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World Energy Projection System Plus Model Documentation 2011: Natural Gas Model

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1. Introduction

Purpose of This Report

The Natural Gas Model of the World Energy Projection System Plus (WEPS+) is a computer-based energy supply modeling system that is primarily used to estimate the retail and wholesale price regional natural gas. This report describes the version of the Natural Gas Model that was used to produce the projections published in the *International Energy Outlook 2011* (*IEO2011*). The Natural Gas Model is one of 13 components of the WEPS+ energy modeling system, but it can also be run as a separate, individual model. The WEPS+ is a modular system, consisting of a number of separate energy models that are joined together through the overall system model in order to communicate and work with each other. These models are each developed independently, but are designed with well-defined protocols for system communication and interactivity. The WEPS+ modeling system uses a common and shared database (the "restart" file) that allows all the models to communicate with each other when they are run in sequence over a number of iterations. The overall WEPS+ system uses an iterative solution technique that allows for convergence of consumption and price to a simultaneous equilibrium solution.

This report documents the objectives, analytical approach and development of the WEPS+ Natural Gas Model. It also catalogues and describes critical assumptions, computational methodology, parameter estimation techniques, and model source code. This document serves three purposes. First, it is a reference document providing a detailed description for model analysts, users, and the public. Second, it meets the legal requirement of the U.S. 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 and analyze their own model enhancements, data updates, and parameter refinements for future projects.

Model Summary

The WEPS+ Natural Gas Model determines wholesale natural gas prices for each of the 16 regions annually through 2035. The wholesale prices are then used to calculate retail prices for each of the demand and transformation sectors, using fixed end use sector specific mark-ups. The retail prices are exported to the shared restart file for use in the WEPS+ demand and transformation models. The Natural Gas Model is a reduced-form model that is estimated from perturbations of demand in the separate, standalone International Natural Gas Model (INGM). This reduced-form model is a response-surface type of model that uses a base price at a base level of consumption, and then models changes to the base price resulting from changes in consumption levels. The resulting consumption projections from a WEPS+ system execution are provided to INGM through a standard interface file. In turn, INGM provides a base price and reduced-form model coefficients for the use of WEPS+, after which WEPS+ uses the Reduced Form Natural Gas (RFNG) Model in subsequent model runs. The INGM is used to derive the detailed projections of natural gas production, imports, exports, LNG, and other supply components that are published in the *IEO2011*.

Model Archival Citation

This documentation refers to the WEPS+ Natural Gas Model, as archived for the *International Energy Outlook 2011* (*IEO2011*).

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Organization of This Report

Chapter 2 of this report discusses the purpose of the Natural Gas Model, the objectives and the analytical issues it addresses, the general types of activities and relationships it embodies, the primary input and output variables, and the relationship of the model to the other models in the WEPS+ system. Chapter 3 of the report describes the rationale behind the Natural Gas Model design, providing insights into further assumptions utilized in the model. Chapter 4 describes the model structure in more detail, including flowcharts, variables, and equations.

2. Model Purpose

Model Objectives

The primary objective of the WEPS+ Natural Gas Model is to determine wholesale natural gas prices for each of the 16 regions annually through 2035. The wholesale prices are then used to calculate retail prices for each of the demand and transformation sectors, using fixed end use sector specific mark-ups. The retail prices are exported to the shared restart file for use in the WEPS+ demand and transformation models.

As part of the WEPS+ system, the Natural Gas Model provides projections for the 16 WEPS+ world regions (Table 1). These regions consist of countries and country groupings within the broad divide of the Organization of Economic Cooperation and Development (OECD) membership.

Table 1. Regional Coverage of the World Energy Projection System Plus Model

OECD Regions	Non-OECD Regions
United States	Russia
Canada	Other Non-OECD Europe and Eurasia
Mexico/Chile	China
OECD Europe	India
Japan	Other Non-OECD Asia
Australia/New Zealand	Middle East
South Korea	Africa
	Brazil
	Other Central and South America

Model Inputs and Outputs

Inputs

The Natural Gas Model uses natural gas consumption projections that are imported from the WEPS+ restart file. These inputs have been previously projected by the source models listed in Table 2.

Table 2. WEPS+ Models that Provide Inputs to the Natural Gas Model

Natural Gas Model Input	Source
Residential natural gas consumption	Residential Model
Commercial natural gas consumption	Commercial Model
Industrial natural gas consumption	World Industrial Model
Transportation natural gas consumption	International Transportation Model
Electricity natural gas consumption	World Electricity Model
District heat natural gas consumption	District Heat Model

A number of exogenous data series are also imported into the Natural Gas Model from the RFNGInput.xml file (Table 3).

Table 3. Major Exogenous Natural Gas Model Input Data Series

Source Input File	Model Input
RFNGInput.xml	INGM "central case" regional wholesale natural gas prices (real 2009 dollars per million Btu)
	INGM "central case" regional natural gas consumption (quadrillion Btu)
	Prior run "Reference case" regional natural gas consumption projections from WEPS+ (quadrillion Btu)
	INGM estimated price effect coefficients for world, sub-region, and individual region
	INGM pipeline natural gas consumption (quadrillion Btu)
	INGM lease and plant fuel natural gas consumption (quadrillion Btu)
	INGM liquefied natural gas consumption (quadrillion Btu)
	INGM gas-to-liquids natural gas consumption (quadrillion Btu)
	INGM gas-to-liquids production of liquid fuels (quadrillion Btu)
	INGM reinjected quantities of natural gas (quadrillion Btu—currently only the world total)
	INGM natural gas production (quadrillion Btu)
	INGM natural gas liquids production (quadrillion Btu)
	Historical lease and plant fuel use from the International Energy Agency and calibrated to the Energy Information Administration history (quadrillion Btu, 1980-2008)
	Historical natural gas use for pipeline transportation from the International Energy Agency and calibrated to Energy Information Administration history

	(quadrillion Btu, 1980-2008)
	Regional natural gas supply elasticities (only imported if NGSwitch = -1)

Outputs

The Natural Gas Model produces projections of wholesale natural gas prices and retail natural gas prices by end use and region. Upon completion of a model run, these values are exported into the WEPS+ restart file for use by the supply and transformation models (Table 4).

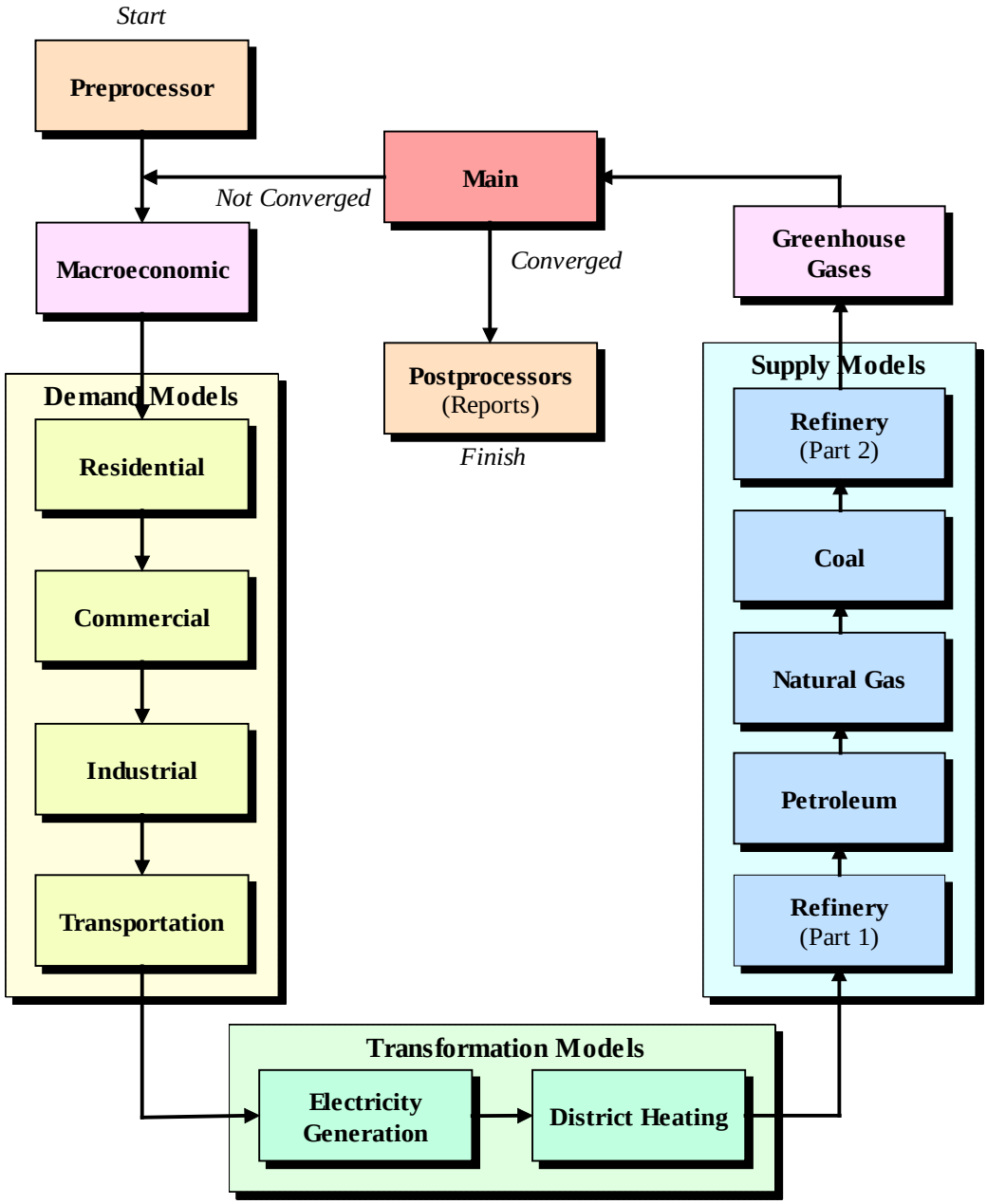
Table 4. Natural Gas Model Outputs and the WEPS+ Models that Use Them

Natural Gas Model Output	Destination
Retail price of natural gas in the residential sector	Residential Model
Retail price of natural gas in the commercial sector	Commercial Model
Retail price of natural gas in the industrial sector	World Industrial Model
Retail price of natural gas in the transportation sector	International Transportation Model
Retail price of natural gas in the electric power sector	World Electricity Model
Retail price of natural gas in the district heat sector	District Heat Model
Retail natural gas prices	Main Model

Relationship to Other Models

The Natural Gas Model is an integral component of the WEPS+ system and depends upon other models in the system for some of its key inputs. In turn, the Natural Gas Model provides projections of natural gas retail prices at the end use sector level, which other models in the system depend upon for their key inputs (Figure 1). A summary description of the models, flows, and mechanics of the WEPS+ system used for the *IEO2011* report is available in a separate *Overview* documentation.

Figure 1. World Energy Projection System Plus (WEPS+) Model Sequence

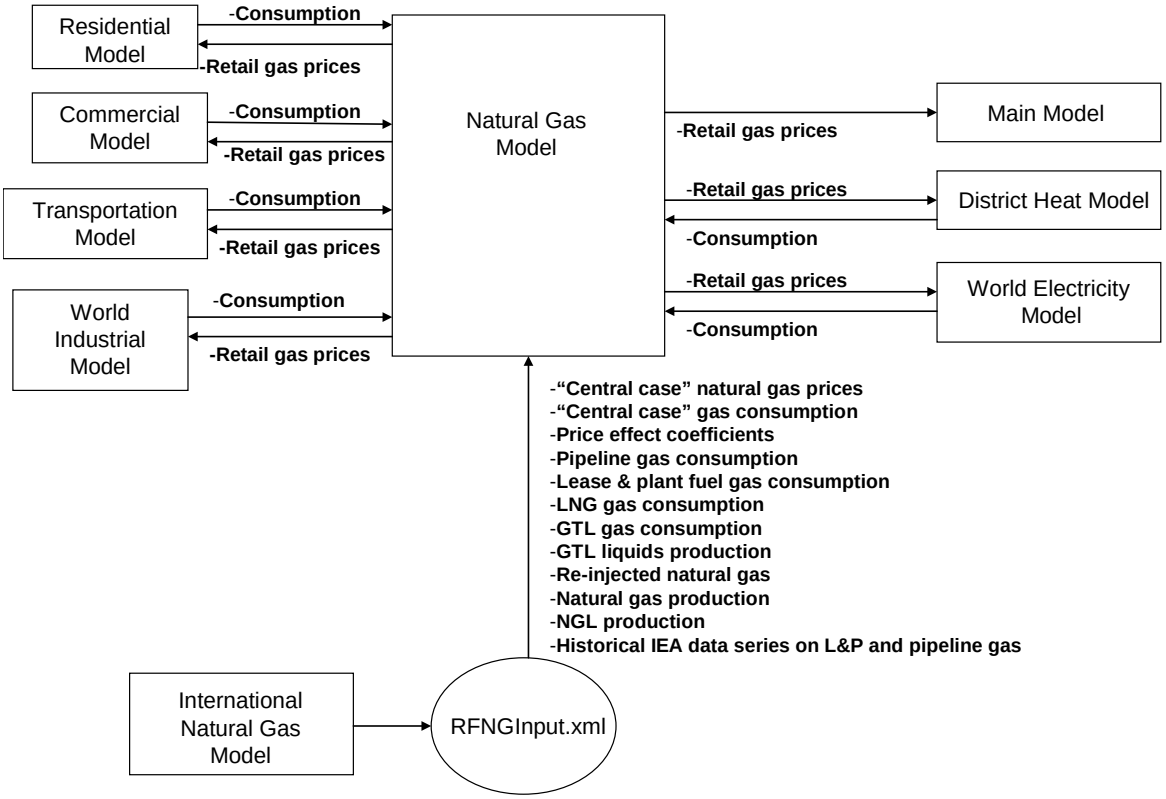


Through the system, the Natural Gas Model receives natural gas consumption projections from the demand and transformation models (Figure 2). In turn, the Natural Gas Model provides price projections, through the system, back to the demand, supply, and transformation models, as well as the Main Model.

Although the Natural Gas Model is an integral part of the WEPS+ system, it can also run easily as a standalone model, outside of the system. To do that, the Natural Gas Model would input

consumption and price projections from the WEPS+ system "restart" file as created in a prior run of the system.

Figure 2. The Natural Gas Model Relationship to Other WEPS+ Models



3. Model Rationale

Theoretical Approach/ Model Assumptions

The Natural Gas Model or RFNG Model is a reduced form version of the U.S. Energy Information Administration's International Natural Gas Model (INGM). It is used to model changes in wholesale natural gas price that occur when natural gas consumption levels change. The RFNG Model employs a set of coefficients estimated by perturbing consumption in INGM to effect changes on price relative to changes in natural gas demand. The algorithms used to accomplish this are designed so that changes in world, sub-region, and individual region or country natural gas consumption totals have an impact on the wholesale prices. Retail natural gas prices by end use sector are then derived from the wholesale natural gas price by using retail mark-ups that are fixed over time.

4. Model Structure

Structural Overview

The WEPS+ Natural Gas Model or Reduced-Form Natural Gas (RFNG) Model determines wholesale natural gas prices for each of 16 regions of the world. The wholesale prices are then used to calculate retail prices for each of the demand and transformation sectors, using fixed end use sector specific mark-ups. The retail prices are exported into the shared restart file to be available for use in the WEPS+ Main Model and the demand and transformation models:

- Residential Model
- Commercial Model
- World Industrial Model
- International Transportation Model
- World Electricity Model
- District Heat Model

The RFNG Model is a reduced-form of the separate, standalone International Natural Gas Model (INGM). This reduced-form model is a response-surface type that begins with a base price at a base level of consumption, and then estimates changes to the base price resulting from changing levels of natural gas consumption. The base consumption, from a previous run of the WEPS+ system, is provided to the INGM through a standard interface file. INGM then returns base prices and reduced-form model coefficients back to WEPS+, which then uses the RFNG Model for subsequent runs. INGM is used to determine the details of natural gas production, imports, exports, natural gas consumed in the production of liquefied natural gas (LNG) and gas-to-liquids (GTL), natural gas used for pipeline transport, and the liquids produced from GTL processes. INGM is a large linear program (LP) that uses Access for its user interface and data repository, uses Visual Basic for Applications to manipulate and calculate intermediate results and set up the LP, and uses an external solver for its LP solution[1].

The basic structure of the Natural Gas Model is illustrated in Figure 3. A call from the WEPS+ interface to the Natural Gas Model initiates importation from the restart file of the supporting information needed to complete the projection calculations. The Natural Gas Model then executes the INGM subroutine, which is the major component of the model and the location in which most of the model computations are made. In its final step, the model executes the subroutine that exports all projections to the restart file for use by other WEPS+ models.

The INGM subroutine (Figure 4) is initiated by a call from the main Natural Gas Model. The subroutine begins by importing data from the RFNGInput.xml data file, where data from an execution of EIA's International Natural Gas Model are stored. RFNGInput.xml includes:

[1] A separate documentation report for the International Natural Gas Model is available for download on the EIA web site: *International Natural Gas Model (INGM) Model Documentation and Programmers Guide*, DOE/EIA-M0xx, (Draft: August, 2011).

- INGM "central case" natural gas prices (in real 2009 dollars per million Btu)
- INGM "central case" natural gas consumption (2005 through 2035)
- "Reference case" natural gas consumption run from a previous WEPS+ run
- Price effects coefficients (region, aggregated region, and world)
- Pipeline natural gas consumption (from INGM run)
- Lease and plant fuel natural gas consumption (from INGM run)
- Natural gas consumed to produce liquefied natural gas (from INGM run)
- Natural gas consumed to produce gas-to-liquids (from INGM run)
- Gas-to-liquids production (from INGM run)
- Natural gas re-injected for improving petroleum production (from INGM run)
- Natural gas liquids production (from INGM run)
- Historical lease and plant fuel use from the International Energy Agency (1980-2008)
- Historical natural gas pipeline transportation consumption from the International Energy Agency (1980-2008)
- End use sector price mark-up factors
- Regional natural gas supply elasticities (not used in *IEO2011*)

Once the data are imported, the routine begins by projecting lease and plant natural gas consumption and pipeline natural gas consumption using historical International Energy Agency estimates from the *Energy Balances and Statistics of OECD and Non-OECD Countries* and the projected growth rates for these consumption series from the INGM results. After this is completed all data series that were imported or calculated in quadrillion British thermal units (Btu) are converted to trillion Btu. INGM model results of natural gas production and consumption are adjusted to agree with WEPS+ projections, and aggregate regional and world total consumption are calculated for use in adjusting prices based on the price effects coefficients.

Next, the INGM subroutine checks the value of the "NGSwitch" factor. This factor is used to determine the way in which current natural gas demand projections will be calculated. In the *IEO2011*, NGSwitch was set to 0 so that current natural gas demand was calculated as the sum of the end use sector projections of natural gas consumption, minus the natural gas consumed for pipeline transportation, LNG production, lease and plant fuel consumption, and GTL production. NGSwitch can also be set to 1, 2, or 3 to vary the demand calculations, with some use of the INGM model output for consumption in the "central case." If NGSwitch is 1, current natural gas demand is set exactly to the INGM model output. If NGSwitch is 2, current demand is allowed

to increase to 20 percent above the 2035 INGM "central case" demand. Finally, if NGSwitch is equal to 3, the demand in China is set equal to 20 percent above the 2035 INGM central case demand, but to the unadjusted central case demand for all other regions. Once the natural gas demand has been adjusted according to the NGSwitch value, the aggregate regional and world total natural gas consumption is recalculated.

The subroutine is next used to calculate wholesale prices. There is one final value possible for NGSwitch and that is -1. If NGSwitch is -1, the wholesale prices are calculated using exogenously-specified supply elasticities. Otherwise, wholesale prices are set to the INGM model price results and then prices are re-estimated according to regional, aggregate, and world changes in natural gas consumption between the INGM model results and WEPS+ results. End use sector retail natural gas prices are calculated as a product of the wholesale prices and exogenously-specified by-end-use-sector mark-up factors. The residential, commercial, and industrial sector natural gas consumption projections are adjusted to account for the generation of district heat using natural gas in each of these end use sectors.

Finally, the INGMData subroutine is called in the INGM subroutine. INGMData is used to create an output data file (NGR-IEO2010-RefJ-0115a.csv, for the *IEO2011* Reference case) that can be used as input in the next INGM model run. These output data series include energy consumption by sector, fuel, and region; world oil prices; wholesale prices by region for natural gas, coal, and electricity; carbon prices (carbon prices were not used in *IEO2011*), and by-end-use-sector retail prices by region. In all cases, the data series extend annually from 2005 through 2035. After the INGM subroutine has completed, the WriteRestart subroutine is executed. WriteRestart provides Natural Gas Model projections (wholesale and by-end-use sector natural gas prices) to the restart file for use in future iterations of WEPS+.

Flow Diagrams

Figure 3. Flowchart for the Natural Gas Model

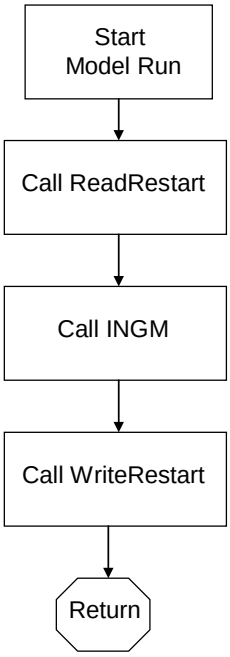
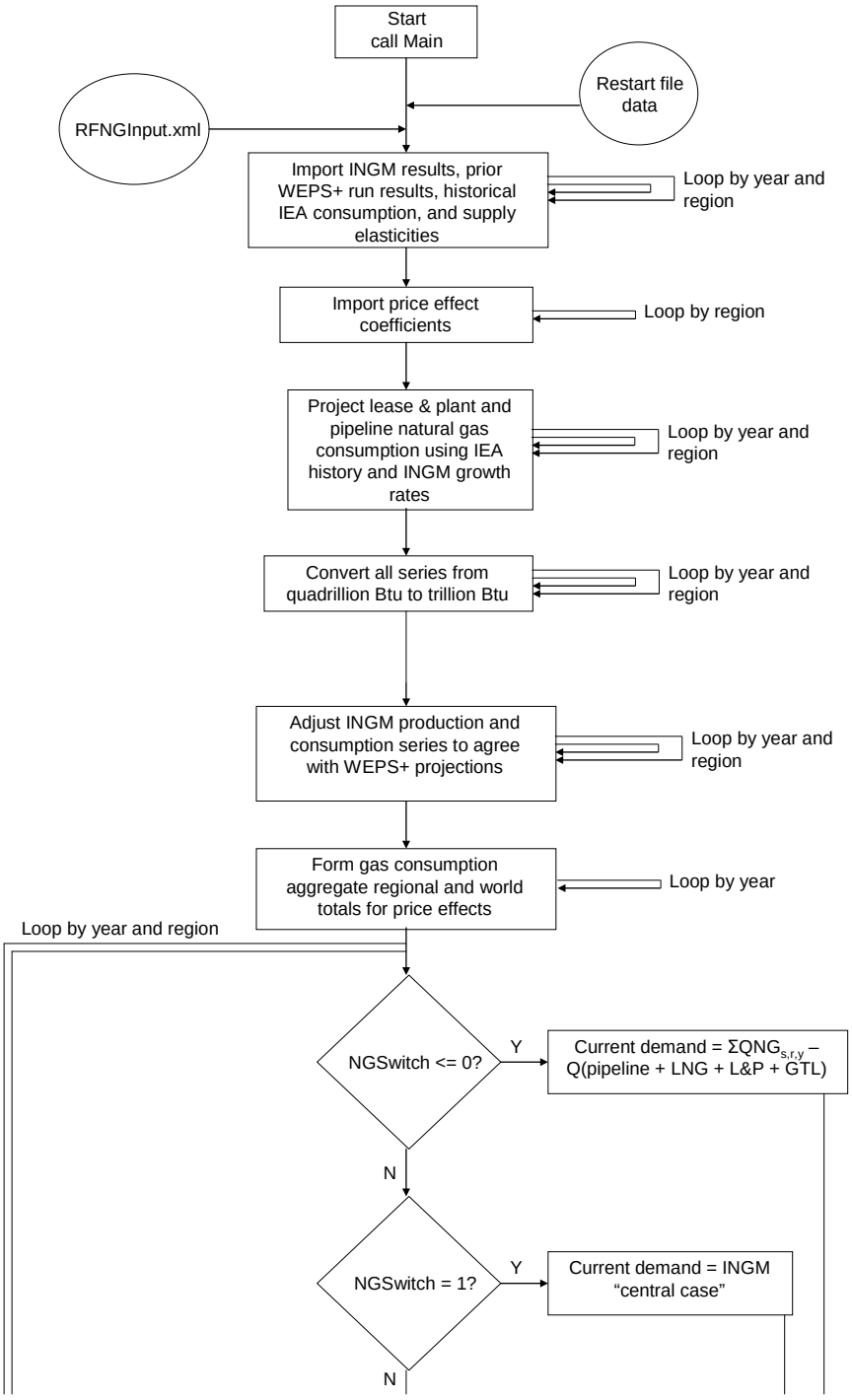
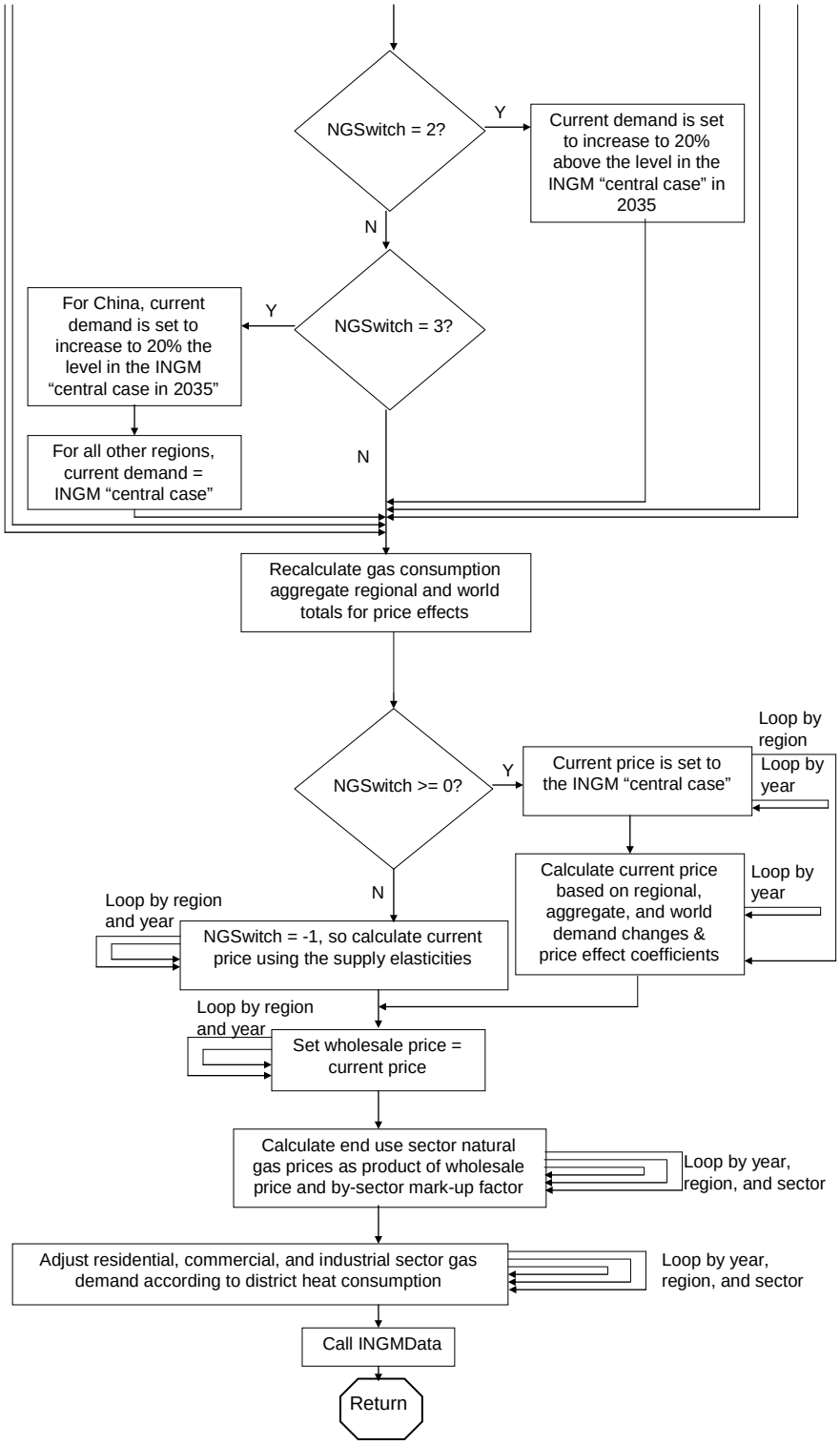


Figure 4. Flowchart for the INGM Subroutine




NGSwitch = 2?
Y
Current demand is set to increase to 20% above the level in the INGM “central case” in 2035
N
NGSwitch = 3?
Y
For China, current demand is set to increase to 20% the level in the INGM “central case in 2035”
For all other regions, current demand = INGM “central case”
N
Recalculate gas consumption aggregate regional and world totals for price effects
NGSwitch >= 0?
Y
Current price is set to the INGM “central case”
Loop by region
Loop by year
Calculate current price based on regional, aggregate, and world demand changes & price effect coefficients
Loop by year
N
Loop by region and year
NGSwitch = -1, so calculate current price using the supply elasticities
Loop by region and year
Set wholesale price = current price
Calculate end use sector natural gas prices as product of wholesale price and by-sector mark-up factor
Loop by year, region, and sector
Adjust residential, commercial, and industrial sector gas demand according to district heat consumption
Loop by year, region, and sector
Call INGMData
Return

Key Computations

The key outputs of the RFNG Model are regional wholesale natural gas prices. In addition, regional price mark-ups are used to allocate the wholesale prices to the retail prices by end use demand sector. The RFNG Model attempts to replicate INGM behavior and results by using a response-surface type of model, in which changes to the latest INGM projections are measured according to changes to the regional natural gas wholesale prices. The wholesale prices can vary according to region because of changes in natural gas demand through behavioral coefficients. Some additional concepts are also projected, but these are currently calculated using assumed relationships rather than using a formal reduced-form model.

To begin the process, a WEPS+ system run for a specific case (such as the *IEO2011* Reference case) is made using world oil price and macroeconomic assumptions appropriate for that scenario. The resulting consumption and price projections are exported into an interface file (for the *IEO2011* Reference case: INGM_input_RefG.csv) and made available to the INGM. Subsequently, the INGM is run in an attempt to replicate the total demands from the WEPS+. The demands resulting from the run made by INGM (referred to here as the "central case") will not necessarily replicate the WEPS+ demands going into that run. In other words, the INGM central case demands are not necessarily the same as the WEPS+ Reference case demands. The INGM also calculates the regional natural gas wholesale prices associated with its central case demands. At this point, INGM is run multiple times around this central case, using perturbations of natural gas demand to reveal the underlying relationship between natural gas demand and natural gas prices. The results from all these runs are used to calculate the coefficients for the reduced-form response-surface model to be used in WEPS+.

INGM then provides the "central case" demands and prices, along with the reduced-form model coefficients and a number of other supply concepts back to the WEPS+ in a standard interface file (for the *IEO2011* Reference case: IngmToWepsInput010711.xls). Subsequently, the WEPS+ imports this data and uses them as inputs to the next run of the RFNG Model within WEPS+. RFNG uses reduced-form coefficients to calculate a revised set of prices based upon the differences in the provided INGM consumption projection and those generated in the WEPS+ run. The model also adjusts the other supply components using assumed relationships resulting from the differences in the INGM central case projections of consumption and those from the WEPS+ consumption projections. The information provided by INGM to WEPS+ includes:

- Natural gas consumption by region and year
- Natural gas wholesale prices by region and year
- Natural gas production by region and year
- Natural gas liquids production by region and year
- Natural gas re-injection by region and year
- Natural gas consumption for pipeline operations by region and year
- Natural gas consumption for lease and plant operations by region and year
- Natural gas consumption for LNG processing by region and year
- Natural gas consumption for GTL feedstocks and processing by region and year
- Liquids production by GTL by region and year

Adjustments of Supply Concepts

Several supply components projected in INGM for its central case are imported by RFNG from the input interface file by the RFNG. The components are associated with the INGM central case consumption projections and, in some cases, must be adjusted for use in WEPS+.

First, pipeline and lease and plant (L&P) consumption values from INGM are overwritten by data from the International Energy Agency's *Energy Statistics and Balances of OECD and Non-OECD Countries*. The quality of the data for these values in INGM was judged to be of lesser accuracy. The consumption values are replaced in the historical period and then projected based upon simple assumptions. As part of this process, total regional natural gas demand is calculated based upon the WEPS+ projections by year:

$$NGasDem(r,y) =$$
$$QNGRS(r,y) + QNGCM(r,y) + QNGIN(r,y) + QNGTR(r,y) + QNGPG(r,y) + QNGDH(r,y)$$

Where:

QNGRS is the residential natural gas consumption by region and year

QNGCM is the commercial natural gas consumption by region and year

QNGIN is the industrial natural gas consumption by region and year

QNGTR is the transportation natural gas consumption by region and year

QNGPG is the power generation natural gas consumption by region and year

QNGDH is the district heat natural gas consumption by region and year

NGasDem is natural gas demand by region and year

The L&P consumption is assumed to increase at the same rate as total natural gas production:

$$LPCon(r,y) = LPCon(r,y-1) * \frac{NGasProd(r,y)}{NGasProd(r,y-1)}$$

Where:

NGasProd is natural gas production by region and year

LPCon is lease and plant natural gas consumption by region and year

In the case of pipeline consumption, the natural gas consumed is assumed to increase either at the same rate as the growth in total natural gas production or the same rate as total natural gas consumption, whichever is higher.

If $NGasDem(r, y) > NGas\,\mathrm{Pr}\,od(r, y)$, then

$$PipeCon(r, y) = PipeCon(r, y-1) * \frac{NGasDem(r, y)}{NGasDem(r, y-1)}$$

otherwise,

$$PipeCon(r, y) = PipeCon(r, y-1) * \frac{NGasProd(r, y)}{NGasProd(r, y-1)}$$

Where: *NGasProd* is natural gas production by region and year

LPCon is lease and plant natural gas consumption by region and year

PipeCon is pipeline natural gas consumption by region and year

In the long term, the total amount of world natural gas production is assumed to balance with the total amount of world natural gas consumption. (The production from INGM is after re-injection, so the total production is equal to total final demand.) Because the INGM central case demand (or production) does not necessarily equal the original Reference case consumption, the other components of supply are associated with the central case from INGM and not the Reference case in WEPS+. The components are adjusted based upon a simple assumption to benchmark them to the WEPS+ Reference case.

$$AdjFac(y) = \frac{RCNGasDem(y)}{CCNGasDem(y)}$$

Where: *RCNGasDem* is the WEPS+ world Reference case demand by year

CCNGasDem is the INGM world central case demand (production) by year

AdjFac is the adjustment factor by year

Each of the following components is adjusted using this factor:

$$NGas\,\mathrm{Pr}od(r,y) = NGas\,\mathrm{Pr}od'(r,y) * AdjFac(y)$$

$$NGL\,\mathrm{Pr}od(r,y) = NGL\,\mathrm{Pr}od'(r,y) * AdjFac(y)$$

$$PipeCon(r,y) = PipeCon'(r,y) * AdjFac(y)$$

$$LPCon(r,y) = LPCon'(r,y) * AdjFac(y)$$

$$LNGCon(r,y) = LNGCon'(r,y) * AdjFac(y)$$

$$GTLCon(r,y) = GTLCon'(r,y) * AdjFac(y)$$

$$GTLOil(r,y) = GTLOil'(r,y) * AdjFac(y)$$

$$Gas\,\mathrm{Re}\,In(r,y) = Gas\,\mathrm{Re}\,In'(r,y) * AdjFac(y)$$

Where:

NGasProd is the natural gas production by region and year

NGLProd is the natural gas liquids production by region and year

PipeCon is the natural gas pipeline consumption by region and year

LPCon is the natural gas lease & plant consumption by region and year

LNGCon is the natural gas LNG consumption by region and year

GTLCon is the natural gas GTL consumption by region and year

GTLOil is the liquids production by GTL by region and year

GasReIn is the natural gas re-injection by region and year

All of these components are exported to the restart file. The natural gas pipeline consumption is added into transportation consumption and reported in the transportation sector. The natural gas lease and plant, LNG, and GTL gas consumption are included in the industrial sector. (Only the increments of LNG and GTL consumption over their value in the initial year are added in because they are not identified specifically in the initial data.) The liquids produced using GTL is

used in the first part of the Refinery Model as a substitute for petroleum consumption. Natural gas production, natural gas liquids production, and gas reinjection are not used in WEPS+ directly. Natural gas production and imports and exports as reported in the *IEO2011* are directly modeled in INGM, as closely as possible to the INGM and WEPS+ results for supply and demand, respectively.

Reduced-Form, Response-Surface Wholesale Price Model

The reduced-form, response-surface model in RFNG attempts to replicate the behavior of regional natural gas wholesale prices to changes in regional natural gas demand as modeled in INGM. There are three types of price effects incorporated into the reduced-form algorithm: price effects that are attributed to changes in 1) regional demand, 2) more aggregate regional demand, and 3) world demand. The regional demand is at the standard 16 WEPS+ regions. The more aggregate regional demand is defined by a set of eight more aggregate set of regions:

- North America = United States, Canada, and Mexico/Chile
- Europe = OECD Europe
- Russia/Eurasia = Russia and other non-OECD Europe and Eurasia
- Middle East = Middle East
- OECD Pacific = Japan, Australia/New Zealand, and South Korea
- Other Asia = China, India, and other non-OECD Asia
- Africa = Africa
- Latin America = Brazil and other Central and South America

The basic concept is that natural gas prices in any one WEPS+ region could impact demand in a wider region or even to the world as a whole. For example, changes in Canada's natural gas prices might have an impact not only on Canada's demand for natural gas, but North America's and even the world. For an equal amount of natural gas demand change, typically the price effect would have the greatest impact on Canadian natural gas demand, a smaller impact on North American gas demand, and the least impact on the total world demand.

The equation for the model price effects can be described in three parts. First, the relationship between a change in the regional demand on the regional price:

$$DeltaReg(r, y) = RegBeta(r) * \ln\left(\frac{CurrReg(r, y) - CentReg(r, y) + CentWorld(y)}{CentWorld(y)}\right)$$

Second, the relationship between a change in the aggregate demand on the regional price:

$$DeltaAgg(r,y) = AggBeta(r) * \ln\left(\frac{(CurrAgg(r,y) - CurrReg(r,y)) - (CentAgg(r,y) - CentReg(r,y)) + CentWorld(y)}{CentWorld(y)}\right)$$

Third, the relationship between a change in the world demand on the regional price:

$$DeltaWorld(r,y) = WorldBeta(r) * \ln\left(\frac{CurrWorld(y)}{CentWorld(y)}\right)$$

These three price effects are combined as an adjustment to the INGM "central case" price:

$$CurrPrc(r,y) = CentPrc(r,y) * \exp(DeltaReg(r,y) + DeltaAgg(r,y) + DeltaWorld(r,y))$$

Where:

CentReg and *CurrReg* are the regional change in demand from the central case to the current case

CentAgg and *CurrAgg* are the more aggregate regional change in demand from the central case to the current case

CentWorld and *CurrWorld* are the overall world change in demand from the central case to the current case

RegBeta, *AggBeta* and *WorldBeta* are the coefficients for the regional, more aggregate regional, and world behavior

DeltaReg, *DeltaAgg* and *DeltaWorld* are the intermediate regional, more aggregate regional, and world effects due to a change in demand

CentPrc and *CurrPrc* are the regional prices from the central case and the resulting current case.

The coefficients that were used for the Reduced Form Natural Gas Model in the *IEO2011* Reference case are provided in Table 5.

Table 5. Reduced-Form Natural Gas Model Coefficients for IEO2011

	Regional Demand	Aggregate Region Demand	World Demand
United States	11.12855	5.32414	1.446876
Canada	2.892406	10.3835	1.49542
Mexico/Chile	15.8617	6.678466	1.915545
Europe	4.244621	0	2.90216
Japan	-17.3944	-24.3844	3.90436
Australia/New Zealand	109.5716	-12.9133	1.714907
South Korea	-71.7019	1.259996	3.545558
Russia	1.420928	-8.02821	4.173952
Other non-OECD Europe and Eurasia	-12.0487	0.718116	4.376255
China	15.62053	-3.65236	3.144395
India	-4.54811	1.672564	3.108664
Other non-OECD Asia	12.09004	-4.55788	2.774624
Middle East	10.36795	0	2.000732
Africa	-10.8759	0	4.377612
Brazil	117.5838	9.617265	0.410639
Other Central and South America	54.67386	31.9071	1.769157

Retail Sectoral Prices

The prices projected in the Reduced Form Natural Gas Model are regional wholesale prices in real 2009 U.S. dollars. These prices are stored in the restart file. It is, however, also necessary to create end use sector specific natural gas prices for use by the WEPS+ demand and transformation models. The prices are created by applying a set of regional sector "mark-ups" in the form of multiplicative factors. The original factors were created by assessing the relationship between the end use sector natural gas prices published for the United States in the *Annual Energy Outlook 2011*. The calculation of the sectoral prices is given by:

$$RetailPrice(s,r,y) = CurrPrc(r,y) * SectorFac(s,r,y)$$

Where:

CurrPrc is the current projected wholesale natural gas price for a region and year

SectorFac is the sector's multiplicative factor for each sector, region and year

RetailPrice is the resulting sector retail price by sector, region and year

Appendix A. Model Abstract

Model Name:

Natural Gas Model or the Reduced Form Natural Gas Model of the World Energy Projection System Plus

Model Acronym:

RFNG

Model Description:

The WEPS+ Natural Gas Model determines wholesale natural gas prices. The wholesale prices are then used to calculate retail prices for each end use sector, using fixed sectoral mark-up factor. The RFNG Model is a reduced-form model that is estimated from perturbations of demand in the separate, standalone U.S. Energy Information Administration's International Natural Gas Model (INGM).

Model Purpose:

The Natural Gas Model determines wholesale natural gas prices by region and subsequently derives the retail natural gas prices for each end use annually through 2035 based upon the impact of natural gas demand changes on a regional, aggregated regional, and world basis.

Most Recent Model Update:

December 2009.

Part of Another Model:

World Energy Projection System Plus (WEPS+).

Model Interfaces:

The Natural Gas Model receives inputs from and provides outputs to the other models in the WEPS+ system, through the common, shared interface file of the WEPS+. It also receives inputs from and provides outputs to the U.S. Energy Information Administration's International Natural Gas Model.

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Documentation:

U.S. Energy Information Administration, *Natural Gas Model of the World Energy Projection System Plus: Model Documentation 2011*, DOE/EIA-M083(2011) (Washington, DC, September 2011).

Archive Information:

The model is archived as part of the World Energy Projection System Plus archive of the runs used to generate the *International Energy Outlook 2011*.

Energy System Described:

International natural gas prices

Coverage:

Geographic: Sixteen WEPS+ regions: U.S., Canada, Mexico/Chile, OECD Europe, Japan, Australia/New Zealand, South Korea, Russia, Other non-OECD Europe and Eurasia, China, India, other non-OECD Asia, Middle East, Africa, Brazil, and other Central and South America.

Mode: wholesale and retail regional natural gas prices.

Time Unit/Frequency: Annual, 2009 through 2035.

Modeling Features:

The WEPS+ Natural Gas Model determines wholesale natural gas prices. The wholesale prices are used to calculate retail prices by end use sector, using fixed end use sector mark-up factors. The Natural Gas Model is a reduced-form model that is estimated from perturbations of demand in the separate, standalone U.S. Energy Information Administration's International Natural Gas Model (INGM). The Natural Gas Model is a reduced-form, response-surface type of model that begins with a base price at a base level of consumption, and then models the impact of changes in natural gas consumption on the base prices. INGM is used to determine the details of natural gas production, imports, exports, LNG, and other supply components that are published in the *IEO2011*.

DOE Input Sources:

U.S. Energy Information Administration, *Annual Energy Outlook 2011*, DOE/EIA-0383 (Washington, DC, April 2011).

U.S. Energy Information Administration, *International Natural Gas Model*, model run date January 7, 2011.

Non-DOE Input Sources:

International Energy Agency (IEA), *Natural Gas Information 2010*, Paris, 2010.

International Energy Agency (IEA), *Energy Statistics and Balances in the OECD and Non-OECD Countries 2010*, Paris, 2010.

International Energy Agency (IEA), *Energy Prices and Taxes*, Quarterly Report (various issues), Paris, 2010.

Independent Expert Reviews:

None

Computing Environment:

Hardware/Operating System: Basic PC with Windows XP (or other Windows OS).

Language/Software Used: Fortran 90/95 (Currently using Compaq Visual Fortran), not required at runtime.

Run Time/Storage: Standalone model with one iteration runs in about 3-4 seconds, CPU memory is minimal, inputs/executable/outputs require less than 20MB storage.

Special Features: None.

Appendix B. Input Data and Variable Descriptions

The following variables represent data input from the file IngmToWepsInput.xls.

Classification: Input variable.

CentPrc(r,y):	"Central case" natural gas prices projected using the International Natural Gas Model (INGM) by region and year (2009 dollars per million Btu, years 2005 through 2035)
CentReg(r,y):	"Central case" natural gas consumption projected using INGM by region and year (quadrillion Btu, years 2005 through 2035)
RegBeta(r):	Price effect coefficient applied to changes in demand at the regional level (that is, United States, Canada, Mexico/Chile, OECD Europe, etc.)
AggBeta(r):	Price effect coefficient applied to aggregated regional changes in demand (that is, North America for the United States, Canada, and Mexico/Chile; OECD Europe for OECD Europe; OECD Asia for Japan, South Korea, and Australia/New Zealand; etc.)
WorldBeta(r):	Price effect coefficient applied to world changes in demand by region (that is, United States, Canada, Mexico/Chile, OECD Europe, etc.)
PipeCon(r,y):	INGM projections of natural gas consumed for pipeline transportation (quadrillion Btu, years 2005 through 2035)
LPCon(r,y):	INGM projections of lease and plant (L&P) fuels natural gas consumption (quadrillion Btu, years 2005 through 2035)
LNGCon(r,y):	INGM projections of natural gas consumed for liquefied natural gas (LNG) production (quadrillion Btu, years 2005 through 2035)
GTLCon(r,y):	INGM projections of natural gas consumed for gas-to-liquids (GTL) production by region and year (quadrillion Btu, years 2005 through 2035)
GTLOil(r,y):	INGM projections of GTL liquids production (quadrillion Btu, years 2005 through 2035)
GasReIn(r,y):	INGM projections of re-injected natural gas at oil reservoirs (quadrillion Btu, years 2005 through 2035, for

	IEO2011 this was only available at the aggregate world total, all individual regions are set to 0.0)
NGasProd(r,y):	INGM projections of natural gas production by region and year (quadrillion Btu, years 2005 through 2035)
NGLProd(r,y):	INGM projections of natural gas liquids (NGL) production by region and year (quadrillion Btu, years 2005 through 2035)
SPFac(s,r,2005):	Mark-up factors applied to wholesale natural gas prices to obtain end use sector retail natural gas prices by region for the year 2005 (s = residential, commercial, industrial, transportation, electric power generation, and district heat)
NGElas(r,y):	Natural gas supply elasticities (used only if NGSwitch is set to -1; not used in *IEO2011*)

The following variables represent data input from the file RFNG.xml.

HistLP(r,y):	Historical estimates of L&P natural gas use from the International Energy Agency and calibrated to U.S. Energy Information Administration natural gas consumption (quadrillion Btu, years 19980 through 2008)
HistPipe(r,y):	Historical estimates of pipeline transportation natural gas use from the International Energy Agency and calibrated to U.S. Energy Information Administration natural gas consumption (quadrillion Btu, years 1980 through 2008)

The following variables represent data input from the restart file.

Classification: Input variable from the Residential Model, Commercial Model, World Industrial Model, International Transportation Model, District Heat Model, and World Electricity Model.

QNGRS(r,y):	Amount of natural gas consumed in the residential sector by region and year (2005 through 2035)
QNGCM(r,y):	Amount of natural gas consumed in the commercial sector by region and year (2005 through 2035)
QNGIN(r,y):	Amount of natural gas consumed in the industrial sector by region and year (2005 through 2035)
QNGTR(r,y):	Amount of natural gas consumed in the transportation sector by region and year (2005 through 2035)

QNGPG(r,y):	Amount of natural gas consumed in the electric power sector by region and year (2005 through 2035)
QNGDH(r,y):	Consumption of natural gas used for district heat generation by region and year (2005 through 2035)

The following variables represent data calculated in the subroutine INGM

Classification: Computed variable.

PNGRS(r,y):	Retail price of natural gas used in the residential sector by region and year (2005 through 2035)
PNGCM(r,y):	Retail price of natural gas used in the commercial sector by region and year (2005 through 2035)
PNGIN(r,y):	Retail price of natural gas in the industrial sector by region and year (2005 through 2035)
PNGTR(r,y):	Retail price of natural gas in the transportation sector by region and year (2005 through 2035)
PNGDH(r,y):	Retail price of natural gas for district heat generation by region and year (2005 through 2035)
PNGPG(r,y):	Retail price of natural gas in the electric power sector by region and year (2005 through 2035)
PNGWD(r,y):	Wholesale price of natural gas by region and year (2005 through 2035)
QNGPPTR(r,y):	Pipeline consumption of natural gas by region and year (2005 through 2035)
QNGLPIN(r,y):	Lease and plant fuel use of natural gas by region and year (2005 through 2035)
QNGLGIN(r,y):	Consumption of natural gas for liquefied natural gas by region and year (2005 through 2035)
QNGGLIN(r,y):	Consumption of natural gas in the gas-to-liquids production process by region and year (2005 through 2035)
QGTLProd(r,y):	Quantity of gas-to-liquids fuel produced by region and year (2005 through 2035)
QNGReIn(r,y):	Natural gas re-injected into oil reservoirs for oil recovery improvement by region and year (for *IEO2011* only available for total world, years 2005 through 2035)

Appendix C. References

1. Walter Nicholson, *Microeconomic Theory: Basic Principles and Extensions* (Harcourt College Publishers, Fort Worth: Texas, 1972).

2. Alpha C. Chiang, *Fundamental Methods of Mathematical Economics* (McGraw-Hill Book Company, NY: NY, 1967).

3. Wayne L. Winston, *Operations Research: Applications and Algorithms* (Brooks/Cole—Thomson Learning, Belmont, CA, 2004).

4. U.S. Energy Information Administration, *Annual Energy Outlook 2011*, DOE/EIA-0383(2011) (Washington, DC, April 2011).

5. U.S. Energy Information Administration, *Documentation of the Oil and Gas Supply Module (OGSM)*, DOE/EIA-M063(2011) (Washington, DC, July 2011).

6. International Energy Agency, *Natural Gas Information 2010* (Paris, France, 2010).

7. International Energy Agency, *Energy Prices and Taxes* (Quarterly report, Paris, France, 2010).

8. International Energy Agency, *Energy Statistics and Balances of OECD Countries*, web site www.iea.org (subscription site).

9. International Energy Agency, *Energy Statistics and Balances of Non-OECD Countries*, web site www.iea.org (subscription site).

10. International Energy Agency, *World Energy Outlook 2010 Edition* (Paris, France, November 2010).

Appendix D. Data Quality

Introduction

The WEPS+ Natural Gas Model develops projections of world wholesale and retail natural gas prices for 16 regions of the world. These projections are based upon the data elements as detailed in Appendix B of this report. The documentation details transformations, estimation methodologies, and resulting inputs required to implement the model algorithms in Chapter 4: Model Structure. The quality of the principal sources of input data is discussed in Appendix D. Information regarding the quality of parameter estimates and user inputs is provided where available.

Source and Quality of Input Data

Source of Input Data

- *International Natural Gas Model (2011)* – The U.S. Energy Information Administration's International Natural Gas Model provides projections of world natural gas supply and prices projections by region through 2035. These data are used for regional supply projections that appear in the *IEO2011* and as a basis for natural gas price estimates in the WEPS+ model.

- *International Energy Agency* – The international historical data on lease and plant natural gas use and natural gas use for pipeline transportation were estimated, in part, using information from the International Energy Agency's *Energy Statistics and Balances of OECD and Non-OECD Countries* (2010).

Data Quality Verification

As a part of the input and editing procedure, an extensive program of edits and verifications was used, including:

- Checks on world and U.S. retail natural gas prices, based on previous values, responses, and regional and technical knowledge

- Consistency checks

- Technical edits to detect and correct errors, extreme variability