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World Energy Projection System Plus Model Documentation 2010: 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 an energy supply modeling system used primarily to estimate regional retail and wholesale natural gas prices. This report describes the version of the Natural Gas Model that was used to produce the projections published in the *International Energy Outlook 2010* (*IEO2010*). The Natural Gas Model is one of 13 components of the WEPS+ energy modeling system, but it can also be run as a standalone model. The WEPS+ is a modular system, consisting of a number of separate energy models that communicate and work together through the overall system model. These models are each developed independently, but are designed with well-defined protocols for system communication and interactivity. The WEPS+ modeling system uses a 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 projects annual wholesale natural gas prices for each of the 16 regions 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 mark-up factors. 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 relies on estimated perturbations of demand projected by a separate standalone model, the International Natural Gas Model (INGM). This reduced-form model projects prices by adjusting the prices for a base year to account for changes over time resulting from changes in natural gas consumption levels. The consumption projections from a WEPS+ system execution are provided to the INGM through a standard interface file. In turn, the INGM provides base prices and reduced-form model coefficients for use by the WEPS+, which uses the Reduced Form Natural Gas (RFNG) Model in subsequent system runs. The INGM was used to derive the detailed projections of natural gas production, imports, exports, LNG, and other supply components that are published in the *IEO2010*.

Model Archival Citation

This documentation refers to the WEPS+ Natural Gas Model, as archived for the *International Energy Outlook 2010* (*IEO2010*).

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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 used 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 project wholesale natural gas prices for each of the 16 regions annually through 2035. The wholesale prices are then used to estimate retail prices for each of the demand and transformation sectors, using fixed end use sector mark-up factors. 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 defined either within or outside of 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	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 imports natural gas consumption projections from the WEPS+ restart file. These inputs have been previously projected by the source models listed in Table 2. The Natural Gas Model also imports the exogenous data series listed in Table 3 from the input file RFNGInput.xml.

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

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 2008 dollars per million Btu); “central case” prices are the initial output of an INGM Reference case trial run
	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 historical data (quadrillion Btu, 1980-2007)
	Historical natural gas use for pipeline transportation from the International Energy Agency and calibrated to Energy Information Administration historical data (quadrillion Btu, 1980-2007)
	Regional natural gas supply elasticities (only imported if NGSwitch = -1)

Outputs

The Natural Gas Model projects regional wholesale natural gas prices and regional retail natural gas prices by end-use sector. It exports these values to the WEPS+ restart file for use by the supply and transformation models (Table 4).

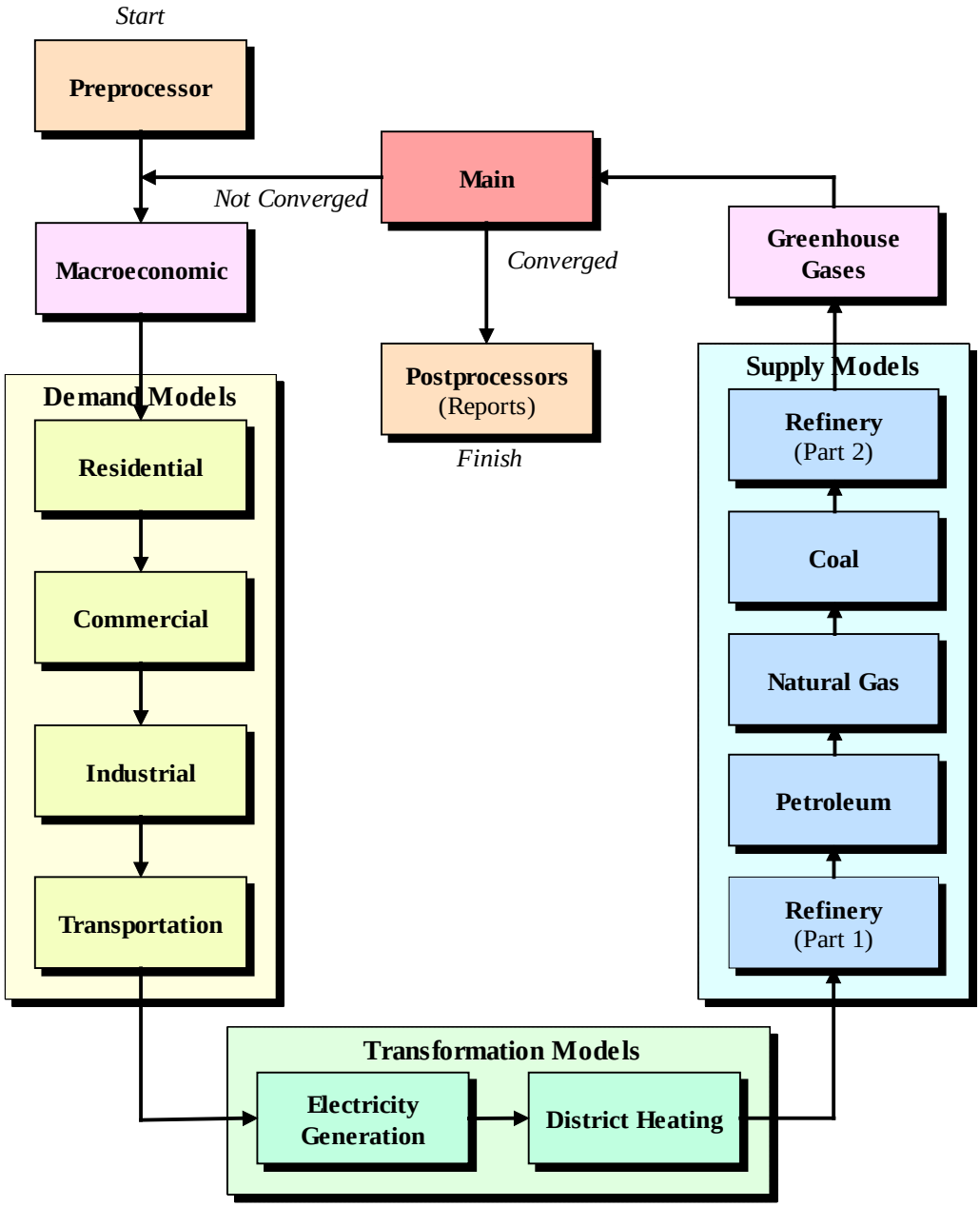
Table 4. Natural Gas Model Outputs and the WEPS+ Models that Use Them

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 on 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 are key inputs for other WEPS+ models (Figure 1). A summary description of the models, flows, and mechanics of the WEPS+ system that was used for the *IEO2010* report is available in a separate *Overview* document.

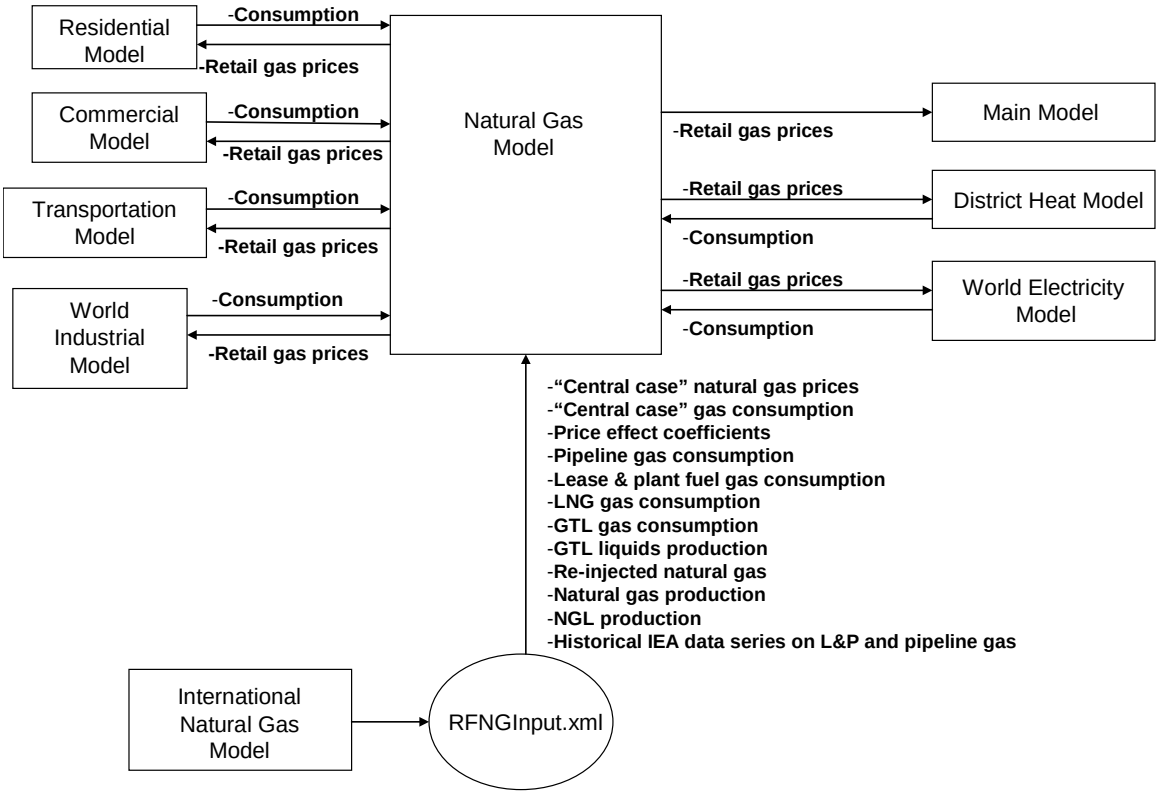
Figure 1. World Energy Projection System Plus (WEPS+) Model Sequence



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 to the Main Model.

Although the Natural Gas Model is an integral part of the WEPS+ system, it can also be run as a standalone model. In standalone mode, the Natural Gas Model imports consumption and price projections from the WEPS+ system "restart" file created in a prior full system run.

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 in response to change in natural gas consumption levels. The RFNG Model employs a set of coefficients estimated by perturbing consumption levels in the INGM to simulate changes in price relative to changes in demand. The algorithms used to perform the simulations ensure that changes in world, sub-region, and individual region (or country) natural gas consumption levels appropriately affect the projected wholesale prices. (Supply curves are estimated within the INGM.) Retail natural gas prices by end use sector are then derived from the wholesale natural gas prices using fixed retail mark-up factors.

4. Model Structure

Structural Overview

The WEPS+ Natural Gas Model or Reduced-Form Natural Gas (RFNG) Model projects wholesale natural gas prices for each of 16 international WEPS+ regions. The wholesale prices are then adjusted, using fixed end-use sector mark-up factors, to calculate retail prices for each of the demand and transformation sectors. The retail prices are exported into the shared restart file 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.

The INGM is a linear programming (LP) model that projects detailed data on natural gas production, imports, exports, production of liquefied natural gas (LNG) and gas-to-liquids (GTL), natural gas used for pipeline transport, and the liquids produced from GTL processes. The INGM uses Microsoft Access for its user interface and data repository and Visual Basic for Applications to manipulate and calculate intermediate results and set up the LP. It uses an external solver to optimize the LP objective function[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, the major component of the model, which performs most of the model computations. In its final step, the model executes the subroutine that exports all projections to the restart file for use by other WEPS+ models.

[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: March 25, 2010).

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. The file provides the following data, which have been read from exogenous sources or generated from a previous run of either the WEPS+ system or EIA's International Natural Gas Model (INGM):

- INGM "central case" natural gas prices (2005 through 2035, in real 2008 dollars per million Btu); "central case" prices are the prices projected by an INGM Reference case trial run
- INGM "central case" natural gas consumption (2005 through 2035)
- "Reference case" natural gas consumption projections from a previous WEPS+ run
- Price effect demand elasticity 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 (1980-2007)
- Historical natural gas pipeline transportation consumption from the International Energy Agency (1980-2007)
- End use sector price mark-up factors (from the *Annual Energy Outlook 2010* for the United States)
- Regional natural gas supply elasticities (not used in *IEO2010*)

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 projections 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 projecting prices based on the price effects coefficients.

Next, the INGM subroutine checks the value of the "NGSwitch" variable. This variable specifies the method of projecting current natural gas demand. When NGSwitch is set to 0, as it was in the *IEO2010*, current natural gas demand is calculated by adding the end use sector projections of natural gas consumption and then subtracting the amounts of 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." (It can also be set to -1, as explained below.) 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 set to 3, the demand in China is set equal to 20 percent above the 2035 INGM central case demand; for all other regions, it is set to the unadjusted central case demand. Once the natural gas demand has been estimated according to the value of NGSwitch, the model recalculates the aggregate regional and world total natural gas consumption estimates.

Next the subroutine projects wholesale prices. If NGSwitch is set to -1, the wholesale prices are calculated using exogenously-specified supply elasticities. Otherwise, the model uses the following two-step method:

1) Wholesale prices initially are set to the INGM model price projections. These projections reflect the effects of changes in natural gas consumption as estimated by the INGM.
2) The INGM prices are adjusted, at the regional, aggregate and world levels, to be consistent with the changes over time in the WEPS+ natural gas consumption estimates (rather than the consumption changes estimated by the INGM)

End use sector retail natural gas prices are calculated as a product of the wholesale prices and exogenously-specified 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 the end-use sectors.

The INGM subroutine then calls the INGMData subroutine, which creates an output data file (NGR-IEO2010-RefJ-0115a.csv, for the *IEO2010* Reference case) that can be used as input in the next INGM model run. The output data series, most of which are generated by other WEPS+ modules, 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 *IEO2010*), and end-use-sector retail prices by region. In all cases, the annual data series extend from 2005 through 2035. After the INGM subroutine has completed, Natural Gas Model calls the WriteRestart subroutine, which writes the 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

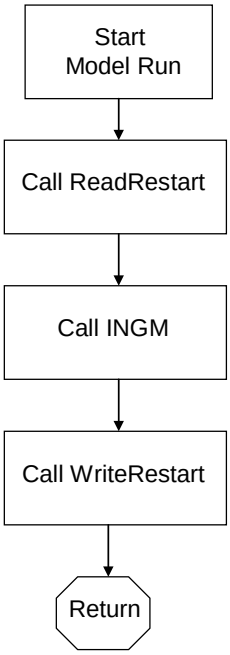
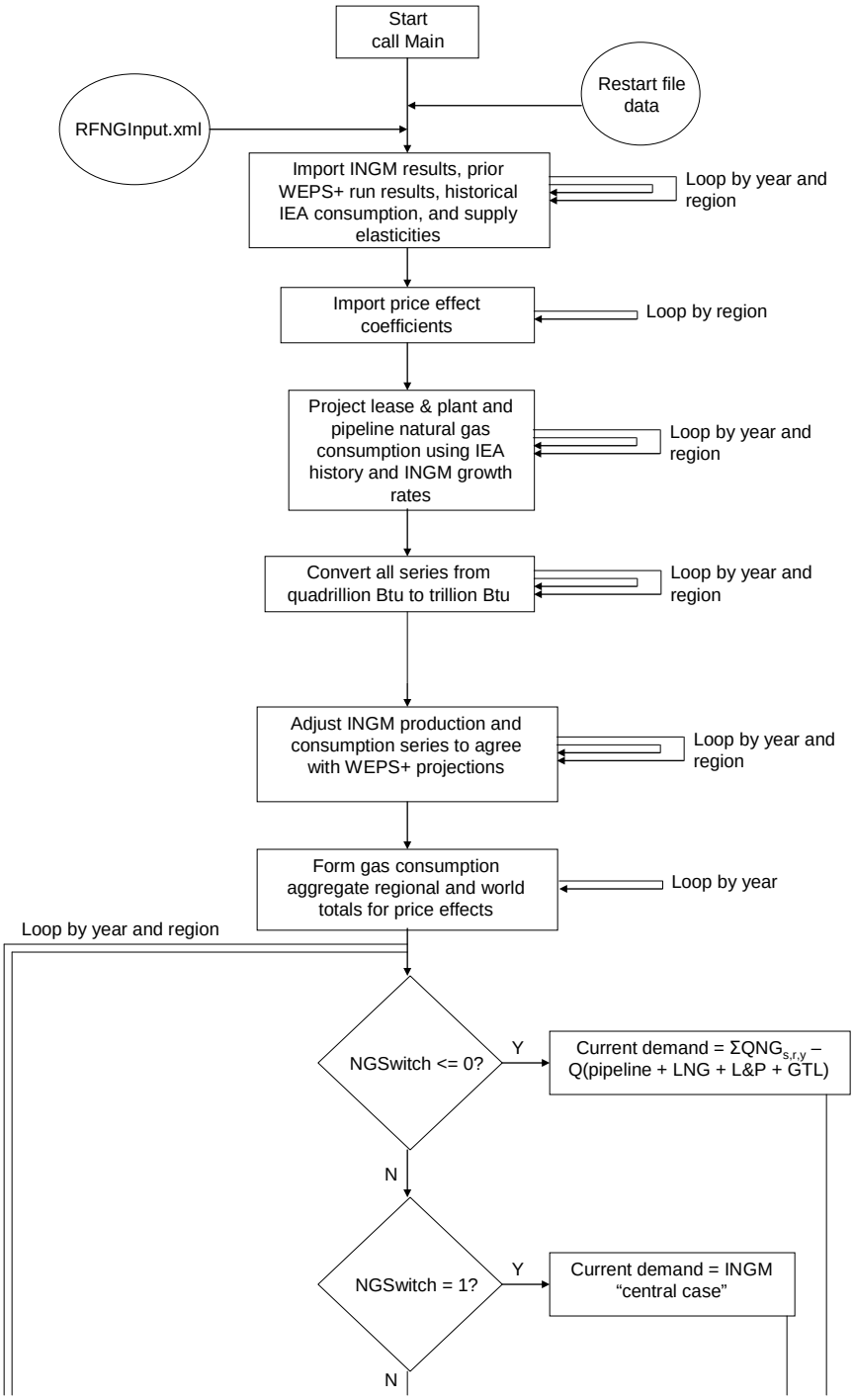
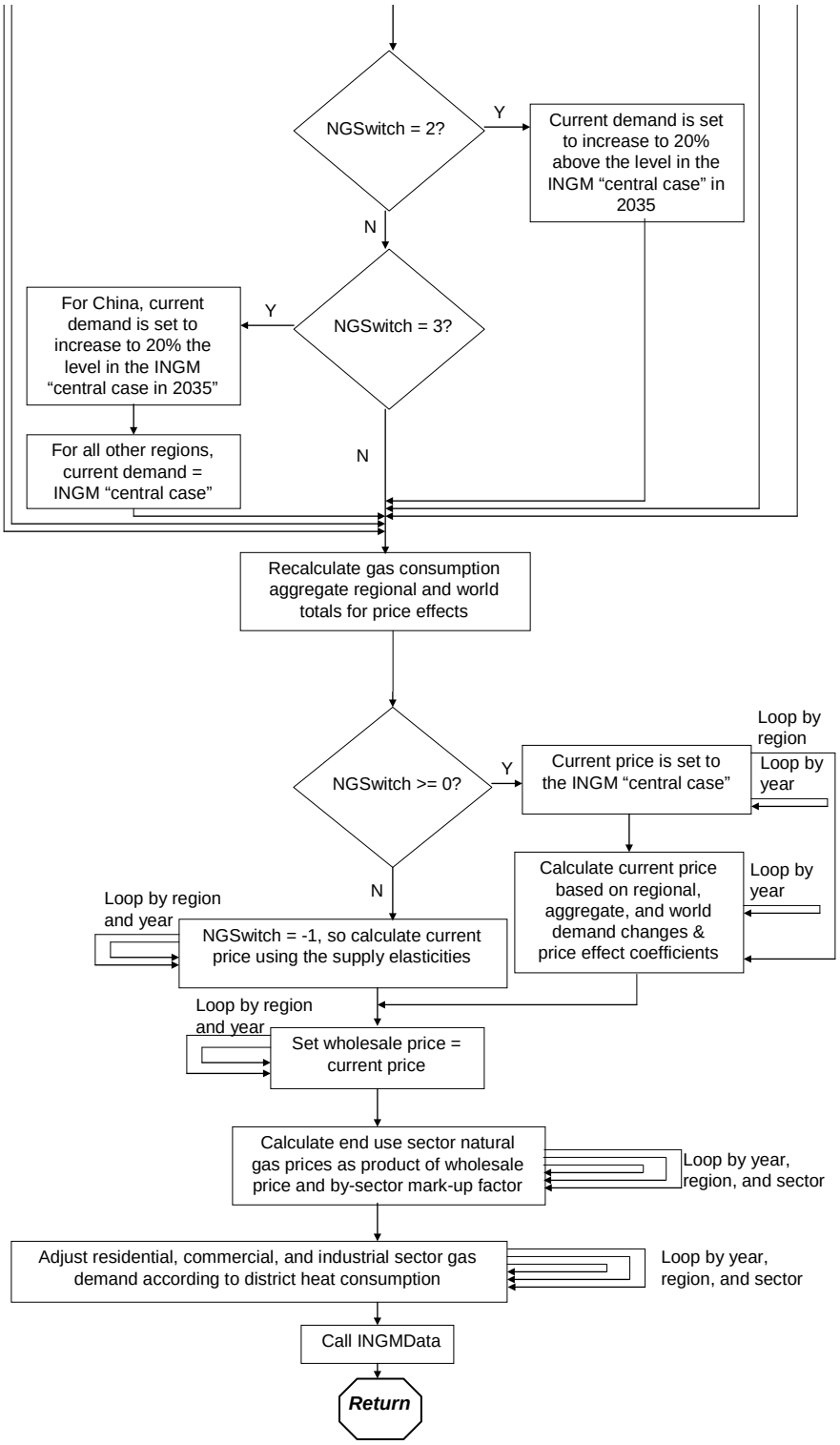


Figure 4. Flowchart for the INGM Subroutine




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. To estimate retail prices, the model applies regional sector-level mark-up factors to the wholesale prices. The reduced model attempts to replicate the results of the full INGM using a response-surface approach. Changes in the INGM wholesale natural gas price projections are estimated using changes in regional demand quantities along with regional behavioral coefficients. The reduced model also projects some additional variables using assumed relationships rather than a formal model.

To begin the process, a WEPS+ system is run for a specific case (such as the *IEO2010* Reference case) using world oil price and macroeconomic assumptions appropriate for that scenario. The resulting consumption and price projections are exported to an interface file (for the *IEO2010* Reference case, the file is called NGR-IEO2010-.csv) and made available to the INGM. The INGM is then run in an attempt to replicate the demand totals imported from the WEPS+ system. The demand totals from the INGM run (referred to here as the "central case") will not necessarily replicate the demand totals imported from the WEPS+. That is, the INGM central case demand totals may differ from the demand totals of the WEPS+ Reference case.

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+.

The 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 *IEO2010* Reference case: RFNGInput-JH121409.xml). The WEPS+ imports these 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 that account for the differences in the INGM consumption projections and those generated in the WEPS+ run. The model also adjusts the other supply components using the relationships between the INGM central case projections of consumption and the WEPS+ consumption projections. The information provided by INGM to WEPS+ includes the following data items, calculated for each WEPS+ region in each projection year:

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

Adjustments of Supply Concepts

From an interface file, the RFNG imports several supply components that have been projected in the INGM for its central case. Because the components are associated with the INGM central case consumption projections, some of them must be adjusted for use in WEPS+.

First the model replaces the pipeline and lease and plant (L&P) consumption values from INGM are with data from the International Energy Agency's (IEA) *Energy Statistics and Balances of OECD and Non-OECD Countries*. (The INGM estimates of these values were judged to be less accurate than the IEA estimates.) The model first replaces the historical data and then uses simple assumptions to project the series forward. As part of this process, the model recalculates the regional natural gas demand projections as sums of the demand projections from the WEPS+ demand and transformation models:

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

where, for region *r* in year *y*,

QNGRS(r,y) = residential natural gas consumption

QNGCM(r,y) = commercial natural gas consumption

QNGIN(r,y) = industrial natural gas consumption

QNGTR(r,y) = transportation natural gas consumption

QNGPG(r,y) = electric power generation natural gas consumption

QNGDH(r,y) = district heat natural gas consumption

NGasDem(r,y) = total natural gas demand

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, for region *r* in year *y*,

NGasProd(r,y) = natural gas production

LPCon(r,y) = lease and plant natural gas consumption

The model assumes that the amount of natural gas consumed for pipeline transport increase either at the same rate as the total natural gas production *or* the same rate as total natural gas consumption, whichever rate is higher:

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

where, for region *r* in year *y*,

NGasProd(r,y) = natural gas production

PipeCon(r,y) = pipeline natural gas consumption

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 WEPS+ Reference case consumption, the components of supply associated with the central case from INGM are adjusted to ensure consistency with the WEPS+ Reference case. The model calculates an adjustment factor for each projection year *y*:

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

where *RCNGasDem(y)* = WEPS+ world Reference case demand by year

CCNGasDem(y) = INGM world central case demand (production) by year

AdjFac(y) = adjustment factor

Each of the following components is adjusted using this factor:

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

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

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

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

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

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

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

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

where, for region *r* in year *y*,

NGasProd(r,y) = adjusted natural gas production

NGLProd(r,y) = natural gas liquids production

PipeCon(r,y) = natural gas pipeline consumption

LPCon(r,y) = natural gas lease & plant consumption

LNGCon(r,y) = natural gas LNG consumption

GTLCon(r,y) = natural gas GTL consumption

GTLOil(r,y) = liquids production by GTL

GasReIn(r,y) = natural gas re-injection

All of the adjusted components are exported to the restart file. The natural gas pipeline consumption is added to the transportation consumption estimated by the WEPS+ transportation model and reported in the transportation sector. The natural gas lease and plant, LNG, and GTL gas consumption are added to the industrial sector consumption. 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 *IEO2010* are directly modeled in INGM, to be as close as possible to the demand projected in WEPS+ results.

Reduced-Form, Response-Surface Wholesale Price Model

The reduced-form, response-surface model in RFNG attempts to replicate the responses of regional natural gas wholesale prices to changes in regional natural gas demand as modeled in INGM. The RFNG uses estimated elasticity parameters computed at three levels of aggregation: 1) regional, as defined by the 16 WEPS+ regions; 2) more aggregate regional, as defined by the eight larger regions given below; and 3) world. The eight aggregated regions are formed by combining some of the original 16 WEPS+ regions, as follows:

- North America = United States, Canada, and Mexico
- 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 in 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's. A change in Canada's natural gas price would typically 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. These three levels of aggregation are used to estimate the price differences that result from the differences in demand levels between the current case and the INGM central case.

The effect of the demand difference on prices within an individual WEPS+ region *r* in year *y* is estimated as:

$$DeltaReg(r,y) = RegBeta(r) * \ln\left\{1 + \frac{CurrReg(r,y) - CentReg(r,y)}{CentWorld(y)}\right\}$$

where *DeltaReg(r,y)* = effect on natural gas prices in region *r* and year *y*, due to the difference in demand within region *r* between the current case and the INGM central case

RegBeta(r) = elasticity parameter measuring the impact of demand change in region *r* on natural gas prices in region *r*

CentWorld(y) = world natural gas demand in year *y*, from the INGM central case

CentReg(r,y) = regional natural gas demand in year *y* and region *r*, from the INGM central case

CurrReg(r,y) = regional natural gas demand in year *y* and region *r*, from the current case

Next, the effect on prices in WEPS+ region *r* due to demand difference (again between the current case and the INGM central case) is considered in the aggregate region (as defined above) that contains region *r*. For example, if region *r* is Canada, the aggregate region comprises Canada, the United States, and Mexico. The effect of prices difference in region *r* that results from the demand difference within its aggregate region is estimated as

$$DeltaAgg(r,y) = AggBeta(r) * \ln\left\{1 + \frac{[CurrAgg(r,y) - CentAgg(r,y)] - [CurrReg(r,y) - CentReg(r,y)]}{CentWorld(y)}\right\}$$

where *DeltaAgg(r,y)* = effect on natural gas prices in region *r* and year *y* due to the difference in demand within the aggregate region containing region *r* between the current case and the INGM reference case

AggBeta(r) = elasticity coefficient measuring the impact of demand differences in the aggregate region containing region *r* on natural gas prices within region *r*

CurrAgg(r,y) = natural gas demand in year *y* in the aggregate region containing region *r*, from the current case

CentAgg(r,y) = natural gas demand in year *y* in the aggregate region containing region *r*, from the INGM central case

Third, the effect of the difference in the world demand, between the current case and the INGM central case, on natural gas prices in region *r* is estimated as

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

where *DeltaWorld(r,y)* = effect on natural gas prices in region *r* and year *y* due to the difference in world demand between the current case and the INGM central case

WorldBeta (r,y) = elasticity coefficient measuring the impact of world demand on natural gas prices within region *r*

CurrWorld(y) = world demand for natural gas in the current case

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, for region *r* in year *y*,

CurrPrc(r,y) = the price of natural gas in the current case

CentPrc(r,y) = the price of natural gas in the INGM central case

The coefficients that were used for the Reduced Form Natural Gas Model in the *IEO2010* Reference case are provided in Table 5.

Table 5. Reduced-Form Natural Gas Model Coefficients for IEO2010

	Regional Demand	Aggregate Region Demand	World Demand
United States	4.636	3.153	1.505
Canada	4.186	4.579	1.482
Mexico	20.092	1.022	4.179
Europe	4.172	0.000	3.639
Japan	5.243	0.271	3.790
Australia/New Zealand	26.539	3.579	3.199
South Korea	7.404	3.931	3.674
Russia	1.160	-1.781	4.676
Other non-OECD Europe and Eurasia	0.112	-0.494	4.573
China	3.503	3.993	4.408
India	14.909	1.744	4.507
Other non-OECD Asia	6.511	3.502	2.770
Middle East	11.422	0.000	4.632
Africa	-1.552	0.000	4.950
Brazil	-29.350	12.735	3.333
Other Central and South America	-6.116	-94.523	5.111

Retail Sectoral Prices

The prices projected in the Reduced Form Natural Gas Model are regional wholesale prices in real 2008 U.S. dollars. These prices are stored in the restart file. The model also estimates end-use sector natural gas prices, for use by the WEPS+ demand and transformation models, by applying a set of regional sector-level mark-ups factors. The original factors were estimated based on historical relationships between the wholesale and end use sector natural gas prices published for the United States in the *Annual Energy Outlook 2010*.

The retail price for end-use sector *s* in region *r* and projection year *y* is given by

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

where, for region *r* and year *y*,

CurrPrc(r,y) = projected wholesale natural gas price

SectorFac(s,r,y) = retail markup factor for sector *s*

RetailPrice(s,r,y) = retail natural gas price for sector *s*

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 projects annual wholesale natural gas prices. The wholesale prices are then used to estimate retail prices for each end use sector, using fixed sectoral mark-up factors. The RFNG Model is a reduced-form model that uses coefficients 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 projects annual wholesale natural gas prices through 2035 by region based on the impact of natural gas demand changes—estimated regional, aggregated regional, and world levels—on regional natural gas prices.

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 2010*, DOE/EIA-M083(2010) (Washington, DC, September 2010).

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 2010*.

Energy System Described:

International natural gas prices

Coverage:

Geographic: Sixteen WEPS+ regions: U.S., Canada, Mexico, 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, 2008 through 2035.

Modeling Features:

The WEPS+ Natural Gas Model projects 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 uses parameters estimated from perturbations of demand in the separate, standalone U.S. Energy Information Administration's International Natural Gas Model (INGM). The Natural Gas Model 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. The model relies on the INGM for projections of natural gas production, imports, exports, LNG, and other supply components that are published in the *IEO2010*.

DOE Input Sources:

U.S. Energy Information Administration, *Annual Energy Outlook 2010*, DOE/EIA-0383 (Washington, DC, April 2010).

U.S. Energy Information Administration, *International Natural Gas Model*, model run date December 7, 2009.

Non-DOE Input Sources:

International Energy Agency (IEA), *Natural Gas Information 2009*, Paris, 2009.

International Energy Agency (IEA), *Energy Statistics and Balances in the OECD and Non-OECD Countries 2009*, Paris, 2009.

International Energy Agency (IEA), *Energy Prices and Taxes*, Quarterly Report (various issues), Paris, 2009.

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 RFNGInput-JH121409.xml.

Classification: Input variable.

CentPrc(r,y):	"Central case" natural gas prices projected using the International Natural Gas Model (INGM) by region and year (2008 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)
OrigDem(r,y):	Natural gas consumption projections from a prior iteration of the WEPS+ model by region and year (quadrillion Btu; years 2005 through 2035; for *IEO2010*, these consumption values were the result of a run made on December 4, 2009)
RegBeta(r):	Price effect coefficient applied to changes in demand at the regional level (that is, United States, Canada, Mexico, 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; 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, 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 *IEO2010* 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)
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 2007)
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 2007)
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 *IEO2010*)

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 *IEO2010* 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 2010*, DOE/EIA-0383(2010) (Washington, DC, April 2010).

5. U.S. Energy Information Administration, *Documentation of the Oil and Gas Supply Module (OGSM)*, DOE/EIA-M063(2010) (Washington, DC, May 2010).

6. International Energy Agency, *Natural Gas Information 2009* (Paris, France, 2009).

7. International Energy Agency, *Energy Prices and Taxes* (Quarterly report, Paris, France, 2009).

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 2009 Edition* (Paris, France, November 2009).

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 (2010)* – 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 *IEO2010* 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* (2009).

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