0.124504	0.124504

B.3. Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
US - East North Central to Canada East	2013	2060	0	999999
US - East North Central to US - East South Central	2006	2006	0.618	0.618
US - East North Central to US - East South Central	2013	2060	0	999999
US - East North Central to US - Middle Atlantic	2008	2008	2.316397	2.316397
US - East North Central to US - Middle Atlantic	2010	2010	0.24273	0.24273
US - East North Central to US - Middle Atlantic	2011	2011	0.42687	0.42687
US - East North Central to US - Middle Atlantic	2013	2060	0	999999
US - East North Central to US - South Atlantic	2008	2008	3.140841	3.140841
US - East North Central to US - South Atlantic	2013	2060	0	999999
US - East North Central to US - West North Central	2008	2008	1.043111	1.043111
US - East North Central to US - West North Central	2013	2060	0	999999
US - East South Central to US - East North Central	2008	2008	10.02098	10.02098
US - East South Central to US - East North Central	2013	2060	0	999999
US - East South Central to US - Florida	2008	2008	3.999812	3.999812
US - East South Central to US - Florida	2011	2011	0.810843	0.810843
US - East South Central to US - Florida	2013	2060	0	999999
US - East South Central to US - South Atlantic	2008	2008	11.13733	11.13733
US - East South Central to US - South Atlantic	2011	2011	0.236452	0.236452
US - East South Central to US - South Atlantic	2012	2012	0.134966	0.134966
US - East South Central to US - South Atlantic	2013	2060	0	999999
US - East South Central to US - West South Central	2008	2008	0.438379	0.438379
US - East South Central to US - West South Central	2013	2060	0	999999
US - Middle Atlantic to Canada East	2008	2008	0.107764	0.107764
US - Middle Atlantic to Canada East	2012	2012	0.189371	0.189371
US - Middle Atlantic to Canada East	2013	2060	0	999999
US - Middle Atlantic to US - East North Central	2006	2006	0.505	0.505
US - Middle Atlantic to US - East North Central	2013	2060	0	999999
US - Middle Atlantic to US - New England	2008	2008	3.828227	3.828227
US - Middle Atlantic to US - New England	2013	2060	0	999999
US - Middle Atlantic to US - South Atlantic	2008	2008	3.045632	3.045632
US - Middle Atlantic to US - South Atlantic	2013	2060	0	999999
US - Mountain to Canada West	2006	2006	0.081	0.081

B.3. Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
US - Mountain to Canada West	2013	2060	0	999999
US - Mountain to US - AZNM	2008	2008	2.376033	2.376033
US - Mountain to US - AZNM	2013	2060	0	999999
US - Mountain to US - California	2008	2008	1.923007	1.923007
US - Mountain to US - California	2010	2010	0.156937	0.156937
US - Mountain to US - California	2013	2060	0	999999
US - Mountain to US - Pacific Northwest	2008	2008	3.615839	3.615839
US - Mountain to US - Pacific Northwest	2013	2060	0	999999
US - Mountain to US - West North Central	2008	2008	10.74289	10.74289
US - Mountain to US - West North Central	2009	2009	0.081607	0.081607
US - Mountain to US - West North Central	2010	2010	0.515801	0.515801
US - Mountain to US - West North Central	2013	2060	0	999999
US - Mountain to US - West South Central	2006	2006	0.527	0.527
US - Mountain to US - West South Central	2013	2060	0	999999
US - New England to Canada East	2008	2008	0.233314	0.233314
US - New England to Canada East	2013	2060	0	999999
US - New England to US - Middle Atlantic	2008	2008	0.561836	0.561836
US - New England to US - Middle Atlantic	2013	2060	0	999999
US - Pacific Northwest to Canada West	2006	2006	0.055	0.055
US - Pacific Northwest to Canada West	2013	2060	0	999999
US - Pacific Northwest to US - California	2008	2008	2.585283	2.585283
US - Pacific Northwest to US - California	2013	2060	0	999999
US - Pacific Northwest to US - Mountain	2006	2006	0.065	0.065
US - Pacific Northwest to US - Mountain	2013	2060	0	999999
US - South Atlantic to US - East North Central	2006	2006	1.766	1.766
US - South Atlantic to US - East North Central	2013	2060	0	999999
US - South Atlantic to US - East South Central	2006	2006	0.23	0.23
US - South Atlantic to US - East South Central	2013	2060	0	999999
US - South Atlantic to US - Florida	2008	2008	0.444656	0.444656
US - South Atlantic to US - Florida	2013	2060	0	999999
US - South Atlantic to US - Middle Atlantic	2008	2008	9.334639	9.334639
US - South Atlantic to US - Middle Atlantic	2009	2009	0.162169	0.162169
US - South Atlantic to US - Middle Atlantic	2010	2010	0.107764	0.107764

B.3. Pipeline capacity (cont.)

Pipeline Route	First Year	Last Year	Mininum Capacity Build (PJ/day)	Maxinum Capacity Build (PJ/day)
US - South Atlantic to US - Middle Atlantic	2011	2011	0.648675	0.648675
US - South Atlantic to US - Middle Atlantic	2012	2012	0.524171	0.524171
US - South Atlantic to US - Middle Atlantic	2013	2060	0	999999
US - West North Central to Canada East	2008	2008	0.068006	0.068006
US - West North Central to Canada East	2013	2060	0	999999
US - West North Central to US - East North Central	2008	2008	13.95592	13.95592
US - West North Central to US - East North Central	2009	2009	1.730497	1.730497
US - West North Central to US - East North Central	2013	2060	0	999999
US - West North Central to US - Mountain	2008	2008	3.82195	3.82195
US - West North Central to US - Mountain	2013	2060	0	999999
US - West North Central to US - West South Central	2008	2008	0.986613	0.986613
US - West North Central to US - West South Central	2013	2060	0	999999
US - West South Central to Mexico Northeast	2008	2008	2.757914	2.757914
US - West South Central to Mexico Northeast	2013	2060	0	999999
US - West South Central to US - AZNM	2008	2008	5.014674	5.014674
US - West South Central to US - AZNM	2013	2060	0	999999
US - West South Central to US - East South Central	2008	2008	27.06962	27.06962
US - West South Central to US - East South Central	2009	2009	2.703509	2.703509
US - West South Central to US - East South Central	2010	2010	1.621687	1.621687
US - West South Central to US - East South Central	2011	2011	2.551803	2.551803
US - West South Central to US - East South Central	2012	2012	2.811273	2.811273
US - West South Central to US - East South Central	2013	2060	0	999999
US - West South Central to US - Mountain	2008	2008	0.216574	0.216574
US - West South Central to US - Mountain	2013	2060	0	999999
US - West South Central to US - West North Central	2008	2008	9.135851	9.135851
US - West South Central to US - West North Central	2011	2011	0.216574	0.216574
US - West South Central to US - West North Central	2013	2060	0	999999

B.4 Storage asset regional constraints

Node	First Year for Build	Last Year for Build	Minimum Capacity Build (EJ Working Gas)	Maximum Capacity Build (EJ Working Gas)
Australia and NZ - Demand	2007	2007	43.29992	43.29992
Australia and NZ - Demand	2013	2013	0	0
Australia and NZ - Demand	2014	2060	0	999999
Brazil	2007	2007	0	20
Brazil	2014	2060	0	999999
Canada East	2007	2007	269.4179	269.4179
Canada East	2013	2013	0	0
Canada East	2014	2060	0	999999
Canada West	2007	2007	357.2893	357.2893
Canada West	2013	2013	0	0
Canada West	2014	2060	0	999999
China - Northeast	2007	2007	38.18335	38.18335
China - Northeast	2013	2013	0	0
China - Northeast	2014	2060	0	999999
China - South	2007	2007	5.345669	5.345669
China - South	2013	2013	0	0
China - South	2014	2060	0	999999
China - West	2008	2060	0	999999
Europe- East	2007	2007	1479.528	1479.528
Europe- East	2013	2013	57.27503	57.27503
Europe- East	2014	2060	0	999999
Europe- North	2007	2007	2338.039	2338.039
Europe- North	2010	2013	702.8409	702.8409
Europe- North	2014	2060	0	999999
Europe- South	2007	2007	639.7621	639.7621
Europe- South	2013	2013	275.4929	275.4929
Europe- South	2014	2060	0	999999
Europe- South West	2007	2007	75.1792	75.1792
Europe- South West	2013	2013	149.4115	149.4115
Europe- South West	2014	2060	0	999999
Europe- Turkey	2007	2007	61.09336	61.09336
Europe- Turkey	2013	2013	0	0
Europe- Turkey	2014	2060	0	999999
FSU Central Asia	2007	2007	394.1667	394.1667
FSU Central Asia	2013	2013	0	0
FSU Central Asia	2014	2060	0	999999
Iran	2007	2007	0	0
Iran	2013	2013	134.7872	134.7872
Iran	2014	2060	0	999999
Japan	2007	2007	21.00084	21.00084
Japan	2008	2060	0	999999

B.4 Storage asset regional constraints (cont.)

Node	First Year for Build	Last Year for Build	Minimum Capacity Build (EJ Working Gas)	Maximum Capacity Build (EJ Working Gas)
Latin America - Southern Cone	2007	2007	3.818335	3.818335
Latin America - Southern Cone	2013	2013	0	0
Latin America - Southern Cone	2014	2060	0	999999
Russia Caspian Sea	2007	2007	1147.41	1147.41
Russia Caspian Sea	2013	2013	0	0
Russia Caspian Sea	2014	2060	0	999999
Russia East	2007	2007	116.2683	116.2683
Russia East	2013	2013	0	0
Russia East	2014	2060	0	999999
Russia West	2007	2007	1239.661	1239.661
Russia West	2013	2013	0	0
Russia West	2014	2060	0	999999
US - AZNM	2007	2007	51.39097	51.39097
US - AZNM	2013	2013	0	0
US - AZNM	2014	2060	0	999999
US - California	2007	2007	264.729	264.729
US - California	2013	2013	0	0
US - California	2014	2060	0	999999
US - East North Central	2007	2007	1248.179	1248.179
US - East North Central	2013	2013	0	0
US - East North Central	2014	2060	0	999999
US - East South Central	2007	2007	182.673	182.673
US - East South Central	2013	2013	0	0
US - East South Central	2014	2060	0	999999
US - Middle Atlantic	2007	2007	548.5458	548.5458
US - Middle Atlantic	2013	2013	0	0
US - Middle Atlantic	2014	2060	0	999999
US - Mountain	2007	2007	355.7734	355.7734
US - Mountain	2013	2013	0	0
US - Mountain	2014	2060	0	999999
US - Pacific Northwest	2007	2007	43.76194	43.76194
US - Pacific Northwest	2013	2013	0	0
US - Pacific Northwest	2014	2060	0	999999
US - South Atlantic	2007	2007	256.9625	256.9625
US - South Atlantic	2013	2013	0	0
US - South Atlantic	2014	2060	0	999999
US - West North Central	2007	2007	206.9156	206.9156
US - West North Central	2013	2013	0	0
US - West North Central	2014	2060	0	999999

B.5 Resource availability constraints

Node	Supply Catagory	Year	Share of Resource that is available for development
Africa - North	Conventional Onshore	2008	1
Africa - North	Conventional Offshore	2008	1
Africa - North	Tight Gas	2008	0
Africa - North	Tight Gas	2010	0
Africa - North	Tight Gas	2012	1
Africa - North	Tight Gas	2020	1
Africa - North	CoalBed Methane	2008	0
Africa - North	CoalBed Methane	2018	0
Africa - North	CoalBed Methane	2023	0.3
Africa - North	CoalBed Methane	2028	1
Africa - North	Shale Gas	2008	0
Africa - North	Shale Gas	2013	0
Africa - North	Shale Gas	2018	0.2
Africa - North	Shale Gas	2028	1
Africa - Rest	Conventional Onshore	2008	1
Africa - Rest	Conventional Offshore	2008	1
Africa - Rest	Tight Gas	2008	0
Africa - Rest	Tight Gas	2020	0
Africa - Rest	Tight Gas	2025	0.3
Africa - Rest	Tight Gas	2030	1
Africa - Rest	CoalBed Methane	2008	0
Africa - Rest	CoalBed Methane	2013	0
Africa - Rest	CoalBed Methane	2018	0.3
Africa - Rest	CoalBed Methane	2023	1
Africa - Rest	Shale Gas	2008	0
Africa - Rest	Shale Gas	2023	0
Africa - Rest	Shale Gas	2028	0.2
Africa - Rest	Shale Gas	2038	1
Africa - South	Conventional Onshore	2008	1
Africa - South	Conventional Offshore	2008	1
Africa - South	Tight Gas	2008	0
Africa - South	Tight Gas	2015	0
Africa - South	Tight Gas	2020	0.3
Africa - South	Tight Gas	2025	1

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Africa - South	CoalBed Methane	2008	0
Africa - South	CoalBed Methane	2013	0
Africa - South	CoalBed Methane	2018	0.3
Africa - South	CoalBed Methane	2023	1
Africa - South	Shale Gas	2008	0
Africa - South	Shale Gas	2018	0
Africa - South	Shale Gas	2023	0.2
Africa - South	Shale Gas	2033	1
Africa - West	Conventional Onshore	2008	1
Africa - West	Conventional Offshore	2008	1
Africa - West	Tight Gas	2008	0
Africa - West	Tight Gas	2020	0
Africa - West	Tight Gas	2025	0.3
Africa - West	Tight Gas	2030	1
Africa - West	CoalBed Methane	2008	0
Africa - West	CoalBed Methane	2018	0
Africa - West	CoalBed Methane	2023	0.3
Africa - West	CoalBed Methane	2028	1
Africa - West	Shale Gas	2008	0
Africa - West	Shale Gas	2023	0
Africa - West	Shale Gas	2028	0.2
Africa - West	Shale Gas	2038	1
Asia - Northwest	Conventional Onshore	2008	1
Asia - Northwest	Conventional Offshore	2008	1
Asia - Northwest	Tight Gas	2008	0
Asia - Northwest	Tight Gas	2015	0
Asia - Northwest	Tight Gas	2020	0.3
Asia - Northwest	Tight Gas	2025	1
Asia - Northwest	CoalBed Methane	2008	0
Asia - Northwest	CoalBed Methane	2018	0
Asia - Northwest	CoalBed Methane	2023	0.3
Asia - Northwest	CoalBed Methane	2028	1
Asia - Northwest	Shale Gas	2008	0
Asia - Northwest	Shale Gas	2018	0

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Asia - Northwest	Shale Gas	2023	0.2
Asia - Northwest	Shale Gas	2033	1
Asia - Other Developed	Conventional Onshore	2008	1
Asia - Other Developed	Conventional Offshore	2008	1
Asia - Other Developed	Tight Gas	2008	0
Asia - Other Developed	Tight Gas	2020	0
Asia - Other Developed	Tight Gas	2025	0.3
Asia - Other Developed	Tight Gas	2030	1
Asia - Other Developed	CoalBed Methane	2008	0
Asia - Other Developed	CoalBed Methane	2018	0
Asia - Other Developed	CoalBed Methane	2023	0.3
Asia - Other Developed	CoalBed Methane	2028	1
Asia - Other Developed	Shale Gas	2008	0
Asia - Other Developed	Shale Gas	2023	0
Asia - Other Developed	Shale Gas	2028	0.2
Asia - Other Developed	Shale Gas	2038	1
Asia - Other Developing SE	Conventional Onshore	2008	1
Asia - Other Developing SE	Conventional Offshore	2008	1
Asia - Other Developing SE	Tight Gas	2008	0
Asia - Other Developing SE	Tight Gas	2020	0
Asia - Other Developing SE	Tight Gas	2025	0.3
Asia - Other Developing SE	Tight Gas	2030	1
Asia - Other Developing SE	CoalBed Methane	2008	0
Asia - Other Developing SE	CoalBed Methane	2018	0
Asia - Other Developing SE	CoalBed Methane	2023	0.3
Asia - Other Developing SE	CoalBed Methane	2028	1
Asia - Other Developing SE	Shale Gas	2008	0
Asia - Other Developing SE	Shale Gas	2023	0
Asia - Other Developing SE	Shale Gas	2028	0.2
Asia - Other Developing SE	Shale Gas	2038	1
Asia - Producers	Conventional Onshore	2008	1
Asia - Producers	Conventional Offshore	2008	1
Asia - Producers	Tight Gas	2008	0
Asia - Producers	Tight Gas	2020	0

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Asia - Producers	Tight Gas	2025	0.3
Asia - Producers	Tight Gas	2030	1
Asia - Producers	CoalBed Methane	2008	0
Asia - Producers	CoalBed Methane	2013	0.5
Asia - Producers	CoalBed Methane	2015	1
Asia - Producers	Shale Gas	2008	0
Asia - Producers	Shale Gas	2018	0
Asia - Producers	Shale Gas	2023	0.2
Asia - Producers	Shale Gas	2033	1
Australia and NZ - Demand	Conventional Onshore	2008	1
Australia and NZ - Demand	Conventional Offshore	2008	1
Australia and NZ - Demand	Tight Gas	2008	0
Australia and NZ - Demand	Tight Gas	2010	0
Australia and NZ - Demand	Tight Gas	2015	0.3
Australia and NZ - Demand	Tight Gas	2020	1
Australia and NZ - Demand	CoalBed Methane	2008	0.5
Australia and NZ - Demand	CoalBed Methane	2014	1
Australia and NZ - Demand	Shale Gas	2008	0
Australia and NZ - Demand	Shale Gas	2013	0
Australia and NZ - Demand	Shale Gas	2018	0.2
Australia and NZ - Demand	Shale Gas	2028	1
Australia and NZ - NW Shelf	Conventional Onshore	2008	1
Australia and NZ - NW Shelf	Conventional Offshore	2008	1
Australia and NZ - NW Shelf	Tight Gas	2008	0
Australia and NZ - NW Shelf	Tight Gas	2015	0
Australia and NZ - NW Shelf	Tight Gas	2020	0.3
Australia and NZ - NW Shelf	Tight Gas	2025	1
Australia and NZ - NW Shelf	CoalBed Methane	2008	0
Australia and NZ - NW Shelf	CoalBed Methane	2018	0
Australia and NZ - NW Shelf	CoalBed Methane	2023	0.3
Australia and NZ - NW Shelf	CoalBed Methane	2028	1
Australia and NZ - NW Shelf	Shale Gas	2008	0
Australia and NZ - NW Shelf	Shale Gas	2018	0
Australia and NZ - NW Shelf	Shale Gas	2023	0.2

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Australia and NZ - NW Shelf	Shale Gas	2033	1
Brazil	Conventional Onshore	2008	1
Brazil	Conventional Offshore	2008	1
Brazil	Tight Gas	2008	0
Brazil	Tight Gas	2015	0
Brazil	Tight Gas	2020	0.3
Brazil	Tight Gas	2025	1
Brazil	CoalBed Methane	2008	0
Brazil	CoalBed Methane	2013	0
Brazil	CoalBed Methane	2018	0.3
Brazil	CoalBed Methane	2023	1
Brazil	Shale Gas	2008	0
Brazil	Shale Gas	2023	0
Brazil	Shale Gas	2028	0.2
Brazil	Shale Gas	2038	1
Canada East	Conventional Onshore	2008	1
Canada East	Conventional Offshore	2008	1
Canada East	Tight Gas	2008	1
Canada East	CoalBed Methane	2008	0.5
Canada East	CoalBed Methane	2014	0.5
Canada East	CoalBed Methane	2024	1
Canada East	Shale Gas	2008	0
Canada East	Shale Gas	2012	1
Canada West	Conventional Onshore	2008	1
Canada West	Conventional Offshore	2008	1
Canada West	Tight Gas	2008	1
Canada West	CoalBed Methane	2008	0.5
Canada West	CoalBed Methane	2014	0.5
Canada West	CoalBed Methane	2024	1
Canada West	Shale Gas	2008	0
Canada West	Shale Gas	2012	1
Chile	Conventional Onshore	2008	1
Chile	Conventional Offshore	2008	1
Chile	Tight Gas	2008	0

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Chile	Tight Gas	2015	0
Chile	Tight Gas	2020	0.3
Chile	Tight Gas	2025	1
Chile	CoalBed Methane	2008	0
Chile	CoalBed Methane	2018	0
Chile	CoalBed Methane	2023	0.3
Chile	CoalBed Methane	2028	1
Chile	Shale Gas	2008	0
Chile	Shale Gas	2018	0
Chile	Shale Gas	2023	0.2
Chile	Shale Gas	2033	1
China - Northeast	Conventional Onshore	2008	1
China - Northeast	Conventional Offshore	2008	1
China - Northeast	Tight Gas	2008	1
China - Northeast	CoalBed Methane	2008	0
China - Northeast	CoalBed Methane	2013	0.5
China - Northeast	CoalBed Methane	2018	1
China - Northeast	Shale Gas	2008	0
China - Northeast	Shale Gas	2018	0
China - Northeast	Shale Gas	2023	0.2
China - Northeast	Shale Gas	2033	1
China - South	Conventional Onshore	2008	1
China - South	Conventional Offshore	2008	1
China - South	Tight Gas	2008	1
China - South	CoalBed Methane	2008	0
China - South	CoalBed Methane	2013	0.5
China - South	CoalBed Methane	2018	1
China - South	Shale Gas	2008	0
China - South	Shale Gas	2018	0
China - South	Shale Gas	2023	0.2
China - South	Shale Gas	2033	1
China - West	Conventional Onshore	2008	1
China - West	Conventional Offshore	2008	1
China - West	Tight Gas	2008	1
China - West	CoalBed Methane	2008	0

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
China - West	CoalBed Methane	2013	0.5
China - West	CoalBed Methane	2018	1
China - West	Shale Gas	2008	0
China - West	Shale Gas	2013	0
China - West	Shale Gas	2018	0.2
China - West	Shale Gas	2028	1
Europe- East	Conventional Onshore	2008	1
Europe- East	Conventional Offshore	2008	1
Europe- East	Tight Gas	2008	0
Europe- East	Tight Gas	2015	0
Europe- East	Tight Gas	2020	0.3
Europe- East	Tight Gas	2025	1
Europe- East	CoalBed Methane	2008	0
Europe- East	CoalBed Methane	2013	0
Europe- East	CoalBed Methane	2018	0.3
Europe- East	CoalBed Methane	2023	1
Europe- East	Shale Gas	2008	0
Europe- East	Shale Gas	2018	0
Europe- East	Shale Gas	2030	0.2
Europe- East	Shale Gas	2040	1
Europe- North	Conventional Onshore	2008	1
Europe- North	Conventional Offshore	2008	1
Europe- North	Tight Gas	2008	0
Europe- North	Tight Gas	2015	0
Europe- North	Tight Gas	2020	0.3
Europe- North	Tight Gas	2025	1
Europe- North	CoalBed Methane	2008	0
Europe- North	CoalBed Methane	2013	0.3
Europe- North	CoalBed Methane	2018	1
Europe- North	Shale Gas	2008	0
Europe- North	Shale Gas	2013	0
Europe- North	Shale Gas	2018	0.2
Europe- North	Shale Gas	2028	1
Europe- South	Conventional Onshore	2008	1

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Europe- South	Conventional Offshore	2008	1
Europe- South	Tight Gas	2008	0
Europe- South	Tight Gas	2015	0
Europe- South	Tight Gas	2020	0.3
Europe- South	Tight Gas	2025	1
Europe- South	CoalBed Methane	2008	0
Europe- South	CoalBed Methane	2013	0
Europe- South	CoalBed Methane	2018	0.3
Europe- South	CoalBed Methane	2023	1
Europe- South	Shale Gas	2008	0
Europe- South	Shale Gas	2018	0
Europe- South	Shale Gas	2023	0.2
Europe- South	Shale Gas	2033	1
Europe- South West	Conventional Onshore	2008	1
Europe- South West	Conventional Offshore	2008	1
Europe- South West	Tight Gas	2008	0
Europe- South West	Tight Gas	2015	0
Europe- South West	Tight Gas	2020	0.3
Europe- South West	Tight Gas	2025	1
Europe- South West	CoalBed Methane	2008	0
Europe- South West	CoalBed Methane	2018	0
Europe- South West	CoalBed Methane	2023	0.3
Europe- South West	CoalBed Methane	2028	1
Europe- South West	Shale Gas	2008	0
Europe- South West	Shale Gas	2018	0
Europe- South West	Shale Gas	2023	0.2
Europe- South West	Shale Gas	2033	1
Europe- Turkey	Conventional Onshore	2008	1
Europe- Turkey	Conventional Offshore	2008	1
Europe- Turkey	Tight Gas	2008	0
Europe- Turkey	Tight Gas	2015	0
Europe- Turkey	Tight Gas	2020	0.3
Europe- Turkey	Tight Gas	2025	1
Europe- Turkey	CoalBed Methane	2008	0

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Europe- Turkey	CoalBed Methane	2018	0
Europe- Turkey	CoalBed Methane	2023	0.3
Europe- Turkey	CoalBed Methane	2028	1
Europe- Turkey	Shale Gas	2008	0
Europe- Turkey	Shale Gas	2018	0
Europe- Turkey	Shale Gas	2023	0.2
Europe- Turkey	Shale Gas	2033	1
FSU Central Asia	Conventional Onshore	2008	1
FSU Central Asia	Conventional Offshore	2008	1
FSU Central Asia	Tight Gas	2008	0
FSU Central Asia	Tight Gas	2020	0
FSU Central Asia	Tight Gas	2025	0.3
FSU Central Asia	Tight Gas	2030	1
FSU Central Asia	CoalBed Methane	2008	0
FSU Central Asia	CoalBed Methane	2018	0
FSU Central Asia	CoalBed Methane	2023	0.3
FSU Central Asia	CoalBed Methane	2028	1
FSU Central Asia	Shale Gas	2008	0
FSU Central Asia	Shale Gas	2023	0
FSU Central Asia	Shale Gas	2028	0.2
FSU Central Asia	Shale Gas	2038	1
India - North	Conventional Onshore	2008	1
India - North	Conventional Offshore	2008	1
India - North	Tight Gas	2008	0
India - North	Tight Gas	2020	0
India - North	Tight Gas	2025	0.3
India - North	Tight Gas	2030	1
India - North	CoalBed Methane	2008	0
India - North	CoalBed Methane	2013	0.3
India - North	CoalBed Methane	2018	1
India - North	Shale Gas	2008	0
India - North	Shale Gas	2018	0
India - North	Shale Gas	2023	0.2
India - North	Shale Gas	2033	1
India - Southeast	Conventional Onshore	2008	1

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
India - Southeast	Conventional Offshore	2008	1
India - Southeast	Tight Gas	2008	0
India - Southeast	Tight Gas	2020	0
India - Southeast	Tight Gas	2025	0.3
India - Southeast	Tight Gas	2030	1
India - Southeast	CoalBed Methane	2008	0
India - Southeast	CoalBed Methane	2013	0.3
India - Southeast	CoalBed Methane	2018	1
India - Southeast	Shale Gas	2008	0
India - Southeast	Shale Gas	2018	0
India - Southeast	Shale Gas	2023	0.2
India - Southeast	Shale Gas	2033	1
India - Southwest	Conventional Onshore	2008	1
India - Southwest	Conventional Offshore	2008	1
India - Southwest	Tight Gas	2008	0
India - Southwest	Tight Gas	2020	0
India - Southwest	Tight Gas	2025	0.3
India - Southwest	Tight Gas	2030	1
India - Southwest	CoalBed Methane	2008	0
India - Southwest	CoalBed Methane	2013	0.3
India - Southwest	CoalBed Methane	2018	1
India - Southwest	Shale Gas	2008	0
India - Southwest	Shale Gas	2018	0
India - Southwest	Shale Gas	2023	0.2
India - Southwest	Shale Gas	2033	1
Japan	Conventional Onshore	2008	1
Japan	Conventional Offshore	2008	1
Japan	Tight Gas	2008	0
Japan	Tight Gas	2020	0
Japan	Tight Gas	2025	0.3
Japan	Tight Gas	2030	1
Japan	CoalBed Methane	2008	0
Japan	CoalBed Methane	2018	0
Japan	CoalBed Methane	2023	0.3
Japan	CoalBed Methane	2028	1

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Japan	Shale Gas	2008	0
Japan	Shale Gas	2023	0
Japan	Shale Gas	2028	0.2
Japan	Shale Gas	2038	1
Latin America - Andean	Conventional Onshore	2008	1
Latin America - Andean	Conventional Offshore	2008	1
Latin America - Andean	Tight Gas	2008	0
Latin America - Andean	Tight Gas	2020	0
Latin America - Andean	Tight Gas	2025	0.3
Latin America - Andean	Tight Gas	2030	1
Latin America - Andean	CoalBed Methane	2008	0
Latin America - Andean	CoalBed Methane	2018	0
Latin America - Andean	CoalBed Methane	2023	0.3
Latin America - Andean	CoalBed Methane	2028	1
Latin America - Andean	Shale Gas	2008	0
Latin America - Andean	Shale Gas	2018	0
Latin America - Andean	Shale Gas	2023	0.2
Latin America - Andean	Shale Gas	2033	1
Latin America - Central America	Conventional Onshore	2008	1
Latin America - Central America	Conventional Offshore	2008	1
Latin America - Central America	Tight Gas	2008	0
Latin America - Central America	Tight Gas	2020	0
Latin America - Central America	Tight Gas	2025	0.3
Latin America - Central America	Tight Gas	2030	1
Latin America - Central America	CoalBed Methane	2008	0
Latin America - Central America	CoalBed Methane	2018	0
Latin America - Central America	CoalBed Methane	2023	0.3
Latin America - Central America	CoalBed Methane	2028	1
Latin America - Central America	Shale Gas	2008	0
Latin America - Central America	Shale Gas	2023	0
Latin America - Central America	Shale Gas	2028	0.2
Latin America - Central America	Shale Gas	2038	1
Latin America - Northern Producers	Conventional Onshore	2008	1
Latin America - Northern Producers	Conventional Offshore	2008	1

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Latin America - Northern Producers	Tight Gas	2008	0
Latin America - Northern Producers	Tight Gas	2015	0
Latin America - Northern Producers	Tight Gas	2020	0.3
Latin America - Northern Producers	Tight Gas	2025	1
Latin America - Northern Producers	CoalBed Methane	2008	0
Latin America - Northern Producers	CoalBed Methane	2018	0
Latin America - Northern Producers	CoalBed Methane	2023	0.3
Latin America - Northern Producers	CoalBed Methane	2028	1
Latin America - Northern Producers	Shale Gas	2008	0
Latin America - Northern Producers	Shale Gas	2018	0
Latin America - Northern Producers	Shale Gas	2023	0.2
Latin America - Northern Producers	Shale Gas	2033	1
Latin America - Southern Cone	Conventional Onshore	2008	1
Latin America - Southern Cone	Conventional Offshore	2008	1
Latin America - Southern Cone	Tight Gas	2008	0
Latin America - Southern Cone	Tight Gas	2010	0.3
Latin America - Southern Cone	Tight Gas	2015	1
Latin America - Southern Cone	CoalBed Methane	2008	0
Latin America - Southern Cone	CoalBed Methane	2018	0
Latin America - Southern Cone	CoalBed Methane	2023	0.3
Latin America - Southern Cone	CoalBed Methane	2028	1
Latin America - Southern Cone	Shale Gas	2008	0
Latin America - Southern Cone	Shale Gas	2013	0
Latin America - Southern Cone	Shale Gas	2018	0.2
Latin America - Southern Cone	Shale Gas	2028	1
Arabian Producers	Conventional Onshore	2008	1
Arabian Producers	Conventional Offshore	2008	1
Arabian Producers	Tight Gas	2008	0
Arabian Producers	Tight Gas	2010	0
Arabian Producers	Tight Gas	2015	0.3
Arabian Producers	Tight Gas	2020	1
Arabian Producers	CoalBed Methane	2008	0
Arabian Producers	CoalBed Methane	2018	0
Arabian Producers	CoalBed Methane	2023	0.3

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Arabian Producers	CoalBed Methane	2028	1
Arabian Producers	Shale Gas	2008	0
Arabian Producers	Shale Gas	2023	0
Arabian Producers	Shale Gas	2028	0.2
Arabian Producers	Shale Gas	2038	1
Iran	Conventional Onshore	2008	1
Iran	Conventional Offshore	2008	1
Iran	Tight Gas	2008	0
Iran	Tight Gas	2020	0
Iran	Tight Gas	2025	0.3
Iran	Tight Gas	2030	1
Iran	CoalBed Methane	2008	0
Iran	CoalBed Methane	2018	0
Iran	CoalBed Methane	2023	0.3
Iran	CoalBed Methane	2028	1
Iran	Shale Gas	2008	0
Iran	Shale Gas	2023	0
Iran	Shale Gas	2028	0.2
Iran	Shale Gas	2038	1
Iraq	Conventional Onshore	2008	1
Iraq	Conventional Offshore	2008	1
Iraq	Conventional Offshore	2013	1
Iraq	Conventional Offshore	2018	1
Iraq	Tight Gas	2008	0
Iraq	Tight Gas	2020	0
Iraq	Tight Gas	2025	0.3
Iraq	Tight Gas	2030	1
Iraq	CoalBed Methane	2008	0
Iraq	CoalBed Methane	2018	0
Iraq	CoalBed Methane	2023	0.3
Iraq	CoalBed Methane	2028	1
Iraq	Shale Gas	2008	0
Iraq	Shale Gas	2023	0
Iraq	Shale Gas	2028	0.2

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Iraq	Shale Gas	2038	1
Qatar	Conventional Onshore	2008	1
Qatar	Conventional Offshore	2008	1
Qatar	Tight Gas	2008	0
Qatar	Tight Gas	2020	0
Qatar	Tight Gas	2025	0.3
Qatar	Tight Gas	2030	1
Qatar	CoalBed Methane	2008	0
Qatar	CoalBed Methane	2018	0
Qatar	CoalBed Methane	2023	0.3
Qatar	CoalBed Methane	2028	1
Qatar	Shale Gas	2008	0
Qatar	Shale Gas	2023	0
Qatar	Shale Gas	2028	0.2
Qatar	Shale Gas	2038	1
Rest of Middle East	Conventional Onshore	2008	1
Rest of Middle East	Conventional Offshore	2008	1
Rest of Middle East	Tight Gas	2008	0
Rest of Middle East	Tight Gas	2015	0
Rest of Middle East	Tight Gas	2020	0.3
Rest of Middle East	Tight Gas	2025	1
Rest of Middle East	CoalBed Methane	2008	0
Rest of Middle East	CoalBed Methane	2018	0
Rest of Middle East	CoalBed Methane	2023	0.3
Rest of Middle East	CoalBed Methane	2028	1
Rest of Middle East	Shale Gas	2008	0
Rest of Middle East	Shale Gas	2023	0
Rest of Middle East	Shale Gas	2028	0.2
Rest of Middle East	Shale Gas	2038	1
Saudi Arabia	Conventional Onshore	2008	1
Saudi Arabia	Conventional Offshore	2008	1
Saudi Arabia	Tight Gas	2008	0
Saudi Arabia	Tight Gas	2020	0
Saudi Arabia	Tight Gas	2025	0.3

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Saudi Arabia	Tight Gas	2030	1
Saudi Arabia	CoalBed Methane	2008	0
Saudi Arabia	CoalBed Methane	2018	0
Saudi Arabia	CoalBed Methane	2023	0.3
Saudi Arabia	CoalBed Methane	2028	1
Saudi Arabia	Shale Gas	2008	0
Saudi Arabia	Shale Gas	2023	0
Saudi Arabia	Shale Gas	2028	0.2
Saudi Arabia	Shale Gas	2038	1
Mexico Northeast	Conventional Onshore	2008	1
Mexico Northeast	Conventional Offshore	2008	1
Mexico Northeast	Tight Gas	2008	0
Mexico Northeast	Tight Gas	2020	0
Mexico Northeast	Tight Gas	2025	0.3
Mexico Northeast	Tight Gas	2030	1
Mexico Northeast	CoalBed Methane	2008	0
Mexico Northeast	CoalBed Methane	2018	0
Mexico Northeast	CoalBed Methane	2023	0.3
Mexico Northeast	CoalBed Methane	2028	1
Mexico Northeast	Shale Gas	2008	0
Mexico Northeast	Shale Gas	2018	0
Mexico Northeast	Shale Gas	2023	0.2
Mexico Northeast	Shale Gas	2033	1
Mexico Northwest	Conventional Onshore	2008	1
Mexico Northwest	Conventional Offshore	2008	1
Mexico Northwest	Tight Gas	2008	0
Mexico Northwest	Tight Gas	2020	0
Mexico Northwest	Tight Gas	2025	0.3
Mexico Northwest	Tight Gas	2030	1
Mexico Northwest	CoalBed Methane	2008	0
Mexico Northwest	CoalBed Methane	2018	0
Mexico Northwest	CoalBed Methane	2023	0.3
Mexico Northwest	CoalBed Methane	2028	1
Mexico Northwest	Shale Gas	2008	0

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Mexico Northwest	Shale Gas	2023	0
Mexico Northwest	Shale Gas	2028	0.2
Mexico Northwest	Shale Gas	2038	1
Mexico South	Conventional Onshore	2008	1
Mexico South	Conventional Offshore	2008	1
Mexico South	Tight Gas	2008	0
Mexico South	Tight Gas	2020	0
Mexico South	Tight Gas	2025	0.3
Mexico South	Tight Gas	2030	1
Mexico South	CoalBed Methane	2008	0
Mexico South	CoalBed Methane	2018	0
Mexico South	CoalBed Methane	2023	0.3
Mexico South	CoalBed Methane	2028	1
Mexico South	Shale Gas	2008	0
Mexico South	Shale Gas	2023	0
Mexico South	Shale Gas	2028	0.2
Mexico South	Shale Gas	2038	1
Mexico Southwest LNG	Conventional Onshore	2008	1
Mexico Southwest LNG	Conventional Offshore	2008	1
Mexico Southwest LNG	Tight Gas	2008	0
Mexico Southwest LNG	Tight Gas	2020	0
Mexico Southwest LNG	Tight Gas	2025	0.3
Mexico Southwest LNG	Tight Gas	2030	1
Mexico Southwest LNG	CoalBed Methane	2008	0
Mexico Southwest LNG	CoalBed Methane	2018	0
Mexico Southwest LNG	CoalBed Methane	2023	0.3
Mexico Southwest LNG	CoalBed Methane	2028	1
Mexico Southwest LNG	Shale Gas	2008	0
Mexico Southwest LNG	Shale Gas	2023	0
Mexico Southwest LNG	Shale Gas	2028	0.2
Mexico Southwest LNG	Shale Gas	2038	1
Russia Caspian Sea	Conventional Onshore	2008	1
Russia Caspian Sea	Conventional Offshore	2008	1
Russia Caspian Sea	Tight Gas	2008	0

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Russia Caspian Sea	Tight Gas	2020	0
Russia Caspian Sea	Tight Gas	2025	0.3
Russia Caspian Sea	Tight Gas	2030	1
Russia Caspian Sea	CoalBed Methane	2008	0
Russia Caspian Sea	CoalBed Methane	2013	0.3
Russia Caspian Sea	CoalBed Methane	2018	1
Russia Caspian Sea	Shale Gas	2008	0
Russia Caspian Sea	Shale Gas	2023	0
Russia Caspian Sea	Shale Gas	2028	0.2
Russia Caspian Sea	Shale Gas	2038	1
Russia East	Conventional Onshore	2008	1
Russia East	Conventional Offshore	2008	1
Russia East	Tight Gas	2008	0
Russia East	Tight Gas	2020	0
Russia East	Tight Gas	2025	0.3
Russia East	Tight Gas	2030	1
Russia East	CoalBed Methane	2008	0
Russia East	CoalBed Methane	2013	0.3
Russia East	CoalBed Methane	2018	1
Russia East	Shale Gas	2008	0
Russia East	Shale Gas	2023	0
Russia East	Shale Gas	2028	0.2
Russia East	Shale Gas	2038	1
Russia Sakhalin	Conventional Onshore	2008	1
Russia Sakhalin	Conventional Offshore	2008	1
Russia Sakhalin	Tight Gas	2008	0
Russia Sakhalin	Tight Gas	2020	0
Russia Sakhalin	Tight Gas	2025	0.3
Russia Sakhalin	Tight Gas	2030	1
Russia Sakhalin	CoalBed Methane	2008	0
Russia Sakhalin	CoalBed Methane	2013	0.3
Russia Sakhalin	CoalBed Methane	2018	1
Russia Sakhalin	Shale Gas	2008	0
Russia Sakhalin	Shale Gas	2023	0

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Russia Sakhalin	Shale Gas	2028	0.2
Russia Sakhalin	Shale Gas	2038	1
Russia Shtokman	Conventional Onshore	2008	1
Russia Shtokman	Conventional Offshore	2008	1
Russia Shtokman	Tight Gas	2008	0
Russia Shtokman	Tight Gas	2020	0
Russia Shtokman	Tight Gas	2025	0.3
Russia Shtokman	Tight Gas	2030	1
Russia Shtokman	CoalBed Methane	2008	0
Russia Shtokman	CoalBed Methane	2013	0.3
Russia Shtokman	CoalBed Methane	2018	1
Russia Shtokman	Shale Gas	2008	0
Russia Shtokman	Shale Gas	2023	0
Russia Shtokman	Shale Gas	2028	0.2
Russia Shtokman	Shale Gas	2038	1
Russia West	Conventional Onshore	2008	1
Russia West	Conventional Offshore	2008	1
Russia West	Tight Gas	2008	0
Russia West	Tight Gas	2020	0
Russia West	Tight Gas	2025	0.3
Russia West	Tight Gas	2030	1
Russia West	CoalBed Methane	2008	0
Russia West	CoalBed Methane	2013	0.3
Russia West	CoalBed Methane	2018	1
Russia West	Shale Gas	2008	0
Russia West	Shale Gas	2023	0
Russia West	Shale Gas	2028	0.2
Russia West	Shale Gas	2038	1
Russia Yamal	Conventional Onshore	2008	1
Russia Yamal	Conventional Offshore	2008	1
Russia Yamal	Tight Gas	2008	0
Russia Yamal	Tight Gas	2020	0
Russia Yamal	Tight Gas	2025	0.3
Russia Yamal	Tight Gas	2030	1

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
Russia Yamal	CoalBed Methane	2008	0
Russia Yamal	CoalBed Methane	2013	0.3
Russia Yamal	CoalBed Methane	2018	1
Russia Yamal	Shale Gas	2008	0
Russia Yamal	Shale Gas	2023	0
Russia Yamal	Shale Gas	2028	0.2
Russia Yamal	Shale Gas	2038	1
South Korea	Conventional Onshore	2008	1
South Korea	Conventional Offshore	2008	1
South Korea	Tight Gas	2008	0
South Korea	Tight Gas	2020	0
South Korea	Tight Gas	2025	0.3
South Korea	Tight Gas	2030	1
South Korea	CoalBed Methane	2008	0
South Korea	CoalBed Methane	2018	0
South Korea	CoalBed Methane	2023	0.3
South Korea	CoalBed Methane	2028	1
South Korea	Shale Gas	2008	0
South Korea	Shale Gas	2023	0
South Korea	Shale Gas	2028	0.2
South Korea	Shale Gas	2038	1
US - Arctic	Conventional Onshore	2008	1
US - Arctic	Conventional Offshore	2008	1
US - Arctic	Tight Gas	2008	1
US - Arctic	CoalBed Methane	2008	0.75
US - Arctic	CoalBed Methane	2014	0.75
US - Arctic	CoalBed Methane	2024	1
US - Arctic	Shale Gas	2008	1
US - AZNM	Conventional Onshore	2008	1
US - AZNM	Conventional Offshore	2008	1
US - AZNM	Tight Gas	2008	1
US - AZNM	CoalBed Methane	2008	0.75
US - AZNM	CoalBed Methane	2014	0.75
US - AZNM	CoalBed Methane	2024	1

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
US - AZNM	Shale Gas	2008	1
US - California	Conventional Onshore	2008	1
US - California	Conventional Offshore	2008	1
US - California	Tight Gas	2008	1
US - California	CoalBed Methane	2008	0.75
US - California	CoalBed Methane	2014	0.75
US - California	CoalBed Methane	2024	1
US - California	Shale Gas	2008	1
US - East North Central	Conventional Onshore	2008	1
US - East North Central	Conventional Offshore	2008	1
US - East North Central	Tight Gas	2008	1
US - East North Central	CoalBed Methane	2008	0.75
US - East North Central	CoalBed Methane	2014	0.75
US - East North Central	CoalBed Methane	2024	1
US - East North Central	Shale Gas	2008	1
US - East South Central	Conventional Onshore	2008	1
US - East South Central	Conventional Offshore	2008	1
US - East South Central	Tight Gas	2008	1
US - East South Central	CoalBed Methane	2008	0.75
US - East South Central	CoalBed Methane	2014	0.75
US - East South Central	CoalBed Methane	2024	1
US - East South Central	Shale Gas	2008	1
US - Florida	Conventional Onshore	2008	1
US - Florida	Conventional Offshore	2008	1
US - Florida	Tight Gas	2008	1
US - Florida	CoalBed Methane	2008	0.75
US - Florida	CoalBed Methane	2014	0.75
US - Florida	CoalBed Methane	2024	1
US - Florida	Shale Gas	2008	1
US - Middle Atlantic	Conventional Onshore	2008	1
US - Middle Atlantic	Conventional Offshore	2008	1
US - Middle Atlantic	Tight Gas	2008	1
US - Middle Atlantic	CoalBed Methane	2008	0.75
US - Middle Atlantic	CoalBed Methane	2014	0.75

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
US - Middle Atlantic	CoalBed Methane	2024	1
US - Middle Atlantic	Shale Gas	2008	1
US - Mountain	Conventional Onshore	2008	1
US - Mountain	Conventional Offshore	2008	1
US - Mountain	Tight Gas	2008	1
US - Mountain	CoalBed Methane	2008	0.75
US - Mountain	CoalBed Methane	2014	0.75
US - Mountain	CoalBed Methane	2024	1
US - Mountain	Shale Gas	2008	1
US - New England	Conventional Onshore	2008	1
US - New England	Conventional Offshore	2008	1
US - New England	Tight Gas	2008	1
US - New England	CoalBed Methane	2008	0.75
US - New England	CoalBed Methane	2014	0.75
US - New England	CoalBed Methane	2024	1
US - New England	Shale Gas	2008	1
US - Pacific Northwest	Conventional Onshore	2008	1
US - Pacific Northwest	Conventional Offshore	2008	1
US - Pacific Northwest	Tight Gas	2008	1
US - Pacific Northwest	CoalBed Methane	2008	0.75
US - Pacific Northwest	CoalBed Methane	2014	0.75
US - Pacific Northwest	CoalBed Methane	2024	1
US - Pacific Northwest	Shale Gas	2008	1
US - South Atlantic	Conventional Onshore	2008	1
US - South Atlantic	Conventional Offshore	2008	1
US - South Atlantic	Tight Gas	2008	1
US - South Atlantic	CoalBed Methane	2008	0.75
US - South Atlantic	CoalBed Methane	2014	0.75
US - South Atlantic	CoalBed Methane	2024	1
US - South Atlantic	Shale Gas	2008	1
US - West North Central	Conventional Onshore	2008	1
US - West North Central	Conventional Offshore	2008	1
US - West North Central	Tight Gas	2008	1
US - West North Central	CoalBed Methane	2008	0.75

B.5 Resource availability constraints (cont.)

Node	Supply Catagory	Year	Share of Resource that is available for development
US - West North Central	CoalBed Methane	2014	0.75
US - West North Central	CoalBed Methane	2024	1
US - West North Central	Shale Gas	2008	1
US - West South Central	Conventional Onshore	2008	1
US - West South Central	Conventional Offshore	2008	1
US - West South Central	Tight Gas	2008	1
US - West South Central	CoalBed Methane	2008	0.75
US - West South Central	CoalBed Methane	2014	0.75
US - West South Central	CoalBed Methane	2024	1
US - West South Central	Shale Gas	2008	1

Appendix C. Database Description

The INGM is implemented in Microsoft ACCESS using Visual Basic for Applications. This section defines the database tables that contain input, output, and intermediate output data.

Input data tables

Symbol	Field	FDef	Units
Table: tInp_AA_Base			
This table stores the options for the base physical characteristics of the system such as fuels, nodes, regions, and seasons			
	AA_Base_Id	Id of baseline physical characteristics option	
	AA_Base_Name	Name of baseline physical characteristics option	
	Select_Flag	Selection flag used for data input and review	
Table: tInp_AA_Dmd_Spec			
This table stores the options for the baseline demand			
	AA_DmdSpec_Id	Id of baseline demand option	
	AA_DmdSpec_Name	Name of baseline demand option	
	Select_Flag	Selection flag used for data input and review	
ScaleFlag	Scale_Flag	Flag set to true if demand is to be based on another baseline demand option scaled and false otherwise	
	AA_DmdSpec_Id_Base	Id of baseline demand option to use for scaling	
Table: tInp_AA_DmdSS			
This table stores the options for the demand sectors and seasons specifications			
	AA_DmdSS_Id	Id of baseline demand sector and season option	
	AA_DmdSS_Name	Name of baseline demand sector and season option	
	Select_Flag	Selection flag used for data input and review	
Table: tInp_AA_ImpExp_Cnstr			
This table stores the options for the import/export constraints			
	AA_ImpExp_Id	Id of baseline import/export option	
	AA_ImpExp_Name	Name of baseline import/export option	
	Select_Flag	Selection flag used for data input and review	
Table: tInp_AA_OthDmd			
This table stores the options for the other fuel prices			
	AA_OthDmd_Id	Id of baseline other fuel price option	
	AA_OthDmd_Name	Name of other fuel price option	
	Select_Flag	Selection flag used for data input and review	

Symbol	Field	FDef	Units
Table: tInp_AA_PipelineACnstr			
This table stores the options for the pipeline assets			
	AA_PipelineACnstr_Id	Id of pipeline asset option	
	AA_PipelineACnstr_Name	Name of pipeline asset option	
	Select_Flag	Selection flag used for data input and review	
Table: tInp_AA_PorttoPort			
This table stores the options for the port-to-port links in the network			
	AA_PorttoPort_Id	Id of processing assets option	
	AA_PorttoPort_Name	Name of processing assets option	
	Select_Flag	Selection flag used for data input and review	
Table: tInp_AA_ProcessingACnstr			
This table stores the options for the processing assets			
	AA_ProcessingACnstr_Id		
	AA_ProcessingACnstr_Name		
	Select_Flag		
Table: tInp_AA_StorageACnstr			
This table stores the options for the storage assets			
	AA_StorageACnstr_Id	Id of storage assets option	
	AA_StorageACnstr_Name	Name of storage assets option	
	Select_Flag	Selection flag used for data input and review	
Table: tInp_AA_Supply			
This table stores the options for the base natural gas resource estimates			
	AA_Supply_Id	Id of baseline natural gas resource option	
	AA_Supply_Name	Name of baseline natural gas resource option	
	Select_Flag	Selection flag used for data input and review	
Table: tInp_AA_TankerACnstr			
This table stores the options for the tanker assets			
	AA_TankerACnstr_Id	Id of tanker assets option	
	AA_TankerACnstr_Name	Name of tanker assets option	
	Select_Flag	Selection flag used for data input and review	

Table: tInp_CTax

This table stores the baseline data for carbon taxes. The carbon tax data is defined by node in units of $2006/tonne CO2e.

	AA_DmdSpec_Id	Id of baseline demand option	
n	NodeId	Unique id for node	
y	Year	Year of the demand specification	Year
$CTax_{n,y}$	CTax	Tax on CO_2 assumed in the WEPS+ model and used to estimate the base demand	$2006/tonne CO_2e
$CTax\_Scen_{n,y}$	CTax_Scen	Tax on CO_2 used in the INGM scenario	$2006/tonne CO_2e

Table: tInp_DmdBase

This table stores the baseline data for the demand. The demand data is defined by node and demand sector, and the data includes the base estimates of average daily demand for the year, node and demand sector in units of PJ/day.

	AA_DmdSpec_Id	Id of baseline demand option	
n	NodeId	Unique id for node	
f	FuelId	Unique ID for the fuel type	
k	DmdSectorId	Unique Id for the demand sector	
y	Year	Year of the demand specification	Year
$BDmd_{n,f,k,y}$	BaseDmd	Base demand in year for node, fuel, and sector. Note that if data are not specified for a year then a value is interpolated between years where it is specified. If there are no values past some year then the last specified value is assumed	PJ
$BPro_{n,f,k,y}$	BasePrc	Base price for demand estimate. Note that if the value is not specified for a year then the value is interpolated between years where it is specified. If there are no values past some year then the last specified value is assumed	$/GJ
$BEff_{n,f,k,y}$	BaseEff	Base efficiency for demand sector for node, sector, fuel, and year	Fraction
$SPrc_{n,f,k,y}$	ScnPrc	Scenario price for scenario estimation	$/GJ
$BPrc\_Orig_{n,f,k,y}$	BasePrc_Orig	Base price for demand estimate initially from the WEPS+model and before adjustment to nodal values	$/GJ
$PrcSub_{n,f,k,y}$	PrcSub	Price subsidy assumed for the input demand assumptions for the wholesale price on average for the region	$/GJ
$PrcSubS_{n,f,k,y}$	PrcSub_Scn	Price subsidy used to estimate demand for demand assumptions for the wholesale price on average for the region	$/GJ
$DstMar_{n,f,k,y}$	DistMar	Distribution Margin	$/GJ
NFCstsn,f,k,y	NFCstgs	Non-fuel costs in using fuel	$/GJ

Table: tInp_DmdSclFactor

This table stores the scaling specifications for the demand option

	type	NGTDM or WEPS+	
	AA_DmdSpec_Id	Id of baseline demand option	
	RegionId	Unique ID of the region	
	FuelId	Unique ID of the fuel	
	Scale	Factor to scale demand	Ratio

Table: tInp_DmdSeasAlloc

This table stores the ratio of average daily demand within each season to average annual daily demand. The specification is by node and demand sector.

	AA_DmdSS_Id	Id of baseline demand sector and season option	
n	NodeId	Unique id for node	
k	DmdSectorId	Unique Id for the demand sector	
s	SeaonId	Unique id for season	
$DmdS_{n,k,s}$	SeasAllocFac	Allocation factor for seasonal demand. Sum over seasons of SeasAllocFac*NDs/365 must equal 1.0	Fraction

Table: tInp_DmdSector

This table defines the different sectors in the model and provides constant price and income elasticities for the sector.

	AA_DmdSS_Id	Id of baseline demand sector and season option	
k	DmdSectorId	Unique Id for the demand sector	
	DmdSector_Name	Name of the demand sector	
DPEk or DPE(k)	PriceElas	Price elasticity for demand in demand sector k	Ratio
ALfk or Alf(k)	AvgLife	Average life of energy consuming capital in sector k	Number of years
	Select_Flag	Select flag for output queries – true or false	
	PowerGeneration_Flag	True if sector is power generation sector	
	Dmd_Output_flag	True if sector is part of demand output	
	Sector_Type	“Rinj” for reinjection, “PFU” for pipeline fuel use, “Proc” for processing fuel use, “LNG” for liquefaction and regasification fuel use, “GTL” for GTL fuel use, “FUse” for final fuel use, “Stor” for storage fuel use	

Table: tInp_ErrMessages

This table defines the different error messages potentially produced by INGM.

	ErrId	Unique ID of the error
	GenMessage	Generic message associated with this error

Symbol	Field	FDef	Units
Table: tInp_Fuel			
This table defines the different fuel types used in INGM.			
f	FuelId	Unique ID for the fuel type	
	Fuel_Name	Name of the fuel	
	Select_Flag	Select flag for output queries – true or false	
CarCf	CarContent	CO_2 content of the fuel	Tonne CO_2/GJ
Table: tInp_Fuel_Scn			
This table defines the different fuel types used in INGM for the base physical characteristics scenario. The field Flag indicates if the fuel is the produced gas (wet natural gas), dry gas consumed, NGL, or re-injected gas			
	AA_Base_Id	Id of baseline physical characteristics option	
f	FuelId	Unique ID for the fuel type	
	Flag	"D", "S", “N”, “R”, or "" indicting if the fuel is for demand (processed natural gas), supply (unprocessed natural gas), NGLs, re-injected gas, or other	
Table: tGAMS_Dir			
This table identifies the drive and directory of the GAMS file used when GAMS is used.			
	GAMS_DIR	Directory where the GAMS files reside	
Table: tInp_ImpExp_Cnstr			
This table defines the import and export constraints for the model. Each region can have a limit placed on net imports of natural gas or LNG and/or net exports of natural gas or LNG. Also, this table can be used to adjust production costs to reflect regional limits on the price allowed. These production cost limits can be defined with a fixed number or defined as a function of a fuel price.			
	AA_ImpExp_Id	Id of baseline import/export option	
r	RegionId	RegionId of region that the constraint applies to	
y	Year	Year that the price applies	Year
$ImpLmt_{r,f,y}$	ImpCnstr	Annual limit on imports to the region and only used if FuelId is null	EJ
$ExpLmt_{r,f,y}$	ExpCnstr	Annual limit on exports from the region and only used if FuelId is null	EJ
fp(r)	FuelId	Unique ID for the fuel type used to index the minimum price on	
$MnPrcI_r$	MinPrc_Int	Intercept for minimum price equation. Note that it is specified for only one year but applies to all	$/GJ
$MnPrcF_r$	MinPrc_Fac	Factor for minimum price equation to be multiplied for price for specified fuel. Note that it is specified for only one year but applies to all	Ratio
$InvC_{r,y}$	InvCnstr	Investment costraint for the region and only used if FuelId is null	Million $
$EI\_Cnst_{r,y}$	MinCntrrFlag	Flag if export/import constraint is annual and not seasonal	True/False

Symbol	Field	FDef	Units
Table: tInp_Node			
This table defines the nodes used in INGM.			
n	NodeId	Unique ID number for the node	
	Node_Name	Name of the node	
	Select_Flag	Select flag for output queries – true or false	
usf(n)	US_Flag	Flag set to true if node is in the U.S.	
naf(n)	NA_Flag	Flag set to true if the node is in North America	
atlf(n)	Atl_Flag	Flag set to true if the node is on the Atlantic in North America	
Table: tInp_Node_Scn			
This table maps the nodes to the regions which are used for import/export constraints and reporting. It also specifies the government take for the node			
	AA_Base_Id	Id of baseline physical characteristics option	
n	NodeId	Unique ID number for the node	
r(n)	RegionId	RegionId of region in which node n is located	
$PortC_n$	Port_Capacity	The maximum number of ships in the port at any one time for loading or unloading – not currently used	Number ships per day
$Govt_n$	GovtTake	The government share of the natural gas sales price	Fraction
$PEffB_n$	ProdIEffBase	Base Value for production inefficiency for node – reduces the share of economic resources that can be developed	Fraction
$PEffI_n$	ProdIEffImp	Annual improvement in production inefficiency value with total share capped at 1.0	Fraction/Year
$OthFU_n$	OthFU	Fraction of secondary demand used for internal pipelines and distribution and not captured in the specified pipelines	Fraction
	Rpt_RegionId	IEO reporting region	
	GovtTake_Tx	The government share of the natural gas sales price (fraction that is taxes – used for NGL sales	
Table: tInp_OthDmd			
This table defines the price that the market is willing to pay for other fuels. This is used to define the value of NGLs and GTL fuels.			
	AA_OthDmd_Id	Id of baseline other fuel price option	
f	FuelId	Unique ID for the fuel type	
y	Year	Year that the price applies	Year
$OPrc_{f,y}$	ODPrc	Price of fuel in the market (applies only to NGLs, GTLs, and reinjected gas)	$/GJ

Symbol	Field	FDef	Units
Table: tInp_PipelineAsset			
This table defines the pipelines used to transport dry gas between nodes. The specification includes the origin and destination nodes, fuel use in the transport, capacity costs, operating costs, and the life of different stages of the pipeline asset planning, construction, and operation.			
p	PipelineId	Unique ID for the pipeline	
	Pipeline_Name	Name of the pipeline	
f(p)	FuelId	ID of fuel type that the pipeline transports	
on(p)	Org_NodeId	NodeId of the node at the start of the pipeline	
dn(p)	Dst_NodeId	NodeId of the node at the end of the pipeline	
$CapI_p$	Capacity_Increment	Capacity increment for capacity increases	PJ/day
NYP_p	Num_Yrs_PlnAppr	Number of years required for planning and approvals	Number Years
$PACst_p$	PlanAppr_Cst	Annual Planning and Approval costs	$mil per year per capacity increment
NYC_p	Num_Yrs_Inv	Number of years required for construction	Number Years
$ICst_p$	Investment_Cost	Investment cost per year	$mil per year per capacity increment
MxL_p	Maximum_Life	Maximum operating life of asset (e.g., 30 years)	Number Years
$FOaMC_p$	Fixed_OaM_Cost	Annual fixed operating and maintenance cost per year	$mil per year per capacity increment
$VOaMC_p$	Variable_OaM_Cost	Variable Operating and Maintenance Cost	$/GJ
FUp	Fuel_Use	Pipeline fuel use	fraction
$RCst_p$	Retirement_Cost	Cost of retiring the asset	$mil per year per capacity increment
	Select_Flag	Select flag for output queries – true or false	
Table: tInp_PipelineAsset_Cnstr			
This table defines the constraints on pipeline capacity. Existing capacity or new capacity that is firm is defined with minimum and maximum capacity set equal to the capacity value. New capacity is only built in a year if a capacity expansion record exists for the pipeline covering the year.			
	AA_PipelineACnstr_Id	Id of pipeline asset option	
P	PipelineId	ID for the pipeline that the constraint applies to	
X		x is an index representing a year where FYear < x < LYear	Year
sy	FYear	First year that following data apply for (e.g., 2006)	Year
$EY_{p,sy}$	LYear	Last year that following data apply for (e.g., 2010) – inclusive	Year
$MnCap_{p,sy}$	Min_Capacity	Minimum capacity addition allowed for the pipeline	PJ/day of input fuel to pipeline
$MxCap_{p,sy}$	Max_Capacity	Maximum capacity addition allowed for the pipeline	PJ/day of input fuel to pipeline

Symbol	Field	FDef	Units
Table: tInp_PorttoPort			
This table defines the node to node routes for LNG tankers. This includes the number of days required for a one-way trip.			
	AA_PorttoPort_Id	Id of port-to-port option	
l	PorttoPortId	Id of Port-to-port link	
	PorttoPort_Name	Name of Port-to-Port link	
on(l)	Org_NodeId	NodeId of one end of the link	
dn(l)	Dst_NodeId	NodeId of the other end of the link	
$TrpD_l$	TripDuration	Duration of trip	Days
	Select_Flag	Select flag for output queries – true or false	
	TripDuration_Basis – unadjusted estimates which are not used	Duration of trip	Days
	Suez	Flag if trip is through Suez canal	True/False
	Panama	Flag if trip is through Panama canal	True/False
mnfflg(l)	MinFlow_Flag	Flag if minimum flow is to be assigned to the port-to-port link and is used to control prices for the NGTDM interface. The minimum flow 1e-7 PJ tanker capacity	Yes/No
Table: tInp_ProcessingAsset			
This table defines the processing assets used to convert gas from one form to another. Processing assets include gas processing, liquefaction, regasification, and GTL technology. The specification includes the asset type, capacity costs, operating costs, and the life of different stages of the processing asset planning, construction, and operation.			
a	AssetId	Unique ID number for the Asset	
	Asset_Name	Asset Name	
	Asset_TypeID	AssetID for asset type	
$CapI_a$	Capacity_Increment	Capacity increments required for investment	PJ/day of primary output fuel
f(a)	FuelId	Id of primary output fuel (capacity is measure on output of this fuel)	
NYP_a	Num_Yrs_PlnAppr	Number of years required for planning and approvals	Number Years
$PACst_a$	PlanAppr_Cst	Annual Planning and Approval costs	$mil per year per capacity increment
NYC_a	Num_Yrs_Inv	Number of years required for construction	Number Years
$ICst_a$	Investment_Cost	Investment cost per year	$mil per year per capacity increment
MxL_a	Maximum_Life	Maximum operating life of asset (e.g., 30 years)	Number Years
$FOaMC_a$	Fixed_OaM_Cost	Annual fixed operating and maintenance cost per year	$mil per year per capacity increment
$VOaMC_a$	Variable_OaM_Cost	Variable Operating and Maintenance Cost	$/GJ

Symbol	Field	FDef	Units
$RCst_a$	Retirement_Cost	Cost of retiring the asset	$mil per year per capacity increment
	Select_Flag	Select flag for output queries – true or false	

Table: tInp_ProcessingAsset_Fuel

This table defines the input energy and output energy by fuel type for each processing asset. The input and output fuel quantities should be defined consistent with the capacity increment of the asset and the quantity for the primary output fuel should equal the capacity increment. For example, if a processing asset takes 1 PJ/day of unprocessed gas and produces 0.95 PJ/day of processed gas and 0.03 PJ/day of NGLS then this table should have three records – one for the input fuel at 1PJ/day and two for the output fuels with 0.95 and 0.03 PJ/day. The capacity increment should be 0.95 PJ/day.

a	AssetId	AssetID for asset that data apply to	
f	FuelId	FuelId of the fuel that data apply to	Long
$Qty_{a,f}$	Qty	Quantity input (negative) or output (positive) for capacity increment	PJ/day

Table: tInp_ProcessingAsset_RegCnstr

This table defines the constraints on processing capacity. Existing capacity or new capacity that is firm is defined with minimum and maximum capacity set equal to the capacity value. New capacity is only built in a year if a capacity expansion record exists for the processing asset for the node covering the year.

	AA_ProcessingACnstr_Id	Id of processing assets option	
n	NodeId	Unique ID number for the Node	
a	AssetId	Unique ID number for the Asset	
x		x is an index representing a year where FYear < x < LYear	Year
sy	FYear	First year that following data apply for (e.g., 2006)	Year
$EY_{n,a,sy}$	LYear	Last year that following data apply for (e.g., 2010) – inclusive	Year
$MnCap_{n,a,sy}$	Min_Capacity	Minimum capacity addition allowed in the node	PJ/day output of primary fuel
$MxCap_{n,a,sy}$	Max_Capacity	Maximum capacity addition allowed in the node	PJ/day output of primary fuel

Symbol	Field	FDef	Units

Table: tInp_ProcessingAsset_Type

This table defines the different processing asset types (e.g., liquefaction)

	Asset_TypeID	Unique AssetID for asset type	
	Asset_Type_Name	Name	
	Select_Flag	Selection flag used for data input and review	
	Asset_Type	"LNG" for liquefaction or regasification, "Proc" for gas processing, "GTL" for GTL plant	

Table: tInp_PScalar

This table defines the price scalar by year and for each asset type

Symbol	Field	FDef	Units

b	PS_Type	Asset type (Pipeline, Production, ProcAsset, Storage, or Tanker)	0 for production, 1 for pipeline, 2 for processing asset, 3 for tanker, and 4 for storage
y	Year	Year of the cost scalar	Year
$PScalar_{b,y}$	PScalar	Cost scalar reflecting both increases in asset/production costs and technological improvement	Ratio
Table: tInp_Region			
This table defines the different regions.			
r	RegionId	Unique ID number for the region	
	Region_Name	Name of the region	
	Select_Flag	Select flag for output queries – true or false	
usf(r)	US_Flag	Flag set to true if region is in the U.S.	
naf(r)	NA_Flag	Flag set to true if the region is in North America	
Table: tInp_Region_Scn			
This table defines discount rates for the different regions.			
	AA_Base_Id	Id of baseline physical characteristics option	
r	RegionId	Unique ID number for the region	
DR_r	DRate	Discount rate for the region	fraction
rc(r)	CmbImpExp_RegionId	Id of Region used as aggregate region for combined import/export constraint	
	Agr_RegionId	Aggregate region for the WEPS+ output	
Table: tRpt_Region			
This table defines the different regions for output reports, without any subcountry groupings.			
	Rpt_RegionId	Unique ID for the region	
	Rpt_Region_Name	Name of the region	
Table: tInp_Scenario			
This table defines the different scenarios to run.			
	ScenarioID	Unique ID number for the scenario	
	Scenario_Name	Name of the scenario	
SYear	Start_Year	First year of optimization	Year
EYear	End_Year	Last year of optimization	Year
TStep	Time_Step	Number of years between optimizations	Years

Symbol	Field	FDef	Units
	AA_Base_Id	Id of baseline physical characteristics option	
	AA_DmdSpec_Id	Id of baseline demand option	
	AA_DmdSS_Id	Id of baseline demand sector and season option	
	AA_ImpExp_Id	Id of baseline import/export option	
	AA_OthDmd_Id	Id of baseline other fuel price option	
	AA_PipelineACnstr_Id	Id of pipeline asset option	
	AA_PorttoPort_Id	Id of port-to-port option	
	AA_ProcessingACnstr_Id	Id of processing assets option	
	AA_StorageACnstr_Id	Id of storage assets option	
	AA_Supply_Id	Id of baseline natural gas resource option	
	AA_TankerACnstr_Id	Id of tanker assets option	
DRate	DRate	Global discount rate	Fraction (.12 is 12%)
	Select_Flag	Select flag for output queries – true or false	
StorFrac	Storage_Fraction	Fraction of storage working gas that can be effectively used.	Fraction
	WEPS_Output_Scen	Flag if scenario used to create WEPS+ output regression model	
Table: tInp_Season			
This table defines the different seasons.			
s	SeasonId	Unique ID number for the season	
	Season_Name	Name of the season	
	Select_Flag	Select flag for output queries – true or false	
Table: tInp_Season_Scn			
This table defines the number of days in the seasons. The number of days in the seasons should add to 365.			
	AA_Base_Id	Id of baseline physical characteristics option	
s	SeasonId	Unique ID number for the season	
NDs	NumDays	Number of days in the season	Days
Table: tInp_StorageAsset			
This table defines the storage assets used for seasonal storage. The specification includes the asset type, capacity costs, operating costs, and the life of different stages of the storage asset planning, construction, and operation.			
g	StorageId	Unique ID number for the Asset	
	Storage_Name	Asset Name	
$CapI_g$	Capacity_Increment	Capacity increments required for investment	EJ of working capacity

Symbol	Field	FDef	Units
f(g)	FuelId	Id of fuel type storded	
NYP_g	Num_Yrs_PlnAppr	Number of years required for planning and approvals	Number Years
$PACst_g$	PlanAppr_Cst	Annual Planning and Approval costs	$mil per year
NYC_g	Num_Yrs_Inv	Number of years required for construction	Number Years
$ICst_g$	Investment_Cost	Investment cost per year	$mil per year
MxL_g	Maximum_Life	Maximum operating life of asset (e.g., 30 years)	Number Years
$FOaMC_g$	Fixed_OaM_Cost	Annual fixed operating and maintenance cost	$mil per year
$VOaMC_g$	Variable_OaM_Cost	Variable Operating and Maintenance Cost	$/GJ
$RCst_g$	Retirement_Cost	Cost of retiring the asset	$mil
FU_g	Fuel use	Fuel use from the injection and withdrawal and including losses applied on injections	Fraction as a percentage of injections
	Select_Flag	Select flag for output queries – true or false	

Table: tInp_StorageAsset_RegCnstr

This table defines the constraints on storage capacity. Existing capacity or new capacity that is firm is defined with minimum and maximum capacity set equal to the capacity value. New capacity is only built in a year if a capacity expansion record exists for the storage type and node covering the year.

	AA_StorageACnstr_Id	Id of storage assets option	
n	NodeId	Unique ID number for the Node	
g	StorageId	Unique ID number for the Asset	
x		x is an index representing a year where FYear < x < LYear	Year
sy	FYear	First year that following data apply for (e.g., 2006)	Year
$EY_{n,g,sy}$	LYear	Last year that following data apply for (e.g., 2010) – inclusive	Year
$MnCap_{n,g,sy}$	Min_Capacity	Minimum capacity addition allowed in the node	PJ working gas
$MxCap_{n,g,sy}$	Max_Capacity	Maximum capacity addition allowed in the node	PJ working gas

Table: tInp_SupplyBase

This table specifies the natural gas reserves and resources by node and major price step.

	AA_Supply_Id	Id of baseline natural gas resource option
n	NodeId	Unique id for node
c	SupCatId	Unique Id for the supply category – Note set to “All” now

Symbol	Field	FDef	Units
m	SMPrcStep	Major price step for supply category (0, 1, 2, …)	
$BRsv_{n,c}$	BYrRsv	Base year reserves	EJ
$BURs_{n,c}$	BYrURes	Base year undeveloped resources	EJ
$MnP_{n,c,m}$	MnPrc	Minimum development costs at which reserves come online	$/GJ
$MxP_{n,c,m}$	MxPrc	Maximum development costs at which reserves come online	$/GJ
$\alpha n,_{c,m}$	SPVFac	Supply curve price/volume factor	
$VPC_{n,c,m}$	VrPrdCosts	Variable production costs	$/GJ
$RsvS_{n,c,m}$	RsvShr	Share of economic/undeveloped resources that can be developed in the year	Fraction
$PR_{n,c,m}$	PR_Ratio	Maximum production to reserves ratio	ratio
$NPS_{n,c,m}$	Num_MinPrcStp	Number of minor price steps within major price step	number
m(n,c,i)		Major price step that the minor price step is part of	
$S_{n,c,i}$		The incremental order of the minor price step within the major price step. For example if 16 is the first minor price step for major price step 4 and 20 is the last minor price step for price step 4 then s(n,c,16) is 1 and s(n,c,20) is 5.	
$NGLF_{n,c,m}$	NGL_Frac	Fraction of wet gas that is NGLs	Fraction
Table: tInp_SupplyCat			
This table defines the different supply categories (e.g., conventional onshore or tight gas) used in reporting.			
c	SupCatId	Unique Id for the supply category	
	SupCat_Name	Name of the supply category (allow for All for common modelling of all supply categories simultaneously)	
	Select_Flag	Select flag for output queries – true or false	
Table: tInp_SupplyCatAsgn			
This table specifies the share of undiscovered resources by supply category for each node and major price step.			
	AA_Supply_Id	Id of baseline natural gas resource option	
n	NodeId	Unique id for node	
c	SupCatId	Unique Id for the supply category	
m	SMPrcStep	Major price step for supply category (0, 1, 2, …)	
$URShr_{n,c,m}$	Share	Share of reserves and undiscovered resources by node and major price step represented by supply category.	Fraction

Symbol	Field	FDef	Units
Table: tInp_SupplyCatCnst			
This table specifies the share of undiscovered resources by supply category for each node that is available to be developed in any year.			
	AA_Supply_Id	Id of baseline natural gas resource option	
n	NodeId	Unique id for node	
c	SupCatId	Unique Id for the supply category	
y	Year		
$CCnst_{n,c,y}$	Availability	Share of reserves and undiscovered resources by node and by supply category that is available to be developed in specified year. Note that if data are not specified for a year then a value is interpolated between years where it is specified. If there are no values past some year then the last specified value is assumed	Fraction
Table: tInp_TankerAsset			
This table defines the tanker assets used for LNG transport. The specification includes the tanker type, capacity costs, operating costs, and the life of different stages of the tanker asset planning, construction, and operation. Tankers can also include onboard regasification capabilities and this table includes a field indicating if it does.			
t	TankerId	Unique ID for the tanker type	
	Tanker_Name	Name of the tanker type	
$CapI_t$	Capacity_Increment	Capacity increment for capacity increases – adjusted for expected utilization	Pj per ship
NYP_t	Num_Yrs_PlnAppr	Number of years required for planning and approvals	Number Years
$PACst_t$	PlanAppr_Cst	Annual Planning and Approval costs	$mil per year per ship
NYC_t	Num_Yrs_Inv	Number of years required for construction	Number Years
$ICst_t$	Investment_Cost	Investment cost per year	$mil per year per ship
MxL_t	Maximum_Life	Maximum operating life of asset (e.g., 30 years)	Number Years
$FOaMC_t$	Fixed_OaM_Cost	Annual fixed operating and maintenance cost	$mil per year per ship
$VOaMC_t$	Variable_OaM_Cost	Variable Operating and Maintenance Cost	$ per GJ per day
$RCst_t$	Retirement_Cost	Cost of retiring the asset	$mil per year per capacity increment
RGF_t	Regas_Cap	Flag is True if tanker has regasification capability built onboard	True/False
LdT_t	Loading Time	The number of days required to load the ship	Days
$UnLdT_t$	Unloading Time	The number of days required to unload the ship	Days
	Select_Flag	Select flag for output queries – true or false	
	Capacity_Increment_Orig	Capacity increment for capacity increases - unadjusted	Pj per ship

Symbol	Field	FDef	Units
Table: tInp_TankerAsset_Cnstr			
This table defines the constraints on tanker capacity. Existing capacity or new capacity that is firm is defined with minimum and maximum capacity set equal to the capacity value. New capacity is only built in a year if a capacity expansion record exists for the tanker covering the year.			
	AA_TankerACnstr_Id	Id of tanker assets option	
t	TankerId	ID for the tanker type that the constraint applies to	
x		x is an index representing a year where FYear < x < LYear	Year
sy	FYear	First year that following data apply for (e.g., 2006)	Year
$EY_{t,sy}$	LYear	Last year that following data apply for (e.g., 2010) – inclusive	Year
$MnCap_{t,sy}$	Min_Capacity	Minimum capacity addition allowed for the tanker type	Number of ships
$MxCap_{t,sy}$	Max_Capacity	Maximum capacity addition allowed for the tanker type	Number of ships
Table: tInp_TankerFuel			
This table defines the input and output fuels for each tanker. Typically they will be the same except for tankers with regasification capacity built in.			
t	TankerId	ID for the tanker type that the constraint applies to	
Inpf(t)	Inp_FuelId	Id of input fuel to tanker	
Outf(t)	Out_FuelId	Id of output fuel to tanker corresponding to input fuel	
Table: tInp_TankerPort			
This table defines for each tanker type, the nodes that the tanker can import to or export from.			
t	TankerId	ID for the tanker type that the constraint applies to	
n	NodeId	NodeId of the port	
$TPF_{t,n}$	Tanker_Port_Flag	Flag set to true if tanker allowed in port and false (or not specified) otherwise	True/False
Table: tInp_TimeStep			
This table defines for the time steps for the rolling optimization.			
	TimeStep	Number for time step which must start at 1 and be consecutive	Integer
	NumYears	Number of years in the time step	Years

Debug tables

Field	Description	Units
Table: tMatrix_Coef		
This table stores the coefficients of the LP. The row, 0, contains the objective value and the column 0 contains the right hand side.		
Row	Row number of LP matrix where row 0 is the objective values	Number
Col	Column number of LP matrix where column 0 is the right hand side	Number
Coef	Coefficient in the LP matrix	Varies depending on the column and row
Table: tMatrix_Col		
This table stores the definition of the columns in the LP and includes upper and lower bound of the column, the name of the column, the column number, and the value for the column in the optimal solution.		
Col	Column number of LP matrix where column 0 is the right hand side	Number
Name	Name of the Column	
Lower_Bnd	Lower bound of the column	Varies depending on the column
Upper_Bnd	Upper bound of the column	Varies depending on the column
Solution	LP solution	Varies depending on the column
Table: tMatrix_Row		
This table stores the definition of the rows in the LP and includes the sense of the row, the name of the row, the row number, and the dual of the row and slack for the row in the results.		
Row	Row number of LP matrix where row 0 is the objective values	Number
Name	Name of the row	
Sense	“<”, “=”, “>”, or Null	
Slack	Slack in the solution for the row	Varies depending on the column
Dual	Dual of the row in the solution	Varies depending on the column

Output tables

Field	Description	Units
Table: tOut_Dmd		
This table stores the output average annual demand by node and demand sector.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
DmdSectorId	Unique Id for the demand sector	
Year	Year that the solution data applies to	Year
Qty	Demand in the solution. Note that this number multiplied by the seasonal factor provide seasonal demand in PJ/day	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_DmdOth		
This table stores the natural gas fuel use demands by node, demand sector and season.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
DmdSectorId	Unique Id for the demand sector	
Year	Year that the solution data applies to	Year
SeasonId	Unique Id for the season	
Qty	Demand in PJ/day	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_EOYRsv		
This table stores the output end of year reserves for each supply category and major price step by node.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
SupCatId	Unique Id for the supply category (should be supply category for "All")	
SMPrcStep	Major price step	Number
Year	Year that the solution data applies to	Year
Qty	End of year remaining undiscovered resources in the solution.	EJ
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_ErrLog		
This table stores any error messages produced by an INGM run.		
ScenarioId	Unique ID for the scenario	
MsgNum	Number of the message for the run	
ErrId	Unique ID of the error	
Message	Unique message associated with this error and occurrence of the error	

Field	Description	Units
Table: tOut_NetCshFlw		
This table stores the output net cash flow from investments and operations.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
RegionID	Unique ID of the region	
Year	Year that the solution data applies to	Year
NCI	Net cash flow for asset investments	$mil
NCO	Net cash flow from other activities (production, O&M, sales of products)	$mil
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
ImpExpDual	Dual from fixed import/export constraint	$mil
Table: tOut_OthDmd		
This table stores the output demand for non-natural gas fuels such as GTL diesel and NGLs.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
FuelID	Unique ID of the fuel sold	
Year	Year that the solution data applies to	Year
SeasonID	Unique ID of the season	
Qty	Quantity fuel sold	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False

Field	Description	Units
Table: tOut_Pipe_Capacity		
This table stores the output capacity installed for pipelines.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
PipelineID	Unique ID of the pipeline	
Year	Year that the solution data applies to	Year
Cap	Capacity that comes online in the year, measured as inflow to the pipeline	PJ/day
CumCap	Cumulative capacity online in the year, measured as inflow to the pipeline	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_Pipe_Utilization		
This table stores the output utilization of the pipelines (in terms of fuel into the pipeline)		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
PipelineID	Unique ID of the pipeline	
Year	Year that the solution data applies to	Year
SeasonID	Unique ID of the season	
Utl	Capacity utilization in season	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_Prices		
This table stores the prices for each fuel in each node by year. The price represents a weighted average price based on demand for the fuel.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
FuelID	Unique ID of the fuel sold	
Year	Year that the solution data applies to	Year
Price	Average annual market price of the fuel weighted by total demand by season	$/GJ
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_Prices_Season		
This table stores the prices for each fuel in each node by year and season.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
FuelID	Unique ID of the fuel sold	
Year	Year that the solution data applies to	Year
SeasonID	Unique ID of the season	
Price	Average market price of the fuel for the season	$/GJ
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False

Field	Description	Units
Table: tOut_Proc_Capacity		
This table stores the output capacity installed for gas processing assets.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
AssetID	Unique ID of the asset	
Year	Year that the solution data applies to	Year
Cap	Capacity that comes online in the year, measured in output of primary fuel	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_Proc_Utilization		
This table stores the utilization of the processing capacity measured in PJ/day of primary output fuel.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
AssetID	Unique ID of the asset	
Year	Year that the solution data applies to	Year
SeasonID	Unique ID of the season	
Utl	Utilization of the capacity in the year and season, measured as output of primary fuel	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_Production		
This table stores the output production by node, year, and season.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
SupCatId	Unique ID of the supply category	
SMPrcStep	Major price step for supply category (0, 1, 2, …)	
Year	Year that the solution data applies to	Year
SeasonID	Unique ID of the season	
Qty	Production in the year and season including NGLs and reinjection gas	PJ/day
ReInject	Gas reinjected in year and season	PJ/day
APrd	Accelerated production in year and season	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_Production_Ann		
This table stores the output production by node and year.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year

Field	Description	Units
NodeID	Unique ID of the node	
SupCatId	Unique ID of the supply category	
SMPrcStep	Major price step for supply category (0, 1, 2, …)	
Year	Year that the solution data applies to	Year
Qty	Average annual production in time period (PJ/day)	PJ/day
ReInject	Gas reinjected in year and season	PJ/day
APrd	Accelerated production in year and season	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_Pub		
This table stores the production, consumption and net trade by report region and year.		
ScenarioID	Unique ID number for the scenario	
Rpt_RegionId	Unique ID of the report region	
Year	Year that the solution data applies to	Year
Qty_NetDmd	Net demand quantity	EJ
Qty_NetProd	Net production quantity	EJ
Qty_NetTrade	Net trade	EJ
Table: tOut_RemResources		
This table stores the output end of year undeveloped resources for each supply category and major price step by node.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
SupCatId	Unique ID of the supply category	
SMPrcStep	Major price step	Number
Year	Year that the solution data applies to	Year
Qty	Remaining resources at the end of the year	EJ
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_ResAdd		
This table stores the reserve additions by node and year.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
SupCatId	Unique ID of the supply category	
SMPrcStep	Major price step	Number
Year	Year that the solution data applies to	Year
Qty	Reserve additions in year	EJ
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False

Field	Description	Units
Table: tOut_Stor_Cap		
This table stores the output storage capacity additions by year, node, and storage type.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
StorageId	Unique ID of the storage type	
Year	Year that the capacity comes online	Year
Cap	Capacity, working gas, that comes online in the year	PJ
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_Stor_Utilization		
This table stores the output storage utilization by node, year, season, and storage type. The utilization includes injections and withdrawals.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
NodeID	Unique ID of the node	
StorageId	Unique ID of the storage type	
Year	Year that the solution data applies to	Year
SeasonID	Unique ID of the season	
Inj	Quantity injected during season	PJ/day
Wth	Quantity extracted during season	PJ/day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_SupplyCatAsgn		
This table stores the share of reserves/resources by node, supply category and major price step for each year.		
ScenarioId	Unique ID number for the scenario	
NodeId	Unique Id number for the node	
SupCatId	Unique Id for the supply category	
SMPrcStep	Major price step for the supply category	(0 to n)
Year	Year	
Share	Share of reserves/resources in the category for production and reserves	Fraction
ShareRA	Share of reserves/resources in the category for reserve additions	Fraction
ShareRR	Share of reserves/resources in the category for remaining reserves	Fraction
SYear	Start year of the optimization period	
FnlFlag	Flag set to yes if data represents final solution for year	True/False

Field	Description	Units
Table: tOut_Tnk_Capacity		
This table stores the output tanker capacity added by region and tanker type.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
RegionID	Unique ID of the region	
TankerId	Unique ID of the tanker type	
Year	Year that the the capacity comes online	Year
Cap	Capacity that comes online in the year	PJ capacity of tankers
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False
Table: tOut_Tnk_Utilization		
This table stores the output tanker utilization by tanker route, tanker type, year, and season.		
ScenarioID	Unique ID number for the scenario	
SYear	First year of the optimization period	Year
PorttoPortId	Id of Port-to-port link	
TankerId	Unique ID of the tanker type	
FuelId	Unique ID for the fuel type transported	
Year	Year that the capacity comes online	Year
SeasonID	Unique ID of the season	
Utl	Utilization of the tankers	PJ capacity of tankers
Flow	Utilization in flow (currently not filled)	PJ/Day
FnlFlag	Flag set to yes/true if data represents final solution for year	True/False

Appendix D Programmers Guide

The INGM is implemented in Visual Basic within Microsoft ACCESS and through the use of predefined queries for output. The code is contained in eleven modules each focusing on specific tasks as follows:

- mAdjustBasePrice – adjusts the input regional demand prices based on existing nodal prices
- mBuildMatrix – Builds the LP matrix
- mCleanOutputRslts – Provides utility routines for cleaning out the output tables
- mDocument – Provides summary of database tables for documentation
- mINGM_Main – Main routine for INGM and controls looping, input, processing, and output
- mLPSetUp – Utility routines for setting up the matrix and building the MPS file for the commercial solver
- mOutputQueries – Routines that build the output queries for the report writer
- mReadData – Reads the input data and scenario specifications and stores them in arrays
- mReadMPSRslt – Reads in the output from CPLEX or GAMS and stores in arrays
- mRefIntegrity – Maintenance routines that test the referential integrity of the input data sets
- mShellWait – Utility routine used to control the running of the commercial solver

Module: mAdjustBasePrice

Main Routines

iCorrectNodalBasePrices

Description: The function takes the input nodal prices, which are essentially more aggregate regional averages from the WEPS+ model, and adjusts them based on nodal prices from a previous INGM run.

Input:

lScenarioId – index of the previously run model scenario, the results from which are to be used to adjust the new demand prices

lDmdSpecId –index of the demand inputs for which prices are to be adjusted

Functions Used: None

Return Output: None

Module: mBuildMatrix

Main Routines

iBuild_Matrix

Description: The function initializes the variables, rows, and columns of the LP matrix. The function calls several functions that build the constraints of the model by calculating and introducing coefficients in the LP matrix.

The first function called, iSetUpLP_InitializeVars, calculates some complex variables required for the LP coefficients. The next functions called, iSetUpLP_InitializeRows and iSetUpLP_InitializeCols dimension and initialize the pointer arrays for the rows and columns. The next function called, iEstimateRowCol, estimates the number of rows and columns in the matrix. The function iInitializeLP is then called to set up the arrays that store the rows, columns, and coefficients in the LP. The remaining columns build the rows, columns and coefficients in the LP. The functions are organized by the column in the LP. Rows are added when the first coefficient for the row is added. The very first column is the right hand side and the very first row is the objective function.

Input: None

Functions Used: iSetUpLP_InitializeVars, iSetUpLP_InitializeRows, iSetUpLP_InitializeCols, iEstimateRowCol, iInitializeLP, lAdd_Col, lAdd_Row, iBld_PrCpE, iBld_PrCpU, iBld_PlCpE, iBld_PlCpU, iBld_TCpE, iBld_TCpU, iBld_TD, iBld_TDS, iBld_DRs, iBld_RR, iBld_Rsv, iBld_Prd, iBld_PrA, iBld_RIJ, iBld_ODMD, iBld_Exp, iBld_Imp, iBld_NCI, iBld_NCO, iBld_SCpE, iBld_SCpU, iCreateErrorMsg

Return Output: The function returns a value 0 (false) unless a major program error has occurred in which case it returns a -1 (true).

iClear_Matrix

Description: The matrix is used to clear data from matrix arrays, column and row arrays, and variable arrays and free up the memory. This routine is called at the end of the run.

Input: None

Functions Used: iSetUpLP_InitializeVars, iSetUpLP_InitializeRows, iSetUpLP_InitializeCols, iClearLP, iCreateErrorMsg

Return Output: The function returns a value 0 (false) unless a major program error has occurred in which case it returns a -1 (true).

Initialization and Clearing Routines

iSetUpLP_InitializeVars

Description: The function initializes sub-functions that calculate the demand and supply curves and prices. It also clears arrays.

Input: lFlag – The argument is set to -1 for initializing the rows and -2 for clearing the arrays

Functions Used: iVar_RRQ, iVar_DSF, iCreateErrorMsg

Return Output: 0 if processing completed satisfactorily and -1 if an error occurred somewhere in the processing.

iSetUpLP_InitializeRows

Description: The function initializes and clears the arrays controlling the rows of the LP Matrix. It does this by calling the individual routines for each row which control the initialization, clearing, and adding of the rows.

Input: lFlag – The argument is set to -1 for initializing the rows and -2 for clearing the arrays

Functions Used: lRow_MB, lRow_EI, lRow_EJ, lRow_CI, lRow_CO, lRow_CC, lRow_ADD, lRow_ARC, lRow_RUR, lRow_RSV, lRow_PrA, lRow_PRD, lRow_PCU, lRow_PCG, lRow_PCL, lRow_ACU, lRow_ACG, lRow_ACL, lRow_TCU, lRow_TCG, lRow_TCL, lRow_SCU, lRow_SCG, lRow_SCL, lRow_SCB, iCreateErrorMsg

Return Output: 0 if processing completed satisfactorily and -1 if an error occurred somewhere in the processing.

iSetUpLP_InitializeCols

Description: The function initializes and clears the arrays controlling the rows of the LP Matrix.

Input: lFlag – The argument is set to -1 for initializing the rows and -2 for clearing the arrays

Functions Used: lCol_PrCpE, lCol_PrCpU, lCol_PlCpE, lCol_PlCpU, lCol_TCpE, lCol_TCpU, lCol_SCpE, lCol_SCpI, lCol_SCpW, lCol_TD, lCol_TDS, lCol_DRs, lCol_RR, lCol_Rsv, lCol_Prd, lCol_PrA, lCol_RIJ, lCol_ODmd, lCol_Exp, lCol_Imp, lCol_NCI, lCol_NCO, iCreateErrorMsg

Return Output: 0 if processing completed satisfactorily and -1 if an error occurred somewhere in the processing.

iVar_RRQ

Description: The function calculates the supply price and supply curves by node and supply category.

Input: lFlag – The argument is set to -1 for building up the supply price curve and 0 for clearing the arrays

Functions Used: None

Return Output: iVar_RRQ – Returns 0 if there is no error in execution of the function and -1 otherwise. The function builds the global arrays lSPS_Pnt and fRRQ

iVar_DSF

Description: The function calculates the demand price and demand curves by node and demand sector. The demand price for each region and year is adjusted by the regional GDP and price elasticity.

Input: lFlag – The argument is set to -1 for building up the demand price curve and 0 for clearing the arrays

Functions Used: None

Return Output: iVar_DSF – Returns 0 if there is no error in execution of the function and -1 otherwise.

iEstimateRowCol

Description: The function estimates the number of rows, columns, and density of the LP matrix.

Input: None

Functions Used: None

Return Output: The following global variables are used to pass on estimates;

lEstRow - estimated number of rows
lEstCol - estimated number of columns
fDens = matrix density (average number of coefficients per column)

Build Column and Coefficient Routines

iBld_DRs

Description: This function adds the resource development column to the LP matrix and adds coefficients for constraints CO, ARC, RUR, RSV, and PRD for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_DRs, lRow_CO, lRow_ARC, lRow_RUR, lRow_RSV, lRow_PRD

Return Output: 0 (false)

iBld_Exp

Description: The function adds the export constraint column to the LP matrix and adds coefficients for constraints EI and EJ where appropriate for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_Exp, lRow_EI, lRow_EJ

Return Output: 0 (false)

iBld_Imp

Description: The function adds the import constraint column to the LP matrix and adds coefficients for constraints EI and EJ for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_Imp, lRow_EI, lRow_EJ

Return Output: 0 (false)

iBld_NCI

Description: The function adds the facilities investment column to the LP matrix and adds coefficients for the constraints CI and CC and the objective function for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_NCI, lRow_CI, lRow_CC

Return Output: 0 (false)

iBld_NCO

Description: The function adds the other cash flow column to the LP matrix and adds coefficients for the constraint CO and the objective value for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_NCO, lRow_CO

Return Output: 0 (false)

iBld_ODMD

Description: The function adds the other demand column to the LP matrix and adds coefficients to the constraints MB and CO for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_ODmd, lRow_MB, lRow_CO

Return Output: 0 (false)

iBld_PlCpE

Description: The function adds the pipeline capacity investment column to the LP matrix and adds coefficients to the constraints CI, PCU, PCG, and PCL for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_PlCpE, lRow_CI, lRow_PCU, lRow_PCG, lRow_PCL

Return Output: 0 (false)

iBld_PlCpU

Description: The function adds the pipeline capacity utilization column to the LP matrix and adds coefficients for the constraints MB, EI, CI, and PCU. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: lCol_PlCpU, iAddCoef, lRow_MB, lRow_EI, lRow_CI, lRow_PCU

Return Output: 0 (false)

iBld_PrCpE

Description: This function adds the processing capacity investment column and adds coefficients for constraints CI, ACU, ACG, and ACL. The function estimates the coefficient value of capital costs for the CI constraint. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: lCol_PrCpE, lRow_CI, lRow_ACU, lRow_ACG, lRow_ACL, iAddCoef,

Return Output: 0 (false)

iBld_PrCpU

Description: This function adds the processing capacity utilization column to the LP matrix and adds the coefficients for constraints MB, CI, and ACU. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_PrCpU, lRow_MB, lRow_CI, lRow_ACU

Return Output: 0 (false)

iBld_PrA

Description: The function adds the accelerated production column to the LP matrix and adds coefficients for the constraints MB, CO, RSV, PRD, and PrA for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_Prd, lRow_MB, lRow_CO, lRow_RSV, lRow_PRD, and lRow_PrA

Return Output: 0 (false)

iBld_Prd

Description: The function adds the production column to the LP matrix and adds coefficients for the constraints MB, CO, RSV, PRD, and PrA for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_Prd, lRow_MB, lRow_CO, lRow_RSV, lRow_PRD, and lRow_PrA

Return Output: 0 (false)

iBld_RIJ

Description: The function adds the gas reinjection column to the LP matrix and adds coefficients for the constraints MB, CO, RSV, PRD, and PrA for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_RIJ, lRow_MB, lRow_CO, lRow_RSV

Return Output: 0 (false)

iBld_RR

Description: The function adds the remaining undeveloped resources column to the LP matrix and adds coefficients for constraints CO, ARC, and RUR for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Return Output: 0 (false)

iBld_Rsv

Description: The function adds the reserves column to the LP matrix and adds coefficients for constraints RSV and PRD for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_RSV, lRow_RSV, lRow_PRD

Return Output: 0 (false)

iBld_SCpE

Description: The function adds the storage capacity investment column to the LP matrix and adds coefficients for constraints CI, SCU, SCG, and SCL for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_SCpE, lRow_CI, lRow_SCU, lRow_SCG, lRow_SCL

Return Output: 0 (false)

iBld_SCpU

Description: The function adds the storage capacity utilization column to the LP matrix and adds coefficients for constraints SCU, MB, CI, and SCB for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_SCpI, lCol_SCpW, lRow_SCU, lRow_MB, lRow_CI, lRow_SCB,

Return Output: 0 (false)

iBld_TCpE

Description: The function adds the tanker capacity investment column to the LP matrix and adds coefficients for constraints CI, TCU, TCG, and TCL for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_TCpE, lRow_CI, lRow_TCU, lRow_TCG, lRow_TCL

Return Output: 0 (false)

iBld_TCpU

Description: The function adds the tanker capacity utilization column to the LP matrix and adds coefficients for constraints MB, EI, CI, and TCU for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_TCpU, lRow_MB, lRow_EI, lRow_CI, lRow_TCU

Return Output: 0 (false)

iBld_TD

Description: The function adds the average daily demand column to the LP matrix and adds coefficients for constraints MB, and ADD for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_TD, lRow_MB, lRow_ADD

Return Output: 0 (false)

iBld_TDS

Description: The function adds the average daily demand by step column to the LP matrix and adds coefficients for constraints CO, and ADD for the column. If this function is the first to add a coefficient for a constraint, it adds that constraint first and the right hand side for the constraint.

Input: None

Functions Used: iAddCoef, lCol_TDS , lRow_CO, lRow_ADD

Return Output: 0 (false)

Add Column Routines

lCol_DRs

Description: The function adds the resource development column to the LP matrix.

Input:

lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSPS - supply price step

iYear – year

Functions Used: lAddCol

Return Output: lCol_DRs - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_Exp

Description: The function adds the regional export columns to the LP matrix and sets the upper bound of the column if required.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year
lSeas - index to the season

Functions Used: lAddRow

Return Output: lCol_Exp - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_Imp

Description: The function adds the regional Import columns to the LP matrix and sets the upper bound for the column if required.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year
lSeas - index to the season

Functions Used: lAddRow

Return Output: lCol_Imp - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_NCI
Description: The function adds the net facilities investment column to the LP matrix.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year
iDir - direction (0 or 1)

Functions Used: lAddCol

Return Output: lCol_NCI - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_NCO
Description: The function adds the other cash flow column to the LP matrix.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year
iDir - direction (0 or 1)

Functions Used: lAddCol

Return Output:
lCol_NCO - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_ODmd

Description: The function adds the demand for other fuels column to the LP matrix.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lFuel - index of the fuel type
iYear – year
lSeas - index to the season

Functions Used: lAddCol

Return Output:
lCol_ODmd - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_PlCpE

Description: The function adds the pipeline capacity investment column to the LP matrix.

Input:
lPipe - index of the pipline (set to -1 if initializing the arrays and -2 if clearing them out)
iYearX – year of investment

Functions Used: lAddCol

Return Output: lCol_PlCpE – Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_PlCpU

Description: The function adds the pipeline capacity utilization column to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lPipe - index of the pipeline (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year
lSeas - index of the season

Functions Used: lAddCol

Return Output: lCol_PlCpU – Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_PrCpE

Description: The function adds the processing capacity investment column if it does not yet exist.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lProc - index of the processing asset
iYearX - year of investment

Functions Used: lAddCol

Return Output:
lCol_PrCpE – Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_PrCpU

Description: The function adds the processing capacity utilization column if it does not yet exist.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lProc - index of the processing asset

iYear - year
lSeas - index of the season

Functions Used: lAddCol

Return Output: lCol_PrCpU – Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_PrA
Description: The function adds the accelerated production column to the LP matrix.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSMS - supply major price step
iYear – year
lSeas – index to season

Functions Used: lAddCol

Return Output:
lCol_Prd - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_Prd
Description: The function adds the production column to the LP matrix.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSMS - supply major price step
iYear – year
lSeas – index to season

Functions Used: lAddCol

Return Output: lCol_Prd - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_RIJ
Description: The function adds the natural gas reinjection column to the LP matrix. The column is unbounded for all years.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
iYear – year
lSeas – index to the season

Functions Used: lAddCol

Return Output: lCol_RR - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_RR
Description: The function adds the remaining undeveloped resources column to the LP matrix. The column is unbounded for all years except the first year where it is fixed at the inputted resources value.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSPS - supply price step
iYear – year

Functions Used: lAddCol

Return Output:
lCol_RR - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_Rsv
Description: The function adds the end-of-year reserves column to the LP matrix. The column is fixed at the base year reserves for the first year and upper bound is unbounded for all other years.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSMS - supply major price step
iYear – year

Functions Used: lAddCol

Return Output:
lCol_Rsv - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_SCpE
Description: The function adds the storage capacity investment column to the LP matrix.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lStor - index of the processing asset
iYearX - year of investment

Functions Used: lAddCol

Return Output: lCol_SCpE - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_SCpI
Description: The function adds the storage capacity utilization column (injections) to the LP matrix.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lStor - index of the processing asset
iYear – year
lSeas - index of the season

Functions Used: lAddCol

Return Output: lCol_SCpI - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_SCpW
Description: The function adds the storage capacity utilization column (withdrawals) to the LP matrix.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lStor - index of the processing asset
iYear – year
lSeas - index of the season

Functions Used: lAddCol

Return Output: lCol_SCpW - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_TCpE
Description: The function adds the tanker capacity investment column to the LP matrix.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
lTnk - index of the tanker
iYearX – year of investment

Functions Used: lAddCol

Return Output:
lCol_TCpE – Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_TCpU
Description: The function adds the tanker capacity utilization column to the LP matrix.

Input:
lTnk - index of the tanker (set to -1 if initializing the arrays and -2 if clearing them out)
lFuelI - index of the input fuel type of the tanker
lPtP - index to the port-to-port link
iYear – year
lSeas - index of the season

Functions Used: lAddCol

Return Output: lCol_TCpU – Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_TD
Description: The function adds the total demand column to the LP matrix. The function sets the column as unbounded for all years other than the start year minus one, for which the column is fixed at the initial demand value that is inputted in the model.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lDmdS - index of the demand sector
iYear – year

Functions Used: lAddCol

Return Output: lCol_TD - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

lCol_TDS
Description: The function adds the demand by step column to the LP matrix. The upper bound is set to the incremental quantity in the demand step.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lDmdS - index of the demand sector
lDPS - price step
iYear – year

Functions Used: lAddCol

Return Output: lCol_TDS - Returns column number in the LP matrix if adding column; returns 0 if erasing arrays or initializing

Add Row Routines

lRow_ACG
Description: The function adds the processing asset capacity build constraint (minimum constraint) to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node where the processing asset is (set to -1 if initializing the arrays and -2 if clearing them out)
lProc - index of the processing asset
iYearS - first year of the constraint
lPrcRc - index to processing asset constraint

Functions Used: lAddRow

Return Output: lRow_ACG – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_ACL
Description: The function adds the processing asset capacity build constraint (maximum constraint) to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node where the processing asset is (set to -1 if initializing the arrays and -2 if clearing them out)
lProc - index of the processing asset
iYearS - first year of the constraint
lPrcRc - index to processing asset constraint

Functions Used: None

Return Output: lRow_ACL – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_ACU
Description: The function adds the processing asset utilization constraint row to the LP matrix if it does not already exist and sets the right hand side for the constraint.

Input:
lNode - index of the node where the processing asset is (set to -1 if initializing the arrays and -2 if clearing them out)
lProc - index of the processing asset
iYear – year
lSeas - index of the season

Functions Used: lAddRow

Return Output: lRow_ACU – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_ADD
Description: The function adds the average daily demand constraint to the LP matrix matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lDmdS - index of the demand sector
iYear – year

Functions Used: lAddRow

Return Output: lRow_ADD – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_ARC
Description: The function adds the annual resource constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSPS - supply final price step
iYear – year

Functions Used: lAddRow

Return Output: lRow_ARC – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_CC
Description: The function adds the regional capital constraint row to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year of investment

Functions Used: lAddRow

Return Output:
lRow_CC – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_CI
Description: The function adds the regional investment capital constraint row to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year of investment

Functions Used: lAddRow

Return Output: lRow_CI – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_CO
Description: The function adds the regional other capital constraint row to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year

Functions Used: lAddRow

Return Output: lRow_CO – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_EI
Description: This function adds the export and import rows to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year
lSeas - index of the season

Functions Used: lAddRow

Return Output: lRow_EI – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_EJ
Description: This function adds the annual net export constraint rows to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lReg - index of the region (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year
lSeas - index of the season

Functions Used: lAddRow

Return Output: lRow_EI – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_MB
Description: The function adds the energy balance row to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lFuel - index of the fuel type
iYear – year
lSeas - index of the season

Functions Used: lAddRow

Return Output: lRow_MB – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_PCG
Description: The function adds the pipeline asset capacity build constraint (minimum constraint) to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lPipe - index of the pipline (set to -1 if initializing the arrays and -2 if clearing them out)
iYearS - first year of the constraint
lPipeC - index to the pipeline constraint

Functions Used: lAddRow

Return Output: lRow_PCG – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_PCL
Description: The function adds the pipeline asset capacity constraint build (maximum constraint) to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lPipe - index of the pipline (set to -1 if initializing the arrays and -2 if clearing them out)
iYearS - first year of the constraint
lPipeC - index to the pipeline constraint

Functions Used: lAddRow

Return Output: lRow_PCL – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_PCU
Description: This function adds the pipeline asset capacity utilization constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lPipe - index of the pipeline (set to -1 if initializing the arrays and -2 if clearing them out)
iYear – year
lSeas - index of the season

Functions Used: lAddRow

Return Output: lRow_PCU – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_PrA
Description: The function adds the accelerated production constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSPS - supply final price step
iYear – year
lSeas – index of the season

Functions Used: lAddRow

Return Output: lRow_PrA – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_Prd
Description: The function adds the production constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSPS - supply final price step
iYear – year
lSeas – index of the season

Functions Used: lAddRow

Return Output: lRow_Prd – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_RSV
Description: The function adds the reserves constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSMS - supply major price step
iYear – year

Functions Used: lAddRow

Return Output:
lRow_RSV – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_RUR
Description: The function adds the remaining undeveloped resources constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node (set to -1 if initializing the arrays and -2 if clearing them out)
lSpC - index of the supply category
lSPS - supply final price step
iYear – year

Functions Used: lAddRow

Return Output: lRow_RUR – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_SCB
Description: The function adds the storage asset volume balance constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node where the storage asset is (set to -1 if initializing the arrays and -2 if clearing them out)
lStor - index of the storage asset
iYear - year of the constraint

Functions Used: lAddRow

Return Output: lRow_SCB – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_SCG
Description: The function adds the storage asset capacity build constraint (minimum constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node where the storage asset is(set to -1 if initializing the arrays and -2 if clearing them out)
lStor - index of the storage asset
iYearS - first year of the constraint
lStrRc - index to storage asset constraint

Functions Used: lAddRow

Return Output: lRow_SCG – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_SCL

Description: The function adds the storage asset capacity build constraint (maximum constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node where the storage asset is(set to -1 if initializing the arrays and -2 if clearing them out)
lStor - index of the storage asset
iYearS - first year of the constraint
lStrRc - index to storage asset constraint

Functions Used: lAddRow

Return Output: lRow_SCL – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_SCU
Description: The function adds the storage asset capacity utilization constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lNode - index of the node where the storage asset is (set to -1 if initializing the arrays and -2 if clearing them out)
lStor - index of the storage asset
iYear – year
lSeas - index of the season

Functions Used: lAddRow

Return Output: lRow_SCU – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_TCG
Description: The function adds the tanker asset capacity build constraint (minimum constraint) to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lTnk - index of the tanker type (set to -1 if initializing the arrays and -2 if clearing them out)
iYearS - first year of the constraint
lTnkC - index to tanker capacity constraint

Functions Used: lAddRow

Return Output: lRow_TCG – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_TCL
Description: The function adds the tanker asset capacity build constraint (maximum constraint) to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lTnk - index of the tanker type (set to -1 if initializing the arrays and -2 if clearing them out)
iYearS - first year of the constraint
lTnkC - index to tanker capacity constraint

Functions Used: lAddRow

Return Output: lRow_TCL – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

lRow_TCU
Description: The function adds the tanker asset capacity utilization constraint to the LP matrix if it does not yet exist and sets the right hand side for the constraint.

Input:
lReg - index of the region where the tanker originates(set to -1 if initializing the arrays and -2 if clearing them out)
lTnk - index of the tanker type
iYear – year
lSeas - index of the season

Functions Used: lAddRow

Return Output:
lRow_TCU – Returns row number in the LP matrix if adding row; returns 0 if erasing arrays or initializing

Miscellaneous Functions

iFMod
Description: The function returns last two digits of a year.

Input:
iYear - Year

Functions Used: None

Return Output: Year mod 100

iSaveLPRslts
Description: The function copies the results for all variables in the run to the output tables.

Input: iDeleteFlag – Set to true if output tables need to be cleared of all content, false if the data is to be added to the tables.

Functions Used: None

Return Output: iSaveLPRslts – Returns true if there is error in saving results, false otherwise

iUpdate_CapCnsts
Description: The function updates the constraints on capacity to reflect capacity decisions that are fixed from the last solution. This is the second to last step in the rolling optimization and prepares the arrays for the next solution period

Input: None

Functions Used: None

Return Output: iUpdate_CapCnsts – Returns true if there is error in updating the constraints and false otherwise

iUpdate_RsvRes
Description: The function updates the reserves and available undiscovered resources to reflect production and reserve additions that are fixed from the last solution. This is the last step in the rolling optimization and prepares the arrays for the next solution period

Input: None

Functions Used: None

Return Output: iUpdate_RsvRes – Returns true if there is error in updating the reserves and resources and false otherwise

Module: mCleanOutputRslts

iClean_Output_Tables
Description: The function deletes all records from the output tables for a particular run Id. The output tables include all tables that start with tOut.

Input: lRunId_in – The run Id for which all output tables are to be cleared.

Functions Used: None

Return Output: None

Module: mDocument

iDocument_Tables
Description: The utility function creates a list of all tables and variables in the tables and stores these in the file tZDc_TblDef.

Input: None

Functions Used: None

Return Output: None

iDocument_Queries
Description: The utility function creates a list of all queries and their SQL in the database and stores these in the file tZDc_QryDef.

Input: None

Functions Used: None

Return Output: None

Module: mINGM_Main

iINGM_Main
Description: This is main function of the INGM model. It calls functions that read data from all the input data files, build the LP matrix, convert it into an MPS file, send it to solver for LP solutions, and finally read and save the LP solution results for a particular run Id.

Input:
lRunId_in – Run Id.

Functions Used: iCreateErrorMsg, iRead_Scenario, iRead_All, iGetSolYears, iBuild_Matrix, iBuild_MPS, iRun_CPLEX, iRead_CPLEX, iRun_GAMS, iRead_GAMSRslt, iSaveLPRslts, iOutput_Matrix, iUpdate_CapCnsts, iUpdate_RsvRes, iClear_Matrix

Return Output: None

iRun_CPLEX
Description: The function runs the CPLEX program to solve the LP and output the results.

Input: None

Functions Used: None

Return Output: None

iRun_GAMS
Description: The function runs the GAMS program to solve the LP and output the results.

Input: None

Functions Used: None

Return Output: None

StripFileAndReturnPath
Description: The function strips the file name off of a full DOS path and returns the path less the file name.

Input: FullPath – Full path of the file location (including file name)

Functions Used: None

Return Output: StripFileAndReturnPath – returns the path of the file location without the file name (but includes backslash)

iGetSolYears
Description: The function builds the arrays for the solution periods and mapping of years to solution periods. The start year and input data from tTimeVal provide the initial basis for the solution years but are adjusted to reflect years in the pipeline, processing, storage, or tanker asset constraints.

Input:
iSYear - Start year of solution interval
iEYear - End year of solution interval (returned as global variable value)

Functions Used: None

Return Output: None

Module: mLPSetUp

Initialization/Clearing Routines

iInitializeLP
Description: The function initializes all the LP matrix arrays by dimensioning them and setting the number of rows, columns, and coefficients to be empty.

Input:
lEstRow - estimate of the number of rows
lEstCol - estimate of the number of columns
fDens - estimated density of the matrix (number of coefficients per column on average)

Functions Used: None

Return Output: iInitializeLP – Returns 0 if there is no error in execution of the function.

iClearLP
Description: The function clears data from all the LP matrix arrays, resets the last row, column, and coefficient; and erases the arrays.

Input: None

Functions Used: None

Return Output: iClearLP – Returns 0 if there is no error in execution of the function.

Matrix Building

lAddRow
Description: The function adds a row to the LP matrix and stores the right hand side as the coefficient in column zero. It saves the name, type, and right hand side of the row. The type indicates if it is less than or equal to, greater than or equal to, equal to, and unconstrained. This routine returns the row number.

Input:
sName – Name of the row in the LP matrix
sSense – Sense of the constraint (row) in the LP matrix; -1(<=), 1(>=), 0(=), -2(N)
fRHS – RHS value of the constraint

Functions Used: iAddCoef

Return Output: lAddRow – Row number in the LP matrix

lAddCol

Description: The function adds a column to the LP matrix. It saves the name and lower and upper bounds. It returns the column number.

Input:
sName – Name of the column in the LP matrix
fMin – Minimum value the column (variable) can take
fMax – Maximum value the column (variable) can take

Functions Used: None

Return Output: lAddCol – Column number in the LP matrix

iAddCoef
Description: The function adds a coefficient to a particular row and column in the LP matrix.

Input:
lRow - Index of the row
lCol - Index of the column
fVal - Coefficient value

Functions Used: None

Return Output: iAddCoef – Returns 0 if there is no error in execution of the function.

Debugging

iTestCoef
Description: This is a debugging routine which checks the LP matrix for duplicate entries of coefficients. It is not currently used.

Input: None

Functions Used: None

Return Output: iTestCoef – Returns true value if there is a duplicate co-efficient, false otherwise

iTest_Rows
Description: This is a debugging routine which checks the LP matrix to make sure there are no duplicate row names. It is not currently used.

Input: None

Functions Used: None

Return Output: iTest_Rows – Returns true value if there is a duplicate row name, false otherwise

iTest_Cols

Description: This a debugging routine which checks the LP matrix to make sure there are no duplicate column names. It is not currently used.

Input: None

Functions Used: None

Return Output: iTest_Cols – Returns true value if there is a duplicate row name, false otherwise

iOutput_Matrix
Description: The function clears all data from three arrays tMatrix_Rows, tMatrix_Cols, and tMatrix_Coef and then populates them with the LP matrix and output data from the LP run. The arrays store slack and dual values of variables amongst other details.

Input: None

Functions Used: None

Return Output: None

MPS File Generation

iBuild_MPS
Description: The function builds the MPS file using coefficient values, RHS values, and bound values from the LP matrix. The function converts all values used in the MPS file to a fixed length of 12 characters using sub-function fxLen.

Input: None

Functions Used: fxLen

Return Output: None

fxLen

Description: The function converts the coefficient value into a fixed length string of 12 characters including the decimal point.

Input:
sTextIn – Coefficient value as a string

Functions Used: None

Return Output: fxLen – Returns the coefficient value in fixed length

Module: mOutputQueries

This module contains the routines which build the queries used for the output processing.

iGet_DmdQuery
Description: The function builds the SQL for the demand graphs and reports

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_EOYRsvQuery
Description: The function builds the SQL for the EOY reserves graphs and reports

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_RemResQuery
Description: The function builds the SQL for the EOY remaining undevelop resources graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_RsvAddQuery
Description: The function builds the SQL for the annual reserve additions graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_ProdQuery
Description: The function builds the SQL for the annual production graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_AccProdQuery
Description: The function builds the SQL for the annual accelerated production graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_NCFQuery
Description: The function builds the SQL for the annual net cash flow graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_OFuelQuery
Description: The function builds the SQL for the annual other fuel demand graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_PricesQuery
Description: The function builds the SQL for the annual or seasonal price graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_PipeCQuery
Description: The function builds the SQL for the annual pipeline capacity graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_PipeUtlQuery
Description: The function builds the SQL for the annual and seasonal pipeline utilization graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_StorCQuery
Description: The function builds the SQL for the annual storage capacity graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_StorUtlQuery
Description: The function builds the SQL for the annual and seasonal storage utilization graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_ProcCQuery
Description: The function builds the SQL for the annual processing asset capacity graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_ProcUtlQuery
Description: The function builds the SQL for the annual and seasonal procssing asset utilization graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_TnkCQuery
Description: The function builds the SQL for the annual tanker asset capacity graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_TnkUtlQuery
Description: The function builds the SQL for the annual and seasonal tanker utilization graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

iGet_ReInjQuery
Description: The function builds the SQL for the annual and seasonal gas reinjection graphs and reports.

Input:

- iAgg - regional aggregation (0 - global, 1-regional, 2-nodal)
- iSea - true if seasonal data required
- iSec - true if sector (category) data required
- sSQLO - output SQL string for spreadsheets
- sSQLT - output SQL string for graphs
- sHdr - Header for the graph
- sUnit - Units for the graph

Functions Used: None

Return Output: None

Module: mReadData

Main Controlling Routine

iRead_All
Description: Uses multiple functions to either input the data from the regions or clear out data from all arrays that contain input data.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iRead_DmdSectors, iRead_Fuels, iRead_Regions, iRead_ImpExpCnstr, iRead_Seasons, iRead_SupCat, iRead_Nodes, iRead_DmdBase, iRead_DmdBPrc, iRead_DmdNdeAlloc, iRead_DmdSeasAlloc, iRead_OthDmd, iRead_PipeAsset, iRead_PipeCnst, iRead_PorttoPort, iRead_ProcAssetType, iRead_ProcAsset, iRead_ProcAssetFuel, iRead_ProcRCnst, iRead_StorAsset, iRead_StorRCnst, iRead_SupplyBase, iRead_TankerAsset, iRead_TankerCnst, iRead_TankerFuel, iRead_TankerPort, iRead_TimeVal, iRead_PScalar

Return Output: Returns a 0 if all processing completed normally and -1 if an error occurred.

Routines For Each Input Table

iRead_DmdBase
Description: The function reads demand data by node from tDmdBase and copies the data into arrays. Returns error if gaps exist in data. The function calculates the demand for all years that data has not been provided. It calculates the growth rate from the last ten years that data is available and determines the demand for all subsequent years for which data is not available using the calculated growth rate. The function finally ensures that there is a demand value either inputted or calculated for each year in the run.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_DmdBase - Returns -1 if error exists, otherwise set to 0

iRead_DmdSeasAlloc
Description: The function reads seasonal share (allocation) of demand by node and sector from tDmdSeasAlloc and copies the data into arrays. The function ensures that the seasonal factors add up to one for each season.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_DmdSeasAlloc - Returns -1 if error exists, otherwise set to 0

iRead_DmdSectors
Description: The function ensures that Demand Sector specifications exist in tDmdSectors and copies the data into arrays. Returns error if data does not exist. The function also clears data from all arrays as an option.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_DmdSectors - Returns -1 if error exists, otherwise set to 0.

iRead_Fuels

Description: The function ensures that Fuel Specifications exist in tFuel and then copies the data into arrays depending upon whether the data is either for demand or supply. Returns error if data does not exist. The function also clears data from all arrays as an option.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_Fuels - Returns -1 if error exists, otherwise set to 0.

iRead_ImpExpCnstr
Description: The function reads all import/export constraints from tImpExt_Cnstr and copies the data into arrays. The function converts any NULL values for import constraint, export constraint, or investment constraint into value "-99." The function also returns an error if the Fuel id is missing.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_ImpExpCnstr - Returns -1 if error exists, otherwise set to 0

iRead_Nodes
Description: The function ensures that nodal specifications exist in tNode and copies the data into arrays. Returns error if data does not exist. The function also ensures that the region id specified for each of the nodes exists in the list of regions specified for the run.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_Nodes - Returns -1 if error exists, otherwise set to 0

iRead_OthDmd
Description: The function reads non-natural gas fuel prices from tOthDmd and copies the data into arrays. The function returns an error if the Fuel id is either NULL or is not being used in the current run.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_OthDmd - Returns -1 if error exists, otherwise set to 0

iRead_PipeAsset
Description: The function reads pipeline asset details from tPipelineAsset and copies the data into arrays. The function ensures that each pipeline asset has a fuel id, origin id, and destination id, returning an error in case any one is missing.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_PipeAsset - Returns -1 if error exists, otherwise set to 0

iRead_PipeCnst
Description: The function reads all pipeline constraint data from tPipelineAsset_Cnstr and copies the data into arrays. The function ensures that the pipeline id is included in the list of pipeline ids for the run, that the first year of the constraint is earlier than the last year, and that the minimum capacity of the pipeline is less than the maximum capacity. The function also checks for overlapping constraints.

iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_PipeCnst - Returns -1 if error exists, otherwise set to 0

iRead_PorttoPort
Description: The function reads all port to port specifications from tPorttoPort and copies the data into arrays. The function also ensures that there is an origin and destination node for each port-to-port id.

iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_PorttoPort - Returns -1 if error exists, otherwise set to 0

iRead_ProcAsset
Description: The function reads all processing asset specifications from tProcessingAsset and copies the data into arrays.

iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_ProcAsset - Returns -1 if error exists, otherwise set to 0

iRead_ProcAssetType
Description: The function ensures that all processing asset types are available in tProcessingAsset_Type and copies the data into arrays. Returns error if data does not exist.

iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_ProcAssetType - Returns -1 if error exists, otherwise set to 0

iRead_ProcAssetFuel
Description: The function reads all fuel specifications for each processing asset from tProcessingAsset_Fuel and copies the data into arrays. The function ensures that Asset id and Fuel id used in the database correspond to those used in the run.

iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_ProcAssetFuel - Returns -1 if error exists, otherwise set to 0

iRead_ProcRCnst
Description: The function reads all regional constraints for each processing asset from tProcessingAsset_RegCnstr and copies the data into arrays. The function ensures that the asset id and node id are included, that the first year of the constraint is earlier than the last year, and that the minimum capacity of the asset is less than the maximum capacity. The function sets the start year for all assets. It also checks for overlapping constraints.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_ProcRCnst - Returns -1 if error exists, otherwise set to 0

iRead_PScalar
Description: The function reads the price scalar data for five asset types by year and sets up the regional price discount arrays to account for regional differences in discount rates.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output:iRead_PScalar - Returns -1 if error exists, otherwise set to 0

iRead_Regions
Description: The function ensures that regional specifications exist in tRegion and copies the data into arrays. Returns error if data does not exist. The function converts any NULL values for demand base price adjustment into zero values. The function also clears data from all arrays as an option.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_Regions - Returns -1 if error exists, otherwise set to 0

iRead_Seasons
Description: The function ensures that seasonal specifications exist in tSeason and copies the data into arrays. Returns error if data does not exist. The function also ensures that the total number of days in the different seasons add up to 365, and if not returns an error.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_Seasons - Returns -1 if error exists, otherwise set to 0

iRead_StorAsset
Description: The function reads all storage asset specifications from tStorageAsset and copies the data into arrays.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_StorAsset - Returns -1 if error exists, otherwise set to 0

iRead_StorRCnst
Description: The function reads all storage asset constraints from tStorageAsset_RegCnstr and copies the data into arrays. The function ensures that the storage id and node id are included, that the first year of the constraint is earlier than the last year, and that the minimum capacity of the asset is less than the maximum capacity. The function sets the start year for all storage assets. It also checks for overlapping constraints.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output:
iRead_StorRCnst - Returns -1 if error exists, otherwise set to 0

iRead_SupplyBase
Description: The function reads all supply base specifications from tSupplyBase and copies the data into arrays. The function ensures that the supply category id and node id are included and the minimum development costs at which reserves come online is less than the maximum development costs.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_SupplyBase - Returns -1 if error exists, otherwise set to 0

iRead_SupCat
Description: The function ensures that supply category details exist in tSupplyCat and copies the data into arrays. Returns error if data does not exist.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_SupCat - Returns -1 if error exists, otherwise set to 0

iRead_TankerAsset
Description: The function reads all tanker asset specifications from tTankerAsset and copies the data into arrays.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: iCreateErrorMsg

Return Output: iRead_TankerAsset - Returns -1 if error exists, otherwise set to 0

iRead_TankerCnst
Description: The function reads all tanker constraints from tTankerAsset_Cnstr and copies the data into arrays. The function ensures that the tanker id is available, that the first year of the constraint is earlier than the last year, and that the minimum capacity of the tanker is less than the maximum capacity. The function sets the start year for all storage assets. It also checks for overlapping constraints.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_TankerCnst - Returns -1 if error exists, otherwise set to 0

iRead_TankerFuel
Description: The function reads all tanker input and output fuel data from tTankerFuel and copies the data into arrays. The function ensures that tanker id, input fuel id, and output fuel id are available.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_TankerFuel - Returns -1 if error exists, otherwise set to 0

iRead_TankerPort
Description: The function reads all tanker port details from tTankerPort and copies the data into arrays. The function ensures that tanker id and node id are available.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_TankerPort - Returns -1 if error exists, otherwise set to 0

iRead_Scenario
Description: The function reads the scenario specifications for the selected scenario.

Input: lRunId – the ID of the scenario.

Functions Used: iCreateErrorMsg

Return Output: iRead_Scenario - Returns -1 if error exists, otherwise set to 0

iRead_TimeVal
Description: The function reads all time step details from tTimeStep and copies the data into arrays. The function ensures that tanker id and node id are available.

Input: iRead - the argument is set to True if the arrays should be initialized and the data read, and False if the arrays should be freed up.

Functions Used: lGetId, iCreateErrorMsg

Return Output: iRead_TimeVal - Returns -1 if error exists, otherwise set to 0

Miscellaneous Routines

lGetId
Description: This function is a generic function used to match an ID from the database to the index of the value in arrays used to store the data. If it cannot find the ID then an error code is returned otherwise the index in the array is returned.

Input:
lIdT – Represents either a Demand Sector or Region id
lId – Represents a array with a list of all the Demand Sector or Region ids.
lNId – The value represents the number of Demand Sectors or Regions

Functions Used: None

Return Output: lGetId - Returns -1 if error exists, otherwise set to the index in the array that matches the ID.

iCreateErrorMsg
Description: This routine either stores an error message in the error log or deletes an already existing error message by run id.

Input:
iType - This is the type of call which is set to -1 to initialize and 0 to add error message
lErr – This is the Error Id
sMsg – This is the description of the Error in text

Functions Used: None

Return Output: iCreateErrorMsg - Argument set to -1 if error exists, otherwise set to 0.

Module: mReadMPSRslt

iRead_CPLEX
Description: This function reads in the CPLEX output file and stores the LP results for the rows and columns in the row and column output arrays

Input: None

Functions Used: None

Return Output: None

iRead_GAMSRslt
Description: This function reads in the GAMS output file and stores the LP results for the rows and columns in the row and column output arrays

Input: None

Functions Used: None

Return Output: None

Module: mRefIntegrity

This module contains ancillary programs to identify areas in the database that do not meet referential integrity rules.

iTest
Description: This function controls the evaluation by scenario for node, region, fuel, and season.

Input: None

Functions Used: iRefInt_FuelId, iRefInt_NodeId, iRefInt_RegionId, iRefInt_SeasonId

Return Output: None

iRefInt_FuelId
Description: This function tests the referential integrity of the FuelId.

Input: None

Functions Used: iCreateErrorMsg

Return Output: None

iRefInt_NodeId
Description: This function tests the referential integrity of the NodeId.

Input: None

Functions Used: iCreateErrorMsg

Return Output: None

iRefInt_RegionId
Description: This function tests the referential integrity of the RegionId.

Input: None

Functions Used: iCreateErrorMsg

Return Output: None

iRefInt_SeasonId
Description: This function tests the referential integrity of the SeasonId.

Input: None

Functions Used: iCreateErrorMsg

Return Output: None

Module: mShellWait

ShellWait:

Notice: This code was originally written by Terry Kreft. It is not to be altered or distributed, except as part of an application. You are free to use it in any application, provided the copyright notice is left unchanged.

Description: The subroutine starts an external routine and waits for it to complete.

Input:
PathName: Full command line of application to run
WindowStyle: Set to 1

Functions Used: None

Return Output: None

Miscellaneous Queries

Query	Description	Units
qClean_Matrix_Coef	Deletes all rows from the debug matrix output data for coefficients	
qClean_Matrix_Col	Deletes all rows from the debug matrix output data for columns	
qClean_Matrix_Row	Deletes all rows from the debug matrix output data for rows	
qTest_Rowcol	Debug query to review LP	

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