

# **Documentation of the Oil and Gas Supply Module (OGSM)**

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## Update Information

This edition of the *Documentation of the Oil and Gas Supply Module* reflects changes made to the oil and gas supply module over the past year for the *Annual Energy Outlook 2011*. The major changes include:

- Texas Railroad Commission District 5 is included in the Southwest region instead of the Gulf Coast region.
- Re-estimation of Lower 48 onshore exploration and development costs.
- Updates to crude oil and natural gas resource estimates for emerging shale plays.
- Addition of play-level resource assumptions for tight gas, shale gas, and coalbed methane (Appendix 2.C).
- Updates to the assumptions used for the announced/nonproducing offshore discoveries.
- Revision of the North Slope New Field Wildcat (NFW) exploration wells drilling rate function. The NFW drilling rate is a function of the low-sulfur light projected crude oil prices and was statically estimated based on Alaska Oil and Gas Conservation Commission well counts and success rates.
- Recalibration of the Alaska oil and gas well drilling and completion costs based on the 2007 American Petroleum Institute Joint Association Survey drilling cost data.
- Updates to oil shale plant configuration, cost of capital calculation, and market penetration algorithms.
- Addition of natural gas processing and coal-to-liquids plants as anthropogenic sources of carbon dioxide (CO<sub>2</sub>).

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# 1. Introduction

The purpose of this report is to define the objectives of the Oil and Gas Supply Module (OGSM), to describe the model's basic approach, and to provide detail on how the model works. This report is intended as a reference document for model analysts, users, and the public. It is prepared in accordance with the U.S. Energy Information Administration's (EIA) legal obligation to provide adequate documentation in support of its statistical and forecast reports (Public Law 93-275, Section 57(b)(2)).

Projected production estimates of U.S. crude oil and natural gas are based on supply functions generated endogenously within the National Energy Modeling System (NEMS) by the OGSM. The OGSM encompasses both conventional and unconventional domestic crude oil and natural gas supply. Crude oil and natural gas projections are further disaggregated by geographic region. The OGSM projects U.S. domestic oil and gas supply for six Lower 48 onshore regions, three offshore regions, and Alaska. The general methodology relies on forecasted profitability to determine exploratory and developmental drilling levels for each region and fuel type. These projected drilling levels translate into reserve additions, as well as a modification of the production capacity for each region.

The OGSM utilizes both exogenous input data and data from other modules within the NEMS. The primary exogenous inputs are resource levels, finding-rate parameters, costs, production profiles, and tax rates - all of which are critical determinants of the expected returns from projected drilling activities. Regional projections of natural gas wellhead prices and production are provided by the Natural Gas Transmission and Distribution Module (NGTDM). Projections of the crude oil wellhead prices at the OGSM regional level come from the Petroleum Market Model (PMM). Important economic factors, namely interest rates and GDP deflators, flow to the OGSM from the Macroeconomic Module. Controlling information (e.g., forecast year) and expectations information (e.g., expected price paths) come from the Integrating Module (i.e. system module).

Outputs from the OGSM go to other oil and gas modules (NGTDM and PMM) and to other modules of the NEMS. To equilibrate supply and demand in the given year, the NGTDM employs short-term supply functions (with the parameters provided by the OGSM) to determine non-associated gas production and natural gas imports. Crude oil production is determined within the OGSM using short-term supply functions. These short-term supply functions reflect potential oil or gas flows to the market for a 1-year period. The gas functions are used by the NGTDM and the oil volumes are used by the PMM for the determination of equilibrium prices and quantities of crude oil and natural gas at the wellhead. The OGSM also provides projections of natural gas production to the PMM to estimate the corresponding level of natural gas liquids production. Other NEMS modules receive projections of selected OGSM variables for various uses. Oil and gas production is passed to the Integrating Module for reporting purposes. Forecasts of oil and gas production are also provided to the Macroeconomic Module to assist in forecasting aggregate measures of output.

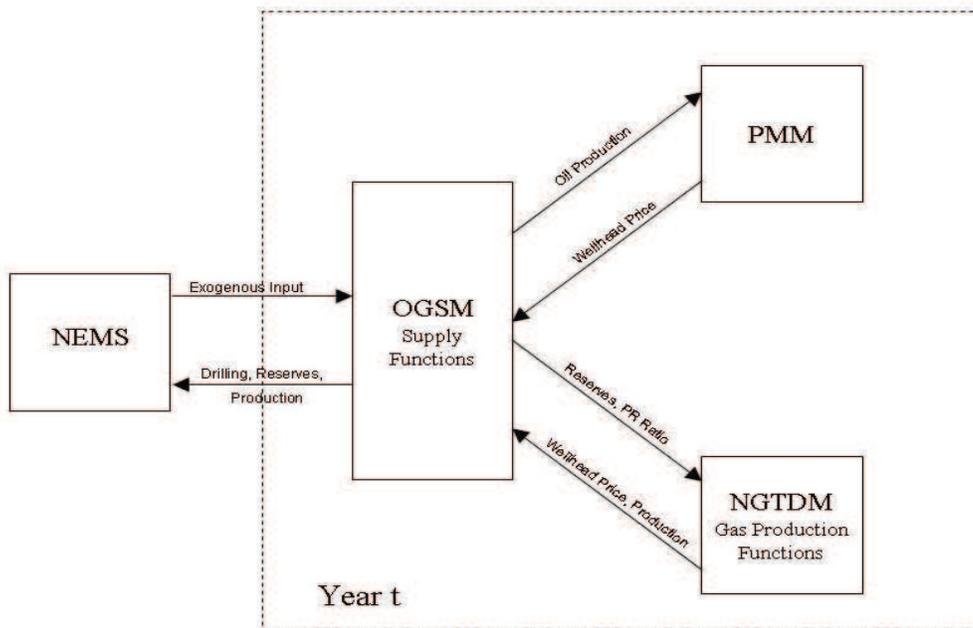
The OGSM is archived as part of the NEMS. The archival package of the NEMS is located under the model acronym NEMS2011. The NEMS version documented is that used to produce the *Annual Energy Outlook 2011 (AEO2011)*. The package is available on the EIA website.<sup>1</sup>

## Model Purpose

The OGSM is a comprehensive framework used to analyze oil and gas supply potential and related issues. Its primary function is to produce domestic projections of crude oil and natural gas production as well as natural gas imports and exports in response to price data received endogenously (within the NEMS) from the NGTDM and PMM. Projected natural gas and crude oil wellhead prices are determined within the NGTDM and PMM, respectively. As the supply component only, the OGSM cannot project prices, which are the outcome of the equilibration of both demand and supply.

The basic interaction between the OGSM and the other oil and gas modules is represented in Figure 1-1. The OGSM provides beginning-of-year reserves and the production-to-reserves ratio to the NGTDM for use in its short-term domestic non-associated gas production functions and associated-dissolved natural gas production. The interaction of supply and demand in the NGTDM determines non-associated gas production.

**Figure 1-1. OGSM Interface with Other Oil and Gas Modules**



<sup>1</sup> <ftp://ftp.eia.doe.gov/pub/forecasts/aeo/>

The OGSM provides domestic crude oil production to the PMM. The interaction of supply and demand in the PMM determines the level of imports. System control information (e.g., forecast year) and expectations (e.g., expect price paths) come from the Integrating Module. Major exogenous inputs include resource levels, finding-rate parameters, costs, production profiles, and tax rates -- all of which are critical determinants of the oil and gas supply outlook of the OGSM.

The OGSM operates on a regionally disaggregated level, further differentiated by fuel type. The basic geographic regions are Lower 48 onshore, Lower 48 offshore, and Alaska, each of which, in turn, is divided into a number of subregions (see Figure 1-2). The primary fuel types are crude oil and natural gas, which are further disaggregated based on type of deposition, method of extraction, or geologic formation. Crude oil supply includes lease condensate. Natural gas is differentiated by non-associated and associated-dissolved gas.<sup>2</sup> Non-associated natural gas is categorized by fuel type: low-permeability carbonate and sandstone (conventional), high-permeability carbonate and sandstone (tight gas), shale gas, and coalbed methane.

The OGSM provides mid-term (through year 2035) projections and serves as an analytical tool for the assessment of alternative supply policies. One publication that utilizes OGSM forecasts is the *Annual Energy Outlook (AEO)*. Analytical issues that OGSM can address involve policies that affect the profitability of drilling through impacts on certain variables, including:

- drilling and production costs;
- regulatory or legislatively mandated environmental costs;
- key taxation provisions such as severance taxes, State or Federal income taxes, depreciation schedules and tax credits; and
- the rate of penetration for different technologies into the industry by fuel type.

The cash flow approach to the determination of drilling levels enables the OGSM to address some financial issues. In particular, the treatment of financial resources within the OGSM allows for explicit consideration of the financial aspects of upstream capital investment in the petroleum industry.

The OGSM is also useful for policy analysis of resource base issues. OGSM analysis is based on explicit estimates for technically recoverable oil and gas resources for each of the sources of domestic production (i.e., geographic region/fuel type combinations). With some modification, this feature could allow the model to be used for the analysis of issues involving:

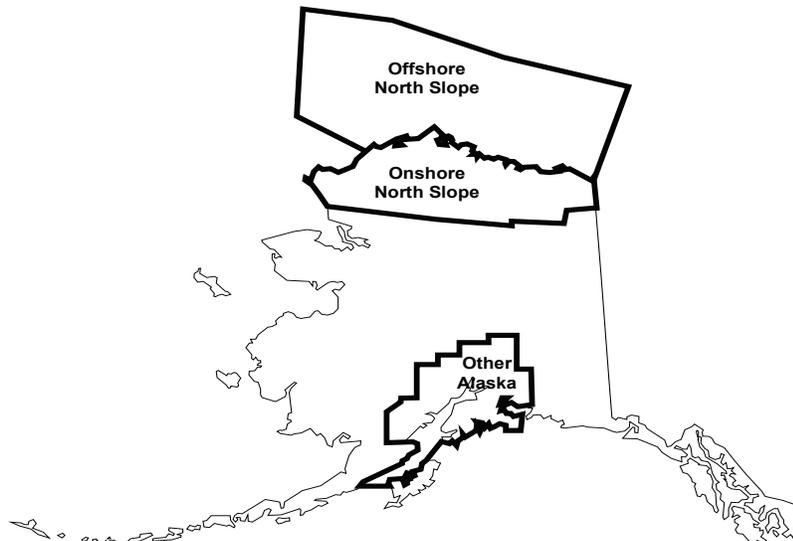
- the uncertainty surrounding the technically recoverable oil and gas resource estimates, and
- access restrictions on much of the offshore Lower 48 states, the wilderness areas of the onshore Lower 48 states, and the 1002 Study Area of the Arctic National Wildlife Refuge (ANWR).

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<sup>2</sup>Nonassociated (NA) natural gas is gas not in contact with significant quantities of crude oil in a reservoir. Associated-dissolved natural gas consists of the combined volume of natural gas that occurs in crude oil reservoirs either as free gas (associated) or as gas in solution with crude oil (dissolved).

In general, the OGSM is used to foster a better understanding of the integral role that the oil and gas extraction industry plays with respect to the entire oil and gas industry, the energy subsector of the U.S. economy, and the total U.S. economy.

**Figure 1-2. Oil and Gas Supply Regions**

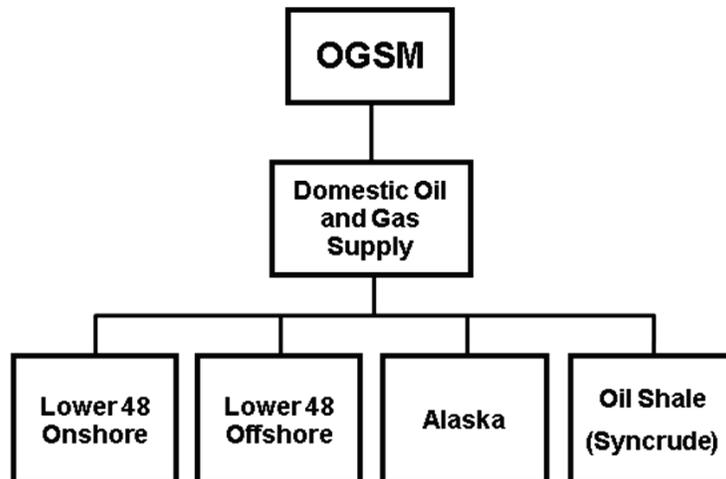


## Model Structure

The OGSM consists of a set of submodules (Figure 1-3) and is used to perform supply analysis of domestic oil and gas as part of the NEMS. The OGSM provides crude oil production and parameter estimates representing natural gas supplies by selected fuel types on a regional basis to support the market equilibrium determination conducted within other modules of the NEMS. The oil and gas supplies in each period are balanced against the regionally-derived demand for the produced fuels to solve simultaneously for the market clearing prices and quantities in the wellhead and end-use markets. The description of the market analysis models may be found in the separate methodology documentation reports for the Petroleum Market Module (PMM) and the Natural Gas Transmission and Distribution Model (NGTDM).

The OGSM represents the activities of firms that produce oil and natural gas from domestic fields throughout the United States. The OGSM encompasses domestic crude oil and natural gas supply by both conventional and unconventional recovery techniques. Natural gas is categorized by fuel type: high-permeability carbonate and sandstone (conventional), low-permeability carbonate and sandstone (tight gas), shale gas, and coalbed methane. Unconventional oil includes production of synthetic crude from oil shale (syncrude). Crude oil and natural gas projections are further disaggregated by geographic region. Liquefied natural gas (LNG) imports and pipeline natural gas import/export trade with Canada and Mexico are determined in the NGTDM.

**Figure 1-3. Submodules within the Oil and Gas Supply Module**



The model's methodology is shaped by the basic principle that the level of investment in a specific activity is determined largely by its expected profitability. Output prices influence oil and gas supplies in distinctly different ways in the OGSM. Quantities supplied as the result of the annual market equilibration in the PMM and the NGTDM are determined as a direct result of the observed market price in that period. Longer-term supply responses are related to investments required for subsequent production of oil and gas. Output prices affect the expected profitability of these investment opportunities as determined by use of a discounted cash flow evaluation of representative prospects. The OGSM incorporates a complete and representative

description of the processes by which oil and gas in the technically recoverable resource base<sup>3</sup> convert to proved reserves.<sup>4</sup>

The breadth of supply processes that are encompassed within OGSM result in different methodological approaches for determining crude oil and natural gas production from Lower 48 onshore, Lower 48 offshore, Alaska, and oil shale. The present OGSM consequently comprises four submodules. The Onshore Lower 48 Oil and Gas Supply Submodule (OLOGSS) models crude oil and natural gas supply from resources in the Lower 48 States. The Offshore Oil and Gas Supply Submodule (OOGSS) models oil and gas exploration and development in the offshore Gulf of Mexico, Pacific, and Atlantic regions. The Alaska Oil and Gas Supply Submodule (AOGSS) models industry supply activity in Alaska. Oil shale (synthetic) is modeled in the Oil Shale Supply Submodule (OSSS). The distinctions of each submodule are explained in individual chapters covering methodology. Following the methodology chapters, four appendices are included: Appendix A provides a description of the discounted cash flow (DCF) calculation; Appendix B is the bibliography; Appendix C contains a model abstract; and Appendix D is an inventory of key output variables.

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<sup>3</sup>*Technically recoverable resources* are those volumes considered to be producible with current recovery technology and efficiency but without reference to economic viability. Technically recoverable volumes include proved reserves and inferred reserves as well as undiscovered and other unproved resources. These resources may be recoverable by techniques considered either conventional or unconventional.

<sup>4</sup>*Proved reserves* are the estimated quantities that analyses of geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions.

## **2. Onshore Lower 48 Oil and Gas Supply Submodule**

### **Introduction**

U.S. onshore lower 48 crude oil and natural gas supply projections are determined by the Onshore Lower 48 Oil and Gas Supply Submodule (OLOGSS). The general methodology relies on a detailed economic analysis of potential projects in known crude oil and natural gas fields, enhanced oil recovery projects, developing natural gas plays, and undiscovered crude oil and natural gas resources. The projects that are economically viable are developed subject to the availability of resource development constraints which simulate the existing and expected infrastructure of the oil and gas industries. The economic production from the developed projects is aggregated to the regional and the national levels.

OLOGSS utilizes both exogenous input data and data from other modules within the National Energy Modeling System (NEMS). The primary exogenous data includes technical production for each project considered, cost and development constraint data, tax information, and project development data. Regional projections of natural wellhead prices and production are provided by the Natural Gas Transmission and Distribution Model (NGTDM). From the Petroleum Market Module (PMM) come projections of the crude oil wellhead prices at the OGSM regional level.

### **Model Purpose**

OLOGSS is a comprehensive model with which to analyze the crude oil and natural gas supply potential and related economic issues. Its primary purpose is to project production of crude oil and natural gas from the onshore lower 48 in response to price data received from the PMM and the NGTDM. As a supply submodule, OLOGSS does not project prices.

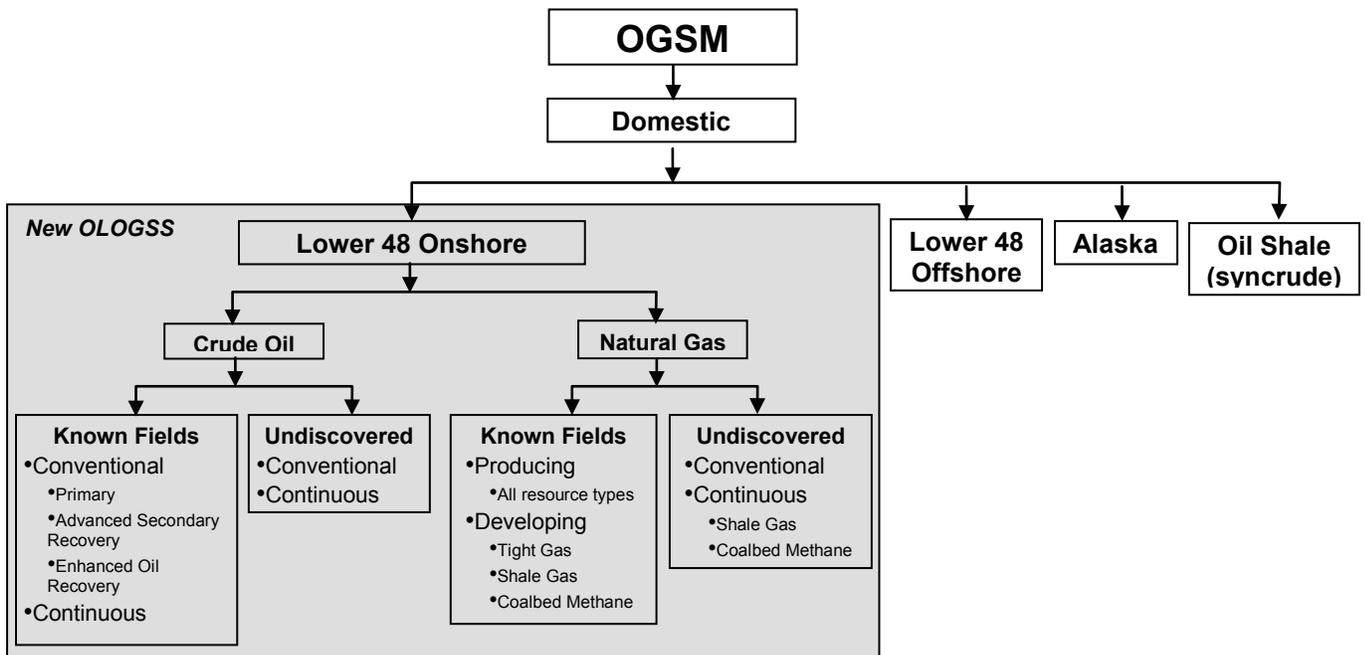
The basic interaction between OLOGSS and the OGSM is illustrated in figure 2-1. As seen in the figure, OLOGSS models the entirety of the domestic crude oil and natural gas production within the onshore lower 48.

### **Resources Modeled**

#### **Crude Oil Resources**

Crude oil resources, as illustrated in figure 2-1, are divided into known fields and undiscovered fields. For known resources, exogenous production type curves are used for quantifying the technical production profiles from known fields under primary, secondary, and tertiary recovery processes. Primary resources are also quantified for their advanced secondary recovery (ASR) processes that include the following: waterflooding, infill drilling, horizontal continuity, and horizontal profile modification. Known resources are evaluated for the potential they may possess when employing enhanced oil recovery (EOR) processes such as CO<sub>2</sub> flooding, steam flooding, polymer flooding and profile modification. Known crude oil resources include highly fractured continuous zones such as the Austin chalk formations and the Bakken shale formations.

**Figure 2-1: Subcomponents within OGSM**



Undiscovered crude oil resources are characterized in a method similar to that used for discovered resources and are evaluated for their potential production from primary and secondary techniques. The potential from an undiscovered resource is defined based on United States Geological Survey (USGS) estimates and is distinguished as either conventional or continuous. Conventional crude oil and natural gas resources are defined as discrete fields with well-defined hydrocarbon-water contacts, where the hydrocarbons are buoyant on a column of water. Conventional resources commonly have relatively high permeability and obvious seals and traps. In contrast, continuous resources commonly are regional in extent, have diffuse boundaries, and are not buoyant on a column of water. Continuous resources have very low permeability, do not have obvious seals and traps, are in close proximity to source rocks, and are abnormally pressured. Included in the category of continuous accumulations are hydrocarbons that occur in tight reservoirs, shale reservoirs, fractured reservoirs, and coal beds.

### Natural Gas Resources

Natural gas resources, as illustrated in figure 2-1, are divided into known producing fields, developing natural gas plays, and undiscovered fields. Exogenous production type curves have been used to estimate the technical production from known fields. The undiscovered resources have been characterized based on resource estimates developed by the USGS. Existing databases of developing plays, such as the Marcellus Shale, have been incorporated into the model's resource base. The natural gas resource estimates have been developed from detailed geological characterizations of producing plays.

## Processes Modeled

OLOGSS models primary, secondary and tertiary oil recovery processes. For natural gas, OLOGSS models discovered and undiscovered fields, as well as discovered and developing fields. Table 2-1 lists the processes modeled by OLOGSS.

**Table 2-1: Processes Modeled by OLOGSS**

<b>Crude Oil Processes</b>	<b>Natural Gas Processes</b>
Existing Fields and Reservoirs	Existing Radial Flow
Waterflooding in Undiscovered Resources	Existing Water Drive
CO <sub>2</sub> Flooding	Existing Tight Sands
Steam Flooding	Existing Dry Coal/Shale
Polymer Flooding	Existing Wet Coal/Shale
Infill Drilling	Undiscovered Conventional
Profile Modification	Undiscovered Tight Gas
Horizontal Continuity	Undiscovered Coalbed Methane
Horizontal Profile	Undiscovered Shale Gas
Undiscovered Conventional	Developing Shale Gas
Undiscovered Continuous	Developing Coalbed Methane
	Developing Tight Gas

## Major Enhancements

OLOGSS is a play-level model that projects the crude oil and natural gas supply from the onshore lower 48. The modeling procedure includes a comprehensive assessment method for determining the relative economics of various prospects based on future financial considerations, the nature of the undiscovered and discovered resources, prevailing risk factors, and the available technologies. The model evaluates the economics of future exploration and development from the perspective of an operator making an investment decision. Technological advances, including improved drilling and completion practices, as well as advanced production and processing operations are explicitly modeled to determine the direct impacts on supply, reserves, and various economic parameters. The model is able to evaluate the impact of research and development (R&D) on supply and reserves. Furthermore, the model design provides the flexibility to evaluate alternative or new taxes, environmental, or other policy changes in a consistent and comprehensive manner.

OLOGSS provides a variety of levers that allow the user to model developments affecting the profitability of development:

- Development of new technologies
- Rate of market penetration of new technologies
- Costs to implement new technologies
- Impact of new technologies on capital and operating costs
- Regulatory or legislative environmental mandates

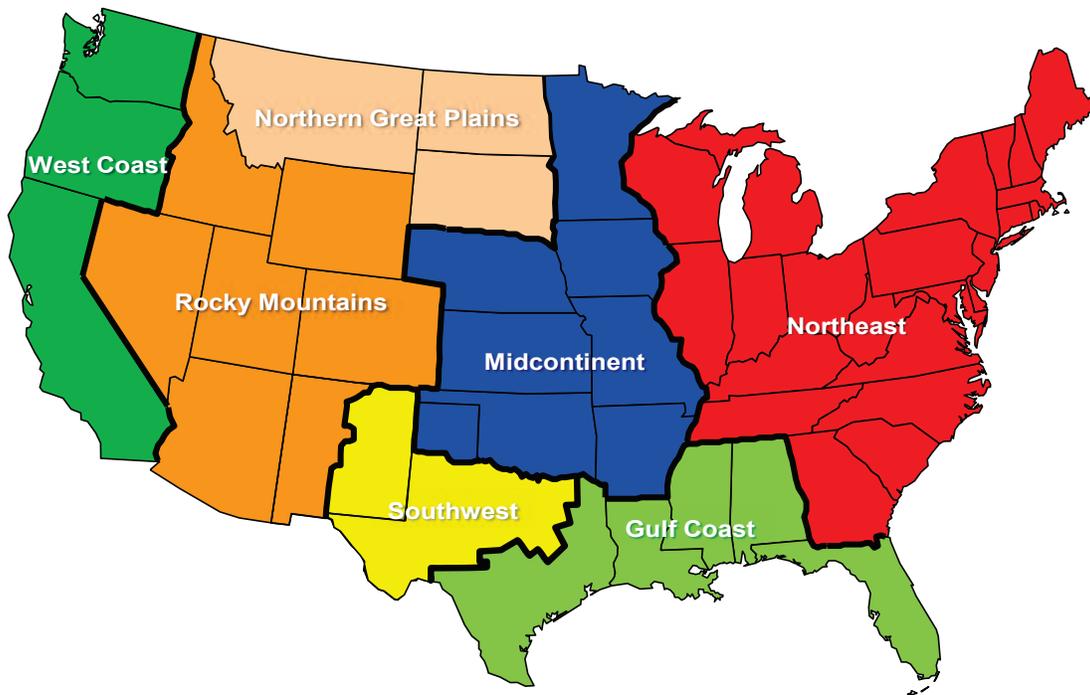
In addition, OLOGSS can quantify the effects of hypothetical developments that affect the resource base. OLOGSS is based on explicit estimates for technically recoverable crude oil and natural gas resources for each source of domestic production (i.e., geographic region/fuel type combinations).

OLOGSS is capable of addressing access issues concerning crude oil and natural gas resources located on federal lands. Undiscovered resources are divided into four categories:

- Officially inaccessible
- Inaccessible due to development constraints
- Accessible with federal lease stipulations
- Accessible under standard lease terms

OLOGSS uses the same geographical regions as the OGSM with one distinction. In order to capture the regional differences in costs and drilling activities in the Rocky Mountain region, the region has been divided into two sub-regions. These regions, along with the original six, are illustrated in figure 2-2. The Rocky Mountain region has been split to add the Northern Great Plains region. The results for these regions are aggregated before being passed to other OGSM or NEMS routines.

**Figure 2-2: Seven OLOGSS Regions for Onshore Lower 48**



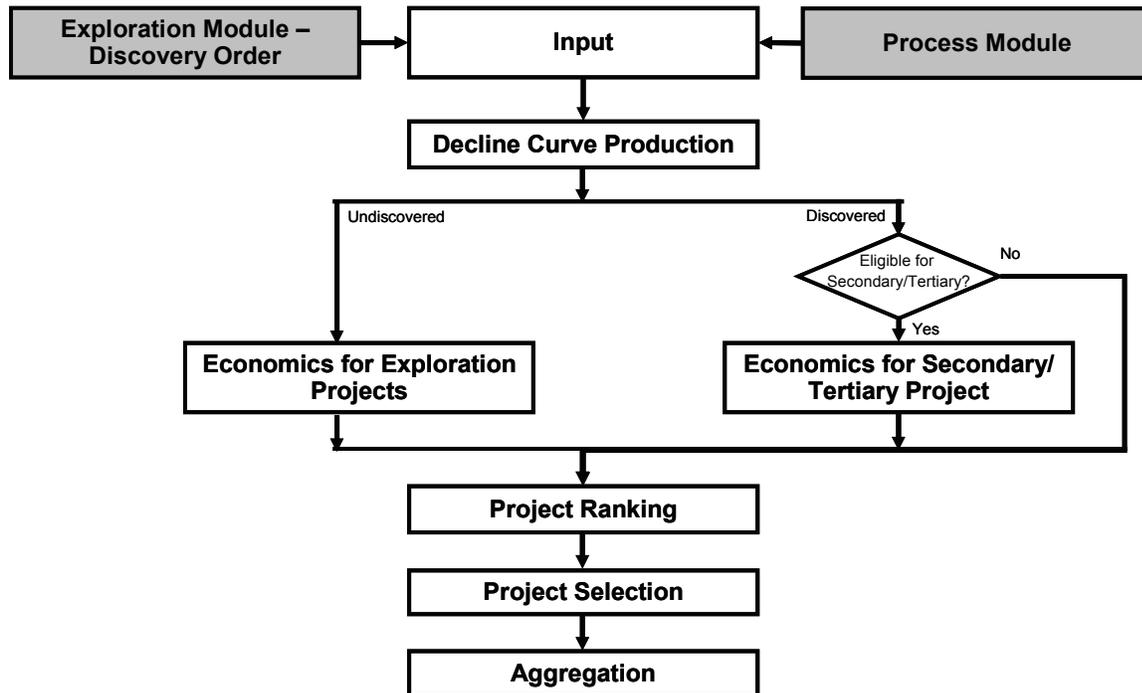
## Model Structure

The OLOGSS projects the annual crude oil and natural gas production from existing fields, reserves growth, and exploration. It performs economic evaluation of the projects and ranks the reserves growth and exploration projects for development in a way designed to mimic the way decisions are made by the oil and gas industry. Development decisions and project selection depend upon economic viability and the competition for capital, drilling, and other available development constraints. Finally, the model aggregates production and drilling statistics using geographical and resource categories.

### Overall System Logic

Figure 2-3 provides the overall system logic for the OLOGSS timing and economic module. This is the only component of OLOGSS which is integrated into NEMS.

Figure 2-3: OLOGSS Timing Module Overall System Logic



As seen in the figure, there are two primary sources of resource data. The exploration module provides the well-level technical production from the undiscovered projects which may be discovered in the next thirty years. It also determines the discovery order in which the projects will be evaluated by OLOGSS. The process module calculates the well-level technical production from known crude oil and natural gas fields, EOR and advanced secondary recovery (ASR) projects, and developing natural gas plays.

OLOGSS determines the potential domestic production in three phases. As seen in Figure 2-3, the first phase is the evaluation of the known crude oil and natural gas fields using a decline curve analysis. As part of the analysis, each project is subject to a detailed economic analysis used to determine the economic viability and expected life span of the project. In addition, the

model applies regional factors used for history matching and resource base coverage. The remaining resources are categorized as either exploration or EOR/ASR. Each year, the exploration projects are subject to economic analysis which determines their economic viability and profitability.

For the EOR/ASR projects, development eligibility is determined before the economic analysis is conducted. The eligibility is based upon the economic life span of the corresponding decline curve project and the process-specific eligibility window. If a project is not currently eligible, it will be re-evaluated in future years. The projects which are eligible are subject to the same type of economic analysis applied to existing and exploration projects in order to determine the viability and relative profitability of the project.

After the economics have been determined for each eligible project, the projects are sorted. The exploration projects maintain their discovery order. The EOR/ASR projects are sorted by their relative profitability. The finalized lists are then considered by the project selection routines.

A project will be selected for development only if it is economically viable and if there are sufficient development resources available to meet the project's requirements. Development resource constraints are used to simulate limits on the availability of infrastructure related to the oil and gas industries. If sufficient resources are not available for an economic project, the project will be reconsidered in future years if it remains economically viable. Other development options are considered in this step, including the waterflooding of undiscovered conventional resources and the extension of CO<sub>2</sub> floods through an increase in total pore volume injected.

The production, reserves, and other key parameters for the timed and developed projects are aggregated at the regional and national levels.

The remainder of this document provides additional details on the logic and particular calculations for each of these steps. These include the decline analysis, economic analysis, timing decisions, project selection, constraints, and modeling of technology.

## **Known Fields**

In this step, the production from existing crude oil and natural gas projects is estimated. A detailed economic analysis is conducted in order to calculate the economically viable production as well as the expected life of each project. The project life is used to determine when a project becomes eligible for EOR and ASR processes.

The logic for this process is provided in figure 2-4. For each crude oil project, regional prices are set and the project is screened to determine whether the user has specified any technology and/or economic levers. The screening considers factors including region, process, depth, and several other petro-physical properties. After applicable levers are determined, the project undergoes a detailed economic analysis.

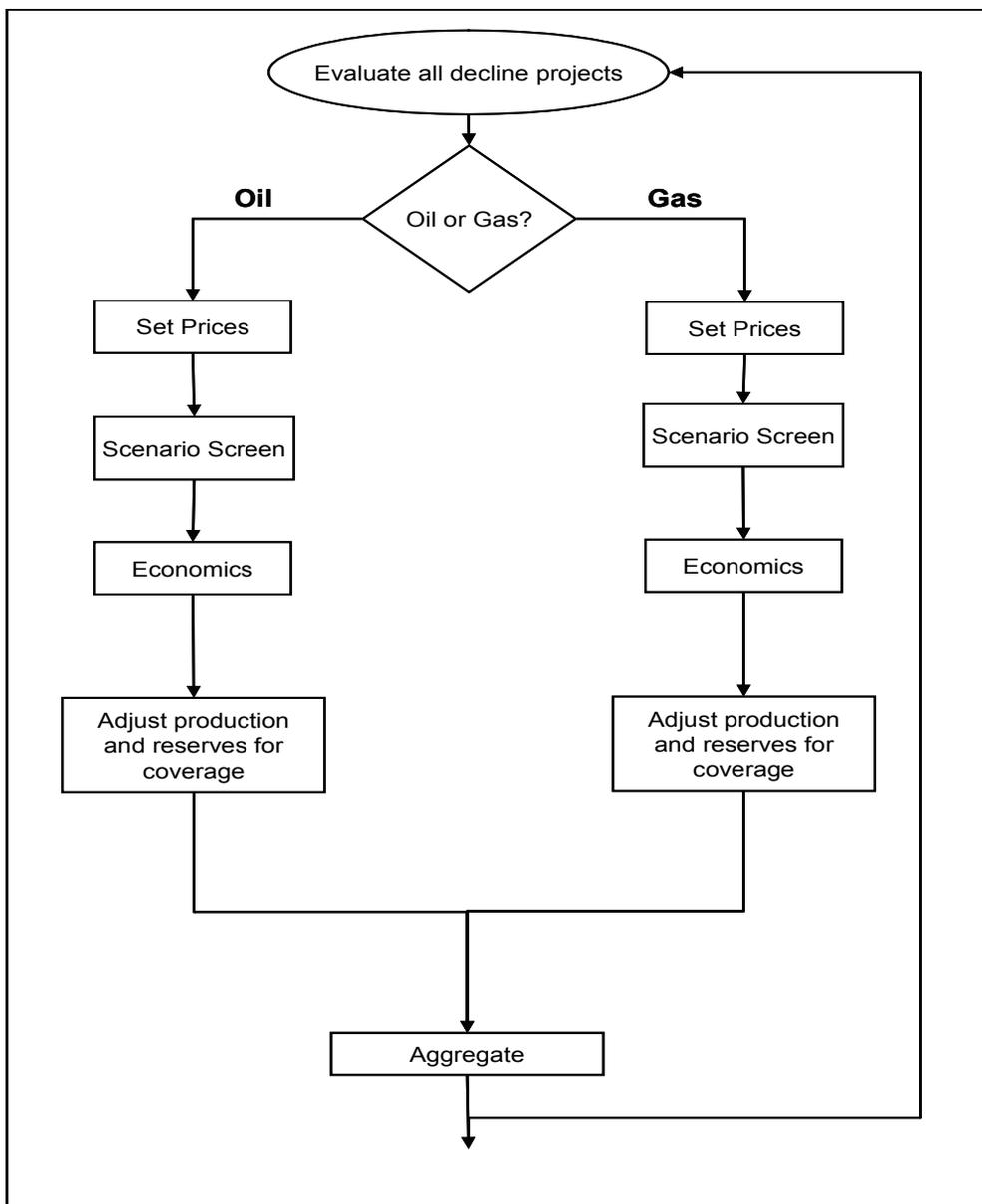
After the analysis, resource coverage factors are applied to the economic production and reserves, and the project results are aggregated at the regional and national levels. In a final step,

key parameters including the economic lifespan of the project are stored. A similar process is applied to the existing natural gas fields and reservoirs.

Resource coverage factors are applied in the model to ensure that historical production from existing fields matches that reported by EIA. These factors are calculated at the regional level and applied to production data for the following resources:

- Crude oil (includes lease condensates)
- High-permeability natural gas
- Coalbed methane
- Shale gas
- Tight gas

**Figure 2-4: Decline Process Flowchart**



## Economics

### Project Costs

OLOGSS conducts the economic analysis of each project using regional crude oil and natural gas prices. After these prices are set, the model evaluates the base and advanced technology cases for the project. The base case is defined as the current technology and cost scenario for the project; while the advanced case includes technology and/or cost improvements associated with the application of model levers. It is important to note that these cases – for which the assumption are applied to data for the project – are not the same as the *AEO* low, reference, or high technology cases.

For each technology case, the necessary petro-physical properties and other project data are set, the regional dryhole rates are determined, and the process specific depreciation schedule is assigned. The capital and operating costs for the project are then calculated and aggregated for both the base and advanced technology cases.

In the next step, a standard cashflow analysis is conducted, the discounted rate of return is calculated, and the ranking criteria are set for the project. Afterwards, the number and type of wells required for the project, and the last year of actual economic production are set. Finally, the economic variables, including production, development requirements, and other parameters, are stored for project timing and aggregation. All of these steps are illustrated in figure 2-5.

The details of the calculations used in conducting the economic analysis of a project are provided in the following description.

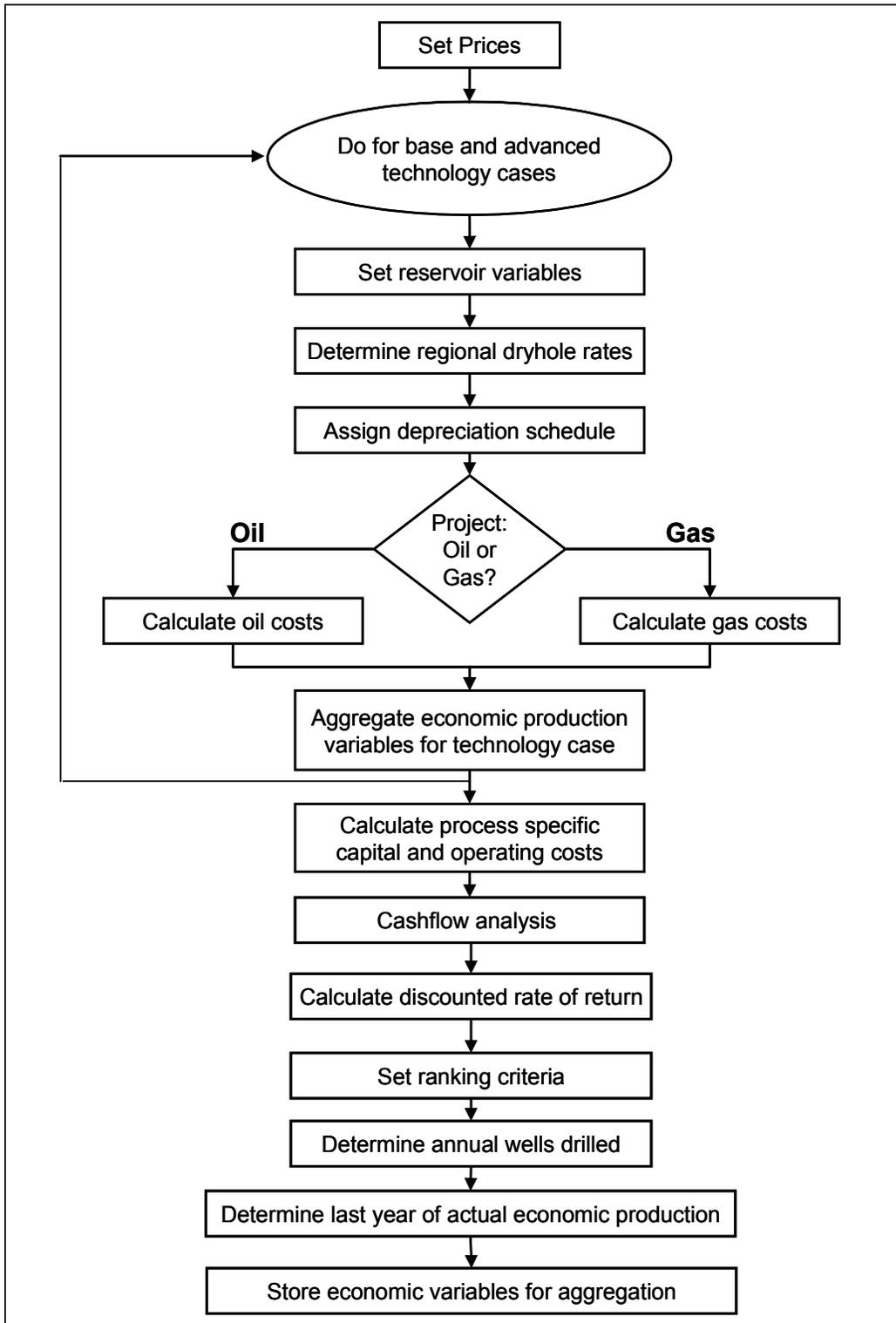
**Determine the project shift:** The first step is to determine the number of years the project development is shifted, i.e., the numbers of years between the discovery of a project and the start of its development. This will be used to determine the crude oil and natural gas price shift. The number of years is dependent upon both the development schedule – when the project drilling begins – and upon the process.

**Determine annual prices:** Determine the annual prices used in evaluating the project. Crude oil and natural gas prices in each year use the average price for the previous 5 years.

**Begin analysis of base and advanced technology:** To capture the impacts of technological improvements on both production and economics, the model divides the project into two categories. The first category – base technology – does not include improvements associated with technology or economic levers. The second category – advanced technology – incorporates the impact of the levers. The division of the project depends on the market penetration algorithm of any applicable technologies.

**Determine the dryhole rate for the project:** Assigns the regional dryhole rates for undiscovered exploration, undiscovered development, and discovered development. Three types of dryhole rates are used in the model: development in known fields and reservoirs, the first (wildcat) well in an exploration project, and subsequent wells in an exploration project. Specific dryhole rates are used for horizontal drilling and the developing natural gas resources.

Figure 2-5: Economic Analysis Logic



In the advanced case, the dryhole rates may also incorporate technology improvements associated with exploration or drilling success.

$$\text{REGDRYUE}_{im} = \left( \frac{\text{SUCEXP}_{im}}{100} \right) * (1.0 - \text{DRILL\_FAC}_{itech}) * \text{EXPLR\_FAC}_{itech} \quad (2-1)$$

$$\text{REGDRYUD}_{im} = \left( \frac{\text{SUCEXP}_{im}}{100} \right) * (1.0 - \text{DRILL\_FAC}_{itech}) \quad (2-2)$$

$$\text{REGDRYKD}_{im} = \left( \frac{\text{SUCDEVE}_{im}}{100} \right) * (1.0 - \text{DRILL\_FAC}_{itech}) \quad (2-3)$$

If evaluating horizontal continuity or horizontal profile, then,

$$\text{REGDRYKD}_{im} = \left( \frac{\text{SUCCHDEV}_{im}}{100} \right) * (1.0 - \text{DRILL\_FAC}_{itech}) \quad (2-4)$$

If evaluating developing natural gas resources, then,

$$\text{REGDRYUD}_{im} = \text{ALATNUM}_{ires} * (1.0 - \text{DRILL\_FAC}_{itech}) \quad (2-5)$$

where

ITECH	=	Technology case number
IM	=	Region number
REGDRYUE	=	Project specific dryhole rate for undiscovered exploration (Wildcat)
REGDRYUD	=	Project specific dryhole rate for undiscovered development
REGDRYKD	=	Project specific dryhole rate for known field development
SUCEXP	=	Regional dryhole rate for undiscovered development
ALATNUM	=	Variable representing the regional dryhole rate for known field development
SUCDEVE	=	Regional dryhole rate for undiscovered exploration (Wildcat)
SUCDEVEH	=	Dryhole rate for horizontal drilling
DRILL_FAC	=	Technology lever applied to dryhole rate
EXPLR_FAC	=	Technology factor applied to exploratory dryhole rate

**Process specific depreciation schedule:** The default depreciation schedule is based on an eight-year declining balance depreciation method. The user may select process-specific depreciation schedules for CO2 flooding, steam flooding, or water flooding in the input file.

**Calculate the capital and operating costs for the project:** The project costs are calculated for each technology case. The costs are specific to crude oil or natural gas resources. The results of

the cost calculations, which include technical crude oil and natural gas production, as well as drilling costs, facilities costs, and operating costs, are then aggregated to the project level.

**G & G factor:** Calculates the geological and geophysical (G&G) factor for each technology case. This is added to the first year cost.

$$GG_{itech} = GG_{itech} + DRL\_CST_{itech} * INTANG\_M_{itech} * GG\_FAC \quad (2-6)$$

where

$GG_{itech}$	=	Geophysical and Geological costs for the first year of the project
$DRL\_CST_{itech}$	=	Total drilling cost for the first year of the project
$INTANG\_M_{itech}$	=	Energy Elasticity factor for intangible investments (first year)
$GG\_FAC$	=	Portion of exploratory costs that is G&G costs

After the variables are aggregated, the technology case loop ends. At this point, the process specific capital costs, which apply to the entire project instead of the technology case, are calculated.

**Cashflow Analysis:** The model then conducts a cashflow analysis on the project and calculates the discounted rate of return. Economic Analysis is conducted using a standard cashflow routine described in Appendix A.

**Calculate the discounted rate of return:** Determines the projected rate of return for all investments and production. The cumulative investments and discounted after tax cashflow are used to calculate the investment efficiency for the project.

**Calculate wells:** The annual number of new and existing wells is calculated for the project. The model tracks five drilling categories:

- New production wells drilled
- New injection wells drilled
- Active production wells
- Active injection wells
- Shut in wells

The calculation of the annual well count depends on the number of existing production and injection wells as well as on the process and project-specific requirements to complete each drilling pattern developed.

**Determine number of years a project is economic:** The model calculates the last year of actual economic production. This is based on both the results of the cashflow analysis and the annual production in year specified by the analysis. The last year of production is used to determine the aggregation range to be used if the project is selected for development.

If the project is economic only in the first year, it will be considered uneconomic and unavailable for development at that time. If this occurs for an existing crude oil or natural gas project, the model will assume that all of the wells will be shut in.

**Non-producing decline project:** Determines if the existing crude oil or natural gas project is non-producing. If there is no production, then the end point for project aggregation is not calculated. This check applies only to the existing crude oil and natural gas projects

**Ranking criteria:** Ranks investment efficiency based on the discounted after tax cashflow over tangible and intangible investments.

**Determine ranking criterion:** The ranking criterion, specified by the user, is the parameter by which the projects will be sorted before development. Ranking criteria options include the project net present value, the rate of return for the project, and the investment efficiency.

### Calculating Unit Costs

To conduct the cost analysis, the model calculates price adjustment factors as well as unit costs for all required capital and operating costs. Unit costs include the cost of drilling and completing a single well, producing one barrel of crude oil, or operating one well for a year. These costs are adjusted using the technology levers and CPI indices. After the development schedule for the project is determined and the economic life of a single well is calculated, the technical production and injection are determined for the project. Based on the project's development schedule and the technical production, the annual capital and operating costs are determined. In the final step, the process and resource specific capital and operating costs are calculated for the project. These steps are illustrated in figure 2-6.

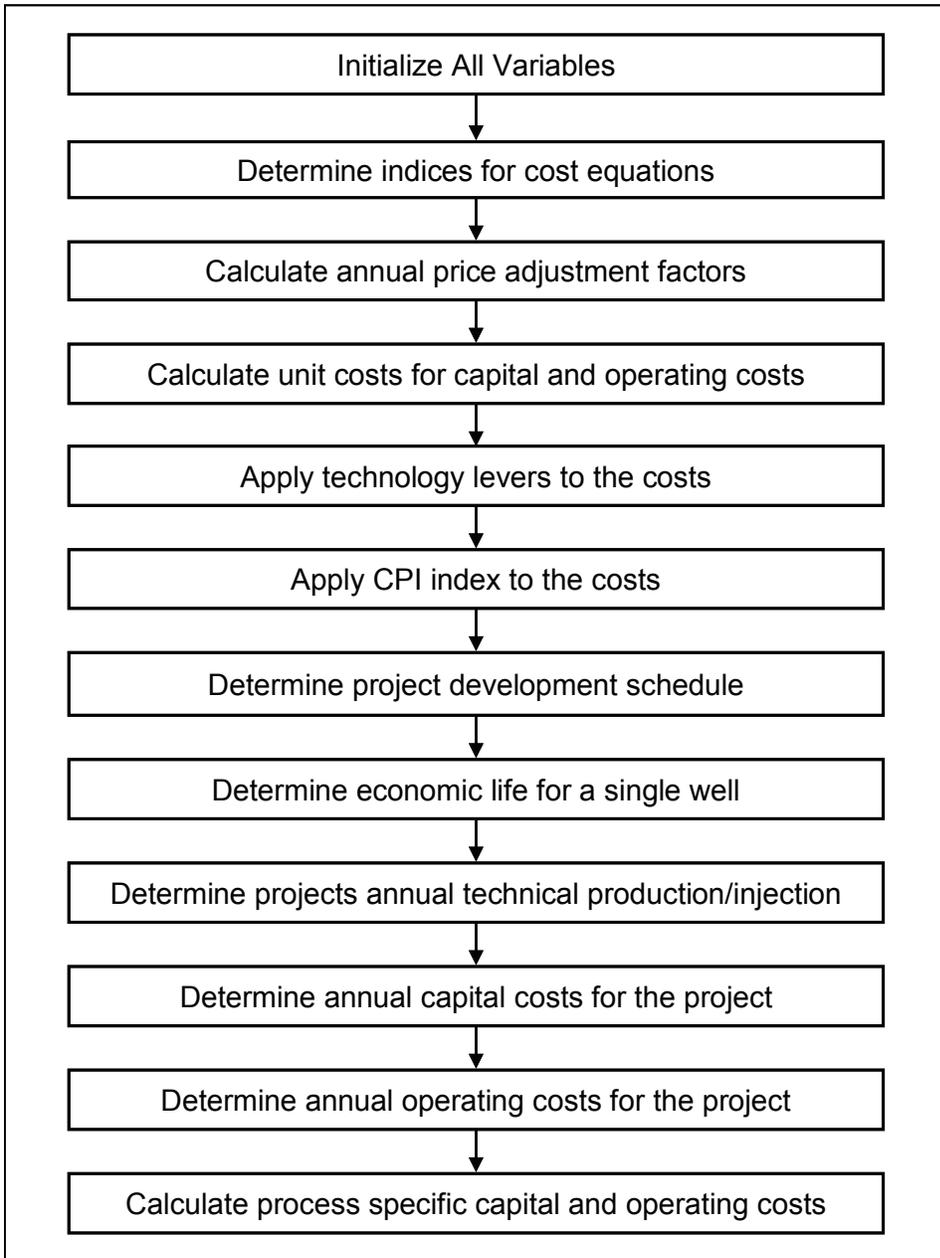
The Onshore Lower 48 Oil and Gas Supply Submodule uses detailed project costs for economic calculations. There are three broad categories of costs used by the model: capital costs, operating costs, and other costs. These costs are illustrated in figure 2-7. Capital costs encompass the costs of drilling and equipment necessary for the production of crude oil and natural gas resources. Operating costs are used to calculate the full life cycle economics of the project. Operating costs consist of normal daily expenses and surface maintenance. Other cost parameters include royalty, state and federal taxes, and other required schedules and factors.

The calculations for capital costs and operating costs for both crude oil and natural gas are described in detail below. The capital and operating costs are used in the timing and economic module to calculate the lifecycle economics for all crude oil and natural gas projects.

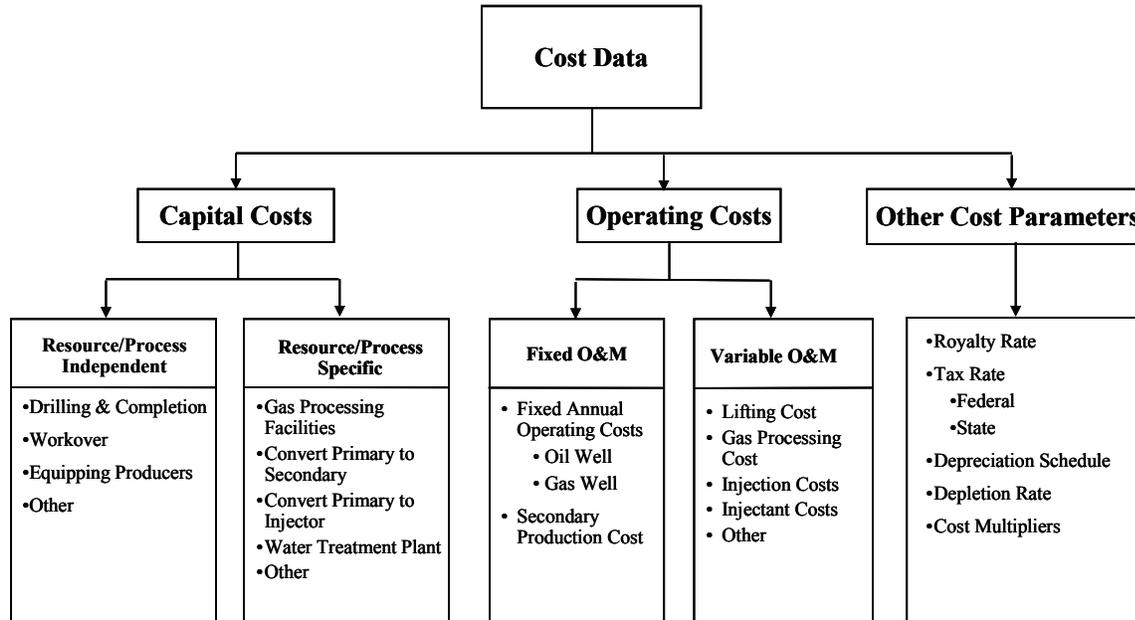
There are two categories for these costs: costs that are applied to all processes, thus defined as *resource independent*, and the process-specific costs, or *resource dependent* costs. Resource dependent costs are used to calculate the economics for existing, reserves growth, and exploration projects. The capital costs for both crude oil and natural gas are calculated first, followed by the resource independent costs, and then the resource dependent costs.

The resource independent and resource dependent costs applied to each of the crude oil and natural gas processes are detailed in tables 2-2 and 2-3 respectively.

**Figure 2-6: Project Cost Calculation Procedure**



**Figure 2-7: Cost Data Types and Requirements**



**Table 2-2: Costs Applied to Crude Oil Processes**

	Capital Cost for Oil	Existing	Water Flooding	CO2 Flooding	Steam Flooding	Polymer Flooding	Infill Drilling	Profile Modification	Undiscovered
Resource Independent	Vertical Drilling Cost	v	v	v	v	V	v	v	v
	Horizontal Drilling Cost								
	Drilling Cost for Dryhole	v	v	v	v	V	v	v	v
	Cost to Equip a Primary Producer		v	v	v	V	v	v	v
	Workover Cost		v	v	v	V	v	v	v
	Facillities Upgrade Cost		v	v	v	V	v	v	
	Fixed Annual Cost for Oil Wells	v	v	v	v	V	v	v	v
	Fixed Annual Cost for Secondary Production		v	v	v	V	v	v	v
	Lifting Cost		v	v	v	V	v	v	v
	O & M Cost for Active Patterns		v			V		v	
	Variable O & M Costs	v	v	v	v	V	v	v	v
	Socondary Workover Cost		v	v	v	V	v	v	v
	Resource Dependent	Cost of Water Handling Plant		v			V		v
Cost of Chemical Plant						V			
CO2 Recycle Plant				v					
Cost of Injectant						V			
Cost to Convert a Primary to Secondary Well			v	v	v	V	v	v	v
Cost to Convert a Producer to an Injector			v	v	v	V	v	v	v
Fixed O & M Cost for Secondary Operations			v	v	v	V	v	v	v
Cost of a Water Injection Plant			v						
O & M Cost for Active Patterns per Year			v			V		v	
Cost to Inject CO2				v					
King Factor						v			
Steam Manifolds Cost						v			
Steam Generators Cost						v			
Cost to Inject Poloymer						V	v		

**Table 2-3: Costs Applied to Natural Gas Processes**

	Capital Costs for Gas	Conventional Radial Gas	Water Drive	Tight Sands	Coal/Shale Gas	Undiscovered Conventional
Resource Independent	Vertical Drilling Cost	v	v	v	v	v
	Horizontal Drilling Cost	v	v	v	v	v
	Drilling Cost for Dryhole	v	v	v	v	v
	Gas Facilities Cost	v	v	v	v	v
	Fixed Annual Costs for Gas Wells	v	v	v	v	v
	Gas Stimulation Costs	v	v	v	v	v
	Overhead Costs	v	v	v	v	v
	Variable O & M Cost	v	v	v	v	v
Resource Dependent	Gas Processing and Treatment Facilities	v	v	v	v	v

The following section details the calculations used to calculate the capital and operating costs for each crude oil and natural gas project. The specific coefficients are econometrically estimated according to the corresponding equations in Appendix 2.B.

### Cost Multipliers

Cost multipliers are used to capture the impact on capital and operating costs associated with changes in energy prices. OLOGSS calculates cost multipliers for tangible and intangible investments, operating costs, and injectants (polymer and CO<sub>2</sub>). The methodology used to calculate the multipliers is based on the National Energy Technology Laboratory (NETL's) Comprehensive Oil and Gas Analysis Model as well as the 1984 Enhanced Oil Recovery Study completed by the National Petroleum Council.

The multipliers for operating costs and injectant are applied while calculating project costs. The investment multipliers are applied during the cashflow analysis. The injectant multipliers are held constant for the analysis period while the others vary with changing crude oil and natural gas prices.

**Operating Costs for Crude Oil:** Operating costs are adjusted by the change between current crude oil prices and the base crude oil price. If the crude oil price in a given year falls below a pre-established minimum price, the adjustment factor is calculated using the minimum crude oil price.

$$\text{TERM} = \left( \frac{\text{OILPRICE}_{\text{yr}} - \text{BASEOIL}}{\text{BASEOIL}} \right) \quad (2-7)$$

$$\text{INTANG\_M}_{\text{yr}} = 1.0 + (\text{OMULT\_INT} * \text{TERM}) \quad (2-8)$$

$$\text{TANG\_M}_{\text{yr}} = 1.0 + (\text{OMULT\_TANG} * \text{TERM}) \quad (2-9)$$

$$\text{OAM\_M}_{\text{yr}} = 1.0 + (\text{OMULT\_OAM} * \text{TERM}) \quad (2-10)$$

where

IYR	=	Year
TERM	=	Fractional change in crude oil prices (from base price)
BASEOIL	=	Base crude oil price used for normalization of capital and operating costs
OMULT_INT	=	Coefficient for intangible crude oil investment factor
OMULT_TANG	=	Coefficient for tangible crude oil investment factor
OMULT_OAM	=	Coefficient for O & M factor
INTANG_M	=	Annual energy elasticity factor for intangible investments
TANG_M	=	Annual energy elasticity factor for tangible investments
OAM_M	=	Annual energy elasticity factor for crude oil O & M

### Cost Multipliers for Natural Gas:

$$TERM = \left( \frac{GASPRICEC_{iyr} - BASEGAS}{BASEGAS} \right) \quad (2-11)$$

$$TANG\_M_{iyr} = 1.0 + (GMULT\_TANG * TERM) \quad (2-12)$$

$$INTANG\_M_{iyr} = 1.0 + (GMULT\_INT * TERM) \quad (2-13)$$

$$OAM\_M_{iyr} = 1.0 + (GMULT\_OAM * TERM) \quad (2-14)$$

where

GASPRICEC	=	Annual natural gas price
IYR	=	Year
TERM	=	Fractional change in natural gas prices
BASEGAS	=	Base natural gas price used for normalization of capital and operating costs
GMULT_INT	=	Coefficient for intangible natural gas investment factor
GMULT_TANG	=	Coefficient for tangible natural gas investment factor
GMULT_OAM	=	Coefficient for O & M factor
INTANG_M	=	Annual energy elasticity factor for intangible investments
TANG_M	=	Annual energy elasticity factor for tangible investments
OAM_M	=	Annual energy elasticity factor for crude oil O & M

### Cost Multipliers for Injectant:

In the first year of the project:

$$FPLY = 1.0 + (0.3913 * TERM) \quad (2-15)$$

$$FCO2 = \frac{0.5 + 0.013 * BASEOIL * (1.0 + TERM)}{0.5 + 0.013 * BASEOIL} \quad (2-16)$$

where

TERM	=	Fractional change in crude oil prices
BASEOIL	=	Base crude oil price used for normalization of capital and operating costs
FPLY	=	Energy elasticity factor for polymer

FCO2 = Energy elasticity factor for natural CO<sub>2</sub> prices

### Resource Independent Capital Costs for Crude Oil

Resource independent capital costs are applied to both crude oil and natural gas projects, regardless of the recovery method applied. The major resource independent capital costs are as follows: drilling and completion costs, the cost to equip a new or primary producer, and workover costs.

**Drilling and Completion Costs:** Drilling and completion costs incorporate the costs to drill and complete a crude oil or natural gas well (including tubing costs), and logging costs. These costs do not include the cost of drilling a dryhole/wildcat during exploration. OLOGSS uses a separate cost estimator, documented below, for dryholes drilled. Vertical well drilling costs include drilling and completion of vertical, tubing, and logging costs. Horizontal well costs include costs for drilling and completing a vertical well and the horizontal laterals.

#### Horizontal Drilling for Crude Oil:

$$DWC\_W = OIL\_DWCK_{r,d} + (OIL\_DWCA_{r,d} * DEPTH^2) + (OIL\_DWCB_{r,d} * DEPTH^2 * NLAT) + (OIL\_DWCC_{r,d} * DEPTH^2 * NLAT * LATLEN) \quad (2-17)$$

#### Vertical Drilling for Crude Oil:

$$DWC\_W = OIL\_DWCK_{r,d} + (OIL\_DWCA_{r,d} * DEPTH) + (OIL\_DWCB_{r,d} * DEPTH^2) + (OIL\_DWCC_{r,d} * DEPTH^3) \quad (2-18)$$

where

DWC_W	=	Cost to drill and complete a crude oil well (K\$/Well)
r	=	Region number
d	=	Depth category number
OIL_DWCA, B, C, K	=	Coefficients for crude oil well drilling cost equation
DEPTH	=	Well depth
NLAT	=	Number of laterals
LATLEN	=	Length of lateral

#### Horizontal Drilling for a Dry Well:

$$DRY\_W = DRY\_DWCK_{r,d} + (DRY\_DWCA_{r,d} * DEPTH^2) + (DRY\_DWCB_{r,d} * DEPTH^2 * NLAT) + (DRY\_DWCC_{r,d} * DEPTH^2 * NLAT * LATLEN) \quad (2-19)$$

#### Vertical Drilling for a Dry Well:

$$DRY\_W = DRY\_DWCK_{r,d} + (DRY\_DWCA_{r,d} * DEPTH) + (DRY\_DWCB_{r,d} * DEPTH^2) + (DRY\_DWCC_{r,d} * DEPTH^3) \quad (2-20)$$

where

DRY_W	=	Cost to drill a dry well (K\$/Well)
R	=	Region number
D	=	Depth category number
DRY_DWCA, B, C, K	=	Coefficients for dry well drilling cost equation
DEPTH	=	Well depth
NLAT	=	Number of laterals
LATLEN	=	Length of lateral

**Cost to Equip a New Producer:** The cost of equipping a primary producing well includes the production equipment costs for primary recovery.

$$\text{NPR}_W = \text{NPRK}_{r,d} + (\text{NPR A}_{r,d} * \text{DEPTH}) + (\text{NPR B}_{r,d} * \text{DEPTH}^2) + (\text{NPR C}_{r,d} * \text{DEPTH}^3) \quad (2-21)$$

where

NPR_W	=	Cost to equip a new producer (K\$/Well)
R	=	Region number
D	=	Depth category number
NPRA, B, C, K	=	Coefficients for new producer equipment cost equation
DEPTH	=	Well depth

**Workover Costs:** Workover, also known as stimulation is done every 2-3 years to increase the productivity of a producing well. In some cases workover or stimulation of a wellbore is required to maintain production rates.

$$\text{WRK}_W = \text{WRKK}_{r,d} + (\text{WRKA}_{r,d} * \text{DEPTH}) + (\text{WRKB}_{r,d} * \text{DEPTH}^2) + (\text{WRKC}_{r,d} * \text{DEPTH}^3) \quad (2-22)$$

Where,

WRK_W	=	Cost for a well workover (K\$/Well)
R	=	Region number
D	=	Depth category number
WRKA, B, C, K	=	Coefficients for workover cost equation
DEPTH	=	Well depth

**Facilities Upgrade Cost:** Additional cost of equipment upgrades incurred when converting a primary producing well to a secondary resource recovery producing well. Facilities upgrade costs consist of plant costs and electricity costs.

$$\text{FAC}_W = \text{FACUPK}_{r,d} + (\text{FACUPA}_{r,d} * \text{DEPTH}) + (\text{FACUPB}_{r,d} * \text{DEPTH}^2) + (\text{FACUPC}_{r,d} * \text{DEPTH}^3) \quad (2-23)$$

where

FAC_W	=	Well facilities upgrade cost (K\$/Well)
R	=	Region number
D	=	Depth category number
FACUPA, B, C, K	=	Coefficients for well facilities upgrade cost equation

DEPTH = Well depth

### Resource Independent Capital Costs for Natural Gas

**Drilling and Completion Costs:** Drilling and completion costs incorporate the costs to drill and complete a crude oil or natural gas well (including tubing costs), and logging costs. These costs do not include the cost of drilling a dryhole/wildcat during exploration. OLOGSS uses a separate cost estimator, documented below, for dryholes drilled. Vertical well drilling costs include drilling and completion of vertical, tubing, and logging costs. Horizontal well costs include costs for drilling and completing a vertical well and the horizontal laterals.

#### Vertical Drilling Costs:

$$DWC\_W = GAS\_DWCK_{r,d} + (GAS\_DWCA_{r,d} * DEPTH) + (GAS\_DWCB_{r,d} * DEPTH^2) + (GAS\_DWCC_{r,d} * DEPTH^3) \quad (2-24)$$

#### Horizontal Drilling Costs:

$$DWC\_W = GAS\_DWCK_{r,d} + (GAS\_DWCA_{r,d} * DEPTH^2) + (GAS\_DWCB_{r,d} * DEPTH^2 * NLAT) + (GAS\_DWCC_{r,d} * DEPTH^2 * NLAT * LATLEN) \quad (2-25)$$

Where,

DWC\_W = Cost to drill and complete a natural gas well (K\$/Well)  
 R = Region number  
 D = Depth category number  
 GAS\_DWCA, B, C, K = Coefficients for natural gas well drilling cost equation  
 DEPTH = Well depth  
 NLAT = Number of laterals  
 LATLEN = Length of lateral

#### Vertical Drilling Costs for a Dry Well:

$$DRY\_W = DRY\_DWCK_{r,d} + (DRY\_DWCA_{r,d} * DEPTH) + (DRY\_DWCB_{r,d} * DEPTH^2) + (DRY\_DWCC_{r,d} * DEPTH^3) \quad (2-26)$$

#### Horizontal Drilling Costs for a Dry Well:

$$DRY\_W = DRY\_DWCK_{r,d} + (DRY\_DWCA_{r,d} * DEPTH^2) + (DRY\_DWCB_{r,d} * DEPTH^2 * NLAT) + (DRY\_DWCC_{r,d} * DEPTH^2 * NLAT * LATLEN) \quad (2-27)$$

where

DRY\_W = Cost to drill a dry well (K\$/Well)  
 R = Region number  
 D = Depth category number  
 DRY\_DWCA, B, C, K = Coefficients for dry well drilling cost equation  
 DEPTH = Well depth  
 NLAT = Number of laterals  
 LATLEN = Length of lateral

**Facilities Cost:** Additional cost of equipment upgrades incurred when converting a primary producing well to a secondary resource recovery producing well. Facilities costs consist of flowlines and connections, production package costs, and storage tank costs.

$$\begin{aligned} \text{FWC\_W}_{\text{ivr}} = & \text{FACGK}_{r,d} + (\text{FACGA}_{r,d} * \text{DEPTH}) + (\text{FACGB}_{r,d} * \text{PEAKDAILY\_RATE}) \\ & + (\text{FACGC}_{r,d} * \text{DEPTH} * \text{PEAKDAILY\_RATE}) \end{aligned} \quad (2-28)$$

where

FWC_W	=	Facilities cost for a natural gas well (K\$/Well)
R	=	Region number
D	=	Depth category number
FACGA, B, C, K	=	Coefficients for facilities cost equation
DEPTH	=	Well depth
PEAKDAILY_RATE	=	Maximum daily natural gas production rate

**Fixed Annual Operating Costs:** The fixed annual operating costs are applied to natural gas projects in decline curve analysis.

$$\begin{aligned} \text{FOAMG\_W} = & \text{OMGK}_{r,d} + (\text{OMGA}_{r,d} * \text{DEPTH}) + (\text{OMGB}_{r,d} * \text{PEAKDAILY\_RATE}) \\ & + (\text{OMGC}_{r,d} * \text{DEPTH} * \text{PEAKDAILY\_RATE}) \end{aligned} \quad (2-29)$$

where

FOAMG_W	=	Fixed annual operating costs for natural gas (K\$/Well)
R	=	Region number
D	=	Depth category number
OMGA, B, C, K	=	Coefficients for fixed annual O & M cost equation for natural gas
DEPTH	=	Well depth
PEAKDAILY_RATE	=	Maximum daily natural gas production rate

### Resource Independent Annual Operating Costs for Crude Oil

**Fixed Operating Costs:** The fixed annual operating costs are applied to crude oil projects in decline curve analysis.

$$\begin{aligned} \text{OMO\_W} = & \text{OMOK}_{r,d} + (\text{OMOA}_{r,d} * \text{DEPTH}) + (\text{OMOB}_{r,d} * \text{DEPTH}^2) \\ & + (\text{OMOC}_{r,d} * \text{DEPTH}^3) \end{aligned} \quad (2-30)$$

where

OMO_W	=	Fixed annual operating costs for crude oil wells (K\$/Well)
R	=	Region number
D	=	Depth category number
OMOA, B, C, K	=	Coefficients for fixed annual operating cost equation for crude oil
DEPTH	=	Well depth

**Annual Costs for Secondary Producers:** The direct annual operating expenses include costs in the following major areas: normal daily expenses, surface maintenance, and subsurface maintenance.

$$\text{OPSEC\_W} = \text{OPSECK}_{r,d} + (\text{OPSECA}_{r,d} * \text{DEPTH}) + (\text{OPSECB}_{r,d} * \text{DEPTH}^2) + (\text{OPSECC}_{r,d} * \text{DEPTH}^3) \quad (2-31)$$

where

OPSEC_W	=	Fixed annual operating cost for secondary oil operations (K\$/Well)
R	=	Region number
D	=	Depth category number
OPSECA, B, C, K	=	Coefficients for fixed annual operating cost for secondary oil operations
DEPTH	=	Well depth

**Lifting Costs:** Incremental costs are added to a primary and secondary flowing well. These costs include pump operating costs, remedial services, workover rig services and associated labor.

$$\text{OML\_W} = \text{OMLK}_{r,d} + (\text{OMLA}_{r,d} * \text{DEPTH}) + (\text{OMLB}_{r,d} * \text{DEPTH}^2) + (\text{OMLC}_{r,d} * \text{DEPTH}^3) \quad (2-32)$$

where

OML_W	=	Variable annual operating cost for lifting (K\$/Well)
R	=	Region number
D	=	Depth category number
OMLA, B, C, K	=	Coefficients for variable annual operating cost for lifting equation
DEPTH	=	Well depth

**Secondary Workover:** Secondary workover, also known as stimulation is done every 2-3 years to increase the productivity of a secondary producing well. In some cases secondary workover or stimulation of a wellbore is required to maintain production rates.

$$\text{SWK\_W} = \text{OMSWRK}_{r,d} + (\text{OMSWR A}_{r,d} * \text{DEPTH}) + (\text{OMSWR B}_{r,d} * \text{DEPTH}^2) + (\text{OMSWR C}_{r,d} * \text{DEPTH}^3) \quad (2-33)$$

where

SWK_W	=	Secondary workover costs (K\$/Well)
R	=	Region number
D	=	Depth category number
OMSWRA, B, C, K	=	Coefficients for secondary workover costs equation
DEPTH	=	Well depth

**Stimulation Costs:** Workover, also known as stimulation is done every 2-3 years to increase the productivity of a producing well. In some cases workover or stimulation of a wellbore is required to maintain production rates.

$$STIM\_W = \left( \frac{STIM\_A + STIM\_B * DEPTH}{1000} \right) \quad (2-34)$$

where

STIM_W	=	Oil stimulation costs (K\$/Well)
STIM_A, B	=	Stimulation cost equation coefficients
DEPTH	=	Well depth

### Resource Dependent Capital Costs for Crude Oil

**Cost to Convert a Primary Well to a Secondary Well:** These costs consist of additional costs to equip a primary producing well for secondary recovery. The cost of replacing the old producing well equipment includes costs for drilling and equipping water supply wells but excludes tubing costs.

$$PSW\_W = PSWK_{r,d} + (PSWA_{r,d} * DEPTH) + (PSWB_{r,d} * DEPTH^2) + (PSWC_{r,d} * DEPTH^3) \quad (2-35)$$

where

PSW_W	=	Cost to convert a primary well into a secondary well (K\$/Well)
R	=	Region number
D	=	Depth category number
PSWA, B, C, K	=	Coefficients for primary to secondary well conversion cost equation
DEPTH	=	Well depth

**Cost to Convert a Producer to an Injector:** Producing wells may be converted to injection service because of pattern selection and favorable cost comparison against drilling a new well. The conversion procedure consists of removing surface and sub-surface equipment (including tubing), acidizing and cleaning out the wellbore, and installing new 2- 7/8 inch plastic-coated tubing and a waterflood packer (plastic-coated internally and externally).

$$PSI\_W = PSIK_{r,d} + (PSIA_{r,d} * DEPTH) + (PSIB_{r,d} * DEPTH^2) + (PSIC_{r,d} * DEPTH^3) \quad (2-36)$$

where

PSI_W	=	Cost to convert a producing well into an injecting well (K\$/Well)
R	=	Region number
D	=	Depth category number
PSIA, B, C, K	=	Coefficients for producing to injecting well conversion cost equation
DEPTH	=	Well depth

**Cost of Produced Water Handling Plant:** The capacity of the water treatment plant is a function of the maximum daily rate of water injected and produced (MBbl) throughout the life of the project.

$$PWP\_F = PWHP * \left( \frac{RMAXW}{365} \right) \quad (2-37)$$

where

PWP\_F = Cost of the produced water handling plant (K\$/Well)  
 PWHP = Produced water handling plant multiplier  
 RMAXW = Maximum pattern level annual water injection rate

**Cost of Chemical Handling Plant (Non-Polymer):** The capacity of the chemical handling plant is a function of the maximum daily rate of chemicals injected throughout the life of the project.

$$CHM\_F = CHMK * CHMA * \left( \frac{RMAXP}{365} \right)^{CHMB} \quad (2-38)$$

where

CHM\_F = Cost of chemical handling plant (K\$/Well)  
 CHMB = Coefficient for chemical handling plant cost equation  
 CHMK, A = Coefficients for chemical handling plant cost equation  
 RMAXP = Maximum pattern level annual polymer injection rate

**Cost of Polymer Handling Plant:** The capacity of the polymer handling plant is a function of the maximum daily rate of polymer injected throughout the life of the project.

$$PLY\_F = PLYPK * PLYPA * \left( \frac{RMAXP}{365} \right)^{0.6} \quad (2-39)$$

where

PLY\_F = Cost of polymer handling plant (K\$/Well)  
 PLYPK, A = Coefficients for polymer handling plant cost equation  
 RMAXP = Maximum pattern level annual polymer injection rate

**Cost of CO<sub>2</sub> Recycling Plant:** The capacity of a recycling/injection plant is a function of the maximum daily injection rate of CO<sub>2</sub> (Mcf) throughout the project life. If the maximum CO<sub>2</sub> rate equals or exceeds 60 MBbl/Day then the costs are divided into two separate plant costs.

$$CO2\_F = CO2rk * \left( \frac{0.75 * RMAXP}{365} \right)^{CO2RB} \quad (2-40)$$

where,

CO2\_F = Cost of CO<sub>2</sub> recycling plant (K\$/Well)  
 CO2RK, CO2RB = Coefficients for CO<sub>2</sub> recycling plant cost equation  
 RMAXP = Maximum pattern level annual CO<sub>2</sub> injection rate

**Cost of Steam Manifolds and Pipelines:** Cost to install and maintain steam manifolds and pipelines for steam flood enhanced oil recovery project.

$$\text{STMM\_F} = \text{TOTPAT} * \text{PATSIZE} * \text{STMMA} \quad (2-41)$$

where

STMM_F	=	Cost for steam manifolds and generation (K\$)
TOTPAT	=	Total number of patterns in the project
PATSIZE	=	Pattern size (Acres)
STMMA	=	Steam manifold and pipeline cost (per acre)

### Resource Dependant Annual Operating Costs for Crude Oil

**Injection Costs:** Incremental costs are added for secondary injection wells. These costs include pump operating, remedial services, workover rig services, and associated labor.

$$\text{OPINJ\_W} = \text{OPINJ}K_{r,d} + (\text{OPINJ}A_{r,d} * \text{DEPTH}) + (\text{OPINJ}B_{r,d} * \text{DEPTH}^2) + (\text{OPINJ}C_{r,d} * \text{DEPTH}^3) \quad (2-42)$$

where

OPINJ_W	=	Variable annual operating cost for injection (K\$/Well)
R	=	Region number
D	=	Depth category number
OPINJA, B, C, K	=	Coefficients for variable annual operating cost for injection equation
DEPTH	=	Well depth

**Injectant Cost:** The injectant costs are added for the secondary injection wells. These costs are specific to the recovery method selected for the project. Three injectants are modeled: polymer, CO<sub>2</sub> from natural sources, and CO<sub>2</sub> from industrial sources.

### Polymer Cost:

$$\text{POLYCOST} = \text{POLYCOST} * \text{FPLY} \quad (2-43)$$

where

POLYCOST	=	Cost of polymer (\$/Lb)
FPLY	=	Energy elasticity factor for polymer

**Natural CO<sub>2</sub> Cost:** Cost to drill, produce and ship CO<sub>2</sub> from natural sources, namely CO<sub>2</sub> fields in Western Texas.

$$\text{CO2COST} = \text{CO2K} + (\text{CO2B} * \text{OILPRICEO}(1)) \quad (2-44)$$

$$\text{CO2COST} = \text{CO2COST} * \text{CO2PR}(\text{IST}) \quad (2-45)$$

where

CO2COST	=	Cost of natural CO <sub>2</sub> (\$/Mcf)
IST	=	State identifier
CO2K, CO2B	=	Coefficients for natural CO <sub>2</sub> cost equation
OILPRICEO(1)	=	Crude oil price for first year of project analysis
CO2PR	=	State CO <sub>2</sub> cost multiplier used to represent changes in cost associated with transportation outside of the Permian Basin

**Industrial CO<sub>2</sub> Cost:** Cost to capture and transport CO<sub>2</sub> from industrial sources. These costs include the capture, compression to pipeline pressure, and the transportation to the project site via pipeline. The regional costs, which are specific to the industrial source of CO<sub>2</sub>, are exogenously determined and provided in the input file.

Industrial CO<sub>2</sub> sources include

- Hydrogen Plants
- Ammonia Plants
- Ethanol Plants
- Cement Plants
- Hydrogen Refineries
- Power Plants
- Natural Gas Processing Plants
- Coal to Liquids

After unit costs have been calculated for the project, they are adjusted using technology levers as well as CPI multipliers. Two types of levers are applied to the costs. The first is the fractional change in cost associated with a new technology. The second is the incremental cost associated with implementing the new technology. These factors are determined by the model user. As an example,

$$\text{NPR\_W} = (\text{NPR\_W} * \text{CHG\_FAC\_FAC}(\text{ITECH})) + \text{CST\_FAC\_FAC}(\text{ITECH}) \quad (2-46)$$

where,

NPR_W	=	Cost to equip a new oil producer (K\$/well)
CHG_FAC_FAC	=	Fractional change in cost associated with technology improvements
CST_FAC_FAC	=	Incremental cost to apply the new technology
ITECH	=	Technology case (Base or Advanced)

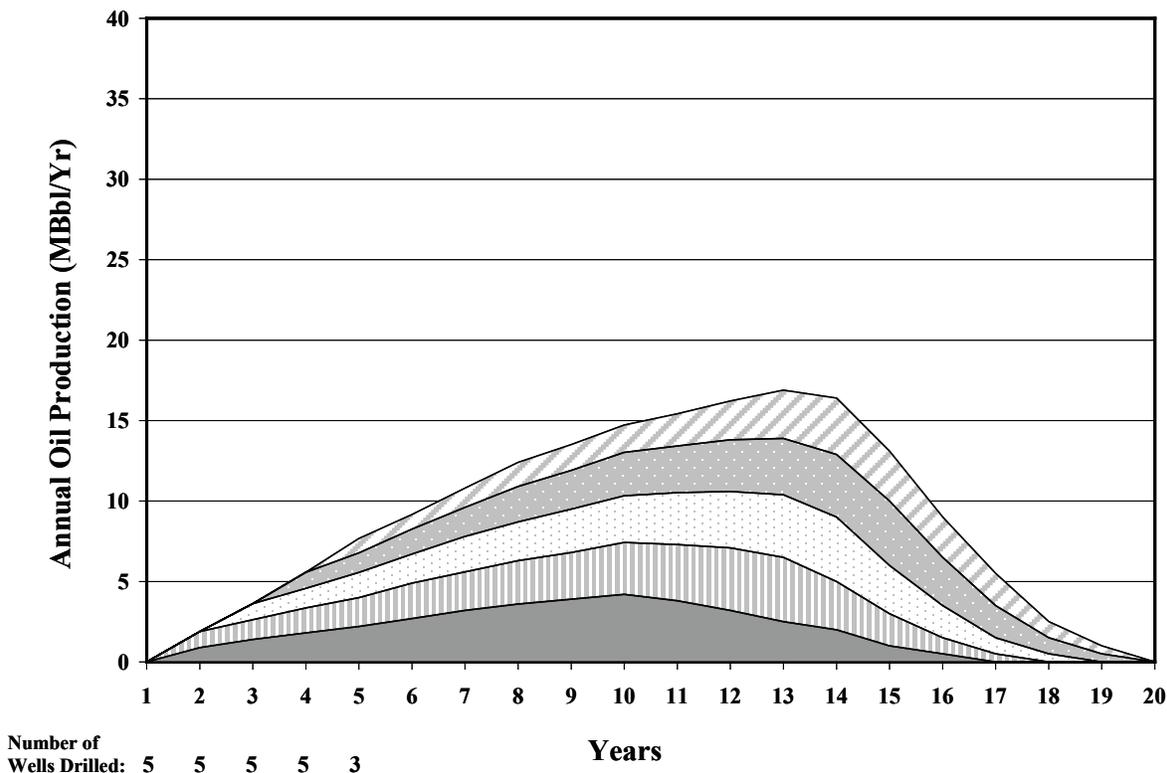
### Determining Technical Production

The development schedule algorithms determine how the project's development over time will be modeled. They calculate the number of patterns initiated per year and the economic life of the well. The economic life is the number of years in which the revenue from production exceeds the costs required to produce the crude oil and natural gas.

The model then aggregates the well-level production of crude oil, natural gas, water, and injectant based upon the pattern life and number of wells initiated each year. The resulting profile is the technical production for the project.

Figure 2-8 shows the crude oil production for one project over the course of its life. The graph shows a hypothetical project. In this scenario patterns are initiated for five years. Each shaded area is the annual technical production associated with the initiated patterns.

Figure 2-8: Calculating Project Level Technical Production



The first step in modeling the technical production is to calculate the number of patterns drilled each year. The model uses several factors in calculating the development schedule:

- Potential delays between the discovery of the project and actual initiation
- The process modeled
- The resource access – the number of patterns developed each year is reduced if the resource is subject to cumulative surface use limitations
- The total number of patterns in the project
- The crude oil and natural gas prices
- The user specified maximum and minimum number of patterns developed each year
- The user specified percentage of the project to be developed each year
- The percentage of the project which is using base or advanced technology.

These apply to the EOR/ASR projects as well as the undiscovered and currently developing ones. The projects in existing fields and reservoirs are assumed to have all of their patterns – the number of active wells – developed in the first year of the project.

After calculating the number of patterns initiated each year, the model calculates the number of patterns which are active for each year of the project life.

**Production Profile of the Project:** For all EOR/ASR, undiscovered, and developing processes, the project level technical production is calculated using well-level production profiles. For infill

projects, the production is doubled because the model assumes that there are two producers in each pattern.

$$\text{OILPROD}_{\text{iyrl}} = \text{OILPROD}_{\text{iyrl}} + (\text{OPROD}_{\text{kyr}} * \text{PATN}_{\text{iyrl}}) \quad (2-47)$$

$$\text{GASPROD}_{\text{iyrl}} = \text{OILPROD}_{\text{iyrl}} + (\text{GPROD}_{\text{kyr}} * \text{PATN}_{\text{iyrl}}) \quad (2-48)$$

$$\text{NGLPROD}_{\text{iyrl}} = \text{NGLPROD}_{\text{iyrl}} + (\text{NPROD}_{\text{kyr}} * \text{PATN}_{\text{iyrl}}) \quad (2-49)$$

$$\text{WATPROD}_{\text{iyrl}} = \text{WATPROD}_{\text{iyrl}} + (\text{WPROD}_{\text{kyr}} * \text{PATN}_{\text{iyrl}}) \quad (2-50)$$

$$\text{TOTINJ}_{\text{iyrl}} = \text{TOTINJ}_{\text{iyrl}} + (\text{OINJ}_{\text{kyr}} * \text{PATN}_{\text{iyrl}}) \quad (2-51)$$

$$\text{WATINJ}_{\text{iyrl}} = \text{WATINJ}_{\text{iyrl}} + (\text{WINJ}_{\text{kyr}} * \text{PATN}_{\text{iyrl}}) \quad (2-52)$$

$$\text{TORECY}_{\text{iyrl}} = \text{TORECY}_{\text{iyrl}} + (\text{ORECY}_{\text{kyr}} * \text{PATN}_{\text{iyrl}}) \quad (2-53)$$

$$\text{SUMP}_{\text{iyrl}} = \text{SUMP}_{\text{iyrl}} + \text{PATN}_{\text{iyrl}} \quad (2-54)$$

where

IYR1	=	Number of years
IYR	=	Year of project development
JYR	=	Number of years the project is developed
KYR	=	Year (well level profile)
LYR	=	Last project year in which pattern level profile is applied
OPROD	=	Pattern level annual crude oil production
GPROD	=	Pattern level annual natural gas production
NPROD	=	Pattern level annual NGLI production
WPROD	=	Pattern level annual water production
WINJ	=	Pattern level annual water injection
OINJ	=	Pattern level annual injectant injection
ORECY	=	Pattern level annual injectant recycled
PATN	=	Number of patterns initiated each year
SUMP	=	Cumulative number of patterns developed
OILPROD	=	Project level annual crude oil production
GASPROD	=	Project level annual natural gas production
NGLPROD	=	Project level annual NGL production
WATPROD	=	Project level annual water production
WATINJ	=	Project level annual water injection
TOTINJ	=	Project level annual injectant injection
TORECY	=	Project level annual injectant recycled

Reviewer's note: The equations above are confusing, because the same variable appears on the LHS and RHS. I'm guessing that the variable is simply being incremented on an annual basis, i.e., that the first equation should read something like

In any case, please clarify what is happening in the equations and use a new variable name on the LHS.

## Resource Accounting

OLOGSS incorporates a complete and representative description of the processes by which crude oil and natural gas in the technically recoverable resource base<sup>1</sup> are converted to proved reserves.<sup>2</sup>

OLOGSS distinguishes between drilling for new fields (new field wildcats) and drilling for additional deposits within old fields (other exploratory and developmental wells). This enhancement recognizes important differences in exploratory drilling, both by its nature and in its physical and economic returns. New field wildcats convert resources in previously undiscovered fields<sup>3</sup> into both proved reserves (as new discoveries) and inferred reserves.<sup>4</sup> Other exploratory drilling and developmental drilling add to proved reserves from the stock of inferred reserves. The phenomenon of reserves appreciation is the process by which initial assessments of proved reserves from a new field discovery grow over time through extensions and revisions.

**End of Year Reserves:** The model calculates two types of end of year (EOY) reserves at the project level: inferred reserves and proved reserves. Inferred reserves are calculated as the total technical production minus the technical production from patterns initiated through a particular year. Proved reserves are calculated as the technical production from wells initiated through a particular year minus the cumulative production from those patterns.

Inferred reserves = total technical production – technical production for wells initiated

$$\text{airsvoil(ires, n)} = \sum_{i=1}^{\text{max\_yr}} \left[ \sum_{j=1}^{\text{ilife}} (\text{oprod}(j)) \times \text{patn}(i) \right] - \sum_{i=1}^n \left[ \sum_{j=1}^{\text{ilife}} (\text{oprod}(j)) \times \text{patn}(i) \right] \quad (2-55)$$

$$\text{airsvgas(ires, n)} = \sum_{i=1}^{\text{max\_yr}} \left[ \sum_{j=1}^{\text{ilife}} (\text{gprod}(j)) \times \text{patn}(i) \right] - \sum_{i=1}^n \left[ \sum_{j=1}^{\text{ilife}} (\text{gprod}(j)) \times \text{patn}(i) \right] \quad (2-56)$$

Reviewers note: It's not clear what "ires" is above. Also, it looks like all of these equations can be simplified by writing the outer sums from n+1 to max\_yr, e.g.,

Proved reserves = technical production for patterns initiated – cumulative production

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<sup>1</sup>*Technically recoverable resources* are those volumes considered to be producible with current recovery technology and efficiency but without reference to economic viability. Technically recoverable volumes include proved reserves, inferred reserves, as well as undiscovered and other unproved resources. These resources may be recoverable by techniques considered either conventional or unconventional.

<sup>2</sup>*Proved reserves* are the estimated quantities that analyses of geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions.

<sup>3</sup>*Undiscovered resources* are located outside of oil and gas fields, in which the presence of resources has been confirmed by exploratory drilling, and thus exclude reserves and reserve extensions; however, they include resources from undiscovered pools within confirmed fields to the extent that such resources occur as unrelated accumulations controlled by distinctly separate structural features or stratigraphic conditions.

<sup>4</sup>*Inferred reserves* are that part of expected ultimate recovery from known fields in excess of cumulative production plus current reserves.

$$\text{aresvoil}(\text{ires}, n) = \sum_{i=1}^n \left[ \sum_{j=1}^{\text{ilife}} (\text{oprod}(j)) \times \text{patn}(i) \right] - \sum_{i=1}^n \left[ \sum_{j=1}^n (\text{oprod}(j)) \times \text{patn}(i) \right] \quad (2-57)$$

$$\text{aresvgas}(\text{ires}, n) = \sum_{i=1}^n \left[ \sum_{j=1}^{\text{ilife}} (\text{gprod}(j)) \times \text{patn}(i) \right] - \sum_{i=1}^n \left[ \sum_{j=1}^n (\text{gprod}(j)) \times \text{patn}(i) \right] \quad (2-58)$$

where,

I, J	=	Years
N	=	Current year evaluated
ILIFE	=	Pattern life
MAX_YR	=	Maximum number of years
OPROD	=	Pattern level annual crude oil production
GPROD	=	Pattern level annual natural gas production
PATN	=	Number of patterns developed each year
AIRSVOIL	=	Annual inferred crude oil reserves
AIRSVGAS	=	Annual inferred natural gas reserves
ARESVOIL	=	Annual proved oil reserves
ARESVGAS	=	Annual proved natural gas reserves

For existing crude oil and natural gas projects, the model calculates the proved reserves. For these processes, the proved reserves are defined as the total technical production divided by the life of the project.

### Calculating Project Costs

The model uses four drilling categories for the calculation of drilling and facilities costs. These categories are:

- New producers
- New injectors
- Conversions of producers to injectors
- Conversions of primary wells to secondary wells.

The number of ??? in each category required for the pattern is dependent upon the process and the project.

### Project Level Process Independent Costs

Drilling costs and facility costs are determined at the project level.

**Drilling Costs:** Drilling costs are calculated using one of four approaches, depending on the resource and recovery process. These approaches apply to the following resources:

- Undiscovered crude oil and natural gas
- Existing crude oil and natural gas fields
- EOR/ASR projects
- Developing natural gas projects

For undiscovered crude oil and natural gas resources: The first well drilled in the first year of the project is assumed to be a wildcat well. The remaining wells are assumed to be undiscovered development wells. This is reflected in the application of the dryhole rates.

$$\text{DRL\_CST2}_{\text{iyR}} = \text{DRL\_CST2}_{\text{iyR}} + (\text{DWC\_W} + \text{DRY\_W} * \text{REGDRYUE}_{\text{R}}) * 1.0 * \text{XPP1} \quad (2-59)$$

$$\text{DRL\_CST2}_{\text{iyR}} = \text{DRL\_CST2}_{\text{iyR}} + (\text{DWC\_W} + \text{DRY\_W} * \text{REGDRYUD}_{\text{R}}) * (\text{PATN}_{\text{iyR}} - 1 * \text{XPP1}) \quad (2-60)$$

For existing crude oil and natural gas fields: As the field is already established, the developmental dryhole rate is used.

$$\text{DRL\_CST2}_{\text{iyR}} = \text{DRL\_CST2}_{\text{iyR}} + (\text{DWC\_W} + \text{DRY\_W} * \text{REGDRYKD}_{\text{R}}) * (\text{PATDEV}_{\text{ires,iyR,itech}} * \text{XPP1}) \quad (2-61)$$

For EOR/ASR Projects: As the project is in an established and known field, the developmental dryhole rate is used.

$$\text{DRL\_CST2}_{\text{iyR}} = \text{DRL\_CST2}_{\text{iyR}} + (\text{DWC\_W} + \text{DRY\_W} * \text{REGDRYKD}_{\text{R}}) * (\text{PATN}_{\text{iyR}} * \text{XPP1}) \quad (2-62)$$

For developing natural gas projects: As the project is currently being developed, it is assumed that the wildcat well(s) have previously been drilled. Therefore, the undiscovered developmental dryhole rate is applied to the project.

$$\text{DRL\_CST2}_{\text{iyR}} = \text{DRL\_CST2}_{\text{iyR}} + (\text{DWC\_W} + \text{DRY\_W} * \text{REGDRYUD}_{\text{R}}) * (\text{PATN}_{\text{iyR}} * \text{XPP1}) \quad (2-63)$$

where

IRES	=	Project index number
IYR	=	Year
R	=	Region
PATDEV	=	Number of patterns initiated each year for base and advanced technology cases
PATN	=	Annual number of patterns initiated
DRL_CST2	=	Technology case specific annual drilling cost
DWC_W	=	Cost to drill and complete a well
DRY_W	=	Cost to drill a dryhole
REGDRYUE	=	Dryhole rate for undiscovered exploration (wildcat)
REGDRYUD	=	Dryhole rate for undiscovered development
REGDRYKD	=	Dryhole rate for known fields development
XPP1	=	Number of producing wells drilled per pattern

**Facilities Costs:** Facilities costs depend on both the process and the resource. Five approaches are used to calculate the facilities costs for the project.

For undiscovered and developing natural gas projects:

$$\text{FACCOST}_{\text{iyR}} = \text{FACCOST}_{\text{iyR}} + (\text{FWC\_W} * \text{PATN}_{\text{iyR}} * \text{XPP1}) \quad (2-64)$$

For existing natural gas fields:

$$FACCOST_{iyr} = FACCOST_{iyr} + (FWC\_W * (PATDEV_{IRES, iyr, itech}) * XPP1) \quad (2-65)$$

For undiscovered continuous crude oil:

$$FACCOST_{iyr} = FACCOST_{iyr} + (NPR\_W * PATN_{iyr} * XPP1) \quad (2-66)$$

For existing crude oil fields:

$$FACCOST_{iyr} = FACCOST_{iyr} + (PSW\_W * (PATDEV_{IRES, iyr, itech}) * XPP4) + (PSI\_W * PATDEV_{IRES, iyr, itech} * XPP3) + (FAC\_W * PATDEV_{IRES, iyr, itech} * (XPP1 + XPP2)) \quad (2-67)$$

For undiscovered conventional crude oil and EOR/ASR projects:

$$FACCOST_{iyr} = FACCOST_{iyr} + (PSW\_W * PATN_{iyr} * XPP4) + (PSI\_W * PATN_{iyr} * XPP3) + (FAC\_W * PATN_{iyr} * (XPP1 + XPP2)) \quad (2-68)$$

where

IYR	=	Year
IREs	=	Project index number
ITECH	=	Technology case
PATN	=	Number of patterns initiated each year for the technology case being evaluated
PATDEV	=	Number of patterns initiated each year for base and advanced technology cases
XPP1	=	Number of new production wells drilled per pattern
XPP2	=	Number of new injection wells drilled per pattern
XPP3	=	Number of producers converted to injectors per pattern
XPP4	=	Number of primary wells converted to secondary wells per pattern
FAC_W	=	Crude oil well facilities upgrade cost
NPR_W	=	Cost to equip a new producer
PSW_W	=	Cost to convert a primary well to a secondary well
PSI_W	=	Cost to convert a production well to an injection well
FWC_W	=	Natural gas well facilities cost
FACCOST	=	Annual facilities cost for the well

**Injectant Cost Added to Operating and Maintenance:** The cost of injectant is calculated and added to the operating and maintenance costs.

$$INJ_{iyr} = INJ_{iyr} + INJ\_OAM1 * WATINJ_{iyr} \quad (2-69)$$

where

IYR	=	Year
-----	---	------

INJ	=	Annual injection cost
INJ_OAM1	=	Process specific cost of injection (\$/Bbl)
WATINJ	=	Annual project level water injection

**Fixed Annual Operating Costs for Crude Oil:**

For CO<sub>2</sub> EOR:

$$AOAM_{iyr} = AOAM_{iyr} + OPSEC\_W * SUMP_{iyr} \quad (2-70)$$

For undiscovered conventional crude oil:

Fixed annual operating costs for secondary oil wells are assumed to be zero.

For all crude oil processes except CO<sub>2</sub> EOR:

$$AOAM_{iyr} = AOAM_{iyr} + (OMO\_W * XPATN_{iyr}) + (OPSEC\_W * XPATN_{iyr}) \quad (2-71)$$

**Fixed Annual Operating Costs for Natural Gas:**

For existing natural gas fields:

$$AOAM_{iyr} = AOAM_{iyr} + (FOAMG\_W * OAM\_M_{iyr} * XPATN_{iyr}) \quad (2-72)$$

For undiscovered and developing natural gas resources:

$$AOAM_{iyr} = AOAM_{iyr} + (FOAMG\_W * OAM\_M_{iyr} * XPATN_{iyr}) * XPP1 \quad (2-73)$$

where,

AOAM	=	Annual fixed operating an maintenance costs
IYR	=	Year
SUMP	=	Total cumulative patterns initiated
OPSEC_W	=	Fixed annual operating costs for secondary oil wells
OMO_W	=	Fixed annual operating costs for crude oil wells
FOAMG_W	=	Fixed annual operating costs for natural gas wells
OAM_M	=	Energy elasticity factor for operating and maintenance costs
XPATN	=	Annual number of active patterns
XPP1	=	Number of producing wells drilled per pattern

**Variable Operating Costs:**

$$OAM_{iyr} = OAM_{iyr} + (OILPROD_{iyr} * OIL\_OAM1 * OAM\_M_{iyr}) + (GASPROD_{iyr} * GAS\_OAM1 * OAM\_M_{iyr}) + (WATPROD_{iyr} * WAT\_OAM1 * OAM\_M_{iyr}) \quad (2-74)$$

$$STIM_{iyr} = STIM_{iyr} + (0.2 * STIM\_W * XPATN_{iyr} * XPP1) \quad (2-74)$$

For infill drilling: Injectant costs are zero.

$$OAM_{iyr} = OAM_{iyr} + INJ_{iyr} \quad (2-75)$$

where

OAM	=	Annual variable operating and maintenance costs
OILPROD	=	Annual project level crude oil production
GASPROD	=	Annual project level natural gas production
WATPROD	=	Annual project level water injection
OIL_OAM1	=	Process specific cost of crude oil production (\$/Bbl)
GAS_OAM1	=	Process specific cost of natural gas production (\$/Mcf)
WAT_OAM1	=	Process specific cost of water production (\$/Bbl)
OAM_M	=	Energy elasticity factor for operating and maintenance costs
STIM	=	Project stimulation costs
STIM_W	=	Well stimulation costs
INJ	=	Cost of injection
XPATN	=	Annual number of active patterns
IYR	=	Year
XPP1	=	Number of producing wells drilled per pattern

### **Cost of Compression (Natural Gas Processes):**

Installation costs:

$$COMP_{IYR} = COMP_{IYR} + (COMP\_W * PATN_{IYR} * XPP1) \quad (2-76)$$

O&M cost for compression:

$$OAM\_COMP_{IYR} = OAM\_COMP_{IYR} + (GASPROD_{IYR} * COMP\_OAM * OAM\_M_{IYR}) \quad (2-77)$$

where

COMP	=	Cost of installing natural gas compression equipment
COMP_W	=	Natural gas compression cost
PATN	=	Number of patterns initiated each year
IYR	=	Year
XPP1	=	Number of producing wells drilled per pattern
OAM_COMP	=	Operating and maintenance costs for natural gas compression
GASPROD	=	Annual project level natural gas production
COMP_OAM	=	Compressor O & M costs
OAM_M	=	Energy elasticity factor for operating and maintenance costs

## Process Dependent Costs

Process-specific facilities and capital costs are calculated at the project level.

### Facilities Costs

**Profile Model:** The facilities cost of a water handling plant is added to the first year facilities costs.

$$FACCCOST_1 = FACCCOST_1 + PWHP * \left( \frac{RMAX}{365} \right) \quad (2-78)$$

where

$$\begin{aligned} FACCCOST_1 &= \text{First year of project facilities costs} \\ PWHP &= \text{Produced water handling plant multiplier} \\ RMAX &= \text{Maximum annual water injection rate} \end{aligned}$$

**Polymer Model:** The facilities cost for a water handling plant is added to the first year facilities costs.

$$FACCCOST_1 = FACCCOST_1 + PWP\_F \quad (2-79)$$

where

$$\begin{aligned} FACCCOST_1 &= \text{First year of project facilities costs} \\ PWP\_F &= \text{Produced water handling plant} \end{aligned}$$

**Advanced CO<sub>2</sub>:** Other costs added to the facilities costs include the facilities cost for a CO<sub>2</sub> handling plant and a recycling plant, the O&M cost for a CO<sub>2</sub> handling plant and recycling plant, injectant cost, O&M and fixed O&M costs for a CO<sub>2</sub> handling plant and a recycling plant. If the plant is developed in a single stage, the costs are added to the first year of the facilities costs. If a second stage is required, the additional costs are added to the sixth year of facilities costs.

$$FACCCOST1 = FACCCOST1 + \left( CO2RK * \left( \frac{0.75 * RMAX}{365} \right)^{CO2RB} \right) * 1,000 \quad (2-80)$$

$$FACCCOST6 = FACCCOST6 + \left( CO2RK * \left( \frac{0.75 * RMAX}{365} \right)^{CO2RB} \right) * 1,000$$

$$INJ_{iyr} = INJ_{iyr} + (TOTINJ_{iyr} - TORECY_{iyr}) * CO2COST \quad (2-81)$$

$$OAM_{iyr} = OAM_{iyr} + (OAM\_M_{iyr} * TORECY_{iyr}) * (CO2OAM + PSW\_W * 0.25) \quad (2-82)$$

$$FOAM_{iyr} = (FOAM_{iyr} + TOTINJ_{iyr}) * 0.40 * FCO2 \quad (2-83)$$

$$TORECY\_CST_{iyr} = TORECY\_CST_{iyr} + (TORECY_{iyr} * CO2OAM2 * OAM\_M_{iyr}) \quad (2-84)$$

where

$$\begin{aligned} IYR &= \text{Year} \\ RMAX &= \text{Maximum annual volume of recycled CO}_2 \end{aligned}$$

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CO2OAM	=	O & M cost for CO <sub>2</sub> handling plant
CO2OAM2	=	The O & M cost for the project's CO <sub>2</sub> injection plant
CO2RK, CO2RB	=	CO <sub>2</sub> recycling plant cost coefficients
INJ	=	Cost of purchased CO <sub>2</sub>
TOTINJ	=	Annual project level volume of injected CO <sub>2</sub>
TORECY	=	Annual project level CO <sub>2</sub> recycled volume
CO2COST	=	Cost of CO <sub>2</sub> (\$/mcf)
OAM	=	Annual variable operating and maintenance costs
OAM_M	=	Energy elasticity factor for operating and maintenance costs
FOAM	=	Fixed annual operating and maintenance costs
FCO2	=	Energy elasticity factor for CO <sub>2</sub>
FACCOST	=	Annual project facilities costs
TORECY_CST	=	The annual cost of operating the CO <sub>2</sub> recycling plant

**Steam Model:** Facilities and O&M costs for steam generators and recycling.

Recalculate the facilities costs: Facilities costs include the capital cost for injection plants, which is based upon the OOIP of the project, the steam recycling plant, and the steam generators required for the project.

$$\begin{aligned}
 \text{FACCOST1} = & \text{FACCOST1} + \left( \frac{\text{OOIP} * 0.1 * 2.0 * \text{APAT}}{\text{TOTPAT}} \right) + (\text{RECY\_WAT} * \text{RMAXWAT} \\
 & + \text{RECY\_OIL} * \text{RMAXOIL}) + (\text{STMMA} * \text{TOTPAT} * \text{PATSIZE}) \\
 & + (\text{IGEN}_{\text{iy}} - \text{IG}) * \text{STMGA} \tag{2-85}
 \end{aligned}$$

$$\begin{aligned}
 \text{OAM}_{\text{iy}} = & \text{OAM}_{\text{iy}} + (\text{WAT\_OAM1} * \text{WATPROD}_{\text{iy}} * \text{OAM\_M}_{\text{iy}}) + (\text{OIL\_OAM1} \\
 & * \text{OILPROD}_{\text{iy}} * \text{OAM\_M}_{\text{iy}}) + (\text{INJ\_OAM1} * \text{WATINJ}_{\text{iy}} * \text{OAM\_M}_{\text{iy}}) \tag{2-86}
 \end{aligned}$$

where

IYR	=	Year
IGEN	=	Number of active steam generators each year
IG	=	Number of active steam generators in previous year
FACCOST	=	Annual project level facilities costs
RMAXWAT	=	Maximum daily water production rate
RMAXOIL	=	Maximum daily crude oil production rate
APAT	=	Number of developed patterns
TOTPAT	=	Total number of patterns in the project
OOIP	=	Original oil in place (mmbbl)
PATSIZE	=	Pattern size (acres)
STMMA	=	Unit cost for steam manifolds
STMGA	=	Unit cost for steam generators
OAM	=	Annual variable operating and maintenance costs
OAM_M	=	Energy elasticity factor for operating and maintenance costs
WAT_OAM1	=	Process specific cost of water production (\$/Bbl)
OIL_OAM1	=	Process specific cost of crude oil production (\$/Bbl)

INJ_OAM1	=	Process specific cost of water injection (\$/Bbl)
OILPROD	=	Annual project level crude oil production
WATPROD	=	Annual project level water production
WATINJ	=	Annual project level water injection
RECY_WAT	=	Recycling plant cost – water factor
RECY_OIL	=	Recycling plant cost – oil factor

### Operating and Maintenance Cost

This subroutine calculates the process specific O&M costs.

**Profile Model:** Add the O&M costs of injected polymer.

$$INJ_{iyr} = INJ_{iyr} + \frac{OAM\_M_{iyr} * TOTINJ_{iyr} * POLYCOST}{1000} \quad (2-87)$$

$$OAM_{iyr} = OAM_{iyr} + (XPATN_{iyr} * 0.25 * PSI\_W) \quad (2-88)$$

where

IYR	=	Year
MAX_YR	=	Maximum number of years
INJ	=	Annual Injection cost
OAM_M	=	Energy elasticity factor for operating and maintenance cost
TOTINJ	=	Annual project level injectant injection volume
POLYCOST	=	Polymer cost
OAM	=	Annual variable operating and maintenance cost
XPATN	=	Number of active patterns
PSI_W	=	Cost to convert a primary well to an injection well

**Polymer:** Add the O&M costs of injected polymer.

$$INJ_{iyr} = INJ_{iyr} + \frac{TOTINJ_{iyr} * POLYCOST}{1,000} \quad (2-89)$$

$$OAM_{iyr} = OAM_{iyr} + (XPATN_{iyr} * 0.25 * PSI\_W) \quad (2-90)$$

where

IYR	=	Year
MAX_YR	=	Maximum number of years
INJ	=	Annual Injection cost
TOTINJ	=	Annual project level injectant injection volume
POLYCOST	=	Polymer cost
OAM	=	Annual variable operating and maintenance cost
XPATN	=	Number of active patterns
PSI_W	=	Cost to convert a primary well to an injection well

**Waterflood:** Add the O&M costs of water injected as well as the cost to convert a primary well to an injection well.

$$OAM_{iyr} = OAM_{iyr} + (XPATN_{iyr} * 0.25 * PSI\_W) \quad (2-91)$$

where

IYR	=	Year
MAX_YR	=	Maximum number of years
OAM	=	Annual variable operating and maintenance cost
XPATN	=	Number of active patterns
PSI_W	=	Cost to convert a primary well to an injection well

**Existing crude oil fields and reservoirs:** Since no new drilling or major investments are expected for decline, facilities and drilling costs are zeroed out.

$$OAM_{iyr} = OAM_{iyr} + ((OIL\_OAM1 * OILPROD_{iyr}) + (GAS\_OAM1 * GASPROD_{iyr}) + (WAT\_OAM1 * WATPROD_{iyr})) * OAM\_M_{iyr} \quad (2-92)$$

$$AOAM_{iyr} = AOAM_{iyr} + \left( \frac{OPSEC\_W * OAM\_M_{iyr} * SUMP_{iyr}}{5} \right) \quad (2-93)$$

where

IYR	=	Year
OILPROD	=	Annual project level crude oil production
GASPROD	=	Annual project level natural gas production
WATPROD	=	Annual project level water production
OIL_OAM1	=	Process specific cost of crude oil production (\$/Bbl)
GAS_OAM1	=	Process specific cost of natural gas production (\$/Mcf)
WAT_OAM1	=	Process specific cost of water production (\$/Bbl)
OAM_M	=	Energy elasticity factor for operating and maintenance costs
OPSEC_W	=	Fixed annual operating cost for secondary well operations
SUMP	=	Cumulative patterns developed
AOAM	=	Fixed annual operating and maintenance costs
OAM	=	Variable annual operating and maintenance costs

**Overhead Costs:** : General and Administrative (G&A) costs on capitalized and expensed items, which consist of administration, accounting, contracting and legal fees/expenses for the project, are calculated according to the following equations:

$$GNA\_EXP_{itech} = GNA\_EXP_{itech} * CHG\_GNA\_FAC_{itech} \quad (2-94)$$

$$GNA\_CAP_{itech} = GNA\_CAP_{itech} * CHG\_GNA\_FAC_{itech} \quad (2-95)$$

where

ITECH	=	Technology case (base and advanced) number
GNA_EXP	=	The G&A rate applied to expensed items for the project
GNA_CAP	=	The G&A rate applied to capitalized items for the project
CHG_GNA_FAC	=	Technology case specific change in G&A rates

## Timing

### Overview of Timing Module

The timing routine determines which of the exploration and EOR/ASR projects are eligible for development in any particular year. Those that are eligible are subject to an economic analysis and passed to the project sort and development routines. The timing routine has two sections. The first applies to exploration projects while the second is applied to EOR/ASR and developing natural gas projects.

Figure 2-9 provides the overall logic for the exploration component of the timing routine. For each project regional crude oil and natural gas prices are obtained. The project is then examined to see if it has previously been timed and developed. The timed projects are no longer available and thus not considered.

The model uses four resource access categories for the undiscovered projects:

- No leasing due to statutory or executive order
- Leasing available but cumulative timing limitations between 3 and 9 months
- Leasing available but with controlled surface use
- Standard leasing terms

Each project has been assigned to a resource access category. If the access category is not available in the year evaluated, the project fails the resource access check.

After the project is evaluated, the number of considered projects is increased. Figure 2-10 shows the timing logic applied to the EOR/ASR projects as well as the developing natural gas projects.

Before the economics are evaluated, the prices are set and the eligibility is determined. The following conditions must be met:

- Project has not been previously timed
- Project must be eligible for timing, re-passed the economic pre-screening routine
- Corresponding decline curve project must have been timed. This does not apply to the developing natural gas projects.

If the project meets all of these criteria, then it is considered eligible for economic analysis. For an EOR/ASR project to be considered for timing, it must be within a process specific EOR/ASR development window. These windows are listed in Table 2-4.

#### **Table 2-4: EOR/ASR Eligibility Ranges**

Process	Before Economic Limit	After Economic Limit
CO <sub>2</sub> Flooding	After 2009	10 Years
Steam Flooding	5 Years	10 Years
Polymer Flooding	5 Years	10 Years
Infill Drilling	After 2009	7 Years
Profile Modification	5 Years	7 Years
Horizontal Continuity	5 Years	7 Years
Horizontal Profile	5 Years	7 Years
Waterflood	4 Years	6 Years

The economic viability of the eligible projects is then evaluated. A different analytical approach is applied to CO<sub>2</sub> EOR and all other projects. For non-CO<sub>2</sub> EOR projects the project is screened for applicable technology levers, and the economic analysis is conducted. CO<sub>2</sub> EOR projects are treated differently because of the different CO<sub>2</sub> costs associated with the different sources of industrial and natural CO<sub>2</sub>.

For each available source, the economic variables are calculated and stored. These include the source of CO<sub>2</sub> and the project's ranking criterion.

### Detailed description of timing module

**Exploration projects:** The first step in the timing module is to determine which reservoirs are eligible to be timed for conventional and continuous exploration. Prior to evaluation, the constraints, resource access, and technology and economic levers are checked, and the technology case is set.

### Calculate economics for EOR/ASR and developing natural gas projects:

This section determines whether an EOR/ASR or developing natural gas project is eligible for economic analysis and timing. The following resources are processes considered in this step.

EOR Processes:

- CO<sub>2</sub> Flooding
- Steam Flooding
- Polymer Flooding
- Profile Modification

ASR Processes:

- Water Flooding
- Infill Drilling
- Horizontal Continuity
- Horizontal Profile

Developing natural gas

- Tight Gas
- Shale Gas
- Coalbed Methane

A project is eligible for timing if the corresponding decline curve project has previously been timed and the year of evaluation is within the eligibility window for the process, as listed in table 2-4.

**Project Ranking:** Sorts exploration and EOR/ASR projects which are economic for timing. The subroutine matches the discovery order for undiscovered projects and sorts the others by ranking criterion. The criteria include

- Net present value
- Investment efficiency
- Rate of return
- Cumulative discounted after tax cashflow

**Selection and Timing:** Times the exploration and EOR/ASR projects which are considered in that given year.

## **Project Selection**

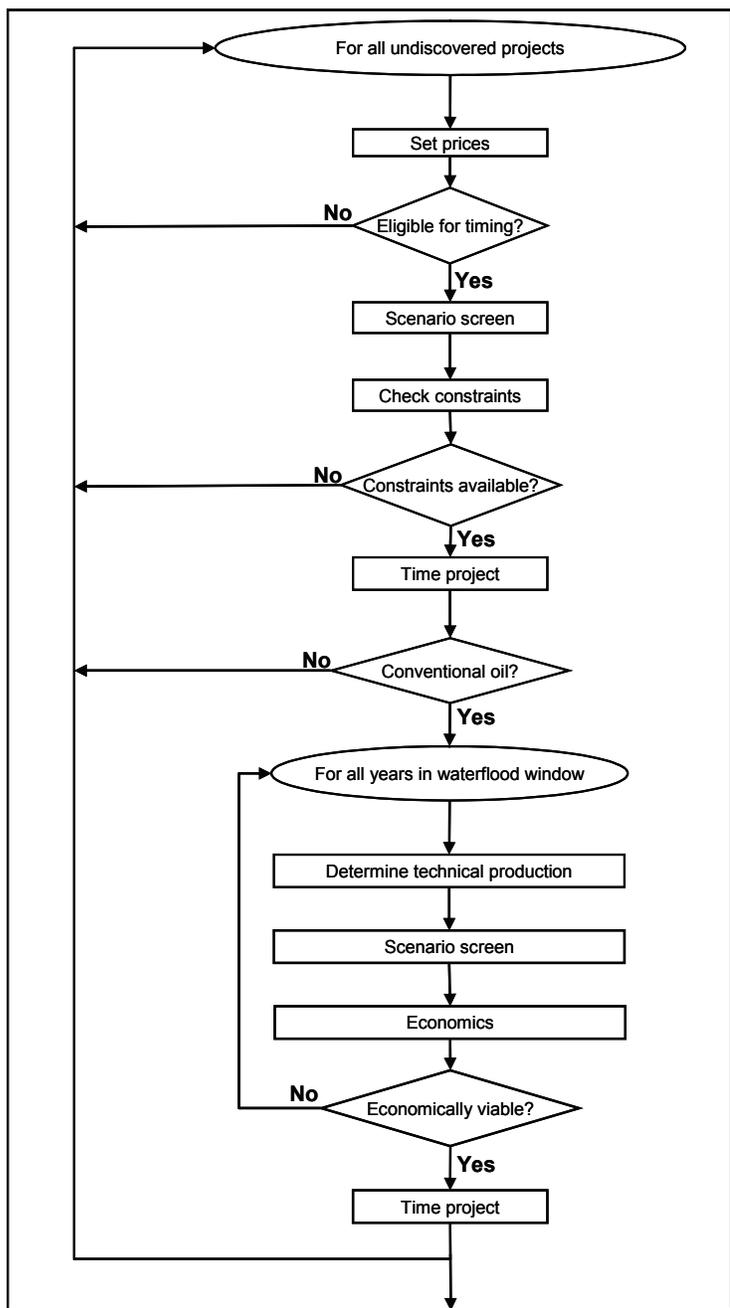
The project selection subroutine determines which exploration, EOR/ASR and developing natural gas projects will be modeled as developed in each year analyzed. In addition, the following development decisions are made:

- Waterflood of conventional undiscovered crude oil projects
- Extension of CO<sub>2</sub> floods as the total CO<sub>2</sub> injected is increased from 0.4 hydrocarbon pore volume (HCPV) to 1.0 HCPV

## **Overview of Project Selection**

The project selection subroutine evaluates undiscovered projects separate from other projects. The logic for the development of exploration projects is provided in figure 2-9.

**Figure 2-9: Selecting Undiscovered Projects**



As illustrated in the figure the prices are set for the project before its eligibility is checked. Eligibility has the following requirements:

- Project is economically viable
- Project is not previously timed and developed

The projects which are eligible are screened for applicable technologies which impact the drilling success rates. The development constraints required for the project are checked against those that are available in the region.

If sufficient development resources are available, the project is timed and developed. As part of this process, the available development constraints are adjusted, the number of available accumulations is reduced and the results are aggregated. If no undiscovered accumulations remain, then the project is no longer eligible for timing. The projects that are eligible, economically viable, and undeveloped due to lack of development resources, are considered again for future projection years. If the project is conventional crude oil, it is possible to time a waterflood project.

The model evaluates the waterflood potential in a window centered upon the end of the economic life for the undiscovered project. For each year of that window, the technical production is determined for the waterflood project, applicable technology and economic levers are applied, and the economics are considered. If the waterflood project is economic, it is timed. This process is continued until either a waterflood project is timed or the window closes.

The second component of the project selection subroutine is applicable to EOR/ASR projects as well as the developing natural gas projects. The major steps applied to these projects are detailed in figures 2-10 and 2-11.

As seen in the flowchart, the prices are set for the project and the eligibility is checked. As with the undiscovered projects, the subroutine checks the candidate project for both economic viability and eligibility for timing. Afterwards, the project is screened for any applicable technology and economic levers.

If the project is eligible for CO<sub>2</sub> EOR, the economics are re-run for the specific source of CO<sub>2</sub>. Afterwards, the availability of resource development constraints is checked for the project. If sufficient drilling and capital resources are available, the project preferences are checked.

The project preferences are rules which govern the competition between projects and selection of projects; these rules are listed below:

- CO<sub>2</sub> EOR and infill drilling are available after 2010
- Profile modification becomes available after 2011
- The annual number of infill drilling and profile modification projects is limited
- Horizontal continuity can compete against any other process except steam flood
- Horizontal profile can compete against any other process except steam flood or profile modification
- Polymer flooding cannot compete against any other process

If the project meets the technology preferences, then it is timed and developed. This process is different for CO<sub>2</sub> EOR and all other processes.

Figure 2-10: Selecting EOR/ASR projects

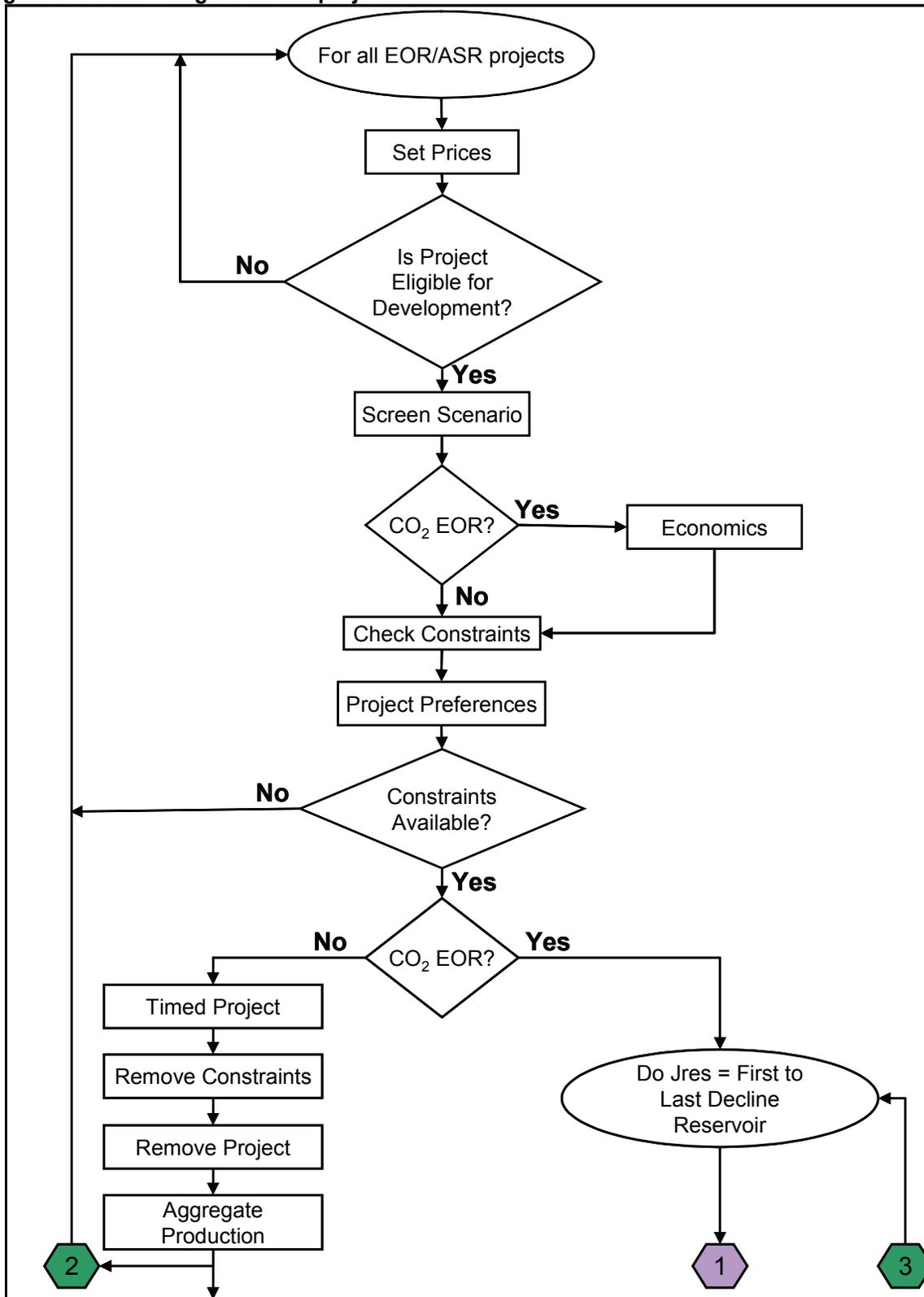
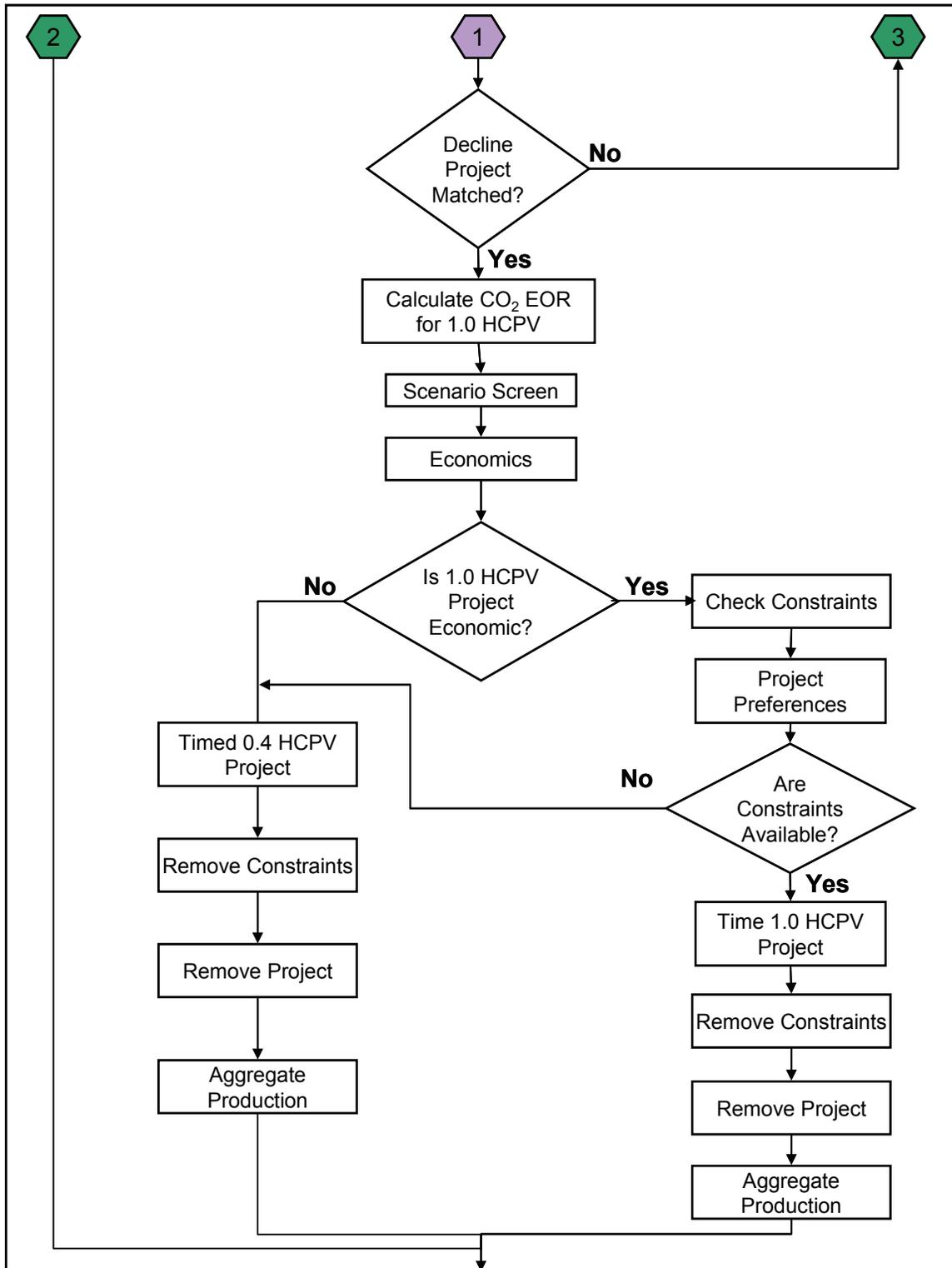


Figure 2-11: Selecting EOR/ASR projects, Continued



For non-CO<sub>2</sub> projects, the constraints are adjusted, the project is removed from the list of eligible projects, and the results are aggregated. It is assumed that most EOR/ASR processes are mutually exclusive and that a reservoir is limited to one process. There are a few exceptions:

- CO<sub>2</sub> EOR and infill drilling can be done in the same reservoir
- CO<sub>2</sub> EOR and horizontal continuity can be done in the same reservoir

For CO<sub>2</sub> EOR projects, a different methodology is used at this step: the decision to increase the total CO<sub>2</sub> injection from 0.4 hydrocarbon pore volume (HCPV) to 1.0 HCPV is made. The model performs the following steps, illustrated in figure 2-10 and continued in figure 2-11.

The CO<sub>2</sub> EOR project is matched to the corresponding decline curve project. Using the project-specific petro-physical properties, the technical production and injection requirements are determined for the 1.0 HCPV project. After applying any applicable technology and economic levers, the model evaluates the project economics. If the 1.0 HCPV project is not economically viable, then the 0.4 HCPV project is timed. If the 1.0 HCPV project is viable, the constraints and project preferences are checked. Assuming that there are sufficient development resources, and competition allows for the development of the project, then the model times the 1.0 HCPV project. If sufficient resources for the 1.0 HCPV project are not available, the model times the 0.4 HCPV project.

### **Detailed description of project selection**

The project selection subroutine analyzes undiscovered crude oil and natural gas projects. If a project is economic and eligible for development, the drilling and capital constraints are examined to determine whether the constraints have been met. The model assumes that the projects for which development resources are available are developed.

Waterflood processing may be considered for undiscovered conventional crude oil projects. The waterflood project will be developed in the first year it is both eligible for implementation and the waterflood project is economically viable.

### **EOR/ASR Projects**

When considering whether a project is eligible for EOR/ASR processing, the model first checks the availability of sufficient development resources are available. Based on the project economics and projected availability of development resources, it also decides whether or not to extend injection in CO<sub>2</sub> EOR projects from 0.4 HCPV to 1.0 HCPV.

If the 1.0 HCPV is economic but insufficient resources are available, the 0.4 HCPV project is selected instead. If the 1.0 HCPV project is uneconomic, the 0.4 HCPV project is selected.

### **Constraints**

Resource development constraints are used during the selection of projects for development in order to mimic the infrastructure limitations of the oil and gas industry. The model assumes that only the projects that do not exceed the constraints available will be developed.

## Types of constraints modeled

The development constraints represented in the model include drilling footage availability, rig depth rating, capital constraints, demand for natural gas, carbon dioxide volumes, and resource access.

In the remainder of this section, additional details will be provided for each of these constraints.

**Drilling:** Drilling constraints are bounding values used to determine the resource production in a given region. OLOGSS uses the following drilling categories:

- Developmental crude oil – applied to EOR/ASR projects
- Developmental natural gas – applied to developing natural gas projects
- Horizontal drilling – applied to horizontal wells
- Dual use – available for either crude oil or natural gas projects
- Conventional crude oil exploration – applied to undiscovered conventional crude oil projects
- Conventional natural gas exploration – applied to undiscovered conventional natural gas projects
- Continuous crude oil exploration – applied to undiscovered continuous crude oil projects
- Continuous natural gas exploration – applied to undiscovered continuous natural gas projects

Except for horizontal drilling, which is calculated as a fraction of the national developmental crude oil footage, all categories are calculated at the national level and apportioned to the regional level. Horizontal drilling is at the national level.

The following equations are used to calculate the national crude oil development drilling. The annual footage available is a function of lagged five year average crude oil prices and the total growth in drilling.

The total growth in drilling is calculated using the following algorithm.

For the first year:

$$\text{TOT\_GROWTH} = 1.0 * \left( 1.0 + \frac{\text{DRILL\_OVER}}{100} \right) \quad (2-96)$$

For the remaining years:

(2-97)

$$\begin{aligned} \text{TOT\_GROWTH} = & \left( \left( \text{TOT\_GROWTH} * \left( 1.0 + \frac{\text{RGR}}{100} \right) \right) - \left( \text{TOT\_GROWTH} * \left( 1.0 + \frac{\text{RGR}}{100} \right) \right) * \left( \frac{\text{RRR}}{100} \right) \right) \\ & * \left( 1.0 * \frac{\text{DRILL\_OVER}}{100} \right) \end{aligned}$$

Reviewers note: The equation above would be clearer if it were written as

where

IYR	=	Year evaluated
MAX_YR	=	Maximum number of years
TOT_GROWTH	=	Annual growth change for drilling at the national level (fraction)
DRILL_OVER	=	Percent of drilling constraint available for footage over run
RGR	=	Annual rig development rate (percent)
RRR	=	Annual rig retirement rate (percent)

The national level crude oil and natural gas development footage available for drilling is calculated using the following equations. The coefficients for the drilling footage equations were estimated by least squares using model equations 2.B-16 and 2.B-17 in Appendix 2.B.

$$\text{NAT\_OIL}_{\text{IYR}} = (\text{OILA0} + \text{OILA1} * \text{OILPRICED}_{\text{IYR}}) * \text{TOTMUL} * \text{TOT\_GROWTH} * \text{OIL\_ADJ}_{\text{IYR}} \quad (2-98)$$

$$\text{NAT\_GAS}_{\text{IYR}} = (\text{GASA0} + \text{GASA1} * \text{GASPRICED}_{\text{IYR}}) * \text{TOTMUL} * \text{TOT\_GROWTH} * \text{GAS\_ADJ}_{\text{IYR}} \quad (2-99)$$

where

IYR	=	Year evaluated
TOT_GROWTH	=	Final calculated annual growth change for drilling at the national level
NAT_OIL	=	National development footage available (Thousand Feet)
NAT_GAS	=	
OILA0,1	=	Footage equation coefficients
GASA0,1	=	
OILPRICED	=	Annual prices used in drilling constraints, five year average
GASPRICED	=	
TOTMUL	=	Total drilling constraint multiplier
OIL_ADJ	=	Annual crude oil, natural gas developmental drilling availability factors
GAS_ADJ	=	

After the available footage for drilling is calculated at the national level, regional allocations are used to allocate the drilling to each of the OLOGSS regions. The drilling which is not allocated, due to the “drill\_trans” factor, is available in any region and represents the drilling which can be transferred among regions. The regional allocations are then subtracted from the national availability.

$$\text{REG\_OIL}_{\text{j,iyR}} = \text{NAT\_OIL}_{\text{IYR}} * \left( \frac{\text{PRO\_REGOIL}_J}{100} \right) * \left( 1.0 - \frac{\text{DRILL\_TRANS}}{100} \right) \quad (2-100)$$

where

J	=	Region number
IYR	=	Year

REG_OIL	=	Regional development oil footage (Thousand Feet) available in a specified region
NAT_OIL	=	National development oil footage (Thousand Feet). After allocation, the footage transferrable among regions.
PRO_REGOIL	=	Regional development oil footage allocation (percent)
DRILL_TRANS	=	Percent of footage that is transferable among regions

**Footage Constraints:** The model determines whether there is sufficient footage available to drill the complete project. The drilling constraint is applied to all projects. Footage requirements are calculated in two stages: vertical drilling and horizontal drilling. The first well for an exploration project is assumed to be a wildcat well and uses a different success rate than the other wells in the project. The vertical drilling is calculated using the following formula.

For non-exploration projects:

$$\begin{aligned} \text{FOOTREQ}_{ii} = & (\text{DEPTH}_{itech} * (1.0 + \text{SUC\_RATEKD}_{itech})) * \text{PATDEV}_{irs,ii-itimeyr+1,itech} \quad (2-101) \\ & * (\text{ATOTPROD}_{irs,itech} + \text{ATOTINJ}_{irs,itech}) + (\text{DEPTH}_{itech} \\ & * \text{PATDEV}_{irs,ii-itimeyr+1,itech}) * 0.5 * \text{ATOTCONV}_{irs,itech} \end{aligned}$$

For exploration projects:

For the first year of the project (2-102)

$$\begin{aligned} \text{FOOTREQ}_{ii} = & (\text{DEPTH}_{itech} * (1.0 + \text{SUC\_RATEUE}_{itech})) * (\text{ATOTPROD}_{irs,itech} \\ & + \text{ATOTINJ}_{irs,itech}) + (0.5 * \text{ATOTCONV}_{irs,itech}) + (\text{DEPTH}_{itech} \\ & * (1.0 + \text{SUC\_RATEUD}_{itech})) * (\text{PATDEV}_{irs,ii-itimeyr+1,itech} - 1 \\ & * \text{ATOTPROD}_{irs,itech} + \text{ATOTINJ}_{ir,itech} + 0.5 * \text{ATOTCONV}_{irs,itech}) \end{aligned}$$

For all other project years (2-103)

$$\begin{aligned} \text{FOOTREQ}_{ii} = & (\text{DEPTH}_{itech} * (1.0 + \text{SUC\_RATEUD}_{itech})) * \text{PATDEV}_{irs,ii-itimeyr+1,itech} \\ & * (\text{ATOTPROD}_{irs,itech} + \text{ATOTINJ}_{irs,itech}) + (\text{DEPTH}_{itech} \\ & * \text{PATDEV}_{irs,ii-itimeyr+1,itech} * 0.5 * \text{ATOTCONV}_{irs,itech}) \end{aligned}$$

where

irs	=	Project index number
itech	=	Technology index number
itimeyr	=	Year in which project is evaluated for development
ii	=	Year evaluated
FOOTREQ	=	Footage required for drilling (Thousand Feet)
DEPTH	=	Depth of formation (Feet)
SUC_RATEKD	=	Success rate for known development
SUC_RATEUE	=	Success rate for undiscovered exploration (wildcat)
SUC_RATEUD	=	Success rate for undiscovered development
PATDEV	=	Annual number of patterns developed for base and advanced technology
ATOTPROD	=	Number of new producers drilled per pattern
ATOTINJ	=	Number of new injectors drilled per patterns
ATOTCONV	=	Number of conversions from producing to injection wells per pattern

Add Laterals and Horizontal Wells: The lateral length and the horizontal well length are added to the footage required for drilling.

$$\text{FOOTREQ}_{ii} = \text{FOOTREQ}_{ii} + (\text{ALATNUM}_{\text{irs,itech}} * \text{ALATLEN}_{\text{irs,itech}} * (1.0 + \text{SUC\_RATEKD}_{\text{itech}}) * \text{PATDEV}_{\text{irs,ii-itimeyr+1,itech}}) \quad (2-104)$$

where

- irs = Project index number
- itech = Technology index number
- itimeyr = Year in which project is evaluated for development
- ii = Year evaluated
- FOOTREQ = Footage required for drilling (Feet)
- ALATNUM = Number of laterals
- ALATLEN = Length of laterals (Feet)
- SUC\_RATEKD = Success rate for known development
- PATDEV = Annual number of patterns developed for base and advanced technology

After determining the footage requirements, the model calculates the footage available for the project. The available footage is specific to the resource, the process, and the constraint options which have been specified by the user. If the footage required to drill the project is greater than the footage available then the project is not feasible.

**Rig depth rating:** The rig depth rating is used to determine whether a rig is available which can drill to the depth required by the project. OLOGSS uses the nine rig depth categories provided in table 2-5.

**Table 2-5 Rig Depth Categories**

Depth Category	Minimum Depth (Ft)	Maximum Depth (Ft)
1	1	2,500
2	2,501	5,000
3	5,001	7,500
4	7,501	10,000
5	10,001	12,500
6	12,501	15,000
7	15,001	17,500
8	17,251	20,000
9	20,001	Deeper

The rig depth rating is applied at the national level. The available footage is calculated using the following equation.

$$\text{RDR\_FOOTAGE}_{j, \text{iyr}} = (\text{NAT\_TOT}_{\text{iyr}} + \text{NAT\_EXP}_{\text{iyr}} + \text{NAT\_EXPG}_{\text{iyr}}) * \frac{\text{RDR}_j}{100} \quad (2-106)$$

where

- J = Rig depth rating category
- IYR = Year
- RDR\_FOOTAGE = Footage available in this interval (K Ft)

NAT_TOT	=	Total national developmental (crude oil, natural gas, and horizontal) drilling footage available (Thousand feet)
NAT_EXPG	=	National gas exploration drilling constraint
NAT_EXP	=	Total national exploration drilling footage available (Thousand feet)
RDR <sub>j</sub>	=	Percentage of rigs which can drill to depth category j

**Capital:** Crude oil and natural gas companies use different investment and project evaluation criteria based upon their specific cost of capital, the portfolio of investment opportunities available, and their perceived technical risks. OLOGSS uses capital constraints to mimic limitations on the amount of investments the oil and gas industry can make in a given year. The capital constraint is applied at the national level.

**Natural Gas Demand:** Demand for natural gas is calculated at the regional level by the NGTDM and supplied to OLOGSS.

**Carbon Dioxide:** For CO<sub>2</sub> miscible flooding, availability of CO<sub>2</sub> gas from natural and industrial sources is a limiting factor in developing the candidate projects. In the Permian Basin, where the majority of the current CO<sub>2</sub> projects are located, the CO<sub>2</sub> pipeline capacity is a major concern.

The CO<sub>2</sub> constraint in OLOGSS incorporates both industrial and natural sources of CO<sub>2</sub>. The industrial sources of CO<sub>2</sub> are ammonia plants, hydrogen plants, existing and planned ethanol plants, cement plants, refineries, fossil fuel power plants, and new IGCC plants.

Technology and market constraints prevent the total volumes of CO<sub>2</sub> produced from becoming immediately available. The development of the CO<sub>2</sub> market is divided into 3 periods:

1) technology R&D, 2) infrastructure construction, and 3) market acceptance. The capture technology is under development during the R&D phase, and no CO<sub>2</sub> produced by the technology is assumed available at that time. During the infrastructure development, the required capture equipment, pipelines, and compressors are being constructed, and no CO<sub>2</sub> is assumed available. During the market acceptance phase, the capture technology is being widely implemented and volumes of CO<sub>2</sub> are assumed to become available.

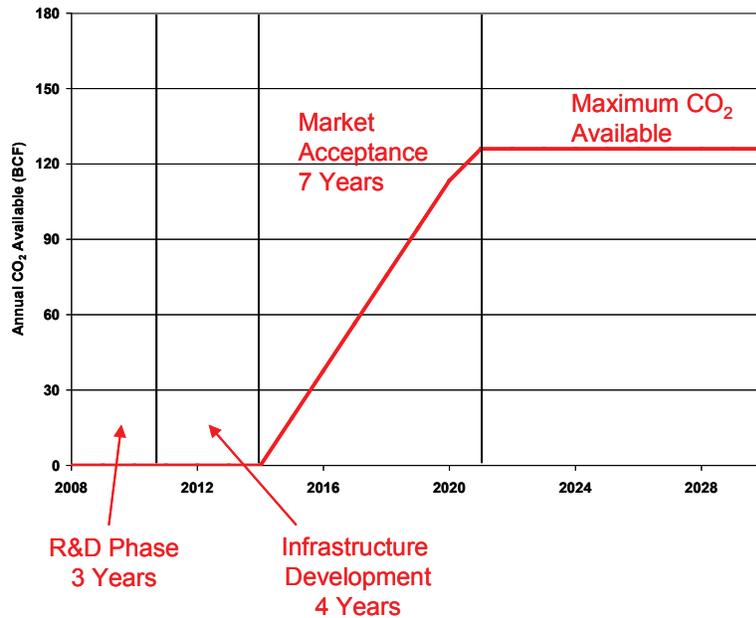
The maximum CO<sub>2</sub> available is achieved when the maximum percentage of the industry that will adopt the technology has adopted it. This provides an upper limit on the volume of CO<sub>2</sub> that will be available. The graph below provides the annual availability of CO<sub>2</sub> from ammonia plants. Availability curves were developed for each source of industrial, as well as natural CO<sub>2</sub>.

CO<sub>2</sub> constraints are calculated at the regional level and are source specific.

**Resource Access:** Restrictions on access to Federal lands constrain the development of undiscovered crude oil and natural gas resources. OLOGSS uses four resource access categories:

- No leasing due to statutory or executive order
- Leasing available but cumulative timing limitations between 3 and 9 months
- Leasing available but with controlled surface use
- Standard leasing terms

The percentage of the undiscovered resource in each category was estimated using data from the Department of Interior’s Basin Inventories of Onshore Federal Land’s Oil and Gas Resources.



**Figure 2-12: CO2 Market Acceptance Curve**

## Technology

Research and development programs are designed to improve technology to increase the amount of resources recovered from crude oil and natural gas fields. Key areas of study include methods of increasing production, extending reserves, and reducing costs. To optimize the impact of R & D efforts, potential benefits of a new technology are weighed against the costs of research and development. OLOGSS has the capability to model the effects of R & D programs and other technology improvements as they impact the production and economics of a project. This is done in two steps: (1) modeling the implementation of the technology within the oil and gas industry and (2) modeling the costs and benefits for a project that applies this technology.

### Impact of technology on economics and recovery

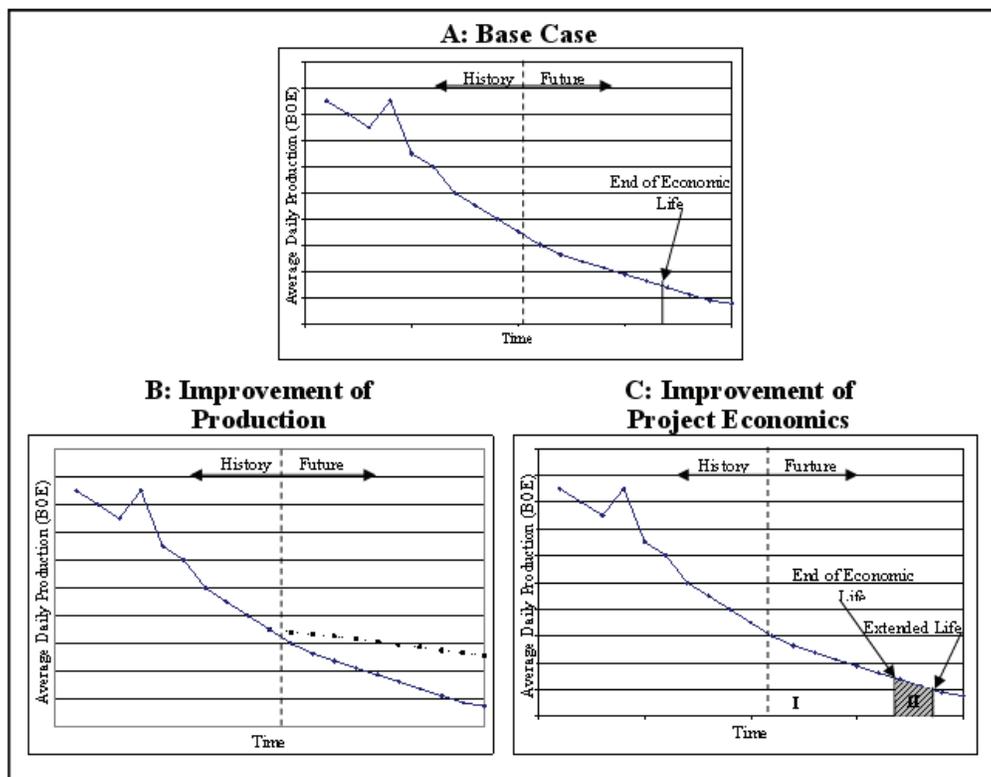
Figure 2-13 illustrates the effects of technology improvement on the production and project economics of a hypothetical well. The graphs plot the daily average production, projected by decline analysis, over the life of the project. Each graph represents a different scenario: (A) base case, (B) production improvement, and (C) economic improvement.

Graph A plots the production for the base case. In the base case, no new technology is applied to the project. The end of the project’s economic life, the point at which potential revenues are less than costs of further production, is indicated. At that point, the project would be subject to reserves-growth processes or shut in.

Graph B plots the production for the base case and a production-increasing technology such as skin reduction. The reduction in skin, through well-bore fracturing or acidizing, increases the daily production flow rate. The increase in daily production rate is shown by the dotted line in graph B. The outcome of the production-increasing technology is reserves growth for the well. The amount of reserves growth for the well is shown by the area between the two lines as illustrated in figure 2-13 graph B.

Another example of technology improvement is captured in graph C. In this case a technology is implemented that reduces the cost of operation and maintenance, thereby extending the reservoir life as shown in figure 2-13 graph C.

**Figure 2-13: Impact of Economic and Technology Levers**



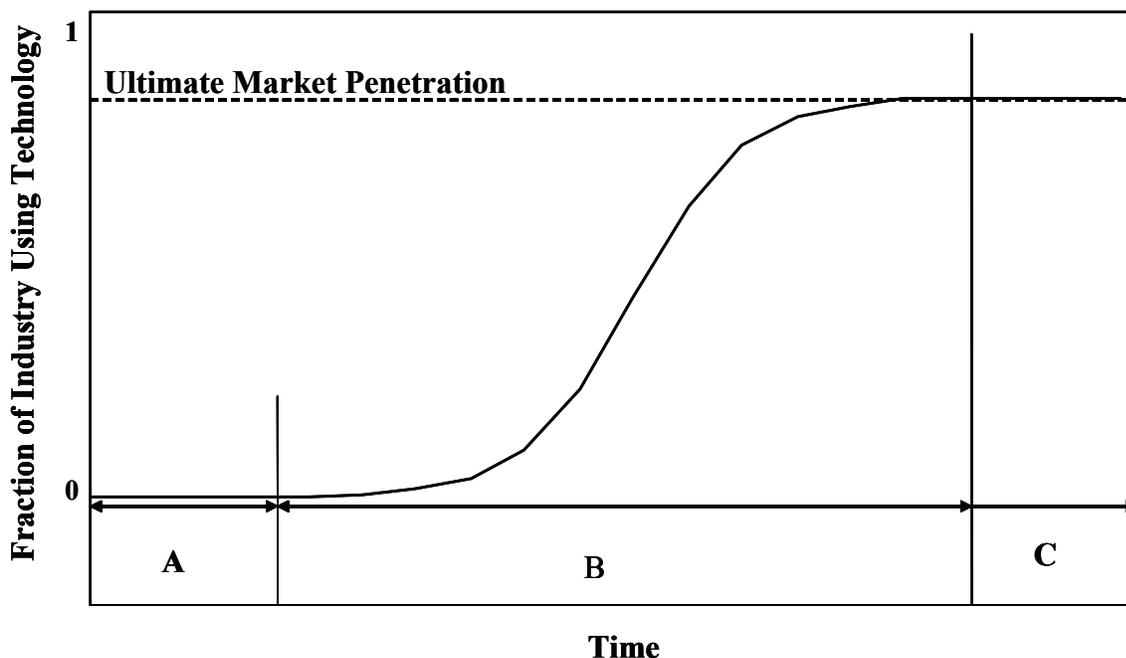
Technology improvements are modeled in OLOGSS using a variety of technology and economic levers. The technology levers, which impact production, are applied to the technical production of the project. The economic levers, which model improvement in project economics, are applied to cashflow calculations. Technology penetration curves are used to model the market penetration of each technology.

The technology-penetration curve is divided into three sections, each of which represents a phase of development. The first section is the research and development phase. In this phase the technology is developed and tested in the laboratory. During these years, the industry may be aware of the technology but has not begun implementation, and therefore does not see a benefit to production or economics. The second section corresponds to the commercialization phase. In the commercialization phase, the technology has successfully left the laboratory and is being

adopted by the industry. The third section represents maximum market penetration. This is the ultimate extent to which the technology is adopted by the industry.

Figure 2-14 provides the graph of a generic technology-penetration curve. This graph plots the fraction of industry using the new technology (between 0 and 1) over time. During the research and development phase (A) the fraction of the industry using the technology is 0. This increases during commercialization phase (B) until it reaches the ultimate market penetration. In phase C, the period of maximum market acceptance, the percentage of industry using the technology remains constant.

Figure 2-14: Generic Technology Penetration Curve



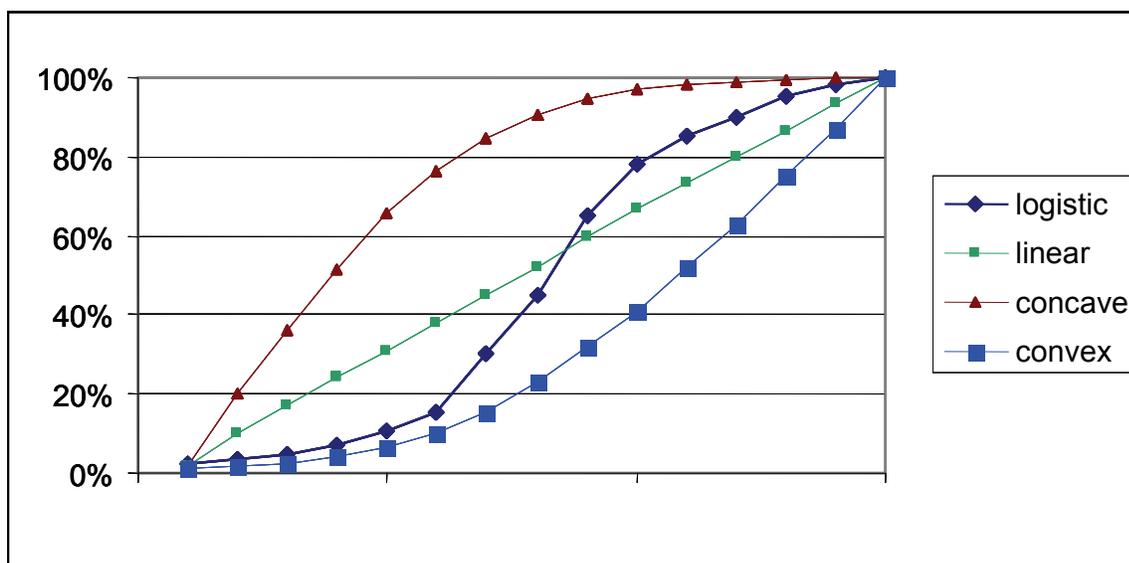
### Technology modeling in OLOGSS

The success of the technology program is measured by estimating the probability that the technology development program will be successfully completed. It reflects the pace at which technology performance improves and the probability that the technology project will meet the program goals. There are four possible curve shapes that may represent the adoption of the technology: convex, concave, sigmoid/logistic or linear, as shown in figure 2-15. The convex curve corresponds to rapid initial market penetration followed by slow market penetration. The concave curve corresponds to slow initial market penetration followed by rapid market penetration. The sigmoid/logistic curve represents a slow initial adoption rate followed by rapid increase in adoption and the slow adoption again as the market becomes saturated. The linear curve represents a constant rate of market penetration, and may be used when no other predictions can be made.

The market penetration curve is a function of the relative economic attractiveness of the technology instead of being a time-dependent function. A technology will not be implemented

unless the benefits through increased production or cost reductions are greater than the cost to apply the technology. As a result, the market penetration curve provides a limiting value on commercialization instead of a specific penetration path. In addition to the curve, the implementation probability captures the fact that not all technologies that have been proved in the lab are able to be successfully implemented in the field. The implementation probability does not reflect resource access, development constraints, or economic factors.

**Figure 2-15: Potential Market Penetration Profiles**



The three phases of the technology penetration curve are modeled using three sets of equations. The first set of equations models the research and development phase, the second set models the commercialization phase, and the third set models the maximum market penetration phase.

In summary, technology penetration curves are defined using the following variables:

- Number of years required to develop a technology =  $Y_d$
- First year of commercialization =  $Y_c$
- Number of years to fully penetrate the market =  $Y_a$
- Ultimate market penetration (%) =  $UP$
- Probability of success =  $P_s$
- Probability of implementation =  $P_i$
- Percent of industry implementing the technology (fraction) in year  $x$  =  $Imp_x$

**Research and Development Phase:**

During the research and development phase, the percentage of industry implementing the new technology for a given year is zero.

This equation is used for all values of *market\_penetration\_profile*.

**Commercialization Phase:**

The commercialization phase covers the years from the beginning of commercialization through the number of years required to fully develop the technology. The equations used to model this phase depend upon the value of *market\_penetration\_profile*.

If the *market\_penetration\_profile* is assumed to be *convex*, then

Step 1: Calculate raw implementation percentage:

$$\text{Imp}_{xr} = -0.9 * 0.4^{[(x - Y_s) / Y_a]} \quad (2-105)$$

Step 2: Normalize  $\text{Imp}_x$  using the following equation:

$$\text{Imp}_x = \frac{[(-0.6523) - \text{Imp}_{xr}]}{[(-0.6523) - (-0.036)]} \quad (2-106)$$

If the *market\_penetration\_profile* is assumed to be *concave*, then

Step 1: Calculate raw implementation percentage:

$$\text{Imp}_x = 0.9 * 0.04^{[1 - \{(x + 1 - Y_s) / Y_a\}]} \quad (2-107)$$

Step 2: Normalize  $\text{Imp}_x$  using the following equation:

$$\text{Imp}_x = \frac{[(0.04) - \text{Imp}_{xr}]}{[(0.04) - (0.74678)]} \quad (2-108)$$

If the *market\_penetration\_profile* is assumed to be *sigmoid*, then

Step 1: Determine midpoint of the sigmoid curve =  $\text{int} \left( \frac{Y_a}{2} \right)$

Where  $\text{int} \left( \frac{Y_a}{2} \right) = \left( \frac{Y_a}{2} \right)$  rounded to the nearest integer

Step 2: Assign a value of 0 to the midpoint year of the commercialization period, incrementally increase the values for the years above the midpoint year, and incrementally decrease the values for the years below the midpoint year.

Step 3: Calculate raw implementation percentage:

$$\text{Imp}_x = \frac{e^{\text{value}_x}}{1 + e^{\text{value}_x}} \quad (2-109)$$

No normalizing of  $\text{Imp}_x$  is required for the sigmoid profile.

If the *market\_penetration\_profile* is assumed to be *linear*, then

Step 1: Calculate the raw implementation percentage:

$$\text{Imp}_x = \left[ \frac{P_s * P_i * \text{UP}}{Y_a + 1} \right] * X_i \quad (2-110)$$

No normalizing of  $\text{Imp}_x$  is required for the linear profile.

Note that the maximum technology penetration is 1.

### **Ultimate Market Penetration Phase:**

For each of the curves generated, the ultimate technology penetration applied per year will be calculated using:

$$\text{Imp}_{\text{final}} = \text{Imp}_x * P_s * P_i \quad (2-111)$$

Note that  $\text{Imp}_{\text{final}}$  is not to exceed Ultimate Market Penetration (“UP”)

Using these three sets of equations, the industry-wide implementation of a technology improvement can be mapped using a technology-penetration curve.

## **Levers included in model**

**Project Level Technology Impact:** Adopting a new technology can impact two aspects of a project. It improves the production and/or improves the economics. Technology and economic levers are variables in OLOGSS. The values for these levers are set by the user.

There are two cost variables to which economic levers can be applied in the cashflow calculations: the cost of applying the technology and the cost reductions that result from the technology’s implementation. The cost to apply is the incremental cost to apply the technology. The cost reduction is the savings associated with using the new technology. The “cost to apply” levers can be applied at the well and/or project level. The model recognizes the distinction between technologies that are applied at the well level – modeling while drilling - and reservoir characterization and simulation, which affects the entire project. By using both types of levers, users can model the relationship between implementation costs and offsetting cost reductions.

The model assumes that the technology will be implemented only if the cost to apply the technology is less than the increased revenue generated through improved production and cost reductions.

**Resource and Filter Levers:** Two other types of levers are incorporated into OLOGSS: resource-access levers and technology levers. Resource-access levers allow the user to model changes in resource-access policy. For example, the user can specify that the federal lands in the Santa Maria Basin, which are currently inaccessible due to statutory or executive orders, will be available for exploration in 2015. A series of filter levers is also incorporated in the model. These are used to specifically locate the impact of technology improvement. For example, a technology can be applied only to CO<sub>2</sub> flooding projects in the Rocky Mountain region that are between 5,000 and 7,000 feet deep.

## Appendix 2.A: Onshore Lower 48 Data Inventory

Variable Name	Variable Type	Description	Unit
AAPI	Input	API gravity	
AARP	Input	CO <sub>2</sub> source acceptance rate	
ABO	Variable	Current formation volume factor	Bbl/stb
ABOI	Input	Initial formation volume factor	Bbl/stb
ABTU	Variable	BTU content	Btu/Cf
ACER	Input	ACE rate	Percent
ACHGASPROD	Input	Cumulative historical natural gas production	MMcf
ACHOILPROD	Input	Cumulative historical crude oil production	MBbl
ACO2CONT	Input	CO <sub>2</sub> impurity content	%
ADEPTH	Input	Depth	Feet
ADGGLA	Variable	Depletable items in the year (G & G and lease acquisition cost)	K\$
ADJGAS	Variable	National natural gas drilling adjustment factor	Fraction
ADJGROSS	Variable	Adjusted gross revenue	K\$
ADJOIL	Variable	National crude oil drilling adjustment factor	Fraction
ADOILPRICE	Variable	Adjusted crude oil price	\$/Bbl
ADVANCED	Variable	Patterns to be developed using advanced technology	Fraction
AECON_LIFE	Variable	Economic life of the project	Years
AFLP	Input	Portion of reservoir on federal lands	Fraction
AGAS_GRAV	Input	Natural gas gravity	
AGOR	Input	Gas/oil ratio	Mcf/bbl
AH2SCONT	Input	H <sub>2</sub> S impurity content	%
AHCPV	Variable	Hydro Carbon Pore Volume	0.4 HCPV
AHEATVAL	Input	Heat content of natural gas	Btu/Cf
AINJINJ	Input	Annual injectant injected	MBbl, Mcf, MLbs
AINJRECY	Variable	Annual injectant recycled	MBbl, Mcf
AIRSVGAS	Variable	End of year inferred natural gas reserves	MMcf
AIRSVOIL	Variable	End of year inferred crude oil reserves	MBbl
ALATLEN	Input	Lateral length	Feet
ALATNUM	Input	Number of laterals	
ALYRGAS	Input	Last year of historical natural gas production	MMcf

ALYROIL	Input	Last year of historical crude oil production	MBbl
AMINT	Variable	Alternative minimum income tax	K\$
AMOR	Variable	Intangible investment depreciation amount	K\$
AMOR_BASE	Variable	Amortization base	K\$
AMORSCHL	Input	Annual fraction amortized	Fraction
AMT	Input	Alternative minimum tax	K\$
AMTRATE	Input	Alternative minimum tax rate	K\$
AN2CONT	Input	N <sub>2</sub> impurity content	%
ANGL	Input	NGL	bbl/MMcf
ANUMACC	Input	Number of accumulations	
ANWELLGAS	Input	Number of natural gas wells	
ANWELLINJ	Input	Number of injection wells	
ANWELLOIL	Input	Number of crude oil wells	
AOAM	Variable	Annual fixed O & M cost	K\$
AOGIP	Variable	Original Gas in Place	Bcf
AOILVIS	Input	Crude Oil viscosity	CP
AOOIP	Variable	Original Oil In Place	MBbl
AORGOOIP	Input	Original OOIP	MBbl
APATSIZ	Input	Pattern size	Acres
APAY	Input	Net pay	Feet
APD	Variable	Annual percent depletion	K\$
APERM	Input	Permeability	MD
APHI	Input	Porosity	Percent
APLAY_CDE	Input	Play number	
APRESIN	Variable	Initial pressure	PSIA
APRODCO2	Input	Annual CO <sub>2</sub> production	MMcf
APRODGAS	Input	Annual natural gas production	MMcf
APRODNGL	Input	Annual NGL production	MBbl
APRODOIL	Input	Annual crude oil production	MBbl
APRODWAT	Input	Annual water production	MBbl
APROV	Input	Province	
AREGION	Input	Region number	
ARESACC	Input	Resource Access	
ARESFLAG	Input	Resource flag	
ARESID	Input	Reservoir ID number	
ARESVGAS	Variable	End of year proven natural gas reserves	MMcf
ARESVOIL	Variable	End of year proven crude oil reserves	MBbl
ARRC	Input	Railroad Commission District	
ASC	Input	Reservoir Size Class	
ASGI	Variable	Gas saturation	Percent
ASOC	Input	Current oil saturation	Percent
ASOI	Input	Initial oil saturation	Percent

ASOR	Input	Residual oil saturation	Percent
ASR_ED	Input	Number of years after economic life of ASR	
ASR_ST	Input	Number of years before economic life of ASR	
ASULFOIL	Input	Sulfur content of crude oil	%
ASWI	Input	Initial water saturation	Percent
ATCF	Variable	After tax cashflow	K\$
ATEMP	Variable	Reservoir temperature	F°
ATOTACRES	Input	Total area	Acres
ATOTCONV	Input	Number of conversions from producing wells to injecting wells per pattern	
ATOTINJ	Input	Number of new injectors drilled per pattern	
ATOTPAT	Input	Total number of patterns	
ATOTPROD	Input	Number of new producers drilled per pattern	
ATOTPS	Input	Number of primary wells converted to secondary wells per pattern	
AVDP	Input	Dykstra Parsons coefficient	
AWATINJ	Input	Annual water injected	MBbl
AWOR	Input	Water/oil ratio	Bbl/Bbl
BAS_PLAY	Input	Basin number	
BASEGAS	Input	Base natural gas price used for normalization of capital and operating costs	\$/Mcf
BASEOIL	Input	Base crude oil price used for normalization of capital and operating costs	K\$
BSE_AVAILCO2	Variable	Base annual volume of CO <sub>2</sub> available by region	Bcf
CAP_BASE	Variable	Capital to be depreciated	K\$
CAPMUL	Input	Capital constraints multiplier	
CATCF	Variable	Cumulative discounted cashflow	K\$
CHG_ANNSEC_FAC	Input	Change in annual secondary operating cost	Fraction
CHG_CHMPNT_FAC	Input	Change in chemical handling plant cost	Fraction
CHG_CMP_FAC	Input	Change in compression cost	Fraction
CHG_CO2PNT_FAC	Input	Change in CO <sub>2</sub> injection/recycling plant cost	Fraction
CHG_COMP_FAC	Input	Change in completion cost	Fraction
CHG_DRL_FAC	Input	Change in drilling cost	Fraction
CHG_FAC_FAC	Input	Change in facilities cost	Fraction

CHG_FACUPG_FAC	Input	Change in facilities upgrade cost	Fraction
CHG_FOAM_FAC	Input	Change in fixed annual O & M cost	Fraction
CHG_GNA_FAC	Input	Change in G & A cost	Fraction
CHG_INJC_FAC	Input	Change in injection cost	Fraction
CHG_INJCONV_FAC	Input	Change in injector conversion cost	Fraction
CHG_INJT_FAC	Input	Change in injectant cost	Fraction
CHG_LFT_FAC	Input	Change in lifting cost	Fraction
CHG_OGAS_FAC	Input	Change in natural gas O & M cost	K\$
CHG_OINJ_FAC	Input	Change in injection O & M cost	K\$
CHG_OOIL_FAC	Input	Change in oil O & M cost	K\$
CHG_OWAT_FAC	Input	Change in water O & M cost	K\$
CHG_PLYPNT_FAC	Input	Change in polymer handling plant cost	Fraction
CHG_PRDWAT_FAC	Input	Change in produced water handling plant cost	Fraction
CHG_SECWRK_FAC	Input	Change in secondary workover cost	Fraction
CHG_SECCONV_FAC	Input	Change in secondary conversion cost	Fraction
CHG_STM_FAC	Input	Change in stimulation cost	Fraction
CHG_STMGEN_FAC	Input	Change in steam generation and distribution cost	Fraction
CHG_VOAM_FAC	Input	Change in variable O & M cost	Fraction
.CHG_WRK_FAC	Input	Change in workover cost	Fraction
CHM_F	Variable	Cost for a chemical handling plant	K\$
CHMA	Input	Chemical handling plant	
CHMB	Input	Chemical handling plant	
CHMK	Input	Chemical handling plant	
CIDC	Input	Capitalize intangible drilling costs	K\$
CO2_F	Variable	Cost for a CO <sub>2</sub> recycling/injection plant	K\$
CO2_RAT_FAC	Input	CO <sub>2</sub> injection factor	
CO2AVAIL	Variable	Total CO <sub>2</sub> available in a region across all sources	Bcf/Yr
CO2BASE	Input	Total Volume of CO <sub>2</sub> Available	Bcf/Yr
CO2COST	Variable	Final cost for CO <sub>2</sub>	\$/Mcf

CO2B	Input	Constant and coefficient for natural CO <sub>2</sub> cost equation	
CO2K	Input	Constant and coefficient for natural CO <sub>2</sub> cost equation	
CO2MUL	Input	CO <sub>2</sub> availability constraint multiplier	
CO2OAM	Variable	CO <sub>2</sub> variable O & M cost	K\$
CO2OM_20	Input	The O & M cost for CO <sub>2</sub> injection < 20 MMcf	K\$
CO2OM20	Input	The O & M cost for CO <sub>2</sub> injection > 20 MMcf	K\$
CO2PR	Input	State/regional multipliers for natural CO <sub>2</sub> cost	
CO2PRICE	Input	CO <sub>2</sub> price	\$/Mcf
CO2RK, CO2RB	Input	CO <sub>2</sub> recycling plant cost	K\$
CO2ST	Input	State code for natural CO <sub>2</sub> cost	
COI	Input	Capitalize other intangibles	
COMP	Variable	Compressor cost	K\$
COMP_OAM	Variable	Compressor O & M cost	K\$
COMP_VC	Input	Compressor O & M costs	K\$
COMP_W	Variable	Compression cost to bring natural gas up to pipeline pressure	K\$
COMYEAR_FAC	Input	Number of years of technology commercialization for the penetration curve	Years
CONTIN_FAC	Input	Continuity increase factor	
COST_BHP	Input	Compressor Cost	\$/Bhp
COTYPE	Variable	CO <sub>2</sub> source, either industrial or natural	
CPI_2003	Variable	CPI conversion for 2003\$	
CPI_2005	Variable	CPI conversion for 2005\$	
CPI_AVG	Input	Average CPI from 1990 to 2010	
CPI_FACTOR	Input	CPI factor from 1990 to 2010	
CPI_YEAR	Input	Year for CPI index	
CREDAMT	Input	Flag that allows AMT to be credited in future years	
CREGPR	Input	The CO <sub>2</sub> price by region and source	\$/Mcf
CST_ANNSEC_FAC	Input	Well level cost to apply secondary producer technology	K\$
CST_ANNSEC_CSTP	Variable	Project level cost to apply secondary producer technology	K\$

CST_CMP_CSTP	Variable	Project level cost to apply compression technology	K\$
CST_CMP_FAC	Input	Well level cost to apply compression technology	K\$
CST_COMP_FAC	Input	Well level cost to apply completion technology	K\$
CST_COMP_CSTP	Variable	Project level cost to apply completion technology	K\$
CST_DRL_FAC	Input	Well level cost to apply drilling technology	K\$
CST_DRL_CSTP	Variable	Project level cost to apply drilling technology	K\$
CST_FAC_FAC	Input	Well level cost to apply facilities technology	K\$
CST_FAC_CSTP	Variable	Project level cost to apply facilities technology	K\$
CST_FACUPG_FAC	Input	Well level cost to apply facilities upgrade technology	K\$
CST_FACUPG_CSTP	Variable	Project level cost to apply facilities upgrade technology	K\$
CST_FOAM_FAC	Input	Well level cost to apply fixed annual O & M technology	K\$
CST_FOAM_CSTP	Variable	Project level cost to apply fixed annual O & M technology	K\$
CST_GNA_FAC	Input	Well level cost to apply G & A technology	K\$
CST_GNA_CSTP	Variable	Project level cost to apply G & A technology	K\$
CST_INJC_FAC	Input	Well level cost to apply injection technology	K\$
CST_INJC_CSTP	Variable	Project level cost to apply injection technology	K\$
CST_INJCONV_FAC	Input	Well level cost to apply injector conversion technology	K\$
CST_INJCONV_CSTP	Variable	Project level cost to apply injector conversion technology	K\$
CST_LFT_FAC	Input	Well level cost to apply lifting technology	K\$
CST_LFT_CSTP	Variable	Project level cost to apply lifting technology	K\$
CST_SECCONV_FAC	Input	Well level cost to apply secondary conversion technology	K\$

CST_SECCONV_CSTP	Variable	Project level cost to apply secondary conversion technology	K\$
CST_SECWRK_FAC	Input	Well level cost to apply secondary workover technology	K\$
CST_SECWRK_CSTP	Variable	Project level cost to apply secondary workover technology	K\$
CST_STM_FAC	Input	Well level cost to apply stimulation technology	K\$
CST_STM_CSTP	Variable	Project level cost to apply stimulation technology	K\$
CST_VOAM_FAC	Input	Well level cost to apply variable annual O & M technology	K\$
CST_VOAM_CSTP	Variable	Project level cost to apply variable annual O & M technology	K\$
CST_WRK_FAC	Input	Well level cost to apply workover technology	K\$
CST_WRK_CSTP	Variable	Project level cost to apply workover technology	K\$
CSTP_ANNSEC_FAC	Input	Project level cost to apply secondary producer technology	K\$
CSTP_CMP_FAC	Input	Project level cost to apply compression technology	K\$
CSTP_COMP_FAC	Input	Project level cost to apply completion technology	K\$
CSTP_DRL_FAC	Input	Project level cost to apply drilling technology	K\$
CSTP_FAC_FAC	Input	Project level cost to apply facilities technology	K\$
CSTP_FACUPG_FAC	Input	Project level cost to apply facilities upgrade technology	K\$
CSTP_FOAM_FAC	Input	Project level cost to apply fixed annual O & M technology	K\$
CSTP_GNA_FAC	Input	Project level cost to apply G & A technology	K\$
CSTP_INJC_FAC	Input	Project level cost to apply injection technology	K\$
CSTP_INJCONV_FAC	Input	Project level cost to apply injector conversion technology	K\$
CSTP_LFT_FAC	Input	Project level cost to apply lifting technology	K\$

CSTP_SECCONV_FAC	Input	Project level cost to apply secondary conversion technology	K\$
CSTP_SECWRK_FAC	Input	Project level cost to apply secondary workover technology	K\$
CSTP_STM_FAC	Input	Project level cost to apply stimulation technology	K\$
CSTP_VOAM_FAC	Input	Project level cost to apply variable annual O & M technology	K\$
CSTP_WRK_FAC	Input	Project level cost to apply workover technology	K\$
CUTOIL	Input	Base crude oil price for the adjustment term of price normalization	\$/Bbl
DATCF	Variable	Discounted cashflow after taxes	K\$
DEP_CRD	Variable	Depletion credit	K\$
DEPLET	Variable	Depletion allowance	K\$
DEPR	Variable	Depreciation amount	K\$
DEPR_OVR	Input	Annual fraction to depreciate	
DEPR_PROC	Input	Process number for override schedule	
DEPR_YR	Input	Number of years for override schedule	
DEPRSCHL	Input	Annual Fraction Depreciated	Fraction
DEPR_SCH	Variable	Process specific depreciation schedule	Years
DGGLA	Variable	Depletion base (G & G and lease acquisition cost)	K\$
DISC_DRL	Variable	Discounted drilling cost	K\$
DISC_FED	Variable	Discounted federal tax payments	K\$
DISC_GAS	Variable	Discounted revenue from natural gas sales	K\$
DISC_INV	Variable	Discounted investment rate	K\$
DISC_NDRL	Variable	Discounted project facilities costs	K\$
DISC_OAM	Variable	Discounted O & M cost	K\$
DISC_OIL	Variable	Discounted revenue from crude oil sales	K\$
DISC_ROY	Variable	Discounted royalty	K\$
DISC_ST	Variable	Discounted state tax rate	K\$
DISCLAG	Input	Number of years between discovery and first production	
DISCOUNT_RT	Input	Process discount rates	Percent

DRCAP_D	Variable	Regional dual use drilling footage for crude oil and natural gas development	Ft
DRCAP_G	Variable	Regional natural gas well drilling footage constraints	Ft
DRCAP_O	Variable	Regional crude oil well drilling footage constraints	Ft
DRILL_FAC	Input	Drilling rate factor	
DRILL_OVER	Input	Drilling constraints available for footage over run	%
DRILL_RES	Input	Development drilling constraints available for transfer between crude oil and natural gas	%
DRILL_TRANS	Input	Drilling constraints transfer between regions	%
DRILLCST	Variable	Drill cost by project	K\$
DRILL48	Variable	Successful well drilling costs	1987\$ per well
DRL_CST	Variable	Drilling cost	K\$
DRY_CST	Variable	Dryhole drilling cost	K\$
DRY_DWCA	Estimated	Dryhole well cost	K\$
DRY_DWCB	Estimated	Dryhole well cost	K\$
DRY_DWCC	Estimated	Dryhole well cost	K\$
DRY_DWCD	Input	Maximum depth range for dry well drilling cost equations	Ft
DRY_DWCK	Estimated	Constant for dryhole drilling cost equation	
DRY_DWCM	Input	Minimum depth range for dry well drilling equations	Ft
DRY_W	Variable	Cost to drill a dry well	K\$
DRYCST	Variable	Dryhole cost by project	K\$
DRYL48	Variable	Dry well drilling costs	1987\$ per well
DRYWELLL48	Variable	Dry Lower 48 onshore wells drilled	Wells
DWC_W	Variable	Cost to drill and complete a crude oil well	K\$
EADGGLA	Variable	G&G and lease acquisition cost depletion	K\$
EADJGROSS	Variable	Adjusted revenue	K\$
EAMINT	Variable	Alternative minimum tax	K\$
EAMOR	Variable	Amortization	K\$
EAOAM	Variable	Fixed annual operating cost	K\$
EATCF	Variable	After tax cash flow	K\$
ECAP_BASE	Variable	Depreciable/capitalized base	K\$

ECATCF	Variable	Cumulative discounted after tax cashflow	K\$
ECO2CODE	Variable	CO <sub>2</sub> source code	
ECO2COST	Variable	CO <sub>2</sub> cost	K\$
ECO2INJ	Variable	Economic CO <sub>2</sub> injection	Bcf/Yr
ECO2LIM	Variable	Source specific project life for CO <sub>2</sub> EOR projects	
ECO2POL	Variable	Injected CO <sub>2</sub>	MMcf
ECO2RANKVAL	Variable	Source specific ranking value for CO <sub>2</sub> EOR projects	
ECO2RCY	Variable	CO <sub>2</sub> recycled	Bcf/Yr
ECOMP	Variable	Compressor tangible capital	K\$
EDATCF	Variable	Discounted after tax cashflow	K\$
EDEP_CRD	Variable	Adjustment to depreciation base for federal tax credits	K\$
EDEPGGLA	Variable	Depletable G & G/lease cost	K\$
EDEPLET	Variable	Depletion	K\$
EDEPR	Variable	Depreciation	K\$
EDGGLA	Variable	Depletion base	K\$
EDRYHOLE	Variable	Number of dryholes drilled	
EEC	Input	Expensed environmental costs	K\$
EEGGLA	Variable	Expensed G & G and lease acquisition cost	K\$
EEORTCA	Variable	Tax credit addback	K\$
EEXIST_ECAP	Variable	Environmental existing capital	K\$
EEXIST_EOAM	Variable	Environmental existing O & M costs	K\$
EFEDCR	Variable	Federal tax credits	K\$
EFEDROY	Variable	Federal royalty	K\$
EFEDTAX	Variable	Federal tax	K\$
EFOAM	Variable	CO <sub>2</sub> FOAM cost	K\$
EGACAP	Variable	G & A capitalized	K\$
EGAEXP	Variable	G & A expensed	K\$
EGASPRICE2	Variable	Natural gas price used in the economics	K\$
EGG	Variable	Expensed G & G cost	K\$
EGGLA	Variable	Expensed G & G and lease acquisition cost	K\$
EGGLAADD	Variable	G & G/lease addback	K\$
EGRAVADJ	Variable	Gravity adjustment	K\$
EGREMRES	Variable	Remaining proven natural gas reserves	Bcf
EGROSSREV	Variable	Gross revenues	K\$
EIA	Variable	Environmental intangible addback	K\$

EICAP	Variable	Environmental intangible capital	
EICAP2	Variable	Environmental intangible capital	
EIGEN	Variable	Number of steam generators	
EIGREMRES	Variable	Remaining inferred natural gas reserves	Bcf
EII	Variable	Intangible investment	K\$
EIIDRL	Variable	Intangible investment drilling	K\$
EINJCOST	Variable	CO <sub>2</sub> /Polymer cost	K\$
EINJDR	Variable	New injection wells drilled per year	
EINJWELL	Variable	Active injection wells per year	
EINTADD	Variable	Intangible addback	K\$
EINTCAP	Variable	Tangible investment drilling	K\$
EINVEFF	Variable	Investment efficiency	
EIREMRES	Variable	Remaining inferred crude oil reserves	MMBbl
EITC	Input	Environmental intangible tax credit	K\$
EITCAB	Input	Environmental intangible tax credit rate addback	%
EITCR	Input	Environmental intangible tax credit rate	K\$
ELA	Variable	Lease and acquisition cost	K\$
ELYRGAS	Variable	Last year of historical natural gas production	MMcf
ELYROIL	Variable	Last year of historical crude oil production	MBbl
ENETREV	Variable	Net revenues	K\$
ENEW_ECAP	Variable	Environmental new capital	K\$
ENEW_EOAM	Variable	Environmental new O & M costs	K\$
ENIAT	Variable	Net income after taxes	K\$
ENIBT	Variable	Net income before taxes	K\$
ENPV	Variable	Net present value	K\$
ENV_FAC	Input	Environmental capital cost multiplier	
ENVOP_FAC	Input	Environmental operating cost multiplier	
ENVSCN	Input	Include environmental costs?	
ENYRSI	Variable	Number of years project is economic	
EOAM	Variable	Variable operating and maintenance	K\$

EOCA	Variable	Environmental operating cost addback	K\$
EOCTC	Input	Environmental operating cost tax credit	K\$
EOCTCAB	Input	Environmental operating cost tax credit rate addback	%
EOCTCR	Input	Environmental operating cost tax credit rate	K\$
EOILPRICE2	Variable	Crude oil price used in the economics	K\$
EORTC	Input	EOR tax credit	K\$
EORTCA	Variable	EOR tax credit addback	K\$
EORTCAB	Input	EOR tax credit rate addback	%
EORTCP	Input	EOR tax credit phase out crude oil price	K\$
EORTCR	Input	EOR tax credit rate	K\$
EORTCRP	Input	EOR tax credit applied by year	%
EOTC	Variable	Other tangible capital	K\$
EPROC_OAM	Variable	Natural gas processing cost	K\$
EPRODDR	Variable	New production wells drilled per year	
EPRODGAS	Variable	Economic natural gas production	MMcf
EPRODOIL	Variable	Economic crude oil production	MBbl
EPRODWAT	Variable	Economic water production	MBbl
EPRODWELL	Variable	Active producing wells per year	
EREMRES	Variable	Remaining proven crude oil reserves	MMBbl
EROR	Variable	Rate of return	
EROY	Variable	Royalty	K\$
ESEV	Variable	Severance tax	K\$
ESHUTIN	Variable	New shut in wells drilled per year	
ESTIM	Variable	Stimulation cost	K\$
ESTTAX	Variable	State tax	K\$
ESUMP	Variable	Number of patterns	
ESURFVOL	Variable	Total volume injected	MMcf/ MBbl/ MLbs
ETAXINC	Variable	Net income before taxes	K\$
ETCADD	Variable	Tax credit addbacks taken from NIAT	K\$
ETCI	Variable	Federal tax credit	K\$
ETCIADJ	Variable	Adjustment for federal tax credit	K\$

ETI	Variable	Tangible investments	K\$
ETOC	Variable	Total operating cost	K\$
ETORECY	Variable	CO <sub>2</sub> /Surf/Steam recycling volume	Bcf/MBbl/Yr
ETORECY_CST	Variable	CO <sub>2</sub> /Surf/Steam recycling cost	Bcf/MBbl/Yr cost
ETTC	Input	Environmental tangible tax credit	K\$
ETTCAB	Input	Environmental tangible tax credit rate addback	%
ETTCR	Input	Environmental tangible tax credit rate	K\$
EWATINJ	Variable	Economic water injected	MBbl
EX_CONRES	Variable	Number of exploration reservoirs	
EX_FCRES	Variable	First exploration reservoir	
EXIST_ECAP	Variable	Existing environmental capital cost	K\$
EXIST_EOAM	Variable	Existing environmental O & M cost	K\$
EXP_ADJ	Input	Fraction of annual crude oil exploration drilling which is made available	Fraction
EXP_ADJG	Input	Fraction of annual natural gas exploration drilling which is made available	Fraction
EXPA0	Estimated	Crude oil exploration well footage A0	
EXPA1	Estimated	Crude oil exploration well footage A1	
EXPAG0	Input	Natural gas exploration well footage A0	
EXPAG1	Input	Natural gas exploration well footage A1	
EXPATN	Variable	Number of active patterns	
EXPCDRCAP	Variable	Regional conventional exploratory drilling footage constraints	Ft
EXPCDRCAPG	Variable	Regional conventional natural gas exploration drilling footage constraint	Ft
EXPGG	Variable	Expensed G & G cost	K\$
EXPL_FRAC	Input	Exploration drilling for conventional crude oil	%
EXPL_FRACG	Input	Exploration drilling for conventional natural gas	%

EXPL_MODEL	Input	Selection of exploration models	
EXPLA	Variable	Expensed lease purchase costs	K\$
EXPLR_FAC	Input	Exploration factor	
EXPLR_CHG	Variable	Change in exploration rate	
EXPLSORTIRES	Variable	Sort pointer for exploration	
EXPMUL	Input	Exploration constraint multiplier	
EXPRDL48	Variable	Expected Production	Oil-MMB Gas-BCF
EXPUDRCAP	Variable	Regional continuous exploratory drilling footage constraints	Ft
EXPUDRCAPG	Variable	Regional continuous natural gas exploratory drilling footage constraints	Ft
FAC_W	Variable	Facilities upgrade cost	K\$
FACOST	Variable	Facilities cost	K\$
FACGA	Estimated	Natural gas facilities costs	
FACGB	Estimated	Natural gas facilities costs	
FACGC	Estimated	Natural gas facilities costs	
FACGD	Input	Maximum depth range for natural gas facilities costs	Ft
FACGK	Estimated	Constant for natural gas facilities costs	
FACGM	Input	Minimum depth range for natural gas facilities costs	Ft
FACUPA	Estimated	Facilities upgrade cost	
FACUPB	Estimated	Facilities upgrade cost	
FACUPC	Estimated	Facilities upgrade cost	
FACUPD	Input	Maximum depth range for facilities upgrade cost	Ft
FACUPK	Estimated	Constant for facilities upgrade costs	
FACUPM	Input	Minimum depth range for facilities upgrade cost	Ft
FCO2	Variable	Cost multiplier for natural CO <sub>2</sub>	
FEDRATE	Input	Federal income tax rate	Percent
FEDTAX	Variable	Federal tax	K\$
FEDTAX_CR	Variable	Federal tax credits	K\$
FIRST_ASR	Variable	First year a decline reservoir will be considered for ASR	
FIRST_DEC	Variable	First year a decline reservoir will be considered for EOR	

FIRSTCOM_FAC	Input	First year of commercialization for technology on the penetration curve	
FIT	Variable	Federal income tax	K\$
FOAM	Variable	CO <sub>2</sub> fixed O & M cost	K\$
FOAMG_1	Variable	Fixed annual operating cost for natural gas 1	K\$
FOAMG_2	Variable	Fixed annual operating cost for natural gas 2	K\$
FOAMG_W	Variable	Fixed operating cost for natural gas wells	K\$
FGASPRICE	Input	Fixed natural gas price	\$/MCF
FOILPRICE	Input	Fixed crude oil price	\$/BBL
FPLY	Variable	Cost multiplier for polymer	
FPRICE	Input	Selection to use fixed prices	
FR1L48	Variable	Finding rates for new field wildcat drilling	Oil-MMB per well Gas-BCF per well
FR2L48	Variable	Finding rates for other exploratory drilling	Oil-MMB per well Gas-BCF per well
FR3L48	Variable	Finding rates for developmental drilling	Oil-MMB per well Gas-BCF per well
FRAC_CO2	Variable	Fraction of CO <sub>2</sub>	Fraction
FRAC_H2S	Variable	Fraction of hydrogen sulfide	Fraction
FRAC_N2	Variable	Fraction of nitrogen	Fraction
FRAC_NGL	Variable	NGL yield	Fraction
FWC_W	Variable	Natural gas facilities costs	K\$
GA_CAP	Variable	G & A on capital	K\$
GA_EXP	Variable	G & A on expenses	K\$
GAS_ADJ	Input	Fraction of annual natural gas drilling which is made available	Fraction
GAS_CASE	Input	Filter for all natural gas processes	
GAS_DWCA	Estimated	Horizontal natural gas drilling and completion costs	
GAS_DWCB	Estimated	Horizontal natural gas drilling and completion costs	
GAS_DWCC	Estimated	Horizontal natural gas drilling and completion costs	

GAS_DWCD	Input	Maximum depth range for natural gas well drilling cost equations	Ft
GAS_DWCK	Estimated	Constant for natural gas well drilling cost equations	
GAS_DWCM	Input	Minimum depth range for natural gas well drilling cost equations	Ft
GAS_FILTER	Input	Filter for all natural gas processes	
GAS_OAM	Input	Process specific operating cost for natural gas production	\$/Mcf
GAS_SALES	Input	Will produced natural gas be sold?	
GASA0	Estimated	Natural gas footage A0	
GASA1	Estimated	Natural gas footage A1	
GASD0	Input	Natural gas drywell footage A0	
GASD1	Input	Natural gas drywell footage A1	
GASPRICE2	Variable	Natural gas price dummy to shift price track	K\$
GASPRICEC	Variable	Annual natural gas prices used by cashflow	K\$
GASPRICED	Variable	Annual natural gas prices used in the drilling constraints	K\$
GASPRICEO	Variable	Annual natural gas prices used by the model	K\$
GASPROD	Variable	Annual natural gas production	MMcf
GG	Variable	G & G cost	K\$
GG_FAC	Input	G & G factor	
GGCTC	Input	G & G tangible depleted tax credit	K\$
GGCTCAB	Input	G & G tangible tax credit rate addback	%
GGCTCR	Input	G & G tangible depleted tax credit rate	K\$
GGETC	Input	G & G intangible depleted tax credit	K\$
GGETCAB	Input	G & G intangible tax credit rate addback	%
GGETCR	Input	G & G intangible depleted tax credit rate	K\$
GGLA	Variable	G & G and lease acquisition addback	K\$
GMULT_INT	Input	Natural gas price adjustment factor, intangible costs	K\$

GMULT_OAM	Input	Natural gas price adjustment factor, O & M	K\$
GMULT_TANG	Input	Natural gas price adjustment factor, tangible costs	K\$
GNA_CAP2	Input	G & A capital multiplier	Fraction
GNA_EXP2	Input	G & A expense multiplier	Fraction
GPROD	Variable	Well level natural gas production	MMcf
GRAVPEN	Variable	Gravity penalty	K\$
GREMRES	Variable	Remaining proven natural gas reserves	MMcf
GROSS_REV	Variable	Gross revenue	K\$
H_GROWTH	Input	Horizontal growth rate	Percent
H_PERCENT	Input	Crude oil constraint available for horizontal drilling	%
H_SUCCESS	Input	Horizontal development well success rate by region	%
H2SPRICE	Input	H <sub>2</sub> S price	\$/Metric ton
HOR_ADJ	Input	Fraction of annual horizontal drilling which is made available	Fraction
HOR_VERT	Input	Split between horizontal and vertical drilling	
HORMUL	Input	Horizontal drilling constraint multiplier	
IAMORYR	Input	Number of years in default amortization schedule	
ICAP	Variable	Other intangible costs	K\$
ICST	Variable	Intangible cost	K\$
IDCA	Variable	Intangible drilling capital addback	K\$
IDCTC	Input	Intangible drilling cost tax credit	K\$
IDCTCAB	Input	Intangible drilling cost tax credit rate addback	%
IDCTCR	Input	Intangible drilling cost tax credit rate	K\$
IDEPRYR	Input	Number of years in default depreciation schedule	
IGREMRES	Variable	Remaining inferred natural gas reserves	MMcf
II_DRL	Variable	Intangible drilling cost	K\$
IINFARV	Variable	Initial inferred AD gas reserves	Bcf
IINFRESV	Variable	Initial inferred reserves	MMBbl
IMP_CAPCR	Input	Capacity for NGL cryogenic expander plant	MMcf/D

IMP_CAPST	Input	Capacity for NGL straight refrigeration	MMcf/D
IMP_CAPSU	Input	Capacity for Claus Sulfur Recovery	Long ton/day
IMP_CAPTE	Input	Natural gas processing plant capacity	MMcf/D
IMP_CO2_LIM	Input	Limit on CO <sub>2</sub> in natural gas	Fraction
IMP_DIS_RATE	Input	Discount rate for natural gas processing plant	
IMP_H2O_LIM	Input	Limit on H <sub>2</sub> O in natural gas	Fraction
IMP_H2S_LIM	Input	Limit on H <sub>2</sub> S in natural gas	Fraction
IMP_N2_LIM	Input	Limit on N <sub>2</sub> in natural gas	Fraction
IMP_NGL_LIM	Input	Limit on NGL in natural gas	Fraction
IMP_OP_FAC	Input	Natural gas processing operating factor	
IMP_PLT_LFE	Input	Natural gas processing plant life	Years
IMP_THRU	Input	Throughput	
IND_SRCCO2	Input	Use industrial source of CO <sub>2</sub> ?	
INDUSTRIAL	Variable	Natural or industrial CO <sub>2</sub> source	
INFLFAC	Input	Annual Inflation Factor	
INFR_ADG	Input	Adjustment factor for inferred AD gas reserves	Tcf
INFR_CBM	Input	Adjustment factor for inferred coalbed methane reserves	Tcf
INFR_DNAG	Input	Adjustment factor for inferred deep non-associated gas reserves	Tcf
INFR_OIL	Input	Adjustment factor for inferred crude oil reserves	Bbl?
INFR_SHL	Input	Adjustment factor for inferred shale gas reserves	Tcf
INFR_SNAG	Input	Adjustment factor for inferred shallow non-associated gas reserves	Tcf
INFR_THT	Input	Adjustment factor for inferred tight gas reserves	Tcf
INFARSV	Variable	Inferred AD gas reserves	Bcf
INFRESV	Variable	Inferred reserves, crude oil or natural gas	MMBbl, Bcf
INJ	Variable	Injectant cost	K\$
INJ_OAM	Input	Process specific operating cost for injection	\$/Bbl
INJ_RATE_FAC	Input	Injection rate increase	fraction
INTADD	Variable	Total intangible addback	K\$
INTANG_M	Variable	Intangible cost multiplier	

INTCAP	Variable	Intangible to be capitalized	K\$
INVCAP	Variable	Annual total capital investments constraints, used for constraining projects	MMS\$
IPDR	Input	Independent producer depletion rate	
IRA	Input	Max alternate minimum tax reduction for independents	K\$
IREMRES	Variable	Remaining inferred crude oil reserves	MBbl
IUNDARES	Variable	Initial undiscovered resource	MMBbl/Tcf
IUNDRES	Variable	Initial undiscovered resource	MMBbl/Tcf
L48B4YR	Input	First year of analysis	
LA	Variable	Lease and acquisition cost	K\$
LACTC	Input	Lease acquisition tangible depleted tax credit	K\$
LACTCAB	Input	Lease acquisition tangible credit rate addback	%
LACTCR	Input	Lease acquisition tangible depleted tax credit rate	K\$
LAETC	Input	Lease acquisition intangible expensed tax credit	K\$
LAETCAB	Input	Lease acquisition intangible tax credit rate addback	%
LAETCR	Input	Lease acquisition intangible expensed tax credit rate	K\$
LAST_ASR	Variable	Last year a decline reservoir will be considered for ASR	
LAST_DEC	Variable	Last year a decline reservoir will be considered for EOR	
LBC_FRAC	Input	Lease bonus fraction	Fraction
LEASCST	Variable	Lease cost by project	K\$
LEASL48	Variable	Lease equipment costs	1987\$/well
MARK_PEN_FAC	Input	Ultimate market penetration	
MAXWELL	Input	Maximum number of dryholes per play per year	
MAX_API_CASE	Input	Maximum API gravity	
MAX_DEPTH_CASE	Input	Maximum depth	
MAX_PERM_CASE	Input	Maximum permeability	
MAX_RATE_CASE	Input	Maximum production rate	
MIN_API_CASE	Input	Minimum API gravity	
MIN_DEPTH_CASE	Input	Minimum depth	
MIN_PERM_CASE	Input	Minimum permeability	
MIN_RATE_CASE	Input	Minimum production rate	
MOB_RAT_FAC	Input	Change in mobility ratio	
MPRD	Input	Maximum depth range for new producer equations	Ft

N_CPI	Input	Number of years	
N2PRICE	Input	N <sub>2</sub> price	\$/Mcf
NAT_AVAILCO2	Input	Annual CO <sub>2</sub> availability by region	Bcf
NAT_DMDGAS	Variable	Annual natural gas demand in region	Bcf/Yr
NAT_DRCAP_D	Variable	National dual use drilling footage for crude oil and natural gas development	Ft
NAT_DRCAP_G	Variable	National natural gas well drilling footage constraints	Ft
NAT_DRCAP_O	Variable	National crude oil well drilling footage constraints	Ft
NAT_DUAL	Variable	National dual use drilling footage for crude oil and natural gas development	Ft
NAT_EXP	Variable	National exploratory drilling constraint	Bcf/Yr
NAT_EXPC	Variable	National conventional exploratory drilling crude oil constraint	MBbl/Yr
NAT_EXPCDRCAP	Variable	National conventional exploratory drilling footage constraints	Ft
NAT_EXPCDRCAPG	Variable	National high-permeability natural gas exploratory drilling footage constraints	Ft
NAT_EXPCG	Variable	National conventional exploratory drilling natural gas constraint	Bcf/Yr
NAT_EXPG	Variable	National natural gas exploration drilling constraint	Bcf/Yr
NAT_EXPU	Variable	National continuous exploratory drilling crude oil constraint	MBbl/Yr
NAT_EXPUDRCAP	Variable	National continuous exploratory drilling footage constraints	Ft
NAT_EXPUDRCAPG	Variable	National continuous natural gas exploratory drilling footage constraints	Ft
NAT_EXPUG	Variable	National continuous exploratory drilling natural gas constraint	Bcf/Yr
NAT_GAS	Variable	National natural gas drilling constraint	Bcf/Yr
NAT_GDR	Variable	National natural gas dry drilling footage	Bcf/Yr

NAT_HGAS	Variable	Annual dry natural gas	MMcf
NAT_HOIL	Variable	Annual crude oil and lease condensates	MBbl
NAT_HOR	Variable	Horizontal drilling constraint	MBbl/Yr
NAT_INVCAP	Input	Annual total capital investment constraint	MMS\$
NAT_ODR	Variable	National crude oil dry drilling footage	MBbl/Yr
NAT_OIL	Variable	National crude oil drilling constraint	MBbl/Yr
NAT_SRCCO2	Input	Use natural source of CO <sub>2</sub> ?	
NAT_TOT	Variable	Total national footage	Ft
NET_REV	Variable	Net revenue	K\$
NEW_ECAP	Variable	New environmental capital cost	K\$
NEW_EOAM	Variable	New environmental O & M cost	K\$
NEW_NRES	Variable	New total number of reservoirs	
NGLPRICE	Input	NGL price	\$/Gal
NGLPROD	Variable	Annual NGL production	MBbl
NIAT	Variable	Net income after taxes	K\$
NIBT	Variable	Net income before taxes	K\$
NIBTA	Variable	Net operating income after adjustments before addback	K\$
NIL	Input	Net income limitations	K\$
NILB	Variable	Net income depletable base	K\$
NILL	Input	Net income limitation limit	K\$
NOI	Variable	Net operating income	K\$
NOM_YEAR	Input	Year for nominal dollars	
NPR_W	Variable	Cost to equip a new producer	K\$
NPRA	Estimated	Constant for new producer equipment	
NPRB	Estimated	Constant for new producer equipment	
NPRC	Estimated	Constant for new producer equipment	
NPRK	Estimated	Constant for new producer equipment	
NPRM	Input	Minimum depth range for new producer equations	Ft
NPROD	Variable	Well level NGL production	MMcf
NRDL48	Variable	Proved reserves added by new field discoveries	Oil-MMB Gas-BCF
NREG	Input	Number of regions	

NSHUT	Input	Number of years after economics life in which EOR can be considered	
NTECH	Input	Number of technology impacts	
NUMPACK	Input	Number of packages per play per year	
NWELL	Input	Number of wells in continuous exploration drilling package	
OAM	Variable	Variable O & M cost	K\$
OAM_COMP	Variable	Compression O & M	K\$
OAM_M	Variable	O & M cost multiplier	
OIA	Variable	Other intangible capital addback	K\$
OIL_ADJ	Input	Fraction of annual crude oil drilling which is made available	Fraction
OIL_CASE	Input	Filter for all crude oil processes	
OIL_DWCA	Estimated	Constant for crude oil well drilling cost equations	
OIL_DWCB	Estimated	Constant for crude oil well drilling cost equations	
OIL_DWCC	Estimated	Constant for crude oil well drilling cost equations	
OIL_DWCD	Input	Maximum depth range for crude oil well drilling cost equations	Ft
OIL_DWCK	Estimated	Constant for crude oil well drilling cost equations	
OIL_DWCM	Input	Minimum depth range for crude oil well drilling cost equations	Ft
OIL_FILTER	Input	Filter for all crude oil processes	
OIL_OAM	Input	Process specific operating cost for crude oil production	\$/Bbl
OIL_RAT_FAC	Input	Change in crude oil production rate	
OIL_RAT_CHG	Variable	Change in crude oil production rate	
OIL_SALES	Input	Sell crude oil produced from the reservoir?	
OILA0	Estimated	Oil footage A0	
OILA1	Estimated	Oil footage A1	

OILCO2	Input	Fixed crude oil price used for economic pre-screening of industrial CO <sub>2</sub> projects	K\$
OILD0	Input	Crude oil drywell footage A0	
OILD1	Input	Crude oil drywell footage A1	
OILPRICEC	Variable	Annual crude oil prices used by cashflow	K\$
OILPRICED	Variable	Annual crude oil prices used in the drilling constraints	K\$
OILPRICEO	Variable	Annual crude oil prices used by the model	K\$
OILPROD	Variable	Annual crude oil production	MBbl
OINJ	Variable	Well level injection	MMcf
OITC	Input	Other intangible tax credit	K\$
OITCAB	Input	Other intangible tax credit rate addback	%
OITCR	Input	Other intangible tax credit rate	K\$
OMGA	Estimated	Fixed annual cost for natural gas	\$/Well
OMGB	Estimated	Fixed annual cost for natural gas	\$/Well
OMGC	Estimated	Fixed annual cost for natural gas	\$/Well
OMGD	Input	Maximum depth range for fixed annual O & M natural gas cost	Ft
OMGK	Estimated	Constant for fixed annual O & M cost for natural gas	
OMGM	Input	Minimum depth range for fixed annual O & M cost for natural gas	Ft
OML_W	Variable	Variable annual operating cost for lifting	K\$
OMLA	Estimated	Lifting cost	\$/Well
OMLB	Estimated	Lifting cost	\$/Well
OMLC	Estimated	Lifting cost	\$/Well
OMLD	Input	Maximum depth range for fixed annual operating cost for crude oil	Ft
OMLK	Estimated	Constant for fixed annual operating cost for crude oil	
OMLM	Input	Minimum depth range for annual operating cost for crude oil	Ft
OMO_W	Variable	Fixed annual operating cost for crude oil	K\$

OMOA	Estimated	Fixed annual cost for crude oil	\$/Well
OMOB	Estimated	Fixed annual cost for crude oil	\$/Well
OMOC	Estimated	Fixed annual cost for crude oil	\$/Well
OMOD	Input	Maximum depth range for fixed annual operating cost for crude oil	Ft
OMOK	Estimated	Constant for fixed annual operating cost for crude oil	
OMOM	Input	Minimum depth range for fixed annual operating cost for crude oil	Ft
OMSWRA	Estimated	Secondary workover cost	\$/Well
OMSWRB	Estimated	Secondary workover cost	\$/Well
OMSWRC	Estimated	Secondary workover cost	\$/Well
OMSWRD	Input	Maximum depth range for variable operating cost for secondary workover	Ft
OMSWRK	Estimated	Constant for variable operating cost for secondary workover	
OMSWRM	Input	Minimum depth range for variable operating cost for secondary workover	Ft
OMULT_INT	Input	Crude oil price adjustment factor, intangible costs	
OMULT_OAM	Input	Crude oil price adjustment factor, O & M	
OMULT_TANG	Input	Crude oil price adjustment factor, tangible costs	
OPCOST	Variable	AOAM by project	K\$
OPERL48	Variable	Operating Costs	1987\$/Well
OPINJ_W	Variable	Variable annual operating cost for injection	K\$
OPINJA	Input	Injection cost	\$/Well
OPINJB	Input	Injection cost	\$/Well
OPINJC	Input	Injection cost	\$/Well
OPINJD	Input	Maximum depth range for variable annual operating cost for injection	Ft
OPINJK	Input	Constant for variable annual operating cost for injection	
OPINJM	Input	Minimum depth range for variable annual operating cost for injection	Ft

OPROD	Variable	Well level crude oil production	MBbl
OPSEC_W	Variable	Fixed annual operating cost for secondary operations	K\$
OPSECA	Estimated	Annual cost for secondary production	\$/Well
OPSECB	Estimated	Annual cost for secondary production	\$/Well
OPSECC	Estimated	Annual cost for secondary production	\$/Well
OPSECD	Input	Maximum depth range for fixed annual operating cost for secondary operations	Ft
OPSECK	Estimated	Constant for fixed annual operating cost for secondary operations	
OPSECM	Input	Minimum depth range for fixed annual operating cost for secondary operations	Ft
OPT_RPT	Input	Report printing options	
ORECY	Variable	Well level recycled injectant	MBbl
OTC	Variable	Other tangible costs	K\$
PATT_DEV	Input	Pattern development	
PATT_DEV_MAX	Input	Maximum pattern development schedule	
PATT_DEV_MIN	Input	Minimum pattern development schedule	
PATDEV	Variable	Annual number of patterns developed for base and advanced technology	
PATN	Variable	Patterns initiated each year	
PATNDCF	Variable	DCF by project	K\$
PATTERNS	Variable	Shifted patterns initiated	
PAYCONT_FAC	Input	Pay continuity factor	
PDR	Input	Percent depletion rate	%
PGGC	Input	Percent of G & G depleted	%
PIIC	Input	Intangible investment to capitalize	%
PLAC	Input	Percent of lease acquisition cost capitalized	%
PLAYNUM	Input	Play number	
PLY_F	Variable	Cost for a polymer handling plant	K\$
PLYPA	Input	Polymer handling plant constant	
PLYPK	Input	Polymer handling plant constant	

POLY	Input	Polymer cost	
POLYCOST	Variable	Polymer cost	\$/Lb
POTENTIAL	Variable	The number of reservoirs in the resource file	
PRICEYR	Input	First year of prices in price track	K\$
PRO_REGEXP	Input	Regional exploration well drilling footage constraint	Ft
PRO_REGEXP_G	Input	Regional exploration well drilling footage constraint	Ft
PRO_REGGAS	Input	Regional natural gas well drilling footage constraint	Ft
PRO_REGOIL	Input	Regional crude oil well drilling footage constraint	Ft
PROB_IMP_FAC	Input	Probability of industrial implementation	
PROB_RD_FAC	Input	Probability of successful R & D	
PROC_CST	Variable	Processing cost	\$/Mcf
PROC_OAM	Variable	Processing and treating cost	K\$
PROCESS_CASE	Input	Filter for crude oil and natural gas processes	
PROCESS_FILTER	Input	Filter for crude oil and natural gas processes	
PROD_IND_FAC	Input	Production impact	
PROVACC	Input	Year file for resource access	
PROVNUM	Input	Province number	
PRRATL48	Variable	Production to reserves ratio	Fraction
PSHUT	Input	Number of years prior to economic life in which EOR can be considered	
PSI_W	Variable	Cost to convert a primary well to an injection well	K\$
PSIA	Estimated	Cost to convert a producer to an injector	
PSIB	Estimated	Cost to convert a producer to an injector	
PSIC	Estimated	Cost to convert a producer to an injector	
PSID	Input	Maximum depth range for producer to injector	Ft
PSIK	Estimated	Constant for producer to injector	
PSIM	Input	Minimum depth range for producer to injector	Ft
PSW_W	Variable	Cost to convert a primary to secondary well	K\$

PSWA	Estimated	Cost to convert a primary to secondary well	
PSWB	Estimated	Cost to convert a primary to secondary well	
PSWC	Estimated	Cost to convert a primary to secondary well	
PSWD	Input	Maximum depth range for producer to injector	Ft
PSWK	Estimated	Constant for primary to secondary	
PSWM	Input	Minimum depth range for producer to injector	Ft
PWHP	Input	Produced water handling plant multiplier	K\$
PWP_F	Variable	Cost for a produced water handling plant	K\$
RDEPTH	Variable	Reservoir depth	ft
RDR	Input	Depth interval	
RDR_FOOTAGE	Variable	Footage available in this interval	Ft
RDR_FT	Variable	Running total of footage used in this bin	Ft
REC_EFF_FAC	Input	Recovery efficiency factor	
RECY_OIL	Input	Produced water recycling cost	K\$
RECY_WAT	Input	Produced water recycling cost	
REG_DUAL	Variable	Regional dual use drilling footage for crude oil and natural gas development	Ft
REG_EXP	Variable	Regional exploratory drilling constraints	MBbl/Yr
REG_EXPC	Variable	Regional conventional crude oil exploratory drilling constraint	MBbl/Yr
REG_EXPCG	Variable	Regional conventional natural gas exploratory drilling constraint	Bcf/Yr
REG_EXPG	Variable	Regional exploratory natural gas drilling constraint	Bcf/Yr
REG_EXPU	Variable	Regional continuous crude oil exploratory drilling constraint	MBbl/Yr
REG_EXPUG	Variable	Regional continuous natural gas exploratory drilling constraint	Bcf/Yr
REG_GAS	Variable	Regional natural gas drilling constraint	Bcf/Yr
REG_HADG	Variable	Regional historical AD gas	MMcf
REG_HCBM	Variable	Regional historical CBM	MMcf

REG_HCNV	Variable	Regional historical high-permeability natural gas	MMcf
REG_HEOIL	Variable	Regional crude oil and lease condensates for continuing EOR	MBbl
REG_HGAS	Variable	Regional dry natural gas	MMcf
REG_HOIL	Variable	Regional crude oil and lease condensates	MBbl
REG_HSHL	Variable	Regional historical shale gas	MMcf
REG_HTHT	Variable	Regional historical tight gas	MMcf
REG_NAT	Input	Regional or national	
REG_OIL	Variable	Regional crude oil drilling constraint	MBbl/Yr
REGDRY	Variable	Regional dryhole rate	
REGDRYE	Variable	Exploration regional dryhole rate	
REGDRYG	Variable	Development natural gas regional dryhole rate	
REGDRYKD	Variable	Regional dryhole rate for discovered development	
REGDRYUD	Variable	Regional dryhole rate for undiscovered development	
REGDRYUE	Variable	Regional dryhole rate for undiscovered exploration	
REGION_CASE	Input	Filter for OLOGSS region	
REGION_FILTER	Input	Filter for OLOGSS region	
REGSCALE_CBM	Input	Regional historical daily CBM gas production for the last year of history	Bcf
REGSCALE_CNV	Input	Regional historical daily high-permeability natural gas production for the last year of history	Bcf
REGSCALE_GAS	Input	Regional historical daily natural gas production for the last year of history	Bcf
REGSCALE_OIL	Input	Regional historical daily crude oil production for the last year of history	MBbl
REGSCALE_SHL	Input	Regional historical daily shale gas production for the last year of history	Bcf
REGSCALE_THT	Input	Regional historical daily tight gas production for the last year of history	Bcf
REM_AMOR	Variable	Remaining amortization base	K\$
REM_BASE	Variable	Remaining depreciation base	K\$

REMRES	Variable	Remaining proven crude oil reserves	MBbl
RESADL48	Variable	Total additions to proved reserves	Oil-MMB Gas-BCF
RESBOYL48	Variable	End of year reserves for current year	Oil-MMB Gas-BCF
RES_CHR_FAC	Input	Reservoir characterization cost	\$/Cumulative BOE
RES_CHR_CHG	Variable	Reservoir characterization cost	\$/Cumulative BOE
RESV_ADGAS	Input	Historical AD gas reserves	Tcf
RESV_CBM	Input	Historical coalbed methane reserves	Tcf
RESV_CONVGAS	Input	Historical high-permeability dry natural gas reserves	Tcf
RESV_OIL	Input	Historical crude oil and lease condensate reserves	BBbl
RESV_SHL	Input	Historical shale gas reserves	Tcf
RESV_THT	Input	Historical tight gas reserves	Tcf
RGR	Input	Annual drilling growth rate	
RIGSL48	Variable	Available rigs	Rigs
RNKVAL	Input	Ranking criteria for the projects	
ROR	Variable	Rate of return	K\$
ROYALTY	Variable	Royalty	K\$
RREG	Variable	Reservoir region	
RRR	Input	Annual drilling retirement rate	
RUNTYPE	Input	Resources selected to evaluate in the Timing subroutine	
RVALUE	Variable	Reservoir technical crude oil production	MBbl
SCALE_DAY	Input	Number of days in the last year of history	Days
SCALE_GAS	Input	Historical daily natural gas production for the last year of history	Bcf
SCALE_OIL	Input	Historical daily crude oil production for the last year of history	MBbl
SEV_PROC	Variable	Process code	
SEV_TAX	Variable	Severance tax	K\$
SFIT	Variable	Alternative minimum tax	K\$
SKIN_FAC	Input	Skin factor	
SKIN_CHG	Variable	Change in skin amount	
SMAR	Input	Six month amortization rate	%

SPLIT_ED	Input	Split exploration and development	
SPLIT_OG	Input	Split crude oil and natural gas constraints	
STARTPR	Variable	First year a pattern is initiated	
STATE_TAX	Variable	State tax	K\$
STIM	Variable	Stimulation cost	K\$
STIM_A, STIM_B	Input	Coefficients for natural gas/oil stimulation cost	K\$
STIM_W	Variable	Natural gas well stimulation cost	K\$
STIM_YR	Input	Number of years between stimulations of natural gas/oil wells	
STIMFAC	Input	Stimulation efficiency factor	
STL	Variable	State identification number	
STMGA	Input	Steam generator cost multiplier	
STMM_F	Variable	Cost for steam manifolds and generators	K\$
STMMA	Input	Steam manifold/pipeline multiplier	
SUCCHDEV	Variable	Horizontal development well success rate by region	Fraction
SUCDEVE	Input	Developmental well dryhole rate by region	%
SUCDEVG	Variable	Final developmental natural gas well success rate by region	Fraction
SUCDEVO	Variable	Final developmental crude oil well success rate by region	Fraction
SUCEXP	Input	Undiscovered exploration well dryhole rate by region	%
SUCEXPD	Input	Exploratory well dryhole rate by region	%
SUCG	Variable	Initial developmental natural gas well success rate by region	Fraction
SUCO	Variable	Initial developmental crude oil well success by region	Fraction
SUCWELL48	Variable	Successful Lower 48 onshore wells drilled	Wells
SUM_DRY	Variable	Developmental dryholes drilled	
SUM_GAS_CONV	Variable	High-permeability natural gas drilling	MMcf

SUM_GAS_UNCONV	Variable	Low-permeability natural gas drilling	MMcf
SUM_OIL_CONV	Variable	Conventional crude oil drilling	MBbl
SUM_OIL_UNCONV	Variable	Continuous crude oil drilling	MBbl
SUMP	Variable	Total cumulative patterns	
SWK_W	Variable	Secondary workover cost	K\$
TANG_FAC_RATE	Input	Percentage of the well costs which are tangible	Percent
TANG_M	Variable	Tangible cost multiplier	
TANG_RATE	Input	Percentage of drilling costs which are tangible	Percent
TCI	Variable	Total capital investments	K\$
TCIADJ	Variable	Adjusted capital investments	K\$
TCOII	Input	Tax credit on intangible investments	K\$
TCOTI	Input	Tax credit on tangible investments	K\$
TDTC	Input	Tangible development tax credit	K\$
TDTCAB	Input	Tangible development tax credit rate addback	%
TDTCR	Input	Tangible development tax credit rate	K\$
TECH01_FAC	Input	WAG ratio applied to CO2EOR	
TECH02_FAC	Input	Recovery Limit	
TECH03_FAC	Input	Vertical Skin Factor for natural gas	
TECH04_FAC	Input	Fracture Half Length	Ft
TECH05_FAC	Input	Fracture Conductivity	Ft
TECH_CO2FLD	Variable	Technical production from CO <sub>2</sub> flood	MBbl
TECH_COAL	Variable	Annual technical coalbed methane gas production	MMcf
TECH_CURVE	Variable	Technology commercialization curve for market penetration	
TECH_CURVE_FAC	Input	Technology commercialization curve for market penetration	
TECH_DECLINE	Variable	Technical decline production	MBbl
TECH_GAS	Variable	Annual technical natural gas production	MMcf
TECH_HORCON	Variable	Technical production from horizontal continuity	MBbl

TECH_HORPRF	Variable	Technical production for horizontal profile	MBbl
TECH_INFILL	Variable	Technical production from infill drilling	MBbl
TECH_NGL	Variable	Annual technical NGL production	MBbl
TECH_OIL	Variable	Annual technical crude oil production	MBbl
TECH_PLYFLD	Variable	Technical production from polymer injection	MBbl
TECH_PRFMOD	Variable	Technical production from profile modification	MBbl
TECH_PRIMARY	Variable	Technical production from primary sources	MBbl
TECH_RADIAL	Variable	Technical production from conventional radial flow	MMcf
TECH_SHALE	Variable	Annual technical shale gas production	MMcf
TECH_STMFLD	Variable	Technical production from steam flood	MBbl
TECH_TIGHT	Variable	Annual technical tight gas production	MMcf
TECH_TIGHTG	Variable	Technical tight gas production	MMcf
TECH_UCOALB	Variable	Technical undiscovered coalbed methane production	MMcf
TECH_UCONTO	Variable	Technical undiscovered continuous crude oil production	MBbl
TECH_UCONVG	Variable	Technical low-permeability natural gas production	MMcf
TECH_UCONVO	Variable	Technical undiscovered conventional crude oil production	MBbl
TECH_UGCOAL	Variable	Annual technical developing coalbed methane gas production	MMcf
TECH_UGSHALE	Variable	Annual technical developing shale gas production	MMcf
TECH_UGTIGHT	Variable	Annual technical developing tight gas production	MMcf
TECH_USHALE	Variable	Technical undiscovered shale gas production	MMcf
TECH_UTIGHT	Variable	Technical undiscovered tight gas production	MMcf
TECH_WATER	Variable	Technical production from waterflood	MBbl

TECH_WTRFLD	Variable	Technical production from waterflood	MBbl
TGGLCD	Variable	Total G & G cost	K\$
TI	Variable	Tangible costs	K\$
TI_DRL	Variable	Tangible drilling cost	K\$
TIMED	Variable	Timing flag	
TIMEDYR	Variable	Year in which the project is timed	
TOC	Variable	Total operating costs	K\$
TORECY	Variable	Annual water injection	MBbl
TORECY_CST	Variable	Water injection cost	K\$
TOTHWCAP	Variable	Total horizontal drilling footage constraint	Ft
TOTINJ	Variable	Annual water injection	MBbl
TOTMUL	Input	Total drilling constraint multiplier	
TOTSTATE	Variable	Total state severance tax	K\$
UCNT	Variable	Number of undiscovered reservoirs	
UDEPTH	Variable	Reservoir depth	K\$
UMPCO2	Input	CO <sub>2</sub> ultimate market acceptance	
UNAME	Variable	Reservoir identifier	
UNDARES	Variable	Undiscovered resource, AD gas or lease condensate	Bcf, MMBbl
UNDRES	Variable	Undiscovered resource	MMBbl, Bcf
UREG	Variable	Reservoir region	
USE_AVAILCO2	Variable	Used annual volume of CO <sub>2</sub> by region	Bcf
USE_RDR	Input	Use rig depth rating	
USEAVAIL	Variable	Used annual CO <sub>2</sub> volume by region across all sources	Bcf
USECAP	Variable	Annual total capital investment constraints, used by projects	MM\$
UVALUE	Variable	Reservoir undiscovered crude oil production	MBbl
UVALUE2	Variable	Reservoir undiscovered natural gas production	MMcf
VEORCP	Input	Volumetric EOR cutoff	%
VIALE	Variable	The number of economically viable reservoirs	
VOL_SWP_FAC	Input	Sweep volume factor	
VOL_SWP_CHG	Variable	Change in sweep volume	
WAT_OAM	Input	Process specific operating cost for water production	\$/Bbl
WATINJ	Variable	Annual water injection	MBbl

WATPROD	Variable	Annual water production	MBbl
WELL48	Variable	Lower 48 onshore wells drilled	Wells
WINJ	Variable	Well level water injection	MBbl
WPROD	Variable	Well level water production	MBbl
WRK_W	Variable	Cost for well workover	K\$
WRKA	Estimated	Constant for workover cost equations	
WRKB	Estimated	Constant for workover cost equations	
WRKC	Estimated	Constant for workover cost equations	
WRKD	Input	Maximum depth range for workover cost	Ft
WRKK	Estimated	Constant for workover cost equations	
WRKM	Input	Minimum depth range for workover cost	Ft
XCAPBASE	Variable	Cumulative cap stream	
XCUMPROD	Variable	Cumulative production	MBbl
XPATN	Variable	Active patterns each year	
XPP1	Variable	Number of new producers drilled per pattern	
XPP2	Variable	Number of new injectors drilled per pattern	
XPP3	Variable	Number of producers converted to injectors	
XPP4	Variable	Number of primary wells converted to secondary wells	
XROY	Input	Royalty rate	Percent
YEARS_STUDY	Input	Number of years of analysis	
YR1	Input	Number of years for tax credit on tangible investments	
YR2	Input	Number of years for tax credit on intangible investments	
YRDI	Input	Years to develop infrastructure	
YRDT	Input	Years to develop technology	
YRMA	Input	Years to reach full capacity	

## Appendix 2.B: Cost and Constraint Estimation

The major sections of OLOGSS consist of a series of equations that are used to calculate project economics and the development of crude oil and natural gas resources subject to the availability of regional development constraints. The cost and constraint calculation was assessed as unit costs per well. The product of the cost equation and cost adjustment factor is the actual cost. The actual cost reflects the influence on the resource, region and oil or gas price. The equations, the estimation techniques, and the statistical results for these equations are documented below. The statistical software included within Microsoft Excel was used for the estimations.

### Drilling and Completion Costs for Crude Oil

The 2004 – 2007 Joint Association Survey (JAS) data was used to calculate the equation for vertical drilling and completion costs for crude oil. The data was analyzed at a regional level. The independent variables were depth, raised to powers of 1 through 3. Drilling cost is the cost of drilling on a per well basis. Depth is also on a per well basis. The method of estimation used was ordinary least squares. The form of the equation is given below.  $\beta_1$  (the coefficient for depth raised to the first power) is statistically insignificant and is therefore assumed zero.

$$\text{Drilling Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-1)$$

where Drilling Cost = DWC\_W

$\beta_0$  = OIL\_DWCK

$\beta_1$  = OIL\_DWCA

$\beta_2$  = OIL\_DWCB

$\beta_3$  = OIL\_DWCC

from equations 2-17 and 2-18 in Chapter 2.

#### Northeast Region:

Regression Statistics	
Multiple R	0.836438789
R Square	0.699629848
Adjusted R Square	0.691168717
Standard Error	629377.1735
Observations	74

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	6.55076E+13	3.27538E+13	82.6875087	2.86296E-19
Residual	71	2.81242E+13	3.96116E+11		
Total	73	9.36318E+13			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	122428.578	126464.5594	0.968086068	0.336287616	-129734.7159	374591.8719	-129734.7159	374591.8719
$\beta_2$	0.058292022	0.020819613	2.799860932	0.006580083	0.016778872	0.099805172	0.016778872	0.099805172
$\beta_3$	5.68014E-07	2.56497E-06	0.221450391	0.825377435	-4.5464E-06	5.68243E-06	-4.5464E-06	5.68243E-06

### Gulf Coast Region:

Regression Statistics								
Multiple R	0.927059199							
R Square	0.859438758							
Adjusted R Square	0.85771408							
Standard Error	754021.7218							
Observations	166							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	5.66637E+14	2.83318E+14	498.3184388	3.55668E-70			
Residual	163	9.26734E+13	5.68549E+11					
Total	165	6.5931E+14						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	171596.0907	99591.43949	1.723000407	0.086784881	-25059.61405	368251.7955	-25059.61405	368251.7955
β2	0.026582707	0.005213357	5.098961204	9.38664E-07	0.016288283	0.036877131	0.016288283	0.036877131
β3	5.10946E-07	3.82305E-07	1.336488894	0.183252113	-2.43962E-07	1.26585E-06	-2.43962E-07	1.26585E-06

### Mid-Continent Region:

Regression Statistics								
Multiple R	0.898305188							
R Square	0.806952211							
Adjusted R Square	0.803343841							
Standard Error	865339.0638							
Observations	110							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	3.34919E+14	1.67459E+14	223.6334505	6.06832E-39			
Residual	107	8.01229E+13	7.48812E+11					
Total	109	4.15042E+14						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	44187.62539	135139.2151	0.326978556	0.744322892	-223710.0994	312085.3502	-223710.0994	312085.3502
β2	0.038468835	0.005870927	6.552429326	2.04023E-09	0.026830407	0.050107263	0.026830407	0.050107263
β3	-9.45921E-07	3.70017E-07	-2.556425591	0.011978314	-1.67944E-06	-2.12405E-07	-1.67944E-06	-2.12405E-07

### Southwest Region:

Regression Statistics								
Multiple R	0.927059199							
R Square	0.859438758							
Adjusted R Square	0.85771408							
Standard Error	754021.7218							
Observations	166							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	5.66637E+14	2.83318E+14	498.3184388	3.55668E-70			
Residual	163	9.26734E+13	5.68549E+11					
Total	165	6.5931E+14						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	171596.0907	99591.43949	1.723000407	0.086784881	-25059.61405	368251.7955	-25059.61405	368251.7955
β2	0.026582707	0.005213357	5.098961204	9.38664E-07	0.016288283	0.036877131	0.016288283	0.036877131
β3	5.10946E-07	3.82305E-07	1.336488894	0.183252113	-2.43962E-07	1.26585E-06	-2.43962E-07	1.26585E-06

### Rocky Mountain Region:

Regression Statistics	
Multiple R	0.905358855
R Square	0.819674657
Adjusted R Square	0.81505093
Standard Error	1524859.577
Observations	81

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	8.24402E+14	4.12201E+14	177.2757561	9.68755E-30
Residual	78	1.81365E+14	2.3252E+12		
Total	80	1.00577E+15			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	85843.77642	334865.8934	0.256352702	0.798353427	-580822.9949	752510.5477	-580822.9949	752510.5477
$\beta_2$	0.024046279	0.017681623	1.35995883	0.177760898	-0.011155127	0.059247685	-0.011155127	0.059247685
$\beta_3$	3.11588E-06	1.35985E-06	2.291329746	0.024643617	4.08613E-07	5.82314E-06	4.08613E-07	5.82314E-06

### West Coast Region:

Regression Statistics	
Multiple R	0.829042211
R Square	0.687310988
Adjusted R Square	0.66961161
Standard Error	1192282.08
Observations	57

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	1.65605E+14	5.52018E+13	38.83249387	2.05475E-13
Residual	53	7.53414E+13	1.42154E+12		
Total	56	2.40947E+14			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	416130.9988	739996.4118	0.562341914	0.576253925	-1068113.806	1900375.804	-1068113.806	1900375.804
$\beta_1$	44.24458907	494.4626992	0.089480135	0.929037628	-947.5219666	1036.011145	-947.5219666	1036.011145
$\beta_2$	0.032683532	0.091113678	0.35871159	0.721235869	-0.150067358	0.215434422	-0.150067358	0.215434422
$\beta_3$	3.38129E-07	4.76464E-06	0.070966208	0.94369176	-9.21853E-06	9.89479E-06	-9.21853E-06	9.89479E-06

### Northern Great Plains Region:

Regression Statistics	
Multiple R	0.847120174
R Square	0.71761259
Adjusted R Square	0.702750095
Standard Error	1967213.576
Observations	61

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	5.60561E+14	1.86854E+14	48.2834529	1.1626E-15
Residual	57	2.20586E+14	3.86993E+12		
Total	60	7.81147E+14			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	98507.54357	1384010.586	0.071175426	0.943507284	-2672925.83	2869940.917	-2672925.83	2869940.917
$\beta_1$	478.7358996	548.203512	0.873281344	0.386173991	-619.0226893	1576.494489	-619.0226893	1576.494489
$\beta_2$	-0.00832112	0.058193043	-0.142991666	0.886801051	-0.124850678	0.108208438	-0.124850678	0.108208438
$\beta_3$	6.1159E-07	1.79131E-06	0.34142064	0.7340424	-2.97545E-06	4.19863E-06	-2.97545E-06	4.19863E-06

## Drilling and Completion Cost for Oil - Cost Adjustment Factor

The cost adjustment factor for vertical drilling and completion costs for oil was calculated using JAS data through 2007. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the

price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Northeast Region:

Regression Statistics								
Multiple R	0.993325966							
R Square	0.986696475							
Adjusted R Square	0.986411399							
Standard Error	0.029280014							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	8.901997029	2.967332343	3461.175482	4.4887E-131			
Residual	140	0.120024694	0.000857319					
Total	143	9.022021723						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.309616442	0.009839962	31.46520591	2.3349E-65	0.290162308	0.329070576	0.290162308	0.329070576
$\beta_1$	0.019837121	0.000434252	45.68110123	5.41725E-86	0.018978581	0.020695661	0.018978581	0.020695661
$\beta_2$	-0.000142411	5.21769E-06	-27.29392193	6.44605E-58	-0.000152727	-0.000132095	-0.000152727	-0.000132095
$\beta_3$	3.45898E-07	1.69994E-08	20.34770764	1.18032E-43	3.1229E-07	3.79507E-07	3.1229E-07	3.79507E-07

### Gulf Coast Region:

Regression Statistics								
Multiple R	0.975220111							
R Square	0.951054265							
Adjusted R Square	0.950005428							
Standard Error	0.054224144							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	7.998414341	2.666138114	906.7701736	1.76449E-91			
Residual	140	0.411636098	0.002940258					
Total	143	8.410050438						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.404677859	0.01822279	22.2072399	1.01029E-47	0.368650426	0.440705292	0.368650426	0.440705292
$\beta_1$	0.016335847	0.000804199	20.31319148	1.41023E-43	0.014745903	0.017925792	0.014745903	0.017925792
$\beta_2$	-0.00010587	9.66272E-06	-10.95654411	1.47204E-20	-0.000124974	-8.67663E-05	-0.000124974	-8.67663E-05
$\beta_3$	2.40517E-07	3.14814E-08	7.639970947	3.10789E-12	1.78277E-07	3.02758E-07	1.78277E-07	3.02758E-07

### Mid-Continent Region:

Regression Statistics	
Multiple R	0.973577019
R Square	0.947852212
Adjusted R Square	0.94673476
Standard Error	0.058882142
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.822668656	2.940889552	848.2258794	1.4872E-89
Residual	140	0.485394925	0.003467107		
Total	143	9.308063582			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.309185338	0.019788175	15.62475232	1.738E-32	0.270063053	0.348307623	0.270063053	0.348307623
$\beta_1$	0.019036286	0.000873282	21.79856116	7.62464E-47	0.017309761	0.020762811	0.017309761	0.020762811
$\beta_2$	-0.000123667	1.04928E-05	-11.78593913	1.05461E-22	-0.000144412	-0.000102922	-0.000144412	-0.000102922
$\beta_3$	2.60516E-07	3.41858E-08	7.620611936	3.45556E-12	1.92929E-07	3.28104E-07	1.92929E-07	3.28104E-07

### Southwest Region:

Regression Statistics	
Multiple R	0.993452577
R Square	0.986948023
Adjusted R Square	0.986668338
Standard Error	0.030207623
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.66004438	3.220014793	3528.781511	1.1799E-131
Residual	140	0.127750066	0.0009125		
Total	143	9.787794446			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.293837119	0.010151698	28.944627	5.92751E-61	0.273766667	0.313907571	0.273766667	0.313907571
$\beta_1$	0.020183122	0.00044801	45.05064425	3.35207E-85	0.019297383	0.021068861	0.019297383	0.021068861
$\beta_2$	-0.000142936	5.38299E-06	-26.55334755	1.63279E-56	-0.000153579	-0.000132294	-0.000153579	-0.000132294
$\beta_3$	3.44926E-07	1.75379E-08	19.66744699	4.04901E-42	3.10253E-07	3.796E-07	3.10253E-07	3.796E-07

### Rocky Mountain Region:

Regression Statistics	
Multiple R	0.993622433
R Square	0.987285538
Adjusted R Square	0.987013086
Standard Error	0.029478386
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.446702681	3.148900894	3623.69457	1.8856E-132
Residual	140	0.121656535	0.000868975		
Total	143	9.568359216			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.297270516	0.009906628	30.00723517	7.63744E-63	0.27768458	0.316856451	0.27768458	0.316856451
$\beta_1$	0.020126228	0.000437194	46.03497443	1.9664E-86	0.019261872	0.020990585	0.019261872	0.020990585
$\beta_2$	-0.000143079	5.25304E-06	-27.23739215	8.23219E-58	-0.000153465	-0.000132693	-0.000153465	-0.000132693
$\beta_3$	3.45557E-07	1.71145E-08	20.19080817	2.6538E-43	3.1172E-07	3.79393E-07	3.1172E-07	3.79393E-07

### West Coast Region:

Regression Statistics	
Multiple R	0.993362569
R Square	0.986769193
Adjusted R Square	0.986485676
Standard Error	0.030158697
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.496912448	3.165637483	3480.455028	3.0585E-131
Residual	140	0.127336582	0.000909547		
Total	143	9.62424903			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	0.297702178	0.010135256	29.37293095	1.01194E-61	0.277664233	0.317740124	0.277664233	0.317740124
β1	0.020091425	0.000447284	44.91872099	4.92225E-85	0.019207121	0.02097573	0.019207121	0.02097573
β2	-0.000142627	5.37427E-06	-26.53879345	1.74092E-56	-0.000153252	-0.000132001	-0.000153252	-0.000132001
β3	3.44597E-07	1.75095E-08	19.68054067	3.78057E-42	3.0998E-07	3.79214E-07	3.0998E-07	3.79214E-07

### Northern Great Plains Region:

Regression Statistics	
Multiple R	0.993744864
R Square	0.987528854
Adjusted R Square	0.987261615
Standard Error	0.029293844
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.513146663	3.171048888	3695.304354	4.8762E-133
Residual	140	0.1201381	0.000858129		
Total	143	9.633284764			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	0.292784596	0.00984461	29.74059899	2.25193E-62	0.273321274	0.312247919	0.273321274	0.312247919
β1	0.020415818	0.000434457	46.99153447	1.31433E-87	0.019556872	0.021274763	0.019556872	0.021274763
β2	-0.000146385	5.22015E-06	-28.04230529	2.6131E-59	-0.000156706	-0.000136065	-0.000156706	-0.000136065
β3	3.5579E-07	1.70074E-08	20.91972526	6.3186E-45	3.22166E-07	3.89415E-07	3.22166E-07	3.89415E-07

## Drilling and Completion Costs for Natural Gas

The 2004 – 2007 JAS data was used to calculate the equation for vertical drilling and completion costs for natural gas. The data was analyzed at a regional level. The independent variable was depth. Drilling cost is the cost of drilling on a per well basis. Depth is also on a per well basis. The method of estimation used was ordinary least squares. The form of the equation is given below.

$$\text{Drilling Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-2)$$

where Drilling Cost = DWC\_W

β0 = GAS\_DWCK

β1 = GAS\_DWCA

β2 = GAS\_DWCB

β3 = GAS\_DWCC

from equations 2-24 and 2-25 in Chapter 2.

### Northeast Region:

Regression Statistics	
Multiple R	0.837701882
R Square	0.701744444
Adjusted R Square	0.694887994
Standard Error	1199562.042
Observations	90

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	2.94547E+14	1.47274E+14	102.3480792	1.39509E-23
Residual	87	1.25189E+14	1.43895E+12		
Total	89	4.19736E+14			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	197454.5012	290676.607	0.679292714	0.498755704	-380296.7183	775205.7207	-380296.7183	775205.7207
β1	19.31146768	128.263698	0.150560665	0.880670823	-235.6265154	274.2494508	-235.6265154	274.2494508
β2	0.040120878	0.009974857	4.022200679	0.000122494	0.020294769	0.059946987	0.020294769	0.059946987

### Gulf Coast Region:

Regression Statistics	
Multiple R	0.842706997
R Square	0.710155083
Adjusted R Square	0.708248209
Standard Error	2573551.438
Observations	307

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	4.93318E+15	2.46659E+15	372.4183744	1.77494E-82
Residual	304	2.01344E+15	6.62317E+12		
Total	306	6.94662E+15			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	318882.7578	272026.272	1.172249855	0.242014577	-216410.0169	854175.5325	-216410.0169	854175.5325
β2	0.019032113	0.008289474	2.295937192	0.022359763	0.002720101	0.035344125	0.002720101	0.035344125
β3	1.12638E-06	4.6744E-07	2.409676918	0.016560642	2.06552E-07	2.04621E-06	2.06552E-07	2.04621E-06

### Mid-Continent Region:

Regression Statistics	
Multiple R	0.92348831
R Square	0.852830659
Adjusted R Square	0.850494637
Standard Error	1309841.335
Observations	129

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	1.25272E+15	6.26359E+14	365.0782904	3.73674E-53
Residual	126	2.16176E+14	1.71568E+12		
Total	128	1.46889E+15			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	355178.8049	240917.4549	1.47427593	0.142901467	-121589.7497	831947.3594	-121589.7497	831947.3594
β1	54.21184769	45.96361807	1.17945127	0.240440741	-36.74880003	145.1724954	-36.74880003	145.1724954
β3	1.20269E-06	1.12352E-07	10.70467954	2.04711E-19	9.80347E-07	1.42503E-06	9.80347E-07	1.42503E-06

### Southwest Region:

Regression Statistics	
Multiple R	0.915492169
R Square	0.838125912
Adjusted R Square	0.834866702
Standard Error	1386872.99
Observations	153

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	1.48386E+15	4.94618E+14	257.1561693	1.088E-58
Residual	149	2.86589E+14	1.92342E+12		
Total	152	1.77044E+15			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	91618.176	571133.886	0.160414534	0.872771817	-1036949.89	1220186.242	-1036949.89	1220186.242
$\beta_1$	376.1968481	269.4896391	1.395960339	0.164802951	-156.3182212	908.7119175	-156.3182212	908.7119175
$\beta_2$	-0.062403125	0.034837969	-1.791238896	0.075284827	-0.131243411	0.00643716	-0.131243411	0.00643716
$\beta_3$	5.03882E-06	1.29778E-06	3.88265606	0.000154832	2.4744E-06	7.60325E-06	2.4744E-06	7.60325E-06

### Rocky Mountain Region:

Regression Statistics	
Multiple R	0.936745489
R Square	0.877492112
Adjusted R Square	0.87539796
Standard Error	2403080.549
Observations	120

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	4.83951E+15	2.41976E+15	419.0202716	4.54566E-54
Residual	117	6.75651E+14	5.7748E+12		
Total	119	5.51516E+15			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	219733.2637	346024.9678	0.635021412	0.526654367	-465551.0299	905017.5572	-465551.0299	905017.5572
$\beta_2$	0.032265399	0.013130355	2.457313594	0.015464796	0.00626142	0.058269377	0.00626142	0.058269377
$\beta_3$	2.6019E-06	7.88034E-07	3.301759413	0.001274492	1.04124E-06	4.16256E-06	1.04124E-06	4.16256E-06

### West Coast Region:

Regression Statistics	
Multiple R	0.901854712
R Square	0.813341922
Adjusted R Square	0.795564962
Standard Error	494573.0787
Observations	24

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	2.23824E+13	1.11912E+13	45.75258814	2.21815E-08
Residual	21	5.13665E+12	2.44603E+11		
Total	23	2.75191E+13			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	385532.8938	215673.5911	1.787575808	0.088286514	-62984.89058	834050.6782	-62984.89058	834050.6782
$\beta_2$	0.01799366	0.016370041	1.099182335	0.284130777	-0.016049704	0.052037025	-0.016049704	0.052037025
$\beta_3$	1.01127E-06	1.49488E-06	0.676491268	0.506112235	-2.0975E-06	4.12005E-06	-2.0975E-06	4.12005E-06

### Northern Great Plains Region:

Regression Statistics	
Multiple R	0.856130745
R Square	0.732959853
Adjusted R Square	0.706255838
Standard Error	2157271.229
Observations	23

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	2.55472E+14	1.27736E+14	27.44755272	1.84402E-06
Residual	20	9.30764E+13	4.65382E+12		
Total	22	3.48548E+14			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	267619.9291	1118552.942	0.239255487	0.813342236	-2065640.615	2600880.473	-2065640.615	2600880.473
$\beta_1$	30.61609506	550.5220307	0.055612843	0.956202055	-1117.752735	1178.984925	-1117.752735	1178.984925
$\beta_2$	0.049406678	0.035529716	1.390573371	0.179635875	-0.024707012	0.123520367	-0.024707012	0.123520367

### Drilling and Completion Cost for Gas - Cost Adjustment Factor

The cost adjustment factor for vertical drilling and completion costs for gas was calculated using JAS data through 2007. The initial cost was normalized at various prices from \$1 to \$20 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$5 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Gas Price} + \beta_2 * \text{Gas Price}^2 + \beta_3 * \text{Gas Price}^3$$

### Northeast Region:

Regression Statistics	
Multiple R	0.988234523
R Square	0.976607472
Adjusted R Square	0.976106203
Standard Error	0.03924461
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.001833192	3.000611064	1948.272332	6.4218E-114
Residual	140	0.215619522	0.001540139		
Total	143	9.217452714			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.315932281	0.013188706	23.95476038	2.2494E-51	0.289857502	0.34200706	0.289857502	0.34200706
$\beta_1$	0.195760743	0.005820373	33.63371152	6.11526E-69	0.184253553	0.207267932	0.184253553	0.207267932
$\beta_2$	-0.013906425	0.000699337	-19.88514708	1.29788E-42	-0.015289053	-0.012523798	-0.015289053	-0.012523798
$\beta_3$	0.000336178	2.27846E-05	14.75458424	2.61104E-30	0.000291131	0.000381224	0.000291131	0.000381224

### Gulf Coast Region:

Regression Statistics	
Multiple R	0.976776879
R Square	0.954093072
Adjusted R Square	0.953109352
Standard Error	0.051120145
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	7.60369517	2.534565057	969.8828784	1.98947E-93
Residual	140	0.365857688	0.002613269		
Total	143	7.969552858			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.343645899	0.017179647	20.00308313	7.02495E-43	0.309680816	0.377610983	0.309680816	0.377610983
$\beta_1$	0.190338822	0.007581635	25.10524794	1.08342E-53	0.175349523	0.205328121	0.175349523	0.205328121
$\beta_2$	-0.013965513	0.000910959	-15.33056399	9.3847E-32	-0.015766527	-0.012164498	-0.015766527	-0.012164498
$\beta_3$	0.000342962	2.96793E-05	11.55560459	4.15963E-22	0.000284285	0.00040164	0.000284285	0.00040164

### Mid-continent Region:

Regression Statistics	
Multiple R	0.973577019
R Square	0.947852212
Adjusted R Square	0.94673476
Standard Error	0.058882142
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.822668656	2.940889552	848.2258794	1.4872E-89
Residual	140	0.485394925	0.003467107		
Total	143	9.308063582			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.309185338	0.019788175	15.62475232	1.738E-32	0.270063053	0.348307623	0.270063053	0.348307623
$\beta_1$	0.019036286	0.000873282	21.79856116	7.62464E-47	0.017309761	0.020762811	0.017309761	0.020762811
$\beta_2$	-0.000123667	1.04928E-05	-11.78593913	1.05461E-22	-0.000144412	-0.000102922	-0.000144412	-0.000102922
$\beta_3$	2.60516E-07	3.41858E-08	7.620611936	3.45556E-12	1.92929E-07	3.28104E-07	1.92929E-07	3.28104E-07

### Southwest Region:

Regression Statistics	
Multiple R	0.966438524
R Square	0.934003421
Adjusted R Square	0.932589209
Standard Error	0.06631093
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.712149531	2.904049844	660.4406967	2.13407E-82
Residual	140	0.615599523	0.004397139		
Total	143	9.327749054			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.323862308	0.022284725	14.53292844	9.46565E-30	0.279804211	0.367920404	0.279804211	0.367920404
$\beta_1$	0.193832047	0.009834582	19.70923084	3.2532E-42	0.174388551	0.213275544	0.174388551	0.213275544
$\beta_2$	-0.013820723	0.001181658	-11.69604336	1.80171E-22	-0.016156924	-0.011484522	-0.016156924	-0.011484522
$\beta_3$	0.000334693	3.84988E-05	8.693602923	8.44808E-15	0.000258579	0.000410807	0.000258579	0.000410807

### Rocky Mountains Region:

Regression Statistics	
Multiple R	0.985593617
R Square	0.971394777
Adjusted R Square	0.970781808
Standard Error	0.0421446
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.444274294	2.814758098	1584.737059	8.3614E-108
Residual	140	0.248663418	0.001776167		
Total	143	8.692937712			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.32536782	0.014163288	22.97261928	2.42535E-49	0.29736624	0.353369401	0.29736624	0.353369401
$\beta_1$	0.194045615	0.006250471	31.04496067	1.21348E-64	0.181688099	0.206403131	0.181688099	0.206403131
$\beta_2$	-0.01396687	0.000751015	-18.59732564	1.18529E-39	-0.015451667	-0.012482073	-0.015451667	-0.012482073
$\beta_3$	0.000339698	2.44683E-05	13.88318297	4.22503E-28	0.000291323	0.000388073	0.000291323	0.000388073

### West Coast Region:

Regression Statistics	
Multiple R	0.994143406
R Square	0.988321112
Adjusted R Square	0.98807085
Standard Error	0.026802603
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.510960152	2.836986717	3949.147599	4.9307E-135
Residual	140	0.100573131	0.00071838		
Total	143	8.611533284			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.325917293	0.009007393	36.18330938	6.29717E-73	0.308109194	0.343725393	0.308109194	0.343725393
$\beta_1$	0.193657091	0.003975097	48.71757347	1.12458E-89	0.185798111	0.201516072	0.185798111	0.201516072
$\beta_2$	-0.013893214	0.000477621	-29.08835053	3.2685E-61	-0.014837497	-0.012948932	-0.014837497	-0.012948932
$\beta_3$	0.000337413	1.5561E-05	21.68318808	1.35414E-46	0.000306648	0.000368178	0.000306648	0.000368178

### Northern Great Plains Region:

Regression Statistics	
Multiple R	0.970035104
R Square	0.940968103
Adjusted R Square	0.939703134
Standard Error	0.057035843
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	7.259587116	2.419862372	743.8663996	8.71707E-86
Residual	140	0.455432229	0.003253087		
Total	143	7.715019345			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.352772153	0.0191677	18.40451098	3.34838E-39	0.31487658	0.390667726	0.31487658	0.390667726
$\beta_1$	0.189510541	0.008458993	22.40344064	3.85701E-48	0.172786658	0.206234423	0.172786658	0.206234423
$\beta_2$	-0.014060192	0.001016376	-13.83364754	5.65155E-28	-0.016069622	-0.012050761	-0.016069622	-0.012050761
$\beta_3$	0.000347364	3.31138E-05	10.49000322	2.34854E-19	0.000281896	0.000412832	0.000281896	0.000412832

## Drilling and Completion Costs for Dryholes

The 2004 – 2007 JAS data was used to calculate the equation for vertical drilling and completion costs for dryholes. The data was analyzed at a regional level. The independent variable was depth. Drilling cost is the cost of drilling on a per well basis. Depth is also on a per well basis. The method of estimation used was ordinary least squares. The form of the equation is given below.

$$\text{Drilling Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-3)$$

where Drilling Cost =  $DWC_W$

$\beta_0 = DRY\_DWCK$

$\beta_1 = DRY\_DWCA$

$\beta_2 = DRY\_DWCB$

$\beta_3 = DRY\_DWCC$

from equations 2-19 and 2-20 in Chapter 2.

### Northeast Region:

Regression Statistics								
Multiple R	0.913345218							
R Square	0.834199487							
Adjusted R Square	0.828851084							
Standard Error	1018952.27							
Observations	97							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	4.85819E+14	1.6194E+14	155.9716777	3.64706E-36			
Residual	93	9.65585E+13	1.03826E+12					
Total	96	5.82378E+14						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	170557.6447	323739.1839	0.526836581	0.599561475	-472323.5706	813438.8601	-472323.5706	813438.8601
$\beta_1$	256.9930321	233.0025772	1.102962187	0.272889552	-205.7034453	719.6895095	-205.7034453	719.6895095
$\beta_2$	-0.043428533	0.043117602	-1.007211224	0.31644672	-0.129051459	0.042194394	-0.129051459	0.042194394
$\beta_3$	5.9031E-06	2.11581E-06	2.789995653	0.006394574	1.70153E-06	1.01047E-05	1.70153E-06	1.01047E-05

### Gulf Coast Region:

Regression Statistics								
Multiple R	0.868545327							
R Square	0.754370985							
Adjusted R Square	0.752096642							
Standard Error	2529468.051							
Observations	328							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	6.36662E+15	2.12221E+15	331.6874692	2.10256E-98			
Residual	324	2.07302E+15	6.39821E+12					
Total	327	8.43964E+15						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	118790.7619	515360.6337	0.230500264	0.81784853	-895084.76	1132666.284	-895084.76	1132666.284
$\beta_1$	126.2333724	241.1698405	0.523421055	0.601039076	-348.2231187	600.6898634	-348.2231187	600.6898634
$\beta_2$	-0.001057252	0.0294162	-0.035941139	0.971351426	-0.058928115	0.056813612	-0.058928115	0.056813612
$\beta_3$	2.32104E-06	1.0194E-06	2.276864977	0.02344596	3.15558E-07	4.32653E-06	3.15558E-07	4.32653E-06

### Mid-Continent Region:

Regression Statistics	
Multiple R	0.80373002
R Square	0.645981944
Adjusted R Square	0.636056204
Standard Error	904657.9939
Observations	111

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	1.59789E+14	5.32631E+13	65.08149035	5.0095E-24
Residual	107	8.75695E+13	8.18406E+11		
Total	110	2.47359E+14			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	163849.8824	309404.7345	0.529564884	0.597510699	-449508.8999	777208.6646	-449508.8999	777208.6646
$\beta_1$	17.95111978	155.7546455	0.115252548	0.908460959	-290.8142902	326.7165297	-290.8142902	326.7165297
$\beta_2$	0.022715716	0.021144885	1.074288957	0.285109837	-0.019201551	0.064632983	-0.019201551	0.064632983
$\beta_3$	-3.50301E-07	7.90957E-07	-0.442882115	0.658745077	-1.91828E-06	1.21768E-06	-1.91828E-06	1.21768E-06

### Southwest Region:

Regression Statistics	
Multiple R	0.916003396
R Square	0.839062222
Adjusted R Square	0.835290243
Standard Error	734795.4183
Observations	132

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	3.60312E+14	1.20104E+14	222.4461445	1.40193E-50
Residual	128	6.91103E+13	5.39924E+11		
Total	131	4.29423E+14			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	22628.66985	252562.1046	0.089596457	0.928747942	-477108.2352	522365.5749	-477108.2352	522365.5749
$\beta_1$	262.7649266	164.1391792	1.600866581	0.111871702	-62.01224262	587.5420958	-62.01224262	587.5420958
$\beta_2$	-0.064989728	0.029352301	-2.21412721	0.02859032	-0.123068227	-0.006911229	-0.123068227	-0.006911229
$\beta_3$	6.52693E-06	1.49073E-06	4.378340081	2.46095E-05	3.57727E-06	9.4766E-06	3.57727E-06	9.4766E-06

### Rocky Mountain Region:

Regression Statistics	
Multiple R	0.908263682
R Square	0.824942917
Adjusted R Square	0.821295894
Standard Error	1868691.311
Observations	99

ANOVA					
	df	SS	MS	F	Significance F
Regression	2	1.57976E+15	7.89879E+14	226.1962739	4.70571E-37
Residual	96	3.35233E+14	3.49201E+12		
Total	98	1.91499E+15			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	288056.5506	314517.8483	0.915867103	0.362031526	-336256.4285	912369.5298	-336256.4285	912369.5298
$\beta_2$	0.018141347	0.017298438	1.048727458	0.296936644	-0.01619578	0.052478474	-0.01619578	0.052478474
$\beta_3$	3.85847E-06	1.27201E-06	3.033362592	0.003110773	1.33355E-06	6.3834E-06	1.33355E-06	6.3834E-06

## West Coast Region:

Regression Statistics	
Multiple R	0.853182771
R Square	0.727920841
Adjusted R Square	0.707514904
Standard Error	907740.218
Observations	44

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.81804E+13	2.93935E+13	35.67201271	2.18647E-11
Residual	40	3.29597E+13	8.23992E+11		
Total	43	1.2114E+14			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	106996.0572	512960.104	0.208585534	0.835830348	-929734.9747	1143727.089	-929734.9747	1143727.089
β1	687.3095347	329.4149478	2.086455212	0.043357214	21.53709715	1353.081972	21.53709715	1353.081972
β2	-0.15898723	0.058188911	-2.732259905	0.009317504	-0.276591406	-0.041383054	-0.276591406	-0.041383054
β3	1.14978E-05	2.91968E-06	3.938046272	0.000320309	5.59694E-06	1.73987E-05	5.59694E-06	1.73987E-05

## Northern Great Plains Region:

Regression Statistics	
Multiple R	0.841621294
R Square	0.708326403
Adjusted R Square	0.687977082
Standard Error	2155533.512
Observations	47

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	4.85193E+14	1.61731E+14	34.80835607	1.41404E-11
Residual	43	1.99792E+14	4.64632E+12		
Total	46	6.84985E+14			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	122507.9534	1373015.289	0.089225484	0.929317007	-2646441.235	2891457.142	-2646441.235	2891457.142
β1	345.4371452	801.6324436	0.430917122	0.668681154	-1271.20873	1962.08302	-1271.20873	1962.08302
β2	-0.014734575	0.126273194	-0.11668807	0.907650548	-0.269388738	0.239919588	-0.269388738	0.239919588
β3	3.23748E-06	5.69952E-06	0.568026219	0.572971531	-8.2567E-06	1.47317E-05	-8.2567E-06	1.47317E-05

## Drilling and Completion Cost for Dry - Cost Adjustment Factor

The cost adjustment factor for vertical drilling and completion costs for dryholes was calculated using JAS data through 2007. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Northeast Region:

Regression Statistics	
Multiple R	0.994846264
R Square	0.989719089
Adjusted R Square	0.989498783
Standard Error	0.026930376
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.774469405	3.258156468	4492.489925	6.5663E-139
Residual	140	0.101534319	0.000725245		
Total	143	9.876003725			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.290689859	0.009050333	32.11924425	1.85582E-66	0.272796865	0.308582854	0.272796865	0.308582854
$\beta_1$	0.020261651	0.000399405	50.72962235	5.26469E-92	0.019472006	0.021051296	0.019472006	0.021051296
$\beta_2$	-0.000143294	4.79898E-06	-29.85918012	1.391E-62	-0.000152782	-0.000133806	-0.000152782	-0.000133806
$\beta_3$	3.45487E-07	1.56352E-08	22.09672004	1.74153E-47	3.14575E-07	3.76399E-07	3.14575E-07	3.76399E-07

### Gulf Coast Region:

Regression Statistics	
Multiple R	0.993347128
R Square	0.986738516
Adjusted R Square	0.986454342
Standard Error	0.031666016
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.44539464	3.481798214	3472.296057	3.5967E-131
Residual	140	0.140383119	0.001002737		
Total	143	10.58577776			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.277940175	0.010641812	26.11774938	1.12431E-55	0.256900742	0.298979608	0.256900742	0.298979608
$\beta_1$	0.020529977	0.000469639	43.71437232	1.71946E-83	0.019601475	0.021458479	0.019601475	0.021458479
$\beta_2$	-0.000143466	5.64287E-06	-25.42421447	2.53682E-54	-0.000154622	-0.000132309	-0.000154622	-0.000132309
$\beta_3$	3.43878E-07	1.83846E-08	18.70465533	6.66256E-40	3.07531E-07	3.80226E-07	3.07531E-07	3.80226E-07

### Mid-Continent Region:

Regression Statistics	
Multiple R	0.984006541
R Square	0.968268874
Adjusted R Square	0.967588921
Standard Error	0.048034262
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.856909541	3.285636514	1424.023848	1.1869E-104
Residual	140	0.323020652	0.00230729		
Total	143	10.17993019			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.289971748	0.016142592	17.96314638	3.67032E-38	0.258056977	0.32188652	0.258056977	0.32188652
$\beta_1$	0.020266191	0.000712397	28.44789972	4.71502E-60	0.018857744	0.021674637	0.018857744	0.021674637
$\beta_2$	-0.000143007	8.55969E-06	-16.70702184	3.8001E-35	-0.00015993	-0.000126084	-0.00015993	-0.000126084
$\beta_3$	3.44462E-07	2.78877E-08	12.35174476	3.63124E-24	2.89326E-07	3.99597E-07	2.89326E-07	3.99597E-07

### Southwest Region:

Regression Statistics	
Multiple R	0.993309425
R Square	0.986663613
Adjusted R Square	0.986377833
Standard Error	0.031536315
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.30103457	3.43367819	3452.531986	5.3348E-131
Residual	140	0.139235479	0.000994539		
Total	143	10.44027005			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.278136296	0.010598224	26.24367047	6.42248E-56	0.257183038	0.299089554	0.257183038	0.299089554
$\beta_1$	0.020381432	0.000467715	43.57656163	2.59609E-83	0.019456733	0.02130613	0.019456733	0.02130613
$\beta_2$	-0.00014194	5.61976E-06	-25.25738215	5.41293E-54	-0.000153051	-0.00013083	-0.000153051	-0.00013083
$\beta_3$	3.38578E-07	1.83093E-08	18.49210412	2.08785E-39	3.0238E-07	3.74777E-07	3.0238E-07	3.74777E-07

### Rocky Mountain Region:

Regression Statistics	
Multiple R	0.9949703
R Square	0.9899658
Adjusted R Square	0.9897508
Standard Error	0.0266287
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.79418782	3.2647293	4604.11	1.199E-139
Residual	140	0.09927263	0.0007091		
Total	143	9.89346045			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.2902761	0.00894897	32.436833	5.504E-67	0.27258355	0.3079687	0.2725836	0.3079687
$\beta_1$	0.0202676	0.00039493	51.319418	1.133E-92	0.01948684	0.0210484	0.0194868	0.0210484
$\beta_2$	-0.0001433	4.7452E-06	-30.194046	3.595E-63	-0.0001527	-0.0001339	-0.0001527	-0.0001339
$\beta_3$	3.454E-07	1.546E-08	22.340389	5.253E-48	3.1482E-07	3.76E-07	3.148E-07	3.76E-07

### West Coast Region:

Regression Statistics	
Multiple R	0.992483684
R Square	0.985023864
Adjusted R Square	0.984702946
Standard Error	0.032081124
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.477071064	3.159023688	3069.401798	1.7868E-127
Residual	140	0.144087788	0.001029198		
Total	143	9.621158852			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.297817853	0.010781315	27.62351924	1.55941E-58	0.276502615	0.31913309	0.276502615	0.31913309
$\beta_1$	0.020092432	0.000475796	42.22913162	1.54864E-81	0.019151759	0.021033105	0.019151759	0.021033105
$\beta_2$	-0.000142719	5.71684E-06	-24.96465108	2.06229E-53	-0.000154021	-0.000131416	-0.000154021	-0.000131416
$\beta_3$	3.44906E-07	1.86256E-08	18.51777816	1.81824E-39	3.08082E-07	3.81729E-07	3.08082E-07	3.81729E-07

## Northern Great Plains Region:

Regression Statistics	
Multiple R	0.993525621
R Square	0.987093159
Adjusted R Square	0.986816584
Standard Error	0.031179889
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.40915184	3.469717279	3568.986978	5.3943E-132
Residual	140	0.136105966	0.000972185		
Total	143	10.5452578			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	0.281568556	0.010478442	26.87122338	4.04796E-57	0.260852113	0.302284998	0.260852113	0.302284998
β1	0.020437386	0.000462429	44.19569691	4.11395E-84	0.019523138	0.021351633	0.019523138	0.021351633
β2	-0.000142671	5.55624E-06	-25.67758357	8.07391E-55	-0.000153656	-0.000131686	-0.000153656	-0.000131686
β3	3.42012E-07	1.81024E-08	18.89319503	2.43032E-40	3.06223E-07	3.77802E-07	3.06223E-07	3.77802E-07

## Drilling and Completion Costs for Horizontal Wells

The costs of horizontal drilling for crude oil, natural gas, and dryholes are based upon cost estimates developed for the Department of Energy's Comprehensive Oil and Gas Analysis Model. The form of the equation is as follows:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth}^2 + \beta_2 * \text{Depth}^2 * \text{nlat} + \beta_3 * \text{Depth}^2 * \text{nlat} * \text{latlen} \quad (2.B-4)$$

Where, nlat is the number of laterals per pattern and latlen is the length of those laterals. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.

Regression Statistics	
Multiple R	1
R Square	1
Adjusted R Square	1
Standard Error	3.12352E-12
Observations	120

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	147,510,801.46	49,170,267.15	5.04E+30	0.00
Residual	116	0.00	0.00		
Total	119	147,510,801.46			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	172.88	4.37E-13	3.95E+14	0.00	172.88	172.88	172.88	172.88
β1	8.07E-06	8.81E-21	9.16E+14	0.00	8.07E-06	8.07E-06	8.07E-06	8.07E-06
β2	1.15E-06	3.20E-21	3.60E+14	0.00	1.15E-06	1.15E-06	1.15E-06	1.15E-06
β3	9.22E-10	1.48E-24	6.23E+14	0.00	9.22E-10	9.22E-10	9.22E-10	9.22E-10

## Cost to Equip a Primary Producer

The cost to equip a primary producer was calculated using an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). The cost to equip a primary producer is equal to the grand total cost minus the producing equipment subtotal. The data was analyzed on a regional level. The independent variable is depth. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-5)$$

where  $\text{Cost} = \text{NPR} \cdot \bar{W}$

$\beta_0 = \text{NPR} \cdot \bar{K}$

$\beta_1 = \text{NPR} \cdot \bar{A}$

$\beta_2 = \text{NPR} \cdot \bar{B}$

$\beta_3 = \text{NPR} \cdot \bar{C}$

from equation 2-21 in Chapter 2.

The cost is on a per well basis. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.  $\beta_2$  and  $\beta_3$  are statistically insignificant and are therefore zero.

### West Texas, applied to OLOGSS regions 2 and 4:

Regression Statistics								
Multiple R	0.921							
R Square	0.849							
Adjusted R Square	0.697							
Standard Error	621.17							
Observations	3							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	2,163,010.81	2,163,010.81	5.61	0.254415			
Residual	1	385,858.01	385,858.01					
Total	2	2,548,868.81						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	51,315.4034	760.7805	67.4510	0.0094	41,648.8117	60,981.9952	41,648.8117	60,981.9952
$\beta_1$	0.3404	0.1438	2.3676	0.2544	-1.4864	2.1672	-1.4864	2.1672

### Mid-Continent, applied to OLOGSS region 3:

Regression Statistics								
Multiple R	0.995							
R Square	0.990							
Adjusted R Square	0.981							
Standard Error	1,193.14							
Observations	3							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	145,656,740.81	145,656,740.81	102.32	0.06			
Residual	1	1,423,576.87	1,423,576.87					
Total	2	147,080,317.68						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	45,821.717	1,461.289	31.357	0.020	27,254.360	64,389.074	27,254.360	64,389.074
$\beta_1$	2.793	0.276	10.115	0.063	-0.716	6.302	-0.716	6.302

### Rocky Mountains, applied to OLOGSS regions 1, 5, and 7:

Regression Statistics								
Multiple R	0.9998							
R Square	0.9995							
Adjusted R Square	0.9990							
Standard Error	224.46							
Observations	3							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	105,460,601.42	105,460,601.42	2,093.17	0.01			
Residual	1	50,383.23	50,383.23					
Total	2	105,510,984.64						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	62,709.378	274.909	228.110	0.003	59,216.346	66,202.411	59,216.346	66,202.411
$\beta_1$	2.377	0.052	45.751	0.014	1.717	3.037	1.717	3.037

### West Coast, applied to OLOGSS regions 6:

Regression Statistics								
Multiple R	0.9095							
R Square	0.8272							
Adjusted R Square	0.7408							
Standard Error	2,257.74							
Observations	4							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	48,812,671.60	48,812,671.60	9.58	0.09			
Residual	2	10,194,785.98	5,097,392.99					
Total	3	59,007,457.58						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	106,959.788	2,219.144	48.199	0.000	97,411.576	116,508.001	97,411.576	116,508.001
$\beta_1$	0.910	0.294	3.095	0.090	-0.355	2.174	-0.355	2.174

### Cost to Equip a Primary Producer - Cost Adjustment Factor

The cost adjustment factor for the cost to equip a primary producer was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Rocky Mountains, Applied to OLOGSS Regions 1, 5, and 7:

Regression Statistics	
Multiple R	0.994410537
R Square	0.988852316
Adjusted R Square	0.988613437
Standard Error	0.026443679
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.683975313	2.894658438	4139.554242	1.896E-136
Residual	140	0.097897541	0.000699268		
Total	143	8.781872854			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.31969898	0.008886772	35.97470366	1.30857E-72	0.302129355	0.337268604	0.302129355	0.337268604
$\beta_1$	0.01951727	0.000392187	49.76527469	6.72079E-91	0.018741896	0.020292644	0.018741896	0.020292644
$\beta_2$	-0.000139868	4.71225E-06	-29.68181785	2.86084E-62	-0.000149185	-0.000130552	-0.000149185	-0.000130552
$\beta_3$	3.39583E-07	1.53527E-08	22.11882142	1.56166E-47	3.0923E-07	3.69936E-07	3.0923E-07	3.69936E-07

### South Texas, Applied to OLOGSS Regions 2:

Regression Statistics	
Multiple R	0.994238324
R Square	0.988509845
Adjusted R Square	0.988263627
Standard Error	0.026795052
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.647535343	2.882511781	4014.781289	1.5764E-135
Residual	140	0.100516472	0.000717975		
Total	143	8.748051814			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.320349357	0.009004856	35.57517997	5.36201E-72	0.302546274	0.33815244	0.302546274	0.33815244
$\beta_1$	0.019534419	0.000397398	49.15583863	3.4382E-90	0.018748742	0.020320096	0.018748742	0.020320096
$\beta_2$	-0.000140302	4.77487E-06	-29.38344709	9.69188E-62	-0.000149742	-0.000130862	-0.000149742	-0.000130862
$\beta_3$	3.41163E-07	1.55567E-08	21.9303828	3.96368E-47	3.10407E-07	3.7192E-07	3.10407E-07	3.7192E-07

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics	
Multiple R	0.994150147
R Square	0.988334515
Adjusted R Square	0.98808454
Standard Error	0.026852947
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.552894405	2.850964802	3953.738464	4.5499E-135
Residual	140	0.100951309	0.000721081		
Total	143	8.653845713			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.322462264	0.009024312	35.73261409	3.07114E-72	0.304620715	0.340303814	0.304620715	0.340303814
$\beta_1$	0.019485751	0.000398256	48.9276546	6.36471E-90	0.018698377	0.020273125	0.018698377	0.020273125
$\beta_2$	-0.000140187	4.78518E-06	-29.29612329	1.3875E-61	-0.000149648	-0.000130727	-0.000149648	-0.000130727
$\beta_3$	3.41143E-07	1.55903E-08	21.88177944	5.04366E-47	3.1032E-07	3.71966E-07	3.1032E-07	3.71966E-07

### West Texas, Applied to OLOGSS Regions 4:

Regression Statistics	
Multiple R	0.99407047
R Square	0.988176099
Adjusted R Square	0.98792273
Standard Error	0.026915882
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.476544403	2.825514801	3900.141282	1.1696E-134
Residual	140	0.101425062	0.000724465		
Total	143	8.577969465			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.324216701	0.009045462	35.84302113	2.08007E-72	0.306333337	0.342100066	0.306333337	0.342100066
$\beta_1$	0.019446254	0.00039919	48.71430741	1.1346E-89	0.018657034	0.020235473	0.018657034	0.020235473
$\beta_2$	-0.000140099	4.7964E-06	-29.20929598	1.98384E-61	-0.000149582	-0.000130617	-0.000149582	-0.000130617
$\beta_3$	3.41157E-07	1.56268E-08	21.8315363	6.47229E-47	3.10262E-07	3.72052E-07	3.10262E-07	3.72052E-07

### West Coast, Applied to OLOGSS Regions 6:

Regression Statistics	
Multiple R	0.994533252
R Square	0.98909639
Adjusted R Square	0.988862741
Standard Error	0.026511278
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.92601569	2.975338563	4233.261276	4.0262E-137
Residual	140	0.098398698	0.000702848		
Total	143	9.024414388			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.314154129	0.008909489	35.26062149	1.64245E-71	0.296539591	0.331768668	0.296539591	0.331768668
$\beta_1$	0.019671366	0.000393189	50.03029541	3.32321E-91	0.01889401	0.020448722	0.01889401	0.020448722
$\beta_2$	-0.000140565	4.7243E-06	-29.75371308	2.13494E-62	-0.000149906	-0.000131225	-0.000149906	-0.000131225
$\beta_3$	3.40966E-07	1.53919E-08	22.15229024	1.32417E-47	3.10535E-07	3.71397E-07	3.10535E-07	3.71397E-07

## Primary Workover Costs

Primary workover costs were calculated using an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). Workover costs consist of the total of workover rig services, remedial services, equipment repair and other costs. The data was analyzed on a regional level. The independent variable is depth. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-6)$$

where  $\text{Cost} = \text{WRK\_W}$

$\beta_0 = \text{WRKK}$

$\beta_1 = \text{WRKA}$

$\beta_2 = \text{WRKB}$

$\beta_3 = \text{WRKC}$

from equation 2-22 in Chapter 2.

The cost is on a per well basis. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.  $\beta_2$  and  $\beta_3$  are statistically insignificant and are therefore zero.

### Rocky Mountains, Applied to OLOGSS Region 1, 5, and 7:

Regression Statistics								
Multiple R	0.9839							
R Square	0.9681							
Adjusted R Square	0.9363							
Standard Error	1,034.20							
Observations	3							

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	32,508,694.98	32,508,694.98	30.39	0.11
Residual	1	1,069,571.02	1,069,571.02		
Total	2	33,578,265.99			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	1,736.081	1,266.632	1.371	0.401	-14,357.935	17,830.097	-14,357.935	17,830.097
$\beta_1$	1.320	0.239	5.513	0.114	-1.722	4.361	-1.722	4.361

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics								
Multiple R	0.7558							
R Square	0.5713							
Adjusted R Square	0.4284							
Standard Error	978.19							
Observations	5							

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	3,824,956.55	3,824,956.55	4.00	0.14
Residual	3	2,870,570.06	956,856.69		
Total	4	6,695,526.61			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	1,949.479	1,043.913	1.867	0.159	-1,372.720	5,271.678	-1,372.720	5,271.678
$\beta_1$	0.364	0.182	1.999	0.139	-0.216	0.945	-0.216	0.945

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics								
Multiple R	0.9762							
R Square	0.9530							
Adjusted R Square	0.9060							
Standard Error	2,405.79							
Observations	3							

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	117,342,912.53	117,342,912.53	20.27	0.14
Residual	1	5,787,839.96	5,787,839.96		
Total	2	123,130,752.49			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	-2,738.051	2,946.483	-0.929	0.523	-40,176.502	34,700.400	-40,176.502	34,700.400
$\beta_1$	2.507	0.557	4.503	0.139	-4.568	9.582	-4.568	9.582

### West Texas, Applied to OLOGSS Region 4:

Regression Statistics	
Multiple R	0.9898
R Square	0.9798
Adjusted R Square	0.9595
Standard Error	747.71
Observations	3

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	27,074,389.00	27,074,389.00	48.43	0.09
Residual	1	559,069.20	559,069.20		
Total	2	27,633,458.19			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	389.821	915.753	0.426	0.744	-11,245.876	12,025.518	-11,245.876	12,025.518
$\beta_1$	1.204	0.173	6.959	0.091	-0.995	3.403	-0.995	3.403

### West Coast, Applied to OLOGSS Region 6:

Regression Statistics	
Multiple R	0.9985
R Square	0.9969
Adjusted R Square	0.9939
Standard Error	273.2
Observations	3

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	24,387,852.65	24,387,852.65	326.67	0.04
Residual	1	74,656.68	74,656.68		
Total	2	24,462,509.32			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	1,326.648	334.642	3.964	0.157	-2,925.359	5,578.654	-2,925.359	5,578.654
$\beta_1$	1.143	0.063	18.074	0.035	0.339	1.947	0.339	1.947

## Primary Workover Costs - Cost Adjustment Factor

The cost adjustment factor for primary workover costs was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Rocky Mountains, Applied to OLOGSS Regions 1, 5, and 7:

Regression Statistics	
Multiple R	0.994400682
R Square	0.988832717
Adjusted R Square	0.988593418
Standard Error	0.02694729
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.001886791	3.00062893	4132.207262	2.1441E-136
Residual	140	0.101661902	0.000726156		
Total	143	9.103548693			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.312539579	0.009056017	34.51181296	2.43715E-70	0.294635346	0.330443812	0.294635346	0.330443812
$\beta_1$	0.019707131	0.000399656	49.31028624	2.26953E-90	0.018916991	0.020497272	0.018916991	0.020497272
$\beta_2$	-0.000140623	4.802E-06	-29.28428914	1.45673E-61	-0.000150117	-0.000131129	-0.000150117	-0.000131129
$\beta_3$	3.40873E-07	1.5645E-08	21.78791181	8.03921E-47	3.09942E-07	3.71804E-07	3.09942E-07	3.71804E-07

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics	
Multiple R	0.994469633
R Square	0.98896985
Adjusted R Square	0.98873349
Standard Error	0.026569939
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.861572267	2.953857422	4184.161269	9.0291E-137
Residual	140	0.098834632	0.000705962		
Total	143	8.960406899			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.315903453	0.008929203	35.37868321	1.07799E-71	0.298249938	0.333556967	0.298249938	0.333556967
$\beta_1$	0.019629392	0.000394059	49.81332121	5.91373E-91	0.018850316	0.020408468	0.018850316	0.020408468
$\beta_2$	-0.000140391	4.73475E-06	-29.65123432	3.24065E-62	-0.000149752	-0.000131303	-0.000149752	-0.000131303
$\beta_3$	3.40702E-07	1.5426E-08	22.08625878	1.83379E-47	3.10204E-07	3.712E-07	3.10204E-07	3.712E-07

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics	
Multiple R	0.994481853
R Square	0.988994155
Adjusted R Square	0.988758316
Standard Error	0.026752366
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.003736634	3.001245545	4193.504662	7.7373E-137
Residual	140	0.100196473	0.000715689		
Total	143	9.103933107			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.312750341	0.00899051	34.78671677	9.00562E-71	0.294975619	0.330525063	0.294975619	0.330525063
$\beta_1$	0.019699787	0.000396765	49.6510621	9.11345E-91	0.018915362	0.020484212	0.018915362	0.020484212
$\beta_2$	-0.000140541	4.76726E-06	-29.480463	6.51147E-62	-0.000149966	-0.000131116	-0.000149966	-0.000131116
$\beta_3$	3.40661E-07	1.55319E-08	21.93302302	3.91217E-47	3.09954E-07	3.71368E-07	3.09954E-07	3.71368E-07

### West Texas, Applied to OLOGSS Regions 4:

Regression Statistics	
Multiple R	0.949969362
R Square	0.902441789
Adjusted R Square	0.900351256
Standard Error	0.090634678
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.63829925	3.546099748	431.6802228	1.59892E-70
Residual	140	1.150050289	0.008214645		
Total	143	11.78834953			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.281549378	0.030459064	9.243533578	3.55063E-16	0.221330174	0.341768582	0.221330174	0.341768582
$\beta_1$	0.020360006	0.001344204	15.14651492	2.70699E-31	0.017702443	0.02301757	0.017702443	0.02301757
$\beta_2$	-0.000140998	1.61511E-05	-8.729925387	6.86299E-15	-0.000172929	-0.000109066	-0.000172929	-0.000109066
$\beta_3$	3.36972E-07	5.26206E-08	6.403797584	2.14112E-09	2.32938E-07	4.41006E-07	2.32938E-07	4.41006E-07

### West Coast, Applied to OLOGSS Regions 6:

Regression Statistics	
Multiple R	0.994382746
R Square	0.988797046
Adjusted R Square	0.988556983
Standard Error	0.026729324
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.828330392	2.942776797	4118.9013	2.6803E-136
Residual	140	0.100023944	0.000714457		
Total	143	8.928354335			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.316566704	0.008982767	35.24155917	1.75819E-71	0.298807292	0.334326116	0.298807292	0.334326116
$\beta_1$	0.019613748	0.000396423	49.47682536	1.45204E-90	0.018829998	0.020397497	0.018829998	0.020397497
$\beta_2$	-0.000140368	4.76315E-06	-29.46957335	6.80842E-62	-0.000149785	-0.000130951	-0.000149785	-0.000130951
$\beta_3$	3.40752E-07	1.55185E-08	21.95777375	3.46083E-47	3.10071E-07	3.71433E-07	3.10071E-07	3.71433E-07

## Cost to Convert a Primary to Secondary Well

The cost to convert a primary to secondary well was calculated using an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). Conversion costs for a primary to a secondary well consist of pumping equipment, rods and pumps, and supply wells. The data was analyzed on a regional level. The secondary operations costs for each region are determined by multiplying the costs in West Texas by the ratio of primary operating costs. This method was used in the National Petroleum Council’s (NPC) EOR study of 1984. The independent variable is depth. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-7)$$

where  $\text{Cost} = \text{PSW\_W}$

$\beta_0 = \text{PSWK}$

$\beta_1 = \text{PSWA}$

$\beta_2 = \text{PSWB}$

$\beta_3 = \text{PSWC}$

from equation 2-35 in Chapter 2.

The cost is on a per well basis. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.  $\beta_2$  and  $\beta_3$  are statistically insignificant and are therefore zero.

### Rocky Mountains, Applied to OLOGSS Regions 1, 5, and 7:

Regression Statistics								
Multiple R	0.999208							
R Square	0.998416							
Adjusted R Square	0.996832							
Standard Error	9968.98							
Observations	3							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	62,643,414,406.49	62,643,414,406.49	630.34	0.03			
Residual	1	99,380,639.94	99,380,639.94					
Total	2	62,742,795,046.43						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	-115.557	12,209.462	-0.009	0.994	-155,250.815	155,019.701	-155,250.815	155,019.701
$\beta_1$	57.930	2.307	25.107	0.025	28.612	87.248	28.612	87.248

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics								
Multiple R	0.996760							
R Square	0.993531							
Adjusted R Square	0.991914							
Standard Error	16909.05							
Observations	6							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	175,651,490,230.16	175,651,490,230.16	614.35	0.00			
Residual	4	1,143,664,392.16	285,916,098.04					
Total	5	176,795,154,622.33						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	-10,733.7	14,643.670	-0.733	0.504	-51,391.169	29,923.692	-51,391.169	29,923.692
$\beta_1$	68.593	2.767	24.786	0.000	60.909	76.276	60.909	76.276

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics								
Multiple R	0.999830							
R Square	0.999660							
Adjusted R Square	0.999320							
Standard Error	4047.64							
Observations	3							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	48,164,743,341	48,164,743,341	2,939.86	0.01			
Residual	1	16,383,350	16,383,350					
Total	2	48,181,126,691						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	-32,919.3	4,957.320	-6.641	0.095	-95,907.768	30,069.148	-95,907.768	30,069.148
$\beta_1$	50.796	0.937	54.220	0.012	38.893	62.700	38.893	62.700

### West Texas, Applied to OLOGSS Region 4:

Regression Statistics	
Multiple R	1.00000
R Square	0.99999
Adjusted R Square	0.99999
Standard Error	552.23
Observations	3

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	44,056,261,873.48	44,056,261,873.48	144,469.3	0.00
Residual	1	304,952.52	304,952.52		
Total	2	44,056,566,825.99			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	-25,175.8	676.335	-37.224	0.017	-33,769.389	-16,582.166	-33,769.389	-16,582.166
$\beta_1$	48.581	0.128	380.091	0.002	46.957	50.205	46.957	50.205

### West Coast, Applied to OLOGSS Region 6:

Regression Statistics	
Multiple R	0.999970
R Square	0.999941
Adjusted R Square	0.999882
Standard Error	2317.03
Observations	3

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	90,641,249,203.56	90,641,249,203.56	16,883.5	0.00
Residual	1	5,368,613.99	5,368,613.99		
Total	2	90,646,617,817.55			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	-47,775.5	2,837.767	-16.836	0.038	-83,832.597	-11,718.412	-83,832.597	-11,718.412
$\beta_1$	69.683	0.536	129.937	0.005	62.869	76.498	62.869	76.498

## Cost to Convert a Primary to Secondary Well - Cost Adjustment Factor

The cost adjustment factor for the cost to convert a primary to secondary well was calculated using data through 2008 from the Cost and Indices data base provided EIA. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Rocky Mountains, Applied to OLOGSS Regions 1, 5, and 7:

Regression Statistics								
Multiple R	0.994210954							
R Square	0.988455421							
Adjusted R Square	0.988208037							
Standard Error	0.032636269							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	12.7675639	4.255854635	3995.634681	2.1943E-135			
Residual	140	0.149117649	0.001065126					
Total	143	12.91668155						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.386844292	0.010967879	35.27065592	1.58464E-71	0.365160206	0.408528378	0.365160206	0.408528378
$\beta_1$	0.023681158	0.000484029	48.92509151	6.40898E-90	0.022724207	0.024638109	0.022724207	0.024638109
$\beta_2$	-0.000169861	5.81577E-06	-29.207048	2.00231E-61	-0.00018136	-0.000158363	-0.00018136	-0.000158363
$\beta_3$	4.12786E-07	1.89479E-08	21.78527316	8.14539E-47	3.75325E-07	4.50247E-07	3.75325E-07	4.50247E-07

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics								
Multiple R	0.965088368							
R Square	0.931395559							
Adjusted R Square	0.929925464							
Standard Error	0.077579302							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	11.43935934	3.813119781	633.5614039	3.21194E-81			
Residual	140	0.842596733	0.006018548					
Total	143	12.28195608						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.403458143	0.02607162	15.4749932	4.09637E-32	0.351913151	0.455003136	0.351913151	0.455003136
$\beta_1$	0.023030837	0.00115058	20.01672737	6.5441E-43	0.02075608	0.025305595	0.02075608	0.025305595
$\beta_2$	-0.000167719	1.38246E-05	-12.13194348	1.34316E-23	-0.000195051	-0.000140387	-0.000195051	-0.000140387
$\beta_3$	4.10451E-07	4.5041E-08	9.112847285	7.57277E-16	3.21403E-07	4.995E-07	3.21403E-07	4.995E-07

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics								
Multiple R	0.930983781							
R Square	0.866730801							
Adjusted R Square	0.863875032							
Standard Error	0.115716747							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	12.19199867	4.063999556	303.5017657	4.7623E-61			
Residual	140	1.874651162	0.013390365					
Total	143	14.06664983						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.39376891	0.038888247	10.12565341	2.02535E-18	0.316884758	0.470653063	0.316884758	0.470653063
$\beta_1$	0.023409924	0.001716196	13.6405849	1.759E-27	0.020016911	0.026802936	0.020016911	0.026802936
$\beta_2$	-0.000169013	2.06207E-05	-8.196307608	1.41642E-13	-0.000209782	-0.000128245	-0.000209782	-0.000128245
$\beta_3$	4.11972E-07	6.71828E-08	6.132113904	8.35519E-09	2.79148E-07	5.44796E-07	2.79148E-07	5.44796E-07

### West Texas, Applied to OLOGSS Regions 4:

Regression Statistics	
Multiple R	0.930623851
R Square	0.866060752
Adjusted R Square	0.863190626
Standard Error	0.117705607
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	12.5418858	4.180628599	301.7500036	6.76263E-61
Residual	140	1.939645392	0.01385461		
Total	143	14.48153119			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.363067907	0.039556632	9.178433366	5.17966E-16	0.284862323	0.441273492	0.284862323	0.441273492
$\beta_1$	0.024133277	0.001745693	13.82446554	5.96478E-28	0.020681947	0.027584606	0.020681947	0.027584606
$\beta_2$	-0.000175479	2.09751E-05	-8.366057262	5.44112E-14	-0.000216948	-0.00013401	-0.000216948	-0.00013401
$\beta_3$	4.28328E-07	6.83375E-08	6.267838182	4.24825E-09	2.93221E-07	5.63435E-07	2.93221E-07	5.63435E-07

### West Coast, Applied to OLOGSS Regions 6:

Regression Statistics	
Multiple R	0.930187107
R Square	0.865248054
Adjusted R Square	0.862360512
Standard Error	0.116469162
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	12.19426209	4.06475403	299.6486777	1.03233E-60
Residual	140	1.899109212	0.013565066		
Total	143	14.0933713			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.393797507	0.039141107	10.06097011	2.96602E-18	0.316413437	0.471181577	0.316413437	0.471181577
$\beta_1$	0.023409194	0.001727356	13.55204156	2.96327E-27	0.01999412	0.026824269	0.01999412	0.026824269
$\beta_2$	-0.000168995	2.07548E-05	-8.142483197	1.91588E-13	-0.000210029	-0.000127962	-0.000210029	-0.000127962
$\beta_3$	4.11911E-07	6.76196E-08	6.091589926	1.02095E-08	2.78223E-07	5.45599E-07	2.78223E-07	5.45599E-07

## Cost to Convert a Producer to an Injector

The cost to convert a production well to an injection well was calculated using an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). Conversion costs for a production to an injection well consist of tubing replacement, distribution lines and header costs. The data was analyzed on a regional level. The secondary operation costs for each region are determined by multiplying the costs in West Texas by the ratio of primary operating costs. This method was used in the National Petroleum Council’s (NPC) EOR study of 1984. The independent variable is depth. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-8)$$

where  $\text{Cost} = \text{PSI}_W$   
 $\beta_0 = \text{PSI}\bar{K}$   
 $\beta_1 = \text{PSIA}$   
 $\beta_2 = \text{PSIB}$   
 $\beta_3 = \text{PSIC}$

from equation 2-36 in Chapter 2.

The cost is on a per well basis. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.  $\beta_2$  and  $\beta_3$  are statistically insignificant and are therefore zero.

**West Texas, applied to OLOGSS region 4:**

<i>Regression Statistics</i>									
Multiple R	0.994714								
R Square	0.989456								
Adjusted R Square	0.978913								
Standard Error	3204.94								
Observations	3								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	963,939,802.16	963,939,802.16	93.84	0.07				
Residual	1	10,271,635.04	10,271,635.04						
Total	2	974,211,437.20							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	11,129.3	3,925.233	2.835	0.216	-38,745.259	61,003.937	-38,745.259	61,003.937	
$\beta_1$	7.186	0.742	9.687	0.065	-2.239	16.611	-2.239	16.611	

**South Texas, applied to OLOGSS region 2:**

<i>Regression Statistics</i>									
Multiple R	0.988716								
R Square	0.977560								
Adjusted R Square	0.971950								
Standard Error	4435.41								
Observations	6								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	3,428,080,322.21	3,428,080,322.21	174.25	0.00				
Residual	4	78,691,571.93	19,672,892.98						
Total	5	3,506,771,894.14							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	24,640.6	3,841.181	6.415	0.003	13,975.763	35,305.462	13,975.763	35,305.462	
$\beta_1$	9.582	0.726	13.201	0.000	7.567	11.598	7.567	11.598	

**Mid-Continent, applied to OLOGSS region 3:**

<i>Regression Statistics</i>									
Multiple R	0.993556								
R Square	0.987154								
Adjusted R Square	0.974307								
Standard Error	3770.13								
Observations	3								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	1,092,230,257.01	1,092,230,257.01	76.84	0.07				
Residual	1	14,213,917.83	14,213,917.83						
Total	2	1,106,444,174.85							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	9,356.411	4,617.453	2.026	0.292	-49,313.648	68,026.469	-49,313.648	68,026.469	
$\beta_1$	7.649	0.873	8.766	0.072	-3.438	18.737	-3.438	18.737	

**Rocky Mountains, applied to OLOGSS regions 1, 5, and 7:**

<i>Regression Statistics</i>									
Multiple R	0.995436								
R Square	0.990893								
Adjusted R Square	0.981785								
Standard Error	3266.39								
Observations	3								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	1,160,837,008.65	1,160,837,008.65	108.80	0.06				
Residual	1	10,669,310.85	10,669,310.85						
Total	2	1,171,506,319.50							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	24,054.311	4,000.496	6.013	0.105	-26,776.589	74,885.211	-26,776.589	74,885.211	
$\beta_1$	7.886	0.756	10.431	0.061	-1.720	17.492	-1.720	17.492	

**West Coast, applied to OLOGSS region 6:**

<i>Regression Statistics</i>									
Multiple R	0.998023								
R Square	0.996050								
Adjusted R Square	0.992100								
Standard Error	2903.09								
Observations	3								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	2,125,305,559.02	2,125,305,559.02	252.17	0.04				
Residual	1	8,427,914.12	8,427,914.12						
Total	2	2,133,733,473.15							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	11,125.846	3,555.541	3.129	0.197	-34,051.391	56,303.083	-34,051.391	56,303.083	
$\beta_1$	10.670	0.672	15.880	0.040	2.133	19.208	2.133	19.208	

**Cost to Convert a Producer to an Injector - Cost Adjustment Factor**

The cost adjustment factor for the cost to convert a producer to an injector was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Rocky Mountains, Applied to OLOGSS Regions 1, 5, and 7:

Regression Statistics								
Multiple R	0.99432304							
R Square	0.988678308							
Adjusted R Square	0.9884357							
Standard Error	0.026700062							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	8.715578807	2.905192936	4075.214275	5.6063E-136			
Residual	140	0.099805061	0.000712893					
Total	143	8.815383869						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.318906241	0.008972933	35.54091476	6.05506E-72	0.301166271	0.336646211	0.301166271	0.336646211
$\beta_1$	0.019564167	0.000395989	49.40584281	1.75621E-90	0.018781276	0.020347059	0.018781276	0.020347059
$\beta_2$	-0.000140323	4.75794E-06	-29.49235038	6.20216E-62	-0.00014973	-0.000130916	-0.00014973	-0.000130916
$\beta_3$	3.40991E-07	1.55015E-08	21.9972576	2.84657E-47	3.10343E-07	3.71638E-07	3.10343E-07	3.71638E-07

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics								
Multiple R	0.994644466							
R Square	0.989317613							
Adjusted R Square	0.989088705							
Standard Error	0.025871111							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	8.678119686	2.892706562	4321.895164	9.5896E-138			
Residual	140	0.093704013	0.000669314					
Total	143	8.771823699						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.316208692	0.008694352	36.36943685	3.2883E-73	0.299019491	0.333397893	0.299019491	0.333397893
$\beta_1$	0.01974618	0.000383695	51.46325116	7.80746E-93	0.018987594	0.020504765	0.018987594	0.020504765
$\beta_2$	-0.000142963	4.61022E-06	-31.00997536	1.39298E-64	-0.000152077	-0.000133848	-0.000152077	-0.000133848
$\beta_3$	3.4991E-07	1.50202E-08	23.29589312	5.12956E-50	3.20214E-07	3.79606E-07	3.20214E-07	3.79606E-07

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics								
Multiple R	0.994321224							
R Square	0.988674696							
Adjusted R Square	0.988432011							
Standard Error	0.026701262							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	8.713550392	2.904516797	4073.899599	5.7329E-136			
Residual	140	0.099814034	0.000712957					
Total	143	8.813364425						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.318954549	0.008973336	35.54470092	5.97425E-72	0.301213782	0.336695317	0.301213782	0.336695317
$\beta_1$	0.019563077	0.000396007	49.40087012	1.77978E-90	0.018780151	0.020346004	0.018780151	0.020346004
$\beta_2$	-0.000140319	4.75815E-06	-29.49027089	6.25518E-62	-0.000149726	-0.000130912	-0.000149726	-0.000130912
$\beta_3$	3.40985E-07	1.55022E-08	21.99592439	2.8654E-47	3.10337E-07	3.71634E-07	3.10337E-07	3.71634E-07

### West Texas, Applied to OLOGSS Regions 4:

Regression Statistics	
Multiple R	0.994322163
R Square	0.988676564
Adjusted R Square	0.988433919
Standard Error	0.026700311
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.714383869	2.904794623	4074.579587	5.667E-136
Residual	140	0.099806922	0.000712907		
Total	143	8.814190792			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.318944377	0.008973016	35.54483358	5.97144E-72	0.301204242	0.336684512	0.301204242	0.336684512
$\beta_1$	0.019563226	0.000395993	49.40300666	1.76961E-90	0.018780328	0.020346125	0.018780328	0.020346125
$\beta_2$	-0.000140317	4.75798E-06	-29.49085218	6.24031E-62	-0.000149724	-0.00013091	-0.000149724	-0.00013091
$\beta_3$	3.40976E-07	1.55017E-08	21.99610109	2.8629E-47	3.10328E-07	3.71624E-07	3.10328E-07	3.71624E-07

### West Coast, Applied to OLOGSS Region 6:

Regression Statistics	
Multiple R	0.994041278
R Square	0.988118061
Adjusted R Square	0.987863448
Standard Error	0.027307293
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.681741816	2.893913939	3880.863048	1.6477E-134
Residual	140	0.104396354	0.000745688		
Total	143	8.78613817			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.31978359	0.009177001	34.84619603	7.26644E-71	0.301640166	0.337927015	0.301640166	0.337927015
$\beta_1$	0.019531533	0.000404995	48.22662865	4.2897E-89	0.018730837	0.02033223	0.018730837	0.02033223
$\beta_2$	-0.000140299	4.86615E-06	-28.83170535	9.47626E-61	-0.00014992	-0.000130679	-0.00014992	-0.000130679
$\beta_3$	3.41616E-07	1.58541E-08	21.54755837	2.66581E-46	3.10272E-07	3.7296E-07	3.10272E-07	3.7296E-07

## Facilities Upgrade Costs for Crude Oil Wells

The facilities upgrading cost for secondary oil wells was calculated using an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). Facilities costs for a secondary oil well consist of plant costs and electrical costs. The data was analyzed on a regional level. The secondary operation costs for each region are determined by multiplying the costs in West Texas by the ratio of primary operating costs. This method was used in the National Petroleum Council’s (NPC) EOR study of 1984. The independent variable is depth. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-9)$$

where

$$\text{Cost} = \text{FAC}_W$$

$$\beta_0 = \text{FAC}_{UPK}$$

$$\beta_1 = \text{FAC}_{UPA}$$

$$\beta_2 = \text{FAC}_{UPB}$$

$$\beta_3 = \text{FAC}_{UPC}$$

from equation 2-23 in Chapter 2.

The cost is on a per well basis. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.  $\beta_2$  and  $\beta_3$  are statistically insignificant and are therefore zero.

**West Texas, applied to OLOGSS region 4:**

Regression Statistics								
Multiple R	0.947660							
R Square	0.898060							
Adjusted R Square	0.796120							
Standard Error	6332.38							
Observations	3							

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	353,260,332.81	353,260,332.81	8.81	0.21
Residual	1	40,099,063.51	40,099,063.51		
Total	2	393,359,396.32			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	20,711.761	7,755.553	2.671	0.228	-77,831.455	119,254.977	-77,831.455	119,254.977
$\beta_1$	4.350	1.466	2.968	0.207	-14.273	22.973	-14.273	22.973

**South Texas, applied to OLOGSS region 2:**

Regression Statistics								
Multiple R	0.942744							
R Square	0.888767							
Adjusted R Square	0.851689							
Standard Error	6699.62							
Observations	5							

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	1,075,905,796.72	1,075,905,796.72	23.97	0.02
Residual	3	134,654,629.89	44,884,876.63		
Total	4	1,210,560,426.61			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	33,665.6	7,149.747	4.709	0.018	10,911.921	56,419.338	10,911.921	56,419.338
$\beta_1$	6.112	1.248	4.896	0.016	2.139	10.085	2.139	10.085

**Mid-Continent, applied to OLOGSS region 3:**

Regression Statistics								
Multiple R	0.950784							
R Square	0.903990							
Adjusted R Square	0.807980							
Standard Error	6705.31							
Observations	3							

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	423,335,427.35	423,335,427.35	9.42	0.20
Residual	1	44,961,183.70	44,961,183.70		
Total	2	468,296,611.04			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	19,032.550	8,212.294	2.318	0.259	-85,314.094	123,379.194	-85,314.094	123,379.194
$\beta_1$	4.762	1.552	3.068	0.201	-14.957	24.482	-14.957	24.482

### Rocky Mountains, applied to OLOGSS regions 1, 5, and 7:

Regression Statistics					
Multiple R	0.90132				
R Square	0.81238				
Adjusted R Square	0.62476				
Standard Error	8,531				
Observations	3				

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	315,132,483.91	315,132,483.91	4.33	0.29
Residual	1	72,780,134.04	72,780,134.04		
Total	2	387,912,617.95			

	Coefficient	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	37,322	10,448.454	3.572	0.174	-95,437.589	170,081.677	-95,437.589	170,081.677
$\beta_1$	4.109	1.975	2.081	0.285	-20.980	29.198	-20.980	29.198

### West Coast, applied to OLOGSS region 6:

Regression Statistics					
Multiple R	0.974616				
R Square	0.949876				
Adjusted R Square	0.899753				
Standard Error	6,765.5				
Observations	3				

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	867,401,274.79	867,401,274.79	18.95	0.14
Residual	1	45,771,551.83	45,771,551.83		
Total	2	913,172,826.62			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	23,746.6	8,285.972	2.866	0.214	-81,536.251	129,029.354	-81,536.251	129,029.354
$\beta_1$	6.817	1.566	4.353	0.144	-13.080	26.713	-13.080	26.713

## Facilities Upgrade Costs for Oil Wells - Cost Adjustment Factor

The cost adjustment factor for facilities upgrade costs for oil wells was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Rocky Mountains, Applied to OLOGSS Regions 1, 5, and 7:

Regression Statistics	
Multiple R	0.994217662
R Square	0.988468759
Adjusted R Square	0.988221661
Standard Error	0.026793237
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.615198936	2.871732979	4000.310244	2.0238E-135
Residual	140	0.100502859	0.000717878		
Total	143	8.715701795			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.321111529	0.009004246	35.66223488	3.93903E-72	0.303309651	0.338913406	0.303309651	0.338913406
$\beta_1$	0.019515262	0.000397371	49.11095778	3.88014E-90	0.018729638	0.020300885	0.018729638	0.020300885
$\beta_2$	-0.00014023	4.77454E-06	-29.37035185	1.02272E-61	-0.00014967	-0.00013079	-0.00014967	-0.00013079
$\beta_3$	3.4105E-07	1.55556E-08	21.92459665	4.07897E-47	3.10296E-07	3.71805E-07	3.10296E-07	3.71805E-07

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics	
Multiple R	0.994217643
R Square	0.988468723
Adjusted R Square	0.988221624
Standard Error	0.026793755
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.615504692	2.871834897	4000.297521	2.0242E-135
Residual	140	0.100506746	0.000717905		
Total	143	8.716011438			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.321091731	0.00900442	35.65934676	3.9795E-72	0.30328951	0.338893953	0.30328951	0.338893953
$\beta_1$	0.019515756	0.000397379	49.11125155	3.87707E-90	0.018730117	0.020301395	0.018730117	0.020301395
$\beta_2$	-0.000140234	4.77464E-06	-29.37065243	1.02145E-61	-0.000149674	-0.000130794	-0.000149674	-0.000130794
$\beta_3$	3.41061E-07	1.55559E-08	21.92486379	4.07357E-47	3.10306E-07	3.71816E-07	3.10306E-07	3.71816E-07

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics	
Multiple R	0.994881087
R Square	0.989788377
Adjusted R Square	0.989569556
Standard Error	0.025598703
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.892246941	2.964082314	4523.289171	4.0903E-139
Residual	140	0.0917411	0.000655294		
Total	143	8.983988041			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.305413562	0.008602806	35.50162345	6.96151E-72	0.288405354	0.32242177	0.288405354	0.32242177
$\beta_1$	0.019922983	0.000379655	52.47659224	5.82045E-94	0.019172385	0.020673581	0.019172385	0.020673581
$\beta_2$	-0.000143398	4.56168E-06	-31.43544891	2.62249E-65	-0.000152417	-0.00013438	-0.000152417	-0.00013438
$\beta_3$	3.48664E-07	1.48621E-08	23.45993713	2.3433E-50	3.1928E-07	3.78047E-07	3.1928E-07	3.78047E-07

### West Texas, Applied to OLOGSS Region 4:

Regression Statistics	
Multiple R	0.994218671
R Square	0.988470767
Adjusted R Square	0.988223712
Standard Error	0.026793398
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.616820316	2.872273439	4001.015021	1.9993E-135
Residual	140	0.100504067	0.000717886		
Total	143	8.717324383			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	0.32105584	0.0090043	35.65583598	4.02926E-72	0.303253856	0.338857825	0.303253856	0.338857825
β1	0.019516684	0.000397373	49.11424236	3.84594E-90	0.018731056	0.020302312	0.018731056	0.020302312
β2	-0.00014024	4.77457E-06	-29.37236101	1.01431E-61	-0.00014968	-0.000130801	-0.00014968	-0.000130801
β3	3.4108E-07	1.55557E-08	21.92639924	4.0427E-47	3.10326E-07	3.71835E-07	3.10326E-07	3.71835E-07

### West Coast, Applied to OLOGSS Region 6:

Regression Statistics	
Multiple R	0.994682968
R Square	0.989394207
Adjusted R Square	0.98916694
Standard Error	0.025883453
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.749810675	2.916603558	4353.444193	5.7951E-138
Residual	140	0.093793438	0.000669953		
Total	143	8.843604113			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
β0	0.320979436	0.0086985	36.90055074	5.22609E-74	0.303782034	0.338176837	0.303782034	0.338176837
β1	0.019117244	0.000383878	49.80033838	6.12166E-91	0.018358297	0.019876191	0.018358297	0.019876191
β2	-0.000134273	4.61242E-06	-29.11109331	2.97526E-61	-0.000143392	-0.000125154	-0.000143392	-0.000125154
β3	3.21003E-07	1.50274E-08	21.36117616	6.78747E-46	2.91293E-07	3.50713E-07	2.91293E-07	3.50713E-07

## Natural Gas Well Facilities Costs

Natural gas well facilities costs were calculated using an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). Well facilities costs consist of flowlines and connections, production package costs, and storage tank costs. The data was analyzed on a regional level. The independent variables are depth and Q, which is the flow rate of natural gas in million cubic feet. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * Q + \beta_3 * \text{Depth} * Q \quad (2.B-10)$$

where

- Cost = FWC\_W
- β0 = FACGK
- β1 = FACGA
- β2 = FACGB
- β3 = FACGC
- Q = PEAKDAILY\_RATE

from equation 2-28 in Chapter 2.

Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.

**West Texas, applied to OLOGSS region 4:**

<i>Regression Statistics</i>									
Multiple R	0.9834								
R Square	0.9672								
Adjusted R Square	0.9562								
Standard Error	5,820.26								
Observations	13								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	3	8,982,542,532.41	2,994,180,844.14	88.39	0.00				
Residual	9	304,879,039.45	33,875,448.83						
Total	12	9,287,421,571.86							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	3,477.41	4,694.03	0.74	0.48	-7,141.24	14,096.05	-7,141.24	14,096.05	
$\beta_1$	5.04	0.40	12.51	0.00	4.13	5.95	4.13	5.95	
$\beta_2$	63.87	19.07	3.35	0.01	20.72	107.02	20.72	107.02	
$\beta_3$	0.00	0.00	-3.18	0.01	-0.01	0.00	-0.01	0.00	

**South Texas, applied to OLOGSS region 2:**

<i>Regression Statistics</i>									
Multiple R	0.9621								
R Square	0.9256								
Adjusted R Square	0.9139								
Standard Error	8,279.60								
Observations	23								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	3	16,213,052,116.02	5,404,350,705.34	78.84	0.00				
Residual	19	1,302,484,315.70	68,551,806.09						
Total	22	17,515,536,431.72							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	14,960.60	4,066.98	3.68	0.00	6,448.31	23,472.90	6,448.31	23,472.90	
$\beta_1$	4.87	0.47	10.34	0.00	3.88	5.85	3.88	5.85	
$\beta_2$	28.49	6.42	4.43	0.00	15.04	41.93	15.04	41.93	
$\beta_3$	0.00	0.00	-3.62	0.00	0.00	0.00	0.00	0.00	

**Mid-Continent, applied to OLOGSS regions 3 and 6:**

<i>Regression Statistics</i>									
Multiple R	0.9917								
R Square	0.9835								
Adjusted R Square	0.9765								
Standard Error	4,030.43								
Observations	11								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	3	6,796,663,629.62	2,265,554,543.21	139.47	0.00				
Residual	7	113,710,456.60	16,244,350.94						
Total	10	6,910,374,086.22							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	10,185.92	3,441.41	2.96	0.02	2,048.29	18,323.54	2,048.29	18,323.54	
$\beta_1$	4.51	0.29	15.71	0.00	3.83	5.18	3.83	5.18	
$\beta_2$	55.38	14.05	3.94	0.01	22.16	88.60	22.16	88.60	
$\beta_3$	0.00	0.00	-3.78	0.01	-0.01	0.00	-0.01	0.00	

**Rocky Mountains, applied to OLOGSS regions 1, 5, and 7:**

Regression Statistics					
Multiple R	0.9594				
R Square	0.9204				
Adjusted R Square	0.8806				
Standard Error	7,894.95				
Observations	10				

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	4,322,988,996.06	1,440,996,332.02	23.12	0.00
Residual	6	373,981,660.54	62,330,276.76		
Total	9	4,696,970,656.60			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	7,922.48	8,200.06	0.97	0.37	-12,142.36	27,987.31	-12,142.36	27,987.31
$\beta_1$	6.51	1.14	5.71	0.00	3.72	9.30	3.72	9.30
$\beta_2$	89.26	28.88	3.09	0.02	18.59	159.94	18.59	159.94
$\beta_3$	-0.01	0.00	-2.77	0.03	-0.01	0.00	-0.01	0.00

## Gas Well Facilities Costs - Cost Adjustment Factor

The cost adjustment factor for gas well facilities cost was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$1 to \$20 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$5 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Gas Price} + \beta_2 * \text{Gas Price}^2 + \beta_3 * \text{Gas Price}^3$$

### Rocky Mountains, Applied to OLOGSS Regions 1, 5, and 7:

Regression Statistics					
Multiple R	0.995733794				
R Square	0.991485789				
Adjusted R Square	0.991303341				
Standard Error	0.025214281				
Observations	144				

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.3648558	3.454951933	5434.365566	1.2179E-144
Residual	140	0.089006392	0.00063576		
Total	143	10.45386219			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.276309237	0.008473615	32.60818851	2.86747E-67	0.259556445	0.293062029	0.259556445	0.293062029
$\beta_1$	0.20599743	0.003739533	55.08640551	8.89871E-97	0.198604173	0.213390688	0.198604173	0.213390688
$\beta_2$	-0.014457925	0.000449317	-32.17753015	1.48375E-66	-0.015346249	-0.0135696	-0.015346249	-0.0135696
$\beta_3$	0.000347281	1.46389E-05	23.72318475	6.71084E-51	0.000318339	0.000376223	0.000318339	0.000376223

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics	
Multiple R	0.99551629
R Square	0.991052684
Adjusted R Square	0.990860956
Standard Error	0.025683748
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.22936837	3.409789455	5169.05027	3.9254E-143
Residual	140	0.092351689	0.000659655		
Total	143	10.32172006			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.280854163	0.008631386	32.5387085	3.73403E-67	0.263789449	0.297918878	0.263789449	0.297918878
$\beta_1$	0.204879431	0.00380916	53.78599024	2.17161E-95	0.197348518	0.212410345	0.197348518	0.212410345
$\beta_2$	-0.014391989	0.000457683	-31.44530093	2.52353E-65	-0.015296854	-0.013487125	-0.015296854	-0.013487125
$\beta_3$	0.000345909	1.49115E-05	23.19753012	8.21832E-50	0.000316428	0.00037539	0.000316428	0.00037539

### Mid-Continent, Applied to OLOGSS Regions 3 and 6:

Regression Statistics	
Multiple R	0.995511275
R Square	0.991042698
Adjusted R Square	0.990850756
Standard Error	0.025690919
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.22356717	3.407855722	5163.235345	4.2442E-143
Residual	140	0.092403264	0.000660023		
Total	143	10.31597043			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.280965064	0.008633796	32.5424714	3.68097E-67	0.263895586	0.298034543	0.263895586	0.298034543
$\beta_1$	0.204856879	0.003810223	53.7650588	2.28751E-95	0.197323863	0.212389895	0.197323863	0.212389895
$\beta_2$	-0.014391983	0.000457811	-31.43650889	2.61165E-65	-0.0152971	-0.013486865	-0.0152971	-0.013486865
$\beta_3$	0.000345929	1.49156E-05	23.19242282	8.42221E-50	0.00031644	0.000375418	0.00031644	0.000375418

### West Texas, Applied to OLOGSS Region 4:

Regression Statistics	
Multiple R	0.995452965
R Square	0.990926606
Adjusted R Square	0.990732176
Standard Error	0.025768075
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.15228252	3.384094173	5096.576002	1.0453E-142
Residual	140	0.092959113	0.000663994		
Total	143	10.24524163			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.282511839	0.008659725	32.62364879	2.704E-67	0.265391097	0.299632581	0.265391097	0.299632581
$\beta_1$	0.204502598	0.003821666	53.51137044	4.3021E-95	0.196946958	0.212058237	0.196946958	0.212058237
$\beta_2$	-0.014382652	0.000459186	-31.32206064	4.08566E-65	-0.015290487	-0.013474816	-0.015290487	-0.013474816
$\beta_3$	0.000345898	1.49604E-05	23.12086258	1.18766E-49	0.00031632	0.000375475	0.00031632	0.000375475

## Fixed Annual Costs for Crude Oil Wells

The fixed annual cost for crude oil wells was calculated using an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). Fixed annual costs consist of supervision and overhead costs, auto usage costs, operative supplies, labor costs, supplies and services costs, equipment usage and other costs.

The data was analyzed on a regional level. The independent variable is depth. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-11)$$

where Cost = OMO\_W

$\beta_0$  = OMOK

$\beta_1$  = OMOA

$\beta_2$  = OMOB

$\beta_3$  = OMOC

from equation 2-30 in Chapter 2.

The cost is on a per well basis. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.  $\beta_2$  and  $\beta_3$  are statistically insignificant and are therefore zero.

#### West Texas, applied to OLOGSS region 4:

<i>Regression Statistics</i>	
Multiple R	0.9895
R Square	0.9792
Adjusted R Square	0.9584
Standard Error	165.6
Observations	3

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	1,290,021.8	1,290,021.8	47.0	0.1
Residual	1	27,419.5	27,419.5		
Total	2	1,317,441.3			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	6,026.949	202.804	29.718	0.021	3,450.097	8,603.802	3,450.097	8,603.802
$\beta_1$	0.263	0.038	6.859	0.092	-0.224	0.750	-0.224	0.750

#### South Texas, applied to OLOGSS region 2:

<i>Regression Statistics</i>	
Multiple R	0.8631
R Square	0.7449
Adjusted R Square	0.6811
Standard Error	2,759.2
Observations	6

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	88,902,026.9	88,902,026.9	11.7	0.0
Residual	4	30,452,068.1	7,613,017.0		
Total	5	119,354,095.0			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	7,171.358	2,389.511	3.001	0.040	536.998	13,805.718	536.998	13,805.718
$\beta_1$	1.543	0.452	3.417	0.027	0.289	2.797	0.289	2.797

### Mid-Continent, applied to OLOGSS region 3:

<i>Regression Statistics</i>	
Multiple R	0.9888
R Square	0.9777
Adjusted R Square	0.9554
Standard Error	325.8
Observations	3

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	4,654,650.4	4,654,650.4	43.9	0.1
Residual	1	106,147.3	106,147.3		
Total	2	4,760,797.7			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	5,572.283	399.025	13.965	0.046	502.211	10,642.355	502.211	10,642.355
$\beta_1$	0.499	0.075	6.622	0.095	-0.459	1.458	-0.459	1.458

### Rocky Mountains, applied to OLOGSS regions 1, 5, and 7:

<i>Regression Statistics</i>	
Multiple R	0.9634
R Square	0.9282
Adjusted R Square	0.8923
Standard Error	455.6
Observations	4

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	5,368,949.5	5,368,949.5	25.9	0.0
Residual	2	415,138.5	207,569.2		
Total	3	5,784,088.0			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	6,327.733	447.809	14.130	0.005	4,400.964	8,254.501	4,400.964	8,254.501
$\beta_1$	0.302	0.059	5.086	0.037	0.046	0.557	0.046	0.557

### West Coast, applied to OLOGSS region 6:

<i>Regression Statistics</i>	
Multiple R	0.9908
R Square	0.9817
Adjusted R Square	0.9725
Standard Error	313.1
Observations	4

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	10,498,366.6	10,498,366.6	107.1	0.0
Residual	2	196,056.3	98,028.2		
Total	3	10,694,422.9			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	5,193.399	307.742	16.876	0.003	3,869.291	6,517.508	3,869.291	6,517.508
$\beta_1$	0.422	0.041	10.349	0.009	0.246	0.597	0.246	0.597

## Fixed Annual Costs for Oil Wells - Cost Adjustment Factor

The cost adjustment factor of the fixed annual cost for oil wells was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The

differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Rocky Mountains, Applied to OLOGSS Regions 1, 5, and 7:

Regression Statistics								
Multiple R	0.994014283							
R Square	0.988064394							
Adjusted R Square	0.987808631							
Standard Error	0.026960479							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	8.424110153	2.808036718	3863.203308	2.2587E-134			
Residual	140	0.101761442	0.000726867					
Total	143	8.525871595						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.325522735	0.00906045	35.9278779	1.54278E-72	0.30760974	0.343435731	0.30760974	0.343435731
$\beta_1$	0.019415379	0.000399851	48.55651174	1.74247E-89	0.018624852	0.020205906	0.018624852	0.020205906
$\beta_2$	-0.000139999	4.80435E-06	-29.14014276	2.63883E-61	-0.000149498	-0.000130501	-0.000149498	-0.000130501
$\beta_3$	3.41059E-07	1.56527E-08	21.78917295	7.98896E-47	3.10113E-07	3.72006E-07	3.10113E-07	3.72006E-07

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics								
Multiple R	0.972995979							
R Square	0.946721175							
Adjusted R Square	0.945579485							
Standard Error	0.052710031							
Observations	144							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	3	6.91165462	2.303884873	829.2285185	6.67464E-89			
Residual	140	0.388968632	0.002778347					
Total	143	7.300623252						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.305890757	0.01771395	17.26835352	1.6689E-36	0.270869326	0.340912188	0.270869326	0.340912188
$\beta_1$	0.019637228	0.000781743	25.11979642	1.01374E-53	0.01809168	0.021182776	0.01809168	0.021182776
$\beta_2$	-0.000147609	9.39291E-06	-15.71490525	1.03843E-32	-0.000166179	-0.000129038	-0.000166179	-0.000129038
$\beta_3$	3.60127E-07	3.06024E-08	11.76795581	1.17387E-22	2.99625E-07	4.2063E-07	2.99625E-07	4.2063E-07

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics	
Multiple R	0.993998856
R Square	0.988033725
Adjusted R Square	0.987777305
Standard Error	0.02698784
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.419321124	2.806440375	3853.182417	2.7032E-134
Residual	140	0.10196809	0.000728344		
Total	143	8.521289214			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.32545185	0.009069645	35.88363815	1.80273E-72	0.307520675	0.343383025	0.307520675	0.343383025
$\beta_1$	0.019419103	0.000400257	48.51658921	1.94263E-89	0.018627774	0.020210433	0.018627774	0.020210433
$\beta_2$	-0.000140059	4.80922E-06	-29.12303298	2.83205E-61	-0.000149567	-0.000130551	-0.000149567	-0.000130551
$\beta_3$	3.41232E-07	1.56686E-08	21.77807458	8.44228E-47	3.10254E-07	3.72209E-07	3.10254E-07	3.72209E-07

### West Texas, Applied to OLOGSS Region 4:

Regression Statistics	
Multiple R	0.977862049
R Square	0.956214186
Adjusted R Square	0.955275919
Standard Error	0.050111949
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	7.677722068	2.559240689	1019.127536	7.26235E-95
Residual	140	0.351569047	0.002511207		
Total	143	8.029291115			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.343679311	0.016840828	20.40750634	8.67459E-44	0.310384089	0.376974533	0.310384089	0.376974533
$\beta_1$	0.020087054	0.000743211	27.02739293	2.04852E-57	0.018617686	0.021556422	0.018617686	0.021556422
$\beta_2$	-0.000153877	8.92993E-06	-17.23164844	2.04504E-36	-0.000171532	-0.000136222	-0.000171532	-0.000136222
$\beta_3$	3.91397E-07	2.9094E-08	13.45286338	5.31787E-27	3.33877E-07	4.48918E-07	3.33877E-07	4.48918E-07

### West Coast, Applied to OLOGSS Region 6:

Regression Statistics	
Multiple R	0.993729589
R Square	0.987498496
Adjusted R Square	0.987230606
Standard Error	0.027203598
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.183798235	2.727932745	3686.217436	5.7808E-133
Residual	140	0.103605007	0.000740036		
Total	143	8.287403242			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.330961672	0.009142153	36.20171926	5.90451E-73	0.312887144	0.3490362	0.312887144	0.3490362
$\beta_1$	0.019295414	0.000403457	47.82521879	1.29343E-88	0.018497758	0.02009307	0.018497758	0.02009307
$\beta_2$	-0.000139784	4.84767E-06	-28.83529781	9.33567E-61	-0.000149368	-0.0001302	-0.000149368	-0.0001302
$\beta_3$	3.4128E-07	1.57939E-08	21.60840729	1.96666E-46	3.10055E-07	3.72505E-07	3.10055E-07	3.72505E-07

## Fixed Annual Costs for Natural Gas Wells

Fixed annual costs for natural gas wells were calculated using an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). Fixed annual costs consist of the lease equipment costs for natural gas production for a given year. The data was analyzed on a regional level. The independent variables are depth and Q which is the flow rate of natural gas in million cubic feet. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * Q + \beta_3 * \text{Depth} * Q \quad (2.B-12)$$

where  $\text{Cost} = \text{FOAMG\_W}$   
 $\beta_0 = \text{OMGK}$   
 $\beta_1 = \text{OMGA}$   
 $\beta_2 = \text{OMGB}$   
 $\beta_3 = \text{OMGC}$   
 $Q = \text{PEAKDAILY\_RATE}$   
 from equation 2-29 in Chapter 2.

Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.

### West Texas, applied to OLOGSS region 4:

<i>Regression Statistics</i>	
Multiple R	0.928
R Square	0.861
Adjusted R Square	0.815
Standard Error	6,471.68
Observations	13

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3	2,344,632,468.49	781,544,156.16	18.66	0.00
Residual	9	376,944,241.62	41,882,693.51		
Total	12	2,721,576,710.11			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	4,450.28	5,219.40	0.85	0.42	-7,356.84	16,257.40	-7,356.84	16,257.40
$\beta_1$	2.50	0.45	5.58	0.00	1.49	3.51	1.49	3.51
$\beta_2$	27.65	21.21	1.30	0.22	-20.33	75.63	-20.33	75.63
$\beta_3$	0.00	0.00	-1.21	0.26	0.00	0.00	0.00	0.00

**South Texas, applied to OLOGSS region 2:**

<i>Regression Statistics</i>	
Multiple R	0.913
R Square	0.834
Adjusted R Square	0.807
Standard Error	6,564.36
Observations	23

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3	4,100,685,576.61	1,366,895,192.20	31.72	0.00
Residual	19	818,725,806.73	43,090,831.93		
Total	22	4,919,411,383.34			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	11,145.70	3,224.45	3.46	0.00	4,396.85	17,894.55	4,396.85	17,894.55
$\beta_1$	2.68	0.37	7.17	0.00	1.90	3.46	1.90	3.46
$\beta_2$	7.67	5.09	1.51	0.15	-2.99	18.33	-2.99	18.33
$\beta_3$	0.00	0.00	-1.21	0.24	0.00	0.00	0.00	0.00

**Mid-Continent, applied to OLOGSS region 3 and 6:**

<i>Regression Statistics</i>	
Multiple R	0.934
R Square	0.873
Adjusted R Square	0.830
Standard Error	6,466.88
Observations	13

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3	2,578,736,610.45	859,578,870.15	20.55	0.00
Residual	9	376,384,484.71	41,820,498.30		
Total	12	2,955,121,095.16			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	8,193.82	5,410.04	1.51	0.16	-4,044.54	20,432.18	-4,044.54	20,432.18
$\beta_1$	2.75	0.45	6.14	0.00	1.74	3.77	1.74	3.77
$\beta_2$	21.21	18.04	1.18	0.27	-19.59	62.01	-19.59	62.01
$\beta_3$	0.00	0.00	-1.12	0.29	0.00	0.00	0.00	0.00

**Rocky Mountains, applied to OLOGSS region 1, 5, and 7:**

<i>Regression Statistics</i>	
Multiple R	0.945
R Square	0.893
Adjusted R Square	0.840
Standard Error	6,104.84
Observations	10

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3	1,874,387,985.75	624,795,995.25	16.76	0.00
Residual	6	223,614,591.98	37,269,098.66		
Total	9	2,098,002,577.72			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	7,534.86	6,340.77	1.19	0.28	-7,980.45	23,050.17	-7,980.45	23,050.17
$\beta_1$	3.81	0.88	4.33	0.00	1.66	5.97	1.66	5.97
$\beta_2$	32.27	22.33	1.44	0.20	-22.38	86.92	-22.38	86.92
$\beta_3$	0.00	0.00	-1.18	0.28	-0.01	0.00	-0.01	0.00

## Fixed Annual Costs for Gas Wells - Cost Adjustment Factor

The cost adjustment factor of the fixed annual cost for gas wells was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$1 to \$20 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$5 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Gas Price} + \beta_2 * \text{Gas Price}^2 + \beta_3 * \text{Gas Price}^3$$

### Rocky Mountains, Applied to OLOGSS Region 1, 5, and 7:

Regression Statistics	
Multiple R	0.994836789
R Square	0.989700237
Adjusted R Square	0.989479527
Standard Error	0.029019958
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	11.32916798	3.776389326	4484.181718	7.4647E-139
Residual	140	0.117902114	0.000842158		
Total	143	11.44707009			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.234219858	0.009752567	24.01622716	1.68475E-51	0.21493851	0.253501206	0.21493851	0.253501206
$\beta_1$	0.216761767	0.004303953	50.36340872	1.37772E-91	0.20825262	0.225270914	0.20825262	0.225270914
$\beta_2$	-0.015234638	0.000517134	-29.45972427	7.08872E-62	-0.01625704	-0.014212235	-0.01625704	-0.014212235
$\beta_3$	0.000365319	1.68484E-05	21.68270506	1.3574E-46	0.000332009	0.000398629	0.000332009	0.000398629

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics	
Multiple R	0.995657421
R Square	0.991333701
Adjusted R Square	0.991147994
Standard Error	0.02551118
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.42258156	3.474193854	5338.176859	4.2055E-144
Residual	140	0.091114842	0.00065082		
Total	143	10.5136964			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.276966489	0.008573392	32.30535588	9.09319E-67	0.260016432	0.293916546	0.260016432	0.293916546
$\beta_1$	0.205740933	0.003783566	54.37751691	5.03408E-96	0.198260619	0.213221246	0.198260619	0.213221246
$\beta_2$	-0.014407802	0.000454608	-31.6927929	9.63037E-66	-0.015306587	-0.013509017	-0.015306587	-0.013509017
$\beta_3$	0.00034576	1.48113E-05	23.34441529	4.06714E-50	0.000316478	0.000375043	0.000316478	0.000375043

### Mid-Continent, Applied to OLOGSS Region 3 and 6:

Regression Statistics	
Multiple R	0.995590124
R Square	0.991199695
Adjusted R Square	0.991011117
Standard Error	0.025596313
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.33109303	3.443697678	5256.179662	1.231E-143
Residual	140	0.091723972	0.000655171		
Total	143	10.42281701			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.278704883	0.008602002	32.4000063	6.33409E-67	0.261698262	0.295711504	0.261698262	0.295711504
$\beta_1$	0.205373482	0.003796192	54.09986358	9.97995E-96	0.197868206	0.212878758	0.197868206	0.212878758
$\beta_2$	-0.014404563	0.000456125	-31.58028284	1.49116E-65	-0.015306347	-0.013502779	-0.015306347	-0.013502779
$\beta_3$	0.000345945	1.48607E-05	23.27919988	5.55628E-50	0.000316565	0.000375325	0.000316565	0.000375325

### West Texas, Applied to OLOGSS Region 4:

Regression Statistics	
Multiple R	0.995548929
R Square	0.99111767
Adjusted R Square	0.990927334
Standard Error	0.02564864
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	10.27673171	3.425577238	5207.209824	2.3566E-143
Residual	140	0.092099383	0.000657853		
Total	143	10.3688311			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.279731342	0.008619588	32.45298388	5.17523E-67	0.262689954	0.296772729	0.262689954	0.296772729
$\beta_1$	0.205151971	0.003803953	53.93125949	1.51455E-95	0.197631352	0.21267259	0.197631352	0.21267259
$\beta_2$	-0.014402579	0.000457058	-31.51151347	1.94912E-65	-0.015306207	-0.013498952	-0.015306207	-0.013498952
$\beta_3$	0.00034606	1.48911E-05	23.23943141	6.72233E-50	0.00031662	0.000375501	0.00031662	0.000375501

## Fixed Annual Costs for Secondary Production

The fixed annual cost for secondary oil production was calculated an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). The data was analyzed on a regional level. The secondary operations costs for each region were determined by multiplying the costs in West Texas by the ratio of primary operating costs. This method was used in the National Petroleum Council’s (NPC) EOR study of 1984. The independent variable is depth. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-13)$$

where

$$\begin{aligned} \text{Cost} &= \text{OPSEC}_W \\ \beta_0 &= \text{OPSECK} \\ \beta_1 &= \text{OPSECA} \\ \beta_2 &= \text{OPSECB} \\ \beta_3 &= \text{OPSECC} \end{aligned}$$

from equation 2-31 in Chapter 2.

The cost is on a per well basis. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.  $\beta_2$  and  $\beta_3$  are statistically insignificant and are therefore zero.

**West Texas, applied to OLOGSS region 4:**

<i>Regression Statistics</i>								
Multiple R		0.9972						
R Square		0.9945						
Adjusted R Square		0.9890						
Standard Error		1,969.67						
Observations		3						
<i>ANOVA</i>								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	698,746,493.71	698,746,493.71	180.11	0.05			
Residual	1	3,879,582.16	3,879,582.16					
Total	2	702,626,075.87						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	30,509.3	2,412.338	12.647	0.050	-142.224	61,160.827	-142.224	61,160.827
$\beta_1$	6.118	0.456	13.420	0.047	0.326	11.911	0.326	11.911

**South Texas, applied to OLOGSS region 2:**

<i>Regression Statistics</i>								
Multiple R		0.935260						
R Square		0.874710						
Adjusted R Square		0.843388						
Standard Error		8414.07						
Observations		6						
<i>ANOVA</i>								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	1,977,068,663.41	1,977,068,663.41	27.93	0.01			
Residual	4	283,186,316.21	70,796,579.05					
Total	5	2,260,254,979.61						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	55,732.7	7,286.799	7.648	0.002	35,501.310	75,964.186	35,501.310	75,964.186
$\beta_1$	7.277	1.377	5.285	0.006	3.454	11.101	3.454	11.101

**Mid-Continent, applied to OLOGSS region 3:**

<i>Regression Statistics</i>								
Multiple R		0.998942						
R Square		0.997884						
Adjusted R Square		0.995768						
Standard Error		1329.04						
Observations		3						
<i>ANOVA</i>								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	833,049,989.02	833,049,989.02	471.62	0.03			
Residual	1	1,766,354.45	1,766,354.45					
Total	2	834,816,343.47						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	28,208.7	1,627.738	17.330	0.037	7,526.417	48,890.989	7,526.417	48,890.989
$\beta_1$	6.680	0.308	21.717	0.029	2.772	10.589	2.772	10.589

### Rocky Mountains, applied to OLOGSS regions 1, 5, and 7:

Regression Statistics								
Multiple R	0.989924							
R Square	0.979949							
Adjusted R Square	0.959899							
Standard Error	3639.10							
Observations	3							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	647,242,187.96	647,242,187.96	48.87	0.09			
Residual	1	13,243,073.43	13,243,073.43					
Total	2	660,485,261.39						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	53,857.06	4,456.973	12.084	0.053	-2,773.909	110,488.034	-2,773.909	110,488.034
$\beta_1$	5.888	0.842	6.991	0.090	-4.814	16.591	-4.814	16.591

### West Coast, applied to OLOGSS region 6:

Regression Statistics								
Multiple R	0.992089							
R Square	0.984240							
Adjusted R Square	0.968480							
Standard Error	5193.40							
Observations	3							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	1,684,438,248.88	1,684,438,248.88	62.45	0.08			
Residual	1	26,971,430.96	26,971,430.96					
Total	2	1,711,409,679.84						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	35,893.465	6,360.593	5.643	0.112	-44,925.189	116,712.119	-44,925.189	116,712.119
$\beta_1$	9.499	1.202	7.903	0.080	-5.774	24.773	-5.774	24.773

### Fixed Annual Costs for Secondary Production - Cost Adjustment Factor

The cost adjustment factor of the fixed annual costs for secondary production was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Rocky Mountains, Applied to OLOGSS Regions 1, 5, and 7:

Regression Statistics	
Multiple R	0.994022382
R Square	0.988080495
Adjusted R Square	0.987825078
Standard Error	0.026956819
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.433336986	2.811112329	3868.484883	2.0551E-134
Residual	140	0.101733815	0.00072667		
Total	143	8.535070802			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.325311813	0.00905922	35.90947329	1.646E-72	0.307401249	0.343222377	0.307401249	0.343222377
$\beta_1$	0.019419982	0.000399797	48.57461816	1.65866E-89	0.018629562	0.020210402	0.018629562	0.020210402
$\beta_2$	-0.000140009	4.80369E-06	-29.14604996	2.57525E-61	-0.000149506	-0.000130512	-0.000149506	-0.000130512
$\beta_3$	3.41057E-07	1.56506E-08	21.79195958	7.87903E-47	3.10115E-07	3.71999E-07	3.10115E-07	3.71999E-07

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics	
Multiple R	0.993830992
R Square	0.987700041
Adjusted R Square	0.987436471
Standard Error	0.027165964
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.296590955	2.765530318	3747.383987	1.8532E-133
Residual	140	0.103318541	0.00073799		
Total	143	8.399909496			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.321750317	0.009129506	35.24290662	1.74974E-71	0.303700794	0.33979984	0.303700794	0.33979984
$\beta_1$	0.019369439	0.000402899	48.0752057	6.49862E-89	0.018572887	0.020165992	0.018572887	0.020165992
$\beta_2$	-0.000140208	4.84096E-06	-28.96291516	5.49447E-61	-0.000149779	-0.000130638	-0.000149779	-0.000130638
$\beta_3$	3.42483E-07	1.5772E-08	21.71459435	1.15795E-46	3.11301E-07	3.73665E-07	3.11301E-07	3.73665E-07

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics	
Multiple R	0.994021683
R Square	0.988079106
Adjusted R Square	0.987823658
Standard Error	0.026959706
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.43414809	2.811382697	3868.028528	2.0719E-134
Residual	140	0.101755604	0.000726826		
Total	143	8.535903693			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.325281756	0.00906019	35.90231108	1.68802E-72	0.307369274	0.343194238	0.307369274	0.343194238
$\beta_1$	0.019420568	0.00039984	48.57088177	1.67561E-89	0.018630063	0.020211072	0.018630063	0.020211072
$\beta_2$	-0.000140009	4.80421E-06	-29.14305099	2.60734E-61	-0.000149507	-0.000130511	-0.000149507	-0.000130511
$\beta_3$	3.41049E-07	1.56523E-08	21.7891193	7.99109E-47	3.10103E-07	3.71994E-07	3.10103E-07	3.71994E-07

### West Texas, Applied to OLOGSS Region 4:

Regression Statistics	
Multiple R	0.994023418
R Square	0.988082555
Adjusted R Square	0.987827181
Standard Error	0.026956158
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.434398087	2.811466029	3869.161392	2.0304E-134
Residual	140	0.101728825	0.000726634		
Total	143	8.536126912			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.325293493	0.009058998	35.90833165	1.65262E-72	0.307383368	0.343203618	0.307383368	0.343203618
$\beta_1$	0.019420405	0.000399787	48.57686713	1.64854E-89	0.018630005	0.020210806	0.018630005	0.020210806
$\beta_2$	-0.000140009	4.80358E-06	-29.14672886	2.56804E-61	-0.000149505	-0.000130512	-0.000149505	-0.000130512
$\beta_3$	3.41053E-07	1.56502E-08	21.792237	7.86817E-47	3.10111E-07	3.71994E-07	3.10111E-07	3.71994E-07

### West Coast, Applied to OLOGSS Region 6:

Regression Statistics	
Multiple R	0.993899019
R Square	0.98783526
Adjusted R Square	0.987574587
Standard Error	0.027222624
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.42499532	2.808331773	3789.557133	8.5487E-134
Residual	140	0.103749972	0.000741071		
Total	143	8.528745292			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.327122709	0.009148547	35.75679345	2.81971E-72	0.30903554	0.345209878	0.30903554	0.345209878
$\beta_1$	0.019283711	0.000403739	47.76280844	1.53668E-88	0.018485497	0.020081925	0.018485497	0.020081925
$\beta_2$	-0.000138419	4.85106E-06	-28.53379985	3.28809E-60	-0.00014801	-0.000128828	-0.00014801	-0.000128828
$\beta_3$	3.36276E-07	1.58049E-08	21.27670912	1.03818E-45	3.05029E-07	3.67523E-07	3.05029E-07	3.67523E-07

## Lifting Costs

Lifting costs for crude oil wells were calculated using average an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). Lifting costs consist of labor costs for the pumper, chemicals, fuel, power and water costs. The data was analyzed on a regional level. The independent variable is depth. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-14)$$

where  $\text{Cost} = \text{OML\_W}$

$\beta_0 = \text{OMLK}$

$\beta_1 = \text{OMLA}$

$\beta_2 = \text{OMLB}$

$\beta_3 = \text{OMLC}$

from equation 2-32 in Chapter 2.

The cost is on a per well basis. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.  $\beta_2$  and  $\beta_3$  are statistically insignificant and are therefore zero.

**West Texas, applied to OLOGSS region 4:**

<i>Regression Statistics</i>								
Multiple R	0.9994							
R Square	0.9988							
Adjusted R Square	0.9976							
Standard Error	136.7							
Observations	3							
<i>ANOVA</i>								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	15,852,301	15,852,301	849	0			
Residual	1	18,681	18,681					
Total	2	15,870,982						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	7,534.515	167.395	45.010	0.014	5,407.565	9,661.465	5,407.565	9,661.465
$\beta_1$	0.922	0.032	29.131	0.022	0.520	1.323	0.520	1.323

**South Texas, applied to OLOGSS region 2:**

<i>Regression Statistics</i>								
Multiple R	0.8546							
R Square	0.7304							
Adjusted R Square	0.6764							
Standard Error	2263.5							
Observations	7							
<i>ANOVA</i>								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	69,387,339	69,387,339	14	0			
Residual	5	25,617,128	5,123,426					
Total	6	95,004,467						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	11,585.191	1,654.440	7.002	0.001	7,332.324	15,838.058	7,332.324	15,838.058
$\beta_1$	0.912	0.248	3.680	0.014	0.275	1.549	0.275	1.549

**Mid-Continent, applied to OLOGSS region 3:**

<i>Regression Statistics</i>								
Multiple R	0.9997							
R Square	0.9995							
Adjusted R Square	0.9990							
Standard Error	82.0							
Observations	3							
<i>ANOVA</i>								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	1	13,261,874	13,261,874	1,972	0			
Residual	1	6,726	6,726					
Total	2	13,268,601						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	8,298.339	100.447	82.614	0.008	7,022.045	9,574.634	7,022.045	9,574.634
$\beta_1$	0.843	0.019	44.403	0.014	0.602	1.084	0.602	1.084

**Rocky Mountains, applied to OLOGSS region 1, 5, and 7:**

<i>Regression Statistics</i>									
Multiple R	1.0000								
R Square	1.0000								
Adjusted R Square	0.9999								
Standard Error	11.5								
Observations	3								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	3,979,238	3,979,238	30,138	0				
Residual	1	132	132						
Total	2	3,979,370							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	10,137.398	14.073	720.342	0.001	9,958.584	10,316.212	9,958.584	10,316.212	
$\beta_1$	0.462	0.003	173.603	0.004	0.428	0.495	0.428	0.495	

### West Coast, applied to OLOGSS region 6:

<i>Regression Statistics</i>									
Multiple R	0.9969								
R Square	0.9937								
Adjusted R Square	0.9874								
Standard Error	1134.3								
Observations	3								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	203,349,853	203,349,853	158	0				
Residual	1	1,286,583	1,286,583						
Total	2	204,636,436							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	5,147.313	1,389.199	3.705	0.168	-12,504.063	22,798.689	-12,504.063	22,798.689	
$\beta_1$	3.301	0.263	12.572	0.051	-0.035	6.636	-0.035	6.636	

### Lifting Costs - Cost Adjustment Factor

The cost adjustment factor for lifting costs for was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Rocky Mountains, Applied to OLOGSS Region 1, 5, and 7:

Regression Statistics	
Multiple R	0.994419415
R Square	0.988869972
Adjusted R Square	0.988631472
Standard Error	0.026749137
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.900010642	2.966670214	4146.195026	1.6969E-136
Residual	140	0.100172285	0.000715516		
Total	143	9.000182927			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.314447949	0.008989425	34.97976138	4.49274E-71	0.296675373	0.332220525	0.296675373	0.332220525
$\beta_1$	0.019667961	0.000396717	49.57683267	1.11119E-90	0.018883631	0.020452291	0.018883631	0.020452291
$\beta_2$	-0.000140635	4.76668E-06	-29.50377541	5.91881E-62	-0.000150059	-0.000131211	-0.000150059	-0.000131211
$\beta_3$	3.41221E-07	1.553E-08	21.97170644	3.23018E-47	3.10517E-07	3.71924E-07	3.10517E-07	3.71924E-07

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics	
Multiple R	0.994725637
R Square	0.989479094
Adjusted R Square	0.989253646
Standard Error	0.026400955
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.177423888	3.059141296	4388.946164	3.302E-138
Residual	140	0.097581462	0.00069701		
Total	143	9.275005349			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.307250046	0.008872414	34.62981435	1.58839E-70	0.289708807	0.324791284	0.289708807	0.324791284
$\beta_1$	0.019843369	0.000391553	50.6786443	6.01683E-92	0.019069248	0.020617491	0.019069248	0.020617491
$\beta_2$	-0.000141338	4.70464E-06	-30.04217841	6.6318E-63	-0.000150639	-0.000132036	-0.000150639	-0.000132036
$\beta_3$	3.42235E-07	1.53279E-08	22.32765206	5.59173E-48	3.11931E-07	3.72539E-07	3.11931E-07	3.72539E-07

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics	
Multiple R	0.994625665
R Square	0.989280214
Adjusted R Square	0.989050504
Standard Error	0.026521235
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.087590035	3.029196678	4306.653909	1.2247E-137
Residual	140	0.09847263	0.000703376		
Total	143	9.186062664			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.309274775	0.008912836	34.69993005	1.23231E-70	0.291653621	0.32689593	0.291653621	0.32689593
$\beta_1$	0.019797213	0.000393337	50.33145871	1.49879E-91	0.019019565	0.020574861	0.019019565	0.020574861
$\beta_2$	-0.000141221	4.72607E-06	-29.88132995	1.27149E-62	-0.000150565	-0.000131878	-0.000150565	-0.000131878
$\beta_3$	3.42202E-07	1.53977E-08	22.22423366	9.29272E-48	3.1176E-07	3.72644E-07	3.1176E-07	3.72644E-07

### West Texas, Applied to OLOGSS Region 4:

Regression Statistics	
Multiple R	0.994686146
R Square	0.98940053
Adjusted R Square	0.989173398
Standard Error	0.026467032
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.154328871	3.051442957	4356.069182	5.5581E-138
Residual	140	0.09807053	0.000700504		
Total	143	9.252399401			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.307664081	0.00889462	34.58990756	1.8356E-70	0.29007894	0.325249222	0.29007894	0.325249222
$\beta_1$	0.019836272	0.000392533	50.53404116	8.79346E-92	0.019060214	0.020612331	0.019060214	0.020612331
$\beta_2$	-0.000141357	4.71641E-06	-29.97123684	8.83426E-63	-0.000150681	-0.000132032	-0.000150681	-0.000132032
$\beta_3$	3.42352E-07	1.53662E-08	22.27954719	7.08083E-48	3.11973E-07	3.72732E-07	3.11973E-07	3.72732E-07

### West Coast, Applied to OLOGSS Region 6:

Regression Statistics	
Multiple R	0.993880162
R Square	0.987797777
Adjusted R Square	0.987536301
Standard Error	0.027114753
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	8.332367897	2.777455966	3777.77319	1.0603E-133
Residual	140	0.102929375	0.00073521		
Total	143	8.435297272			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.326854136	0.009112296	35.86957101	1.8943E-72	0.308838638	0.344869634	0.308838638	0.344869634
$\beta_1$	0.019394839	0.000402139	48.22916512	4.26E-89	0.018599788	0.02018989	0.018599788	0.02018989
$\beta_2$	-0.000140183	4.83184E-06	-29.01231258	4.47722E-61	-0.000149736	-0.00013063	-0.000149736	-0.00013063
$\beta_3$	3.41846E-07	1.57423E-08	21.71513554	1.15483E-46	3.10722E-07	3.72969E-07	3.10722E-07	3.72969E-07

## Secondary Workover Costs

Secondary workover costs were calculated using an average from 2004 – 2007 data from the most recent Cost and Indices data base provided by the U.S. Energy Information Administration (EIA). Secondary workover costs consist of workover rig services, remedial services and equipment repair. The data was analyzed on a regional level. The secondary operations costs for each region were determined by multiplying the costs in West Texas by the ratio of primary operating costs. This method was used in the National Petroleum Council's (NPC) EOR study of 1984. The independent variable is depth. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Depth} + \beta_2 * \text{Depth}^2 + \beta_3 * \text{Depth}^3 \quad (2.B-15)$$

where

- Cost = SWK\_W
- $\beta_0$  = OMSWRK
- $\beta_1$  = OMSWRA
- $\beta_2$  = OMSWRB
- $\beta_3$  = OMSWRC

from equation 2-33 in Chapter 2.

The cost is on a per well basis. Parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.  $\beta_2$  and  $\beta_3$  are statistically insignificant and are therefore zero.

**West Texas, applied to OLOGSS region 4:**

<i>Regression Statistics</i>									
Multiple R	0.9993								
R Square	0.9986								
Adjusted R Square	0.9972								
Standard Error	439.4								
Observations	3								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	136,348,936	136,348,936	706	0				
Residual	1	193,106	193,106						
Total	2	136,542,042							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	4,951.059	538.200	9.199	0.069	-1,887.392	11,789.510	-1,887.392	11,789.510	
$\beta_1$	2.703	0.102	26.572	0.024	1.410	3.995	1.410	3.995	

**South Texas, applied to OLOGSS region 2:**

<i>Regression Statistics</i>									
Multiple R	0.9924								
R Square	0.9849								
Adjusted R Square	0.9811								
Standard Error	1356.3								
Observations	6								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	480,269,759	480,269,759	261	0				
Residual	4	7,358,144	1,839,536						
Total	5	487,627,903							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	10,560.069	1,174.586	8.990	0.001	7,298.889	13,821.249	7,298.889	13,821.249	
$\beta_1$	3.587	0.222	16.158	0.000	2.970	4.203	2.970	4.203	

**Mid-Continent, applied to OLOGSS region 3:**

<i>Regression Statistics</i>									
Multiple R	0.9989								
R Square	0.9979								
Adjusted R Square	0.9958								
Standard Error	544.6								
Observations	3								
<i>ANOVA</i>									
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
Regression	1	140,143,261	140,143,261	473	0				
Residual	1	296,583	296,583						
Total	2	140,439,844							
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>	
$\beta_0$	3,732.510	666.989	5.596	0.113	-4,742.355	12,207.375	-4,742.355	12,207.375	
$\beta_1$	2.740	0.126	21.738	0.029	1.138	4.342	1.138	4.342	

**Rocky Mountains, applied to OLOGSS region 1, 5, and 7:**

<i>Regression Statistics</i>	
Multiple R	0.9996
R Square	0.9991
Adjusted R Square	0.9983
Standard Error	290.9
Observations	3

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	98,740,186	98,740,186	1,167	0
Residual	1	84,627	84,627		
Total	2	98,824,812			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	5,291.954	356.287	14.853	0.043	764.922	9,818.987	764.922	9,818.987
$\beta_1$	2.300	0.067	34.158	0.019	1.444	3.155	1.444	3.155

### West Coast, applied to OLOGSS region 6:

<i>Regression Statistics</i>	
Multiple R	0.9991
R Square	0.9983
Adjusted R Square	0.9966
Standard Error	454.7
Observations	3

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	120,919,119	120,919,119	585	0
Residual	1	206,762	206,762		
Total	2	121,125,881			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
$\beta_0$	4,131.486	556.905	7.419	0.085	-2,944.638	11,207.610	-2,944.638	11,207.610
$\beta_1$	2.545	0.105	24.183	0.026	1.208	3.882	1.208	3.882

### Secondary Workover Costs - Cost Adjustment Factor

The cost adjustment factor for secondary workover costs was calculated using data through 2008 from the Cost and Indices data base provided by EIA. The initial cost was normalized at various prices from \$10 to \$200 per barrel. This led to the development of a series of intermediate equations and the calculation of costs at specific prices and fixed depths. The differentials between estimated costs across the price range and fixed costs at \$50 per barrel were then calculated. The cost factor equation was then estimated using the differentials. The method of estimation used was ordinary least squares. The form of the equation is given below:

$$\text{Cost} = \beta_0 + \beta_1 * \text{Oil Price} + \beta_2 * \text{Oil Price}^2 + \beta_3 * \text{Oil Price}^3$$

### Rocky Mountains, Applied to OLOGSS Region 1, 5, and 7:

Regression Statistics	
Multiple R	0.994646805
R Square	0.989322267
Adjusted R Square	0.989093459
Standard Error	0.026416612
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.051925882	3.017308627	4323.799147	9.3015E-138
Residual	140	0.097697232	0.000697837		
Total	143	9.149623114			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.312179978	0.008877675	35.1646082	2.31513E-71	0.294628337	0.329731619	0.294628337	0.329731619
$\beta_1$	0.019705242	0.000391785	50.29605017	1.64552E-91	0.018930662	0.020479822	0.018930662	0.020479822
$\beta_2$	-0.000140397	4.70743E-06	-29.82464336	1.6003E-62	-0.000149704	-0.000131091	-0.000149704	-0.000131091
$\beta_3$	3.4013E-07	1.53369E-08	22.17714344	1.1716E-47	3.09808E-07	3.70452E-07	3.09808E-07	3.70452E-07

### South Texas, Applied to OLOGSS Region 2:

Regression Statistics	
Multiple R	0.994648271
R Square	0.989325182
Adjusted R Square	0.989096436
Standard Error	0.026409288
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.049404415	3.016468138	4324.992582	9.1255E-138
Residual	140	0.097643067	0.00069745		
Total	143	9.147047482			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.31224985	0.008875214	35.18223288	2.17363E-71	0.294703075	0.329796624	0.294703075	0.329796624
$\beta_1$	0.019703773	0.000391676	50.30624812	1.60183E-91	0.018929408	0.020478139	0.018929408	0.020478139
$\beta_2$	-0.000140393	4.70612E-06	-29.83187838	1.55398E-62	-0.000149697	-0.000131088	-0.000149697	-0.000131088
$\beta_3$	3.40125E-07	1.53327E-08	22.18299399	1.13834E-47	3.09811E-07	3.70439E-07	3.09811E-07	3.70439E-07

### Mid-Continent, Applied to OLOGSS Region 3:

Regression Statistics	
Multiple R	0.994391906
R Square	0.988815263
Adjusted R Square	0.98857559
Standard Error	0.027366799
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.269694355	3.089898118	4125.685804	2.3918E-136
Residual	140	0.104851837	0.000748942		
Total	143	9.374546192			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.301399555	0.009196999	32.7715099	1.54408E-67	0.283216594	0.319582517	0.283216594	0.319582517
$\beta_1$	0.020285999	0.000405877	49.980617	3.79125E-91	0.019483558	0.021088441	0.019483558	0.021088441
$\beta_2$	-0.000145269	4.87675E-06	-29.78803686	1.85687E-62	-0.00015491	-0.000135627	-0.00015491	-0.000135627
$\beta_3$	3.51144E-07	1.58886E-08	22.10035946	1.71054E-47	3.19731E-07	3.82556E-07	3.19731E-07	3.82556E-07

### West Texas, Applied to OLOGSS Region 4:

Regression Statistics	
Multiple R	0.994645783
R Square	0.989320233
Adjusted R Square	0.989091381
Standard Error	0.026422924
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.054508298	3.018169433	4322.966602	9.4264E-138
Residual	140	0.097743924	0.000698171		
Total	143	9.152252223			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.312146343	0.008879797	35.15242029	2.41837E-71	0.294590508	0.329702178	0.294590508	0.329702178
$\beta_1$	0.019706241	0.000391879	50.28658391	1.68714E-91	0.018931476	0.020481006	0.018931476	0.020481006
$\beta_2$	-0.000140397	4.70855E-06	-29.81743751	1.64782E-62	-0.000149706	-0.000131088	-0.000149706	-0.000131088
$\beta_3$	3.4012E-07	1.53406E-08	22.17121727	1.20629E-47	3.09791E-07	3.70449E-07	3.09791E-07	3.70449E-07

### West Coast, Applied to OLOGSS Region 6:

Regression Statistics	
Multiple R	0.994644139
R Square	0.989316964
Adjusted R Square	0.989088042
Standard Error	0.026428705
Observations	144

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	9.05566979	3.018556597	4321.629647	9.6305E-138
Residual	140	0.097786705	0.000698476		
Total	143	9.153456495			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	0.312123671	0.00888174	35.14217734	2.50872E-71	0.294563994	0.329683347	0.294563994	0.329683347
$\beta_1$	0.019707015	0.000391964	50.27755672	1.72782E-91	0.01893208	0.020481949	0.01893208	0.020481949
$\beta_2$	-0.0001404	4.70958E-06	-29.81159891	1.68736E-62	-0.000149711	-0.000131089	-0.000149711	-0.000131089
$\beta_3$	3.40124E-07	1.5344E-08	22.16666321	1.23366E-47	3.09789E-07	3.7046E-07	3.09789E-07	3.7046E-07

## Additional Cost Equations and Factors

The model uses several updated cost equations and factors originally developed for DOE/NETL's Comprehensive Oil and Gas Analysis Model (COGAM). These are:

- The crude oil and natural gas investment factors for tangible and intangible investments as well as the operating costs. These factors were originally developed based upon the 1984 Enhanced Oil Recovery Study completed by the National Petroleum Council.
- The G&A factors for capitalized and expensed costs.
- The limits on impurities, such as N<sub>2</sub>, CO<sub>2</sub>, and H<sub>2</sub>S used to calculate natural gas processing costs.
- Cost equations for stimulation, the produced water handling plant, the chemical handling plant, the polymer handling plant, CO<sub>2</sub> recycling plant, and the steam manifolds and pipelines.

## Natural and Industrial CO2 Prices

The model uses regional CO<sub>2</sub> prices for both natural and industrial sources of CO<sub>2</sub>. The cost equation for natural CO<sub>2</sub> is derived from the equation used in COGAM and updated to reflect current dollar values. According to University of Wyoming, this equation is applicable to the natural CO<sub>2</sub> in the Permian basin (Southwest). The cost of CO<sub>2</sub> in other regions and states is calculated using state calibration factors which represent the additional cost of transportation.

The industrial CO<sub>2</sub> costs contain two components: cost of capture and cost of transportation. The capture costs are derived using data obtained from Denbury Resources, Inc. and other sources. CO<sub>2</sub> capture costs range between \$20 and \$63/ton. The transportation costs were derived using an external economic model which calculates pipeline tariff based upon average distance, compression rate, and volume of CO<sub>2</sub> transported.

## National Crude Oil Drilling Footage Equation

The equation for crude oil drilling footage was estimated for the time period 1999 - 2008. The drilling footage data was compiled from EIA's Annual Energy Review 2008. The form of the estimating equation is given by:

$$\text{Oil Footage} = \beta_0 + \beta_1 * \text{Oil Price} \quad (2.B-16)$$

where  $\beta_0 = \text{OILA0}$

$\beta_1 = \text{OILA1}$

from equation 2-99 in Chapter 2.

Oil footage is the footage of total developmental crude oil wells drilled in the United States in thousands of feet. The crude oil price is a rolling five year average of crude oil prices from 1995 – 2008. The parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.

Dependent variable: Oil Footage

Current sample: (1999 to 2008)

Regression Statistics	
Multiple R	0.9623
R Square	0.9259
Adjusted R Square	0.9167
Standard Error	5,108.20
Observations	10

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	2,609,812,096.02	2,609,812,096.02	100.02	0.00
Residual	8	208,749,712.88	26,093,714.11		
Total	9	2,818,561,808.90			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	3,984.11	4,377.97	0.91	0.39	-6,111.51	14,079.72	-6,111.51	14,079.72
$\beta_1$	1,282.45	128.23	10.00	0.00	986.74	1,578.16	986.74	1,578.16

## Regional Crude Oil Footage Distribution

The regional drilling distributions for crude oil were estimated using an updated EIA well count file. The percent allocations for each region are calculated using the average footage drilled from 2004 – 2008 for developed crude oil or natural gas fields.

Region Name	States Included	Oil
Northeast	IN,IL,KY,MI,NY,OH,PA,TN,VA,WV	7.6%
Gulf Coast	AL,FL,LA,MS,TX	29.3%
Midcontinent	AR,KS,MO,NE,OK,TX	16.8%
Southwest	TX,NM	18.3%
Rocky Mountains	CO,NV,UT,WY,NM	10.7%
West Coast	CA,WA	9.6%
Northern Great Plains	MT,ND,SD	7.6%

### National Natural Gas Drilling Footage Equation

The equation for natural gas drilling footage was estimated for the time period 1999 - 2008. The drilling footage data was compiled from EIA’s Annual Energy Review 2008. The form of the estimating equation is given by:

$$\text{Gas Footage} = \beta_0 + \beta_1 * \text{Gas Price} \tag{2.B-17}$$

where  $\beta_0 = \text{GASA0}$   
 $\beta_1 = \text{GASA1}$

from equation 2-100 in Chapter 2.

Gas footage is footage of total developmental natural gas wells drilled in the United States in thousands of feet. The gas price is a rolling five year average of natural gas prices from 1995 – 2008. The parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.

Dependent variable: Gas Footage

Current sample: (1999 to 2008)

Regression Statistics	
Multiple R	0.9189
R Square	0.8444
Adjusted R Square	0.7666
Standard Error	9,554.63
Observations	4

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	990,785,019.79	990,785,019.79	10.85	0.08
Residual	2	182,581,726.21	91,290,863.10		
Total	3	1,173,366,746.00			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	2,793.29	53,884.13	0.05	0.96	-229,051.57	234,638.14	-229,051.57	234,638.14
$\beta_1$	30,429.72	9,236.81	3.29	0.08	-9,313.08	70,172.52	-9,313.08	70,172.52

## Regional Natural Gas Footage Distribution

The regional drilling distributions for natural gas were estimated using an updated EIA well count file. The percent allocations for each region are calculated using the average footage drilled from 2004 – 2008 for developed crude oil or natural gas fields.

Region Name	States Included	Gas
Northeast	IN,IL,KY,MI,NY,OH,PA,TN,VA,WV	13.2%
Gulf Coast	AL,FL,LA,MS,TX	18.7%
Midcontinent	AR,KS,MO,NE,OK,TX	13.4%
Southwest	TX,NM	34.5%
Rocky Mountains	CO,NV,UT,WY,NM	19.5%
West Coast	CA,WA	0.4%
Northern Great Plains	MT,ND,SD	0.4%

## National Exploration Drilling Footage Equation

The equation for exploration well drilling footage was estimated for the time period 1999 - 2008. The drilling footage data was compiled from EIA's Annual Energy Review 2008. The form of the estimating equation is given by:

$$\text{Exploration Footage} = \beta_0 + \beta_1 * \text{Oil Price} \quad (2.B-18)$$

where  $\beta_0 = \text{EXPA0}$   
 $\beta_1 = \text{EXPA1}$

Exploration footage is footage of total exploratory crude oil, natural gas and dry wells drilled in the United States in thousands of feet. The crude oil price is a rolling five year average of oil prices from 1995 – 2008. The parameter estimates and regression diagnostics are given below. The method of estimation used was ordinary least squares.

Dependent variable: Exploration Footage

Current sample: (1999 to 2008)

Regression Statistics								
Multiple R	0.9467							
R Square	0.8963							
Adjusted R Square	0.8834							
Standard Error	2,825.10							
Observations	10							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	552,044,623.08	552,044,623.08	69.17	0.00			
Residual	8	63,849,573.82	7,981,196.73					
Total	9	615,894,196.90						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$\beta_0$	4,733.91	2,421.24	1.96	0.09	-849.49	10,317.31	-849.49	10,317.31
$\beta_1$	589.83	70.92	8.32	0.00	426.28	753.37	426.28	753.37

## Regional Exploration Footage Distribution

The regional distribution for drilled exploration projects is also estimated using the updated EIA well count file. The percent allocations for each corresponding region are calculated using a 2004 – 2008 average of footage drilled for exploratory fields for both crude oil and natural gas.

Region Name	States Included	Exploration
<b>Northeast</b>	IN,IL,KY,MI,NY,OH,PA,TN,VA,WV	22.3%
<b>Gulf Coast</b>	AL,FL,LA,MS,TX	9.0%
<b>Midcontinent</b>	AR,KS,MO,NE,OK,TX	28.8%
<b>Southwest</b>	TX,NM	14.3%
<b>Rocky Mountains</b>	CO,NV,UT,WY,NM	11.5%
<b>West Coast</b>	CA,WA	0.3%
<b>Northern Great Plains</b>	MT,ND,SD	13.8%

## Regional Dryhole Rate for Discovered Projects

The percent allocation for existing regional dryhole rates was estimated using an updated EIA well count file. The percentage is determined by the average footage drilled from 2004 – 2008 for each corresponding region. Existing dryhole rates calculate the projects which have already been discovered. The formula for the percentage is given below:

$$\text{Existing Dryhole Rate} = \text{Developed Dryhole} / \text{Total Drilling} \quad (2.B-19)$$

Region Name	States Included	Existing
Northeast	IN,IL,KY,MI,NY,OH,PA,TN,VA,WV	5.8%
Gulf Coast	AL,FL,LA,MS,TX	9.4%
Midcontinent	AR,KS,MO,NE,OK,TX	13.2%
Southwest	TX,NM	9.7%
Rocky Mountains	CO,NV,UT,WY,NM	4.3%
West Coast	CA,WA	1.5%
Northern Great Plains	MT,ND,SD	5.2%

### Regional Dryhole Rate for First Exploration Well Drilled

The percent allocation for undiscovered regional exploration dryhole rates was estimated using an updated EIA well count file. The percentage is determined by the average footage drilled from 2004 – 2008 for each region. Undiscovered regional exploration dryhole rates calculate the rate for the first well drilled in an exploration project. The formula for the percentage is given below:

Undiscovered Exploration = Exploration Dryhole / (Exploration Gas + Exploration Oil)

Region Name	States Included	Undisc. Exp
Northeast	IN,IL,KY,MI,NY,OH,PA,TN,VA,WV	30.8%
Gulf Coast	AL,FL,LA,MS,TX	167.8%
Midcontinent	AR,KS,MO,NE,OK,TX	76.4%
Southwest	TX,NM	86.2%
Rocky Mountains	CO,NV,UT,WY,NM	74.0%
West Coast	CA,WA	466.0%
Northern Great Plains	MT,ND,SD	46.9%

### Regional Dryhole Rate for Subsequent Exploration Wells Drilled

The percent allocation for undiscovered regional developed dryhole rates was estimated using an updated EIA well count file. The percentage is determined by the average footage drilled from 2004 – 2008 for each corresponding region. Undiscovered regional developed dryhole rates calculate the rate for subsequent wells drilled in an exploration project. The formula for the percentage is given below:

Undiscovered Developed = (Developed Dryhole + Explored Dryhole) / Total Drilling (2.B-20)

<b>Region Name</b>	<b>States Included</b>	<b>Undisc. Dev</b>
<b>Northeast</b>	IN,IL,KY,MI,NY,OH,PA,TN,VA,WV	7.3%
<b>Gulf Coast</b>	AL,FL,LA,MS,TX	11.6%
<b>Midcontinent</b>	AR,KS,MO,NE,OK,TX	16.8%
<b>Southwest</b>	TX,NM	10.8%
<b>Rocky Mountains</b>	CO,NV,UT,WY,NM	6.5%
<b>West Coast</b>	CA,WA	1.8%
<b>Northern Great Plains</b>	MT,ND,SD	10.5%

### **National Rig Depth Rating**

The national rig depth rating schedule was calculated using a three year average based on the Smith Rig Count as reported by *Oil and Gas Journal*. Percentages are applied to determine the cumulative available rigs for drilling.

## Appendix 2.C: Play-level Resource Assumptions for Tight Gas, Shale Gas, and Coalbed Methane

The detailed resource assumptions underlying the estimates of remaining unproved technically recoverable resources for tight gas, shale gas, and coalbed methane are presented in the following tables.

**Table 2.C-1. Remaining Technically Recoverable Resources (TRR) – Tight Gas**

REGION	BASIN	PLAY	AREA (mi <sup>2</sup> )	WELL SPACING	DEPTH (ft)	EUR (bcf/well)	OFFICIAL NO ACCESS	TRR (bcf)
1	Appalachian	Berea Sandstone	51863	8	4000	0.18	0%	11401
1	Appalachian	Clinton/Medina High	14773	8	5900	0.25	0%	6786
1	Appalachian	Clinton/Medina Moderate/Low	27281	15	5200	0.08	0%	16136
1	Appalachian	Tuscarora Sandstone	42495	8	8000	0.69	0%	1485
1	Appalachian	Upper Devonian High	12775	10	4600	0.21	0%	10493
1	Appalachian	Upper Devonian Moderate/Low	29808	10	5400	0.06	0%	5492
2	East Texas	Cotton Valley/Bossier	2730	12	12500	1.39	0%	36447
2	Texas-Gulf	Olmos	2500	4	5000	0.44	0%	3624
2	Texas-Gulf	Vicksburg	600	8	11000	2.36	0%	4875
2	Texas-Gulf	Wilcox/Lobo	1500	8	9500	1.60	0%	8532
3	Anadarko	Cherokee/Redfork	1500	4	8500	0.90	0%	1168
3	Anadarko	Cleveland	1500	4	6500	0.91	0%	3690
3	Anadarko	Granite Wash/Atoka	1500	4	13000	1.72	0%	6871
3	Arkoma	Arkoma Basin	1000	8	8000	1.30	0%	2281
4	Permian	Abo	1500	8	3800	1.00	0%	9158
4	Permian	Canyon	6000	8	4500	0.22	0%	11535
5	Denver	Denver/Jules	3500	16	4999	0.24	1%	12953
5	Greater Green River	Deep Mesaverde	16416	4	15100	0.41	8%	2939
5	Greater Green River	Fort Union/Fox Hills	3858	8	5000	0.70	12%	1062
5	Greater Green River	Frontier (Deep)	15619	4	17000	2.58	9%	11303
5	Greater Green River	Frontier (Moxa Arch)	2334	8	9500	1.20	15%	3414
5	Greater Green River	Lance	5500	8	10000	6.60	11%	31541
5	Greater Green River	Lewis	5172	8	9500	1.32	6%	18893
5	Greater Green River	Shallow Mesaverde (1)	5239	4	9750	1.25	8%	12606
5	Greater Green River	Shallow Mesaverde (2)	6814	8	10500	0.67	8%	17874
5	Piceance	lles/Mesaverde	972	8	8000	0.73	5%	1858
5	Piceance	North Williams Fork/Mesaverde	1008	8	8000	0.65	2%	4278
5	Piceance	South Williams Fork/Mesaverde	1008	32	7000	0.65	9%	22402
5	San Juan	Central Basin/Dakota	3918	6	6500	0.49	7%	15007
5	San Juan	Central Basin/Mesaverde	3689	8	4500	0.72	2%	8737
5	San Juan	Picture Cliffs	6558	4	3500	0.48	2%	4899
5	Uinta	Basin Flank Mesaverde	1708	8	8000	0.99	33%	5767
5	Uinta	Deep Synclinal Mesaverde	2893	8	18000	0.99	2%	3292
5	Uinta	Tertiary East	1600	16	6000	0.58	16%	5910
5	Uinta	Tertiary West	1603	8	6500	4.06	57%	10630
5	Williston	High Potential	2000	4	2300	0.61	4%	2960
5	Williston	Low Potential	3000	4	2500	0.21	1%	1886
5	Williston	Moderate Potential	2000	4	2300	0.33	4%	2071
5	Wind River	Fort Union/Lance Deep	2500	4	14500	0.54	9%	4261
5	Wind River	Fort Union/Lance Shallow	1500	8	11000	1.17	0%	13197
5	Wind River	Mesaverde/Frontier Deep	250	4	17000	1.99	9%	1221
5	Wind River	Mesaverde/Frontier Shallow	250	4	13500	1.25	0%	1037
6	Columbia	Basin Centered	1500	8	13100	1.26	0%	7508

**Table 2.C-2. Remaining Technically Recoverable Resources (TRR) – Shale Gas**

REGION	BASIN	PLAY	AREA (mi <sup>2</sup> )	WELL SPACING	DEPTH (ft)	EUR (bcf/well)	OFFICIAL NO ACCESS	TRR (bcf)
1	Appalachian	Cincinatti Arch	6000	4	1800	0.12	0%	1435
1	Appalachian	Devonian Big Sandy - Active	8675	8	3800	0.32	0%	6490
1	Appalachian	Devonian Big Sandy - Undeveloped	1994	8	3800	0.32	0%	940
1	Appalachian	Devonian Greater Siltstone Area	22914	11	2911	0.20	0%	8463
1	Appalachian	Devonian Low Thermal Maturity	45844	7	3000	0.30	0%	13534
1	Appalachian	Marcellus - Active	10622	8	6750	3.49	0%	177931
1	Appalachian	Marcellus - Undeveloped	84271	8	6750	1.15	0%	232443
1	Illinois	New Albany	1600	8	2750	1.09	0%	10947
1	Michigan	Antrim	12000	7	1400	0.28	0%	20512
2	Black Warrior	Floyd-Neal/Conasauga	2429	2	8000	0.92	0%	4465
2	TX-LA-MS Salt	Haynesville - Active	3574	8	12000	6.48	0%	60615
2	TX-LA-MS Salt	Haynesville - Undeveloped	5426	8	12000	1.50	0%	19408
2	West Gulf Coast	Eagle Ford - Dry	200	4	7000	5.50	0%	4378
2	West Gulf Coast	Eagle Ford - Wet	890	8	7000	2.31	0%	16429
3	Anadarko	Cana Woodford	688	4	13500	3.42	0%	5718
3	Anadarko	Woodford - Central Oklahoma	1800	4	5000	1.01	0%	2946
3	Arkoma	Fayetteville - Central	4000	8	4000	2.29	0%	29505
3	Arkoma	Fayetteville - West	5000	8	4000	1.17	0%	4639
3	Arkoma	Woodford - Western Arkoma	2900	4	9500	4.06	0%	19771
4	Fort Worth	Barnett - Fort Worth Active	2649	5	7500	1.60	0%	15834
4	Fort Worth	Barnett - Fort Worth Undeveloped	477	8	7500	1.20	0%	4094
4	Permian	Barnett - Permian Active	1426	5	7500	1.60	0%	19871
4	Permian	Barnett - Permian Undeveloped	1906	8	7500	1.20	0%	15823
4	Permian	Barnett-Woodford	2691	4	10200	2.99	0%	32152
5	Greater Green River	Hilliard-Baxter-Mancos	16416	8	14750	0.18	0%	3770
5	San Juan	Lewis	7506	3	4500	1.53	0%	11638
5	Uinta	Mancos	6589	8	15250	1.00	0%	21021
5	Williston	Shallow Niobrara	10000	2	1000	0.46	4%	6757

**Table 2.C-3. Remaining Technically Recoverable Resources (TRR) – Coalbed Methane**

REGION	BASIN	PLAY	AREA (mi <sup>2</sup> )	WELL SPACING	DEPTH (ft)	EUR (bcf/well)	OFFICIAL NO ACCESS	TRR (bcf)
1	Appalachian	Central Basin	3870	8	1900	0.18	0%	1709
1	Appalachian	North Appalachia - High	3817	12	1400	0.12	0%	532
1	Appalachian	North Appalachia - Mod/Low	8906	12	1800	0.08	0%	469
1	Illinois	Central Basin	1214	8	1000	0.12	0%	1161
2	Black Warrior	Extention Area	700	8	1900	0.08	0%	931
2	Black Warrior	Main Area	1000	12	1950	0.21	0%	2190
2	Cahaba	Cahaba Coal Field	387	8	3000	0.18	0%	379
3	Midcontinent	Arkoma	2998	8	1500	0.22	0%	3032
3	Midcontinent	Cherokee & Forest City	2750	8	1000	0.06	0%	1308
4	Raton	Southern	386	8	2000	0.37	2%	962
5	Greater Green River	Deep	3600	4	7000	0.60	15%	3879
5	Greater Green River	Shallow	720	8	1500	0.20	20%	1053
5	Piceance	Deep	2000	4	7000	0.60	3%	3677
5	Piceance	Divide Creek	144	8	3800	0.18	13%	194
5	Piceance	Shallow	2000	4	3500	0.30	9%	2230
5	Piceance	White River Dome	216	8	7500	0.41	8%	657
5	Powder River	Big George/Lower Fort Union	2880	16	1100	0.26	1%	5943
5	Powder River	Wasatch	216	8	1100	0.06	1%	92
5	Powder River	Wyodak/Upper Fort Union	3600	20	600	0.14	1%	18859
5	Raton	Northern	470	8	2500	0.35	0%	957
5	Raton	Purgatoire River	360	8	2000	0.31	0%	430
5	San Juan	Fairway NM	670	4	3250	1.14	7%	774
5	San Juan	North Basin	2060	4	3000	0.28	7%	1511
5	San Juan	North Basin CO	780	4	2800	1.51	7%	10474
5	San Juan	South Basin	1190	4	2000	0.20	7%	820
5	San Juan	South Menefee NM	7454	5	2500	0.10	7%	177
5	Uinta	Blackhawk	586	8	3250	0.16	5%	1864
5	Uinta	Ferron	400	8	3000	0.78	11%	1409
5	Uinta	Sego	534	4	3250	0.31	10%	417

## 3. Offshore Oil and Gas Supply Submodule

### Introduction

The Offshore Oil and Gas Supply Submodule (OOGSS) uses a field-based engineering approach to represent the exploration and development of U.S. offshore oil and natural gas resources. The OOGSS simulates the economic decision-making at each stage of development from frontier areas to post-mature areas. Offshore petroleum resources are divided into 3 categories:

- **Undiscovered Fields.** The number, location, and size of the undiscovered fields is based on the Minerals Management Service's (MMS) 2006 hydrocarbon resource assessment.<sup>1</sup> MMS was renamed Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) in 2010.
- **Discovered, Undeveloped Fields.** Any discovery that has been announced but is not currently producing is evaluated in this component of the model. The first production year is an input and is based on announced plans and expectations.
- **Producing Fields.** The fields in this category have wells that have produced oil and/or gas by 2009. The production volumes are from the BOEMRE production database.

Resource and economic calculations are performed at an evaluation unit basis. An evaluation unit is defined as the area within a planning area that falls into a specific water depth category. Planning areas are the Western Gulf of Mexico (GOM), Central GOM, Eastern GOM, Pacific, and Atlantic. There are six water depth categories: 0-200 meters, 200-400 meters, 400-800 meters, 800-1600 meters, 1600-2400 meters, and greater than 2400 meters. The crosswalk between region and evaluation unit is shown in Table 3-1.

Supply curves for crude oil and natural gas are generated for three offshore regions: Pacific, Atlantic, and Gulf of Mexico. Crude oil production includes lease condensate. Natural gas production accounts for both nonassociated gas and associated-dissolved gas. The model is responsive to changes in oil and natural gas prices, royalty relief assumptions, oil and natural gas resource base, and technological improvements affecting exploration and development.

### Undiscovered Fields Component

Significant undiscovered oil and gas resources are estimated to exist in the Outer Continental Shelf, particularly in the Gulf of Mexico. Exploration and development of these resources is projected in this component of the OOGSS.

Within each evaluation unit, a field size distribution is assumed based on BOEMRE's latest<sup>1</sup> resource assessment (Table 3-2). The volume of resource in barrels of oil equivalence by field size class as defined by the BOEMRE is shown in Table 3-3. In the OOGSS, the mean estimate represents the size of each field in the field size class. Water depth and field size class are used for specifying many of the technology assumptions in the OOGSS. Fields smaller than field size class 2 are assumed to be uneconomic to develop.

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<sup>1</sup>U.S. Department of Interior, Minerals Management Service, *Report to Congress: Comprehensive Inventory of U.S. OCS Oil and Natural Gas Resources*, February 2006.

**Table 3-1. Offshore Region and Evaluation Unit Crosswalk**

No.	Region Name	Planning Area	Water Depth (meters)	Drilling Depth (feet)	Evaluation Unit Name	Region ID
1	Shallow GOM	Western GOM	0 - 200	< 15,000	WGOM0002	3
2	Shallow GOM	Western GOM	0 - 200	> 15,000	WGOMDG02	3
3	Deep GOM	Western GOM	201 - 400	All	WGOM0204	4
4	Deep GOM	Western GOM	401 - 800	All	WGOM0408	4
5	Deep GOM	Western GOM	801 - 1,600	All	WGOM0816	4
6	Deep GOM	Western GOM	1,601 - 2,400	All	WGOM1624	4
7	Deep GOM	Western GOM	> 2,400	All	WGOM2400	4
8	Shallow GOM	Central GOM	0 - 200	< 15,000	CGOM0002	3
9	Shallow GOM	Central GOM	0 - 200	> 15,000	CGOMDG02	3
10	Deep GOM	Central GOM	201 - 400	All	CGOM0204	4
11	Deep GOM	Central GOM	401 - 800	All	CGOM0408	4
12	Deep GOM	Central GOM	801 - 1,600	All	CGOM0816	4
13	Deep GOM	Central GOM	1,601 - 2,400	All	CGOM1624	4
14	Deep GOM	Central GOM	> 2,400	All	CGOM2400	4
15	Shallow GOM	Eastern GOM	0 - 200	All	EGOM0002	3
16	Deep GOM	Eastern GOM	201 - 400	All	EGOM0204	4
17	Deep GOM	Central GOM	401 - 800	All	EGOM0408	4
18	Deep GOM	Eastern GOM	801 - 1600	All	EGOM0816	4
19	Deep GOM	Eastern GOM	1601 - 2400	All	EGOM1624	4
20	Deep GOM	Eastern GOM	> 2400	All	EGOM2400	4
21	Deep GOM	Eastern GOM	> 200	All	EGOML181	4
22	Atlantic	North Atlantic	0 - 200	All	NATL0002	1
23	Atlantic	North Atlantic	201 - 800	All	NATL0208	1
24	Atlantic	North Atlantic	> 800	All	NATL0800	1
25	Atlantic	Mid Atlantic	0 - 200	All	MATL0002	1
26	Atlantic	Mid Atlantic	201 - 800	All	MATL0208	1
27	Atlantic	Mid Atlantic	> 800	All	MATL0800	1
28	Atlantic	South Atlantic	0 - 200	All	SATL0002	1
29	Atlantic	South Atlantic	201 - 800	All	SATL0208	1
30	Atlantic	South Atlantic	> 800	All	SATL0800	1
31	Atlantic	Florida Straits	0 - 200	All	FLST0002	1
32	Atlantic	Florida Straits	201 - 800	All	FLST0208	1
33	Atlantic	Florida Straits	> 800	All	FLST0800	1
34	Pacific	Pacific Northwest	0-200	All	PNW0002	2
35	Pacific	Pacific Northwest	201-800	All	PNW0208	2
36	Pacific	North California	0-200	All	NCA0002	2
37	Pacific	North California	201-800	All	NCA0208	2
38	Pacific	North California	801-1600	All	NCA0816	2
39	Pacific	North California	1600-2400	All	NCA1624	2
40	Pacific	Central California	0-200	All	CCA0002	2
41	Pacific	Central California	201-800	All	CCA0208	2
42	Pacific	Central California	801-1600	All	CCA0816	2
43	Pacific	South California	0-200	All	SCA0002	2
44	Pacific	South California	201-800	All	SCA0208	2
45	Pacific	South California	801-1600	All	SCA0816	2
46	Pacific	South California	1601-2400	All	SCA1624	2

Source: U.S. Energy Information Administration, Energy Analysis, Office of Petroleum, Gas, and Biofuels Analysis

**Table 3-2. Number of Undiscovered Fields by Evaluation Unit and Field Size Class, as of January 1, 2003**

Evaluation Unit	Field Size Class (FSC)																Number of Fields	Total Resource (BBOE)
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
WGOM0002	1	5	11	14	20	23	24	27	30	8	6	8	2	0	0	0	179	4.348
WGOMDG02	0	0	2	4	5	6	8	9	9	3	2	2	1	0	0	0	51	1.435
WGOM0204	0	0	0	0	0	0	2	3	3	4	2	1	1	0	0	0	16	1.027
WGOM0408	0	0	0	0	0	1	3	3	7	7	3	2	1	0	0	0	27	1.533
WGOM0816	0	0	0	0	0	0	4	7	16	16	15	9	3	2	1	0	73	8.082
WGOM1624	0	0	0	1	2	6	10	14	18	18	14	10	6	4	1	0	104	10.945
WGOM2400	0	0	0	0	2	3	3	6	7	6	5	3	3	2	0	0	40	4.017
CGOM0002	1	1	6	11	28	52	79	103	81	53	20	1	0	0	0	0	436	8.063
CGOMDG02	0	0	1	1	4	4	4	6	7	6	5	3	1	0	0	0	42	3.406
CGOM0204	0	0	0	0	0	0	1	2	3	2	2	2	1	0	0	0	13	1.102
CGOM0408	0	0	0	0	0	1	1	4	4	4	1	1	1	1	0	0	18	1.660
CGOM0816	0	0	0	0	2	4	8	11	20	22	19	14	7	3	1	0	111	11.973
CGOM1624	0	0	0	1	2	5	9	15	18	19	15	13	8	4	1	0	110	12.371
CGOM2400	0	0	0	0	2	2	3	5	5	5	5	4	3	2	0	0	36	4.094
EGOM0002	4	6	7	11	16	18	18	16	13	10	6	1	0	0	0	0	126	1.843
EGOM0204	0	1	1	2	3	4	4	3	1	1	1	0	0	0	0	0	21	0.233
EGOM0408	0	1	2	3	5	5	5	4	3	2	1	0	0	0	0	0	31	0.348
EGOM0816	0	1	1	3	4	4	4	3	3	2	1	0	0	0	0	0	26	0.326
EGOM1624	0	0	0	0	2	1	1	1	0	1	0	1	0	0	0	0	7	0.250
EGOM2400	0	0	0	1	1	3	5	7	8	9	7	6	3	2	0	0	52	4.922
EGOML181	0	0	0	0	1	3	3	5	8	5	4	2	2	1	1	0	35	1.836
NATL0002	5	7	10	14	16	17	15	11	10	8	3	2	1	0	0	0	119	1.896
NATL0208	1	1	1	2	2	3	3	3	2	1	1	0	0	0	0	0	20	0.246
NATL0800	1	2	3	5	7	10	13	12	7	6	4	1	0	0	0	0	71	1.229
MATL0002	4	6	8	12	13	14	13	11	8	7	5	2	0	0	0	0	103	1.585
MATL0208	1	1	2	3	3	3	3	4	2	2	2	2	0	0	0	0	28	0.377
MATL0800	2	4	5	8	9	10	10	8	5	5	3	2	0	0	0	0	71	1.173
SATL0002	1	2	2	3	5	6	5	5	4	4	1	1	0	0	0	0	39	0.658
SATL0208	4	5	7	10	12	13	12	10	8	7	3	2	0	0	0	0	93	1.382
SATL0800	2	2	4	5	9	15	20	17	11	7	2	1	1	0	0	0	96	1.854
FLST0002	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0.012
FLST0208	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	0.009
FLST0800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000
PNW0002	10	17	24	29	27	21	13	8	5	2	1	0	0	0	0	0	157	0.597
PNW0208	4	6	9	10	11	7	6	3	2	1	0	0	0	0	0	0	59	0.209
NCA0002	1	2	3	5	5	5	5	4	3	3	2	0	0	0	0	0	38	0.485
NCA0208	9	17	24	28	26	22	15	10	5	3	1	1	0	0	0	0	161	0.859
NCA0816	3	6	9	12	12	11	9	7	4	3	2	1	0	0	0	0	79	0.784
NCA1624	1	2	3	5	6	6	7	6	4	2	1	1	0	0	0	0	44	0.595
CCA0002	1	4	6	11	15	19	20	17	12	8	4	2	0	0	0	0	119	1.758
CCA0208	1	2	3	5	8	10	10	8	7	5	2	0	0	0	0	0	61	0.761
CCA0816	0	1	1	2	3	4	5	3	2	2	0	0	0	0	0	0	23	0.218
SCA0002	1	2	4	10	16	21	22	19	12	6	2	1	0	0	0	0	116	1.348
SCA0208	3	6	12	25	38	49	51	43	28	14	5	3	1	0	0	0	278	3.655
SCA0816	1	3	6	9	13	17	18	15	12	8	2	2	1	0	0	0	107	1.906
SCA1624	0	1	2	3	4	5	5	5	4	3	1	1	0	0	0	0	34	0.608

Source: U.S. Energy Information Administration, Energy Analysis, Office of Petroleum, Gas, and Biofuels Analysis

**Table 3-3. BOEMRE Field Size Definition (MMBOE)**

Field Size Class	Mean
2	0.083
3	0.188
4	0.356
5	0.743
6	1.412
7	2.892
8	5.919
9	11.624
10	22.922
11	44.768
12	89.314
13	182.144
14	371.727
15	690.571
16	1418.883
17	2954.129

Source: Bureau of Ocean Energy Management, Regulation, and Enforcement

## Projection of Discoveries

The number and size of discoveries is projected based on a simple model developed by J. J. Arps and T. G. Roberts in 1958<sup>2</sup>. For a given evaluation unit in the OOGSS, the number of cumulative discoveries for each field size class is determined by

$$\text{DiscoveredFields}_{\text{EU},\text{iFSC}} = \text{TotalFields}_{\text{EU},\text{iFSC}} * (1 - e^{-\gamma_{\text{EU},\text{iFSC}} * \text{CumNFW}_{\text{EU}}}) \quad (3-1)$$

where,

- TotalFields = Total number of fields by evaluation unit and field size class
- CumNFW = Cumulative new field wildcats drilled in an evaluation unit
- $\gamma$  = search coefficient
- EU = evaluation unit
- iFSC = field size class.

The search coefficient ( $\gamma$ ) was chosen to make the Equation 3-1 fit the data. In many cases, however, the sparse exploratory activity in an evaluation unit made fitting the discovery model problematic. To provide reasonable estimates of the search coefficient in every evaluation unit, the data in various field size classes within a region were grouped as needed to obtain enough data points to provide a reasonable fit to the discovery model. A polynomial was fit to all of the relative search coefficients in the region. The polynomial was fit to the resulting search coefficients as follows:

<sup>2</sup>Arps, J. J. and T. G. Roberts, *Economics of Drilling for Cretaceous Oil on the East Flank of the Denver-Julesburg Basin*, Bulletin of the American Association of Petroleum Geologists, November 1958.

$$\gamma_{EU,iFSC} = \beta1 * iFSC^2 + \beta2 * iFSC + \beta3 * \gamma_{EU,10} \quad (3-2)$$

where

$$\begin{aligned} \beta1 &= 0.0243 \text{ for Western GOM and } 0.0399 \text{ for Central and Eastern GOM} \\ \beta2 &= -0.3525 \text{ for Western GOM and } -0.6222 \text{ for Central and Eastern GOM} \\ \beta3 &= 1.5326 \text{ for Western GOM and } 2.2477 \text{ for Central and } 3.0477 \text{ for Eastern GOM} \\ iFSC &= \text{field size class} \\ \gamma &= \text{search coefficient for field size class 10.} \end{aligned}$$

Cumulative new field wildcat drilling is determined by

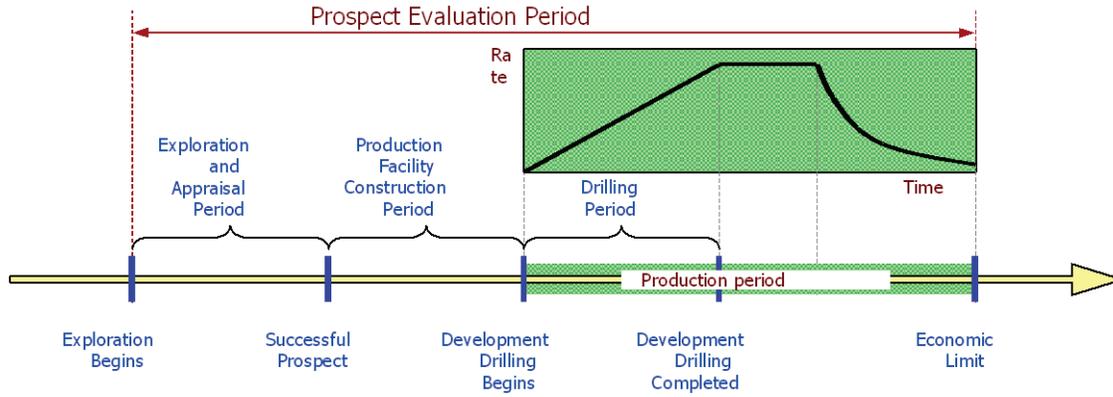
$$\text{CumNFW}_{EU,t} = \text{CumNFW}_{EU,t-1} + \alpha1_{EU} + \beta_{EU} * (\text{OILPRICE}_{t-nlag1} * \text{GASPRICE}_{t-nlag2}) \quad (3-3)$$

where

$$\begin{aligned} \text{OILPRICE} &= \text{oil wellhead price} \\ \text{GASPRICE} &= \text{natural gas wellhead price} \\ \alpha1, \beta &= \text{estimated parameter} \\ nlag1 &= \text{number of years lagged for oil price} \\ nlag2 &= \text{number of years lagged for gas price} \\ EU &= \text{evaluation unit} \end{aligned}$$

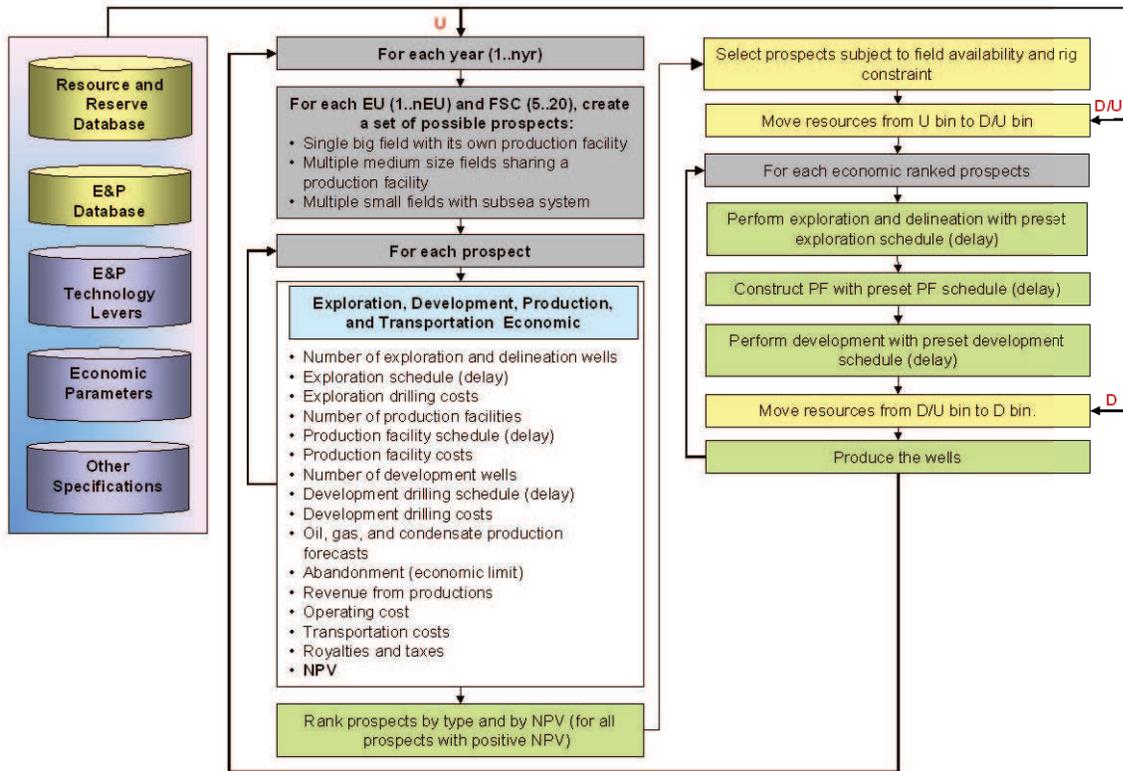
The decision for exploration and development of the discoveries determine from Equation 3-1 is performed at a prospect level that could involve more than one field. A prospect is defined as a potential project that covers exploration, appraisal, production facility construction, development, production, and transportation (Figure 3-1). There are three types of prospects: (1) a single field with its own production facility, (2) multiple medium size fields sharing a production facility, and (3) multiple small fields utilizing nearby production facility. The net present value (NPV) of each possible prospect is generated using the calculated exploration costs, production facility costs, development costs, completion costs, operating costs, flowline costs, transportation costs, royalties, taxes, and production revenues. Delays for exploration, production facility construction, and development are incorporated in this NPV calculation. The possible prospects are then ranked from best (highest NPV) to worst (lowest NPV). The best prospects are selected subject to field availability and rig constraint. The basic flowchart is presented in Figure 3-2.

**Figure 3-1. Prospect Exploration, Development, and Production Schedule**



Source: ICF Consulting

**Figure 3-2. Flowchart for the Undiscovered Field Component of the OOGSS**



Note: U = Undiscovered, D/U = Discovered/Undeveloped, D=Developed  
Source: ICF Consulting

## Calculation of Costs

The technology employed in the deepwater offshore areas to find and develop hydrocarbons can be significantly different than that used in shallower waters, and represents significant challenges for the companies and individuals involved in the deepwater development projects. In many situations in the deepwater OCS, the choice of technology used in a particular situation depends on the size of the prospect being developed. The following base costs are adjusted with the oil price to capture the variation in costs over time as activity level and demand for equipment and other supplies change. The adjustment factor is  $[1 + (\text{oilprice}/\text{baseprice} - 1)*0.4]$ , where  $\text{baseprice} = \$30/\text{barrel}$ .

### *Exploration Drilling*

During the exploration phase of an offshore project, the type of drilling rig used depends on both economic and technical criteria. Offshore exploratory drilling usually is done using self-contained rigs that can be moved easily. Three types of drilling rigs are incorporated into the OOGSS. The exploration drilling costs per well for each rig type are a function of water depth (WD) and well drilling depth (DD), both in feet.

**Jack-up** rigs are limited to a water depth of about 600 feet or less. Jack-ups are towed to their location where heavy machinery is used to jack the legs down into the water until they rest on the ocean floor. When this is completed, the platform containing the work area rises above the water. After the platform has risen about 50 feet out of the water, the rig is ready to begin drilling.

$$\text{ExplorationDrillingCosts}(\$/\text{well}) = 2,000,000 + (5.0\text{E-}09)*\text{WD}*\text{DD}^3 \quad (3-4)$$

**Semi-submersible** rigs are floating structures that employ large engines to position the rig over the hole dynamically. This extends the maximum operating depth greatly, and some of these rigs can be used in water depths up to and beyond 3,000 feet. The shape of a semisubmersible rig tends to dampen wave motion greatly regardless of wave direction. This allows its use in areas where wave action is severe.

$$\text{ExplorationDrillingCosts}(\$/\text{well}) = 2,500,000 + 200*(\text{WD}+\text{DD}) + \text{WD}*(400+(2.0\text{E-}05)*\text{DD}^2) \quad (3-5)$$

**Dynamically positioned drill ships** are a second type of floating vessel used in offshore drilling. They are usually used in water depths exceeding 3,000 feet where the semi-submersible type of drilling rigs can not be deployed. Some of the drillships are designed with the rig equipment and anchoring system mounted on a central turret. The ship is rotated about the central turret using thrusters so that the ship always faces incoming waves. This helps to dampen wave motion.

$$\text{ExplorationDrillingCosts}(\$/\text{well}) = 7,000,000 + (1.0\text{E-}05)*\text{WD}*\text{DD}^2 \quad (3-6)$$

Water depth is the primary criterion for selecting a drilling rig. Drilling in shallow waters (up to 1,500 feet) can be done with jack-up rigs. Drilling in deeper water (greater than 1,500 feet) can

be done with semi-submersible drilling rigs or drill ships. The number of rigs available for exploration is limited and varies by water depth levels. Drilling rigs are allowed to move one water depth level lower if needed.

### ***Production and Development Structure***

Six different options for development/production of offshore prospects are currently assumed in OOGSS, based on those currently considered and/or employed by operators in Gulf of Mexico OCS. These are the conventional fixed platforms, the compliant towers, tension leg platforms, Spar platforms, floating production systems and subsea satellite well systems. Choice of platform tends to be a function of the size of field and water depth, though in reality other operational, environmental, and/or economic decisions influence the choice. Production facility costs are a function of water depth (WD) and number of slots per structure (SLT).

**Conventional Fixed Platform (FP).** A fixed platform consists of a jacket with a deck placed on top, providing space for crew quarters, drilling rigs, and production facilities. The jacket is a tall vertical section made of tubular steel members supported by piles driven into the seabed. The fixed platform is economical for installation in water depths up to 1,200 feet. Although advances in engineering design and materials have been made, these structures are not economically feasible in deeper waters.

$$\text{StructureCost}(\$) = 2,000,000 + 9,000 * \text{SLT} + 1,500 * \text{WD} * \text{SLT} + 40 * \text{WD}^2 \quad (3-7)$$

**Compliant Towers (CT).** The compliant tower is a narrow, flexible tower type of platform that is supported by a piled foundation. Its stability is maintained by a series of guy wires radiating from the tower and terminating on pile or gravity anchors on the sea floor. The compliant tower can withstand significant forces while sustaining lateral deflections, and is suitable for use in water depths of 1,200 to 3,000 feet. A single tower can accommodate up to 60 wells; however, the compliant tower is constrained by limited deck loading capacity and no oil storage capacity.

$$\text{StructureCost}(\$) = (\text{SLT} + 30) * (1,500,000 + 2,000 * (\text{WD} - 1,000)) \quad (3-8)$$

**Tension Leg Platform (TLP).** The tension leg platform is a type of semi-submersible structure which is attached to the sea bed by tubular steel mooring lines. The natural buoyancy of the platform creates an upward force which keeps the mooring lines under tension and helps maintain vertical stability. This type of platform becomes a viable alternative at water depths of 1,500 feet and is considered to be the dominant system at water depths greater than 2,000 feet. Further, the costs of the TLP are relatively insensitive to water depth. The primary advantages of the TLP are its applicability in ultra-deepwaters, an adequate deck loading capacity, and some oil storage capacity. In addition, the field production time lag for this system is only about 3 years.

$$\text{StructureCost}(\$) = (\text{SLT} + 30) * (3,000,000 + 750 * (\text{WD} - 1,000)) \quad (3-9)$$

**Floating Production System (FPS).** The floating production system, a buoyant structure, consists of a semi-submersible or converted tanker with drilling and production equipment anchored in place with wire rope and chain to allow for vertical motion. Because of the movement of this structure in severe environments, the weather-related production downtime is

estimated to be about 10 percent. These structures can only accommodate a maximum of approximately 25 wells. The wells are completed subsea on the ocean floor and are connected to the production deck through a riser system designed to accommodate platform motion. This system is suitable for marginally economic fields in water depths up to 4,000 feet.

$$\text{StructureCost(\$)} = (\text{SLT} + 20) * (7,500,000 + 250 * (\text{WD} - 1,000)) \quad (3-10)$$

**Spar Platform (SPAR).** A Spar Platform consists of a large diameter single vertical cylinder supporting a deck. It has a typical fixed platform topside (surface deck with drilling and production equipment), three types of risers (production, drilling, and export), and a hull which is moored using a taut catenary system of 6 to 20 lines anchored into the seafloor. Spar platforms are presently used in water depths up to 3,000 feet, although existing technology is believed to be able to extend this to about 10,000 feet.

$$\text{StructureCost(\$)} = (\text{SLT} + 20) * (3,000,000 + 500 * (\text{WD} - 1,000)) \quad (3-11)$$

**Subsea Wells System (SS).** Subsea systems range from a single subsea well tied back to a nearby production platform (such as FPS or TLP) to a set of multiple wells producing through a common subsea manifold and pipeline system to a distant production facility. These systems can be used in water depths up to at least 7,000 feet. Since the cost to complete a well is included in the development well drilling and completion costs, no cost is assumed for the subsea well system. However, a subsea template is required for all development wells producing to any structure other than a fixed platform.

$$\text{SubseaTemplateCost(\$ / well)} = 2,500,000 \quad (3-12)$$

The type of production facility for development and production depends on water depth level as shown in Table 3-4.

**Table 3-4. Production Facility by Water Depth Level**

Water Depth Range (feet)		Production Facility Type					
Minimum	Maximum	FP	CT	TLP	FPS	SPAR	SS
0	656	X					X
656	2625		X				X
2625	5249			X			X
5249	7874				X	X	X
7874	10000				X	X	X

Source: ICF Consulting

***Development Drilling***

Pre-drilling of development wells during the platform construction phase is done using the drilling rig employed for exploration drilling. Development wells drilled after installation of the platform which also serves as the development structure is done using the platform itself. Hence, the choice of drilling rig for development drilling is tied to the choice of the production platform.

For water depths less than or equal to 900 meters,

$$\text{DevelopmentDrillingCost}(\$ / \text{well}) = 1,500,000 + (1,500 + 0.04 * \text{DD}) * \text{WD} + (0.035 * \text{DD} - 300) * \text{DD} \tag{3-13}$$

For water depths greater than 900 meters,

$$\text{DevelopmentDrillingCost}(\$ / \text{well}) = 4,500,000 + (150 + 0.004 * \text{DD}) * \text{WD} + (0.035 * \text{DD} - 250) * \text{DD} \tag{3-14}$$

where

- WD = water depth in feet
- DD = drilling depth in feet.

***Completion and Operating***

Completion costs per well are a function of water depth range and drilling depth as shown in Table 3-5.

**Table 3-5. Well Completion and Equipment Costs per Well**

Water Depth (feet)	Development Drilling Depth (feet)		
	< 10,000	10,001 - 20,000	> 20,000
0 - 3,000	800,000	2,100,000	3,300,000
> 3,000	1,900,000	2,700,000	3,300,000

Platform operating costs for all types of structures are assumed to be a function of water depth (WD) and the number of slots (SLT). These costs include the following items:

- primary oil and gas production costs,
- labor,
- communications and safety equipment,
- supplies and catering services,
- routine process and structural maintenance,
- well service and workovers,
- insurance on facilities, and
- transportation of personnel and supplies.

Annual operating costs are estimated by

$$\text{OperatingCost}(\$/ \text{ structure} / \text{ year}) = 1,265,000 + 135,000 * \text{SLT} + 0.0588 * \text{SLT} * \text{WD}^2 \quad (3-15)$$

### ***Transportation***

It is assumed in the model that existing trunk pipelines will be used and that the prospect economics must support only the gathering system design and installation. However, in case of small fields tied back to some existing neighboring production platform, a pipeline is assumed to be required to transport the crude oil and natural gas to the neighboring platform.

### ***Structure and Facility Abandonment***

The costs to abandon the development structure and production facilities depend on the type of production technology used. The model projects abandonment costs for fixed platforms and compliant towers assuming that the structure is abandoned. It projects costs for tension leg platforms, converted semi-submersibles, and converted tankers assuming that the structures are removed for transport to another location for reinstallation. These costs are treated as intangible capital investments and are expensed in the year following cessation of production. Based on historical data, these costs are estimated as a fraction of the initial structure costs, as follows:

	<b>Fraction of Initial Platform Cost</b>
Fixed Platform	0.45
Compliant Tower	0.45
Tension Leg Platform	0.45
Floating Production Systems	0.15
Spar Platform	0.15

## **Exploration, Development, and Production Scheduling**

The typical offshore project development consists of the following phases:<sup>3</sup>

- Exploration phase,
  - Exploration drilling program
  - Delineation drilling program
- Development phase,
- Fabrication and installation of the development/production platform,
  - Development drilling program
  - Pre-drilling during construction of platform
  - Drilling from platform
  - Construction of gathering system
- Production operations, and
- Field abandonment.

---

<sup>3</sup>The pre-development activities, including early field evaluation using conventional geological and geophysical methods and the acquisition of the right to explore the field, are assumed to be completed before initiation of the development of the prospect.

The timing of each activity, relative to the overall project life and to other activities, affects the potential economic viability of the undiscovered prospect. The modeling objective is to develop an exploration, development, and production plan which both realistically portrays existing and/or anticipated offshore practices and also allows for the most economical development of the field. A description of each of the phases is provided below.

### ***Exploration Phase***

An undiscovered field is assumed to be discovered by a successful exploration well (i.e., a new field wildcat). Delineation wells are then drilled to define the vertical and areal extent of the reservoir.

**Exploration drilling.** The exploration success rate (ratio of the number of field discovery wells to total wildcat wells) is used to establish the number of exploration wells required to discover a field as follows:

$$\text{number of exploratory wells} = 1 / [\text{exploration success rate}]$$

For example, a 25 percent exploration success rate will require four exploratory wells: one of the four wildcat wells drilled finds the field and the other three are dry holes.

**Delineation drilling.** Exploratory drilling is followed by delineation drilling for field appraisal (1 to 4 wells depending on the size of the field). The delineation wells define the field location vertically and horizontally so that the development structures and wells may be set in optimal positions. All delineation wells are converted to production wells at the end of the production facility construction.

### ***Development Phase***

During this phase of an offshore project, the development structures are designed, fabricated, and installed; the development wells (successful and dry) are drilled and completed; and the product transportation/gathering system is installed.

**Development structures.** The model assumes that the design and construction of any development structure begins in the year following completion of the exploration and delineation drilling program. However, the length of time required to complete the construction and installation of these structures depends on the type of system used. The required time for construction and installation of the various development structures used in the model is shown in Table 3-6. This time lag is important in all offshore developments, but it is especially critical for fields in deepwater and for marginally economic fields.

**Development drilling schedule.** The number of development wells varies by water depth and field size class as follows.

$$\text{DevelopmentWells} = \frac{5}{\text{FSC}} * \text{FSIZE}^{\beta_{\text{DepthClass}}} \quad (3-16)$$

where

FSC = field size class  
 FSIZE = resource volume (MMBOE)

$\beta$  = 0.8 for water depths < 200 meters; 0.7 for water depths 200-800 meters; 0.65 for water depths > 800 meters.

**Table 3-6. Production Facility Design, Fabrication, and Installation Period (Years)**

PLATFORMS	Water Depth (Feet)														
	0	100	400	800	1000	1500	2000	3000	4000	5000	6000	7000	8000	9000	10000
2	1	1	1	1	1	1	1	1	2	2	3	3	4	4	4
8	2	2	2	2	2	2	2	2	2	2	3	3	4	4	4
12	2	2	2	2	2	2	2	2	2	2	3	3	4	4	4
18	2	2	2	2	2	2	2	2	2	3	3	3	4	4	4
24	2	2	2	2	2	2	2	2	2	3	3	4	4	4	5
36	2	2	2	2	2	2	2	2	2	3	3	4	4	4	5
48	2	2	2	2	2	2	3	3	3	3	4	4	4	4	5
60	2	2	2	2	2	2	3	3	3	3	4	4	4	4	5
<b>OTHERS</b>															
SS	1	1	1	1	1	1	2	2	2	3	3	3	4	4	4
FPS								3	3	3	4	4	4	4	5

Source: ICF Consulting

The development drilling schedule is determined based on the assumed drilling capacity (maximum number of wells that could be drilled in a year). This drilling capacity varies by type of production facility and water depth. For a platform type production facility (FP, CT, or TLP), the development drilling capacity is also a function of the number of slots. The assumed drilling capacity by production facility type is shown in Table 3-7.

**Production transportation/gathering system.** It is assumed in the model that the installation of the gathering systems occurs during the first year of construction of the development structure and is completed within 1 year.

### *Production Operations*

Production operations begin in the year after the construction of the structure is complete. The life of the production depends on the field size, water depth, and development strategy. First production is from delineation wells that were converted to production wells. Development drilling starts at the end of the production facility construction period.

**Table 3-7. Development Drilling Capacity by Production Facility Type**

Maximum Number of Wells Drilled (wells/platform/year, 1 rig)		Maximum Number of Wells Drilled (wells/field/year)			
Drilling Depth (feet)	Drilling Capacity (24 slots)	Water Depth (feet)	SS	FPS	FPSO
0	24	0	4		4
6000	24	1000	4		4
7000	24	2000	4		4
8000	20	3000	4	4	4
9000	20	4000	4	4	4
10000	20	5000	3	3	3
11000	20	6000	2	2	2
12000	16	7000	2	2	2
13000	16	8000	1	1	1
14000	12	9000	1	1	1
15000	8	10000	1	1	1
16000	4				
17000	2				
18000	2				
19000	2				
20000	2				
30000	2				

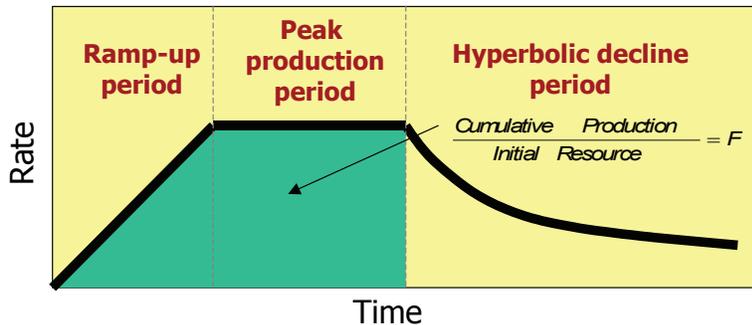
Source: ICF Consulting

## Production profiles

The original hydrocarbon resource (in BOE) is divided between oil and natural gas using a user specified proportion. Due to the development drilling schedule, not all wells in the same field will produce at the same time. This yields a ramp-up profile in the early production period (Figure 3-3). The initial production rate is the same for all wells in the field and is constant for a period of time. Field production reaches its peak when all the wells have been drilled and start producing. The production will start to decline (at a user specified rate) when the ratio of cumulative production to initial resource equals a user specified fraction.

Gas (plus lease condensate) production is calculated based on gas resource, and oil (plus associated gas) production is calculated based on the oil resource. Lease condensate production is separated from the gas production using the user specified condensate yield. Likewise, associated-dissolved gas production is separated from the oil production using the user specified associated gas-to-oil ratio. Associated-dissolved gas production is then tracked separately from the nonassociated gas production throughout the projection. Lease condensate production is added to crude oil production and is not tracked separately.

**Figure 3-3. Undiscovered Field Production Profile**



Source: ICF Consulting

## Field Abandonment

All wells in a field are assumed to be shut-in when the net revenue from the field is less than total State and Federal taxes. Net revenue is total revenue from production less royalties, operating costs, transportation costs, and severance taxes.

## Discovered Undeveloped Fields Component

Announced discoveries that have not been brought into production by 2002 are included in this component of the OOGSS. The data required for these fields include location, field size class, gas percentage of BOE resource, condensate yield, gas to oil ratio, start year of production, initial production rate, fraction produced before decline, and hyperbolic decline parameters. The BOE resource for each field corresponds to the field size class as specified in Table 3-3.

The number of development wells is the same as that of an undiscovered field in the same water depth and of the same field size class (Equation 3-13). The production profile is also the same as that of an undiscovered field (Figure 3-3).

The assumed field size and year of initial production of the major announced deepwater discoveries that were not brought into production by 2009 are shown in Table 3-8. A field that is announced as an oil field is assumed to be 100 percent oil and a field that is announced as a gas field is assumed to be 100 percent gas. If a field is expected to produce both oil and gas, 70 percent is assumed to be oil and 30 percent is assumed to be gas.

## Producing Fields Component

A separate database is used to track currently producing fields. The data required for each producing field include location, field size class, field type (oil or gas), total recoverable resources, historical production (1990-2002), and hyperbolic decline parameters.

Projected production from the currently producing fields will continue to decline if, historically,

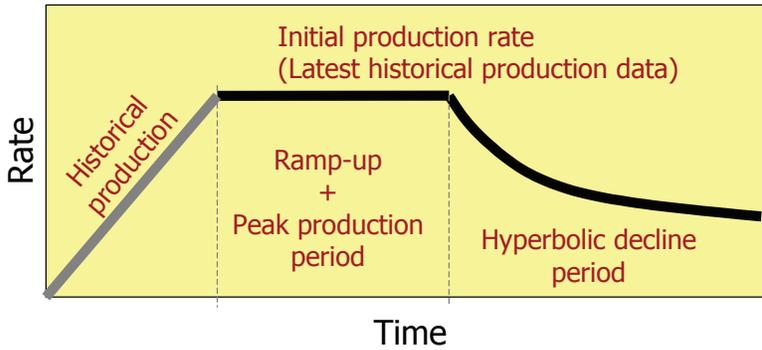
production from the field is declining (Figure 3-4). Otherwise, production is held constant for a period of time equal to the sum of the specified number ramp-up years and number of years at peak production after which it will decline (Figure 3-5). The model assumes that production will decline according to a hyperbolic decline curve until the economic limit is achieved and the field is abandoned. Typical production profile data are shown in Table 3-9. Associated-dissolved gas and lease condensate production are determined the same way as in the undiscovered field component.

**Table 3-8. Assumed Size and Initial Production Year of Major Announced Deepwater Discoveries**

<b>Field/Project Name</b>	<b>Block</b>	<b>Water Depth (feet)</b>	<b>Year of Discovery</b>	<b>Field Size Class</b>	<b>Field Size (MMBoe)</b>	<b>Start Year of Production</b>
Great White	AC857	8717	2002	14	372	2010
Telemark	AT063	4457	2000	12	89	2010
Ozona	GB515	3000	2008	12	89	2011
West Tonga	GC726	4674	2007	12	89	2011
Gladden	MC800	3116	2008	12	89	2011
Pony	GC468	3497	2006	13	182	2013
Knotty Head	GC512	3557	2005	15	691	2013
Puma	GC823	4129	2003	14	372	2013
Big Foot	WR029	5235	2005	12	89	2013
Cascade	WR206	8143	2002	14	372	2013
Chinook	WR469	8831	2003	14	372	2013
Pyrenees	GB293	2100	2009	12	89	2014
Kaskida	KC292	5860	2006	15	691	2014
Appaloosa	MC503	2805	2008	14	372	2014
Jack	WR759	6963	2004	14	372	2014
Samurai	GC432	3400	2009	12	89	2015
Wide Berth	GC490	3700	2009	12	89	2015
Manny	MC199	2478	2010	13	182	2015
Kodiak	MC771	4986	2008	15	691	2015
St. Malo	WR678	7036	2003	14	372	2015
Mission Deep	GC955	7300	2006	13	182	2016
Tiber	KC102	4132	2009	16	1419	2016
Vito	MC984	4038	2009	13	182	2016
Stones	WR508	9556	2005	12	89	2016
Heidelberg	GB859	5000	2009	13	182	2017
Freedom	MC948	6095	2008	15	691	2017
Shenandoah	WR052	5750	2009	13	182	2017
Buckskin	KC872	6920	2009	13	182	2018
Julia	WR627	7087	2007	12	89	2018
Vicksburg	DC353	7457	2009	14	372	2019
Lucius	KC875	7168	2009	13	182	2019

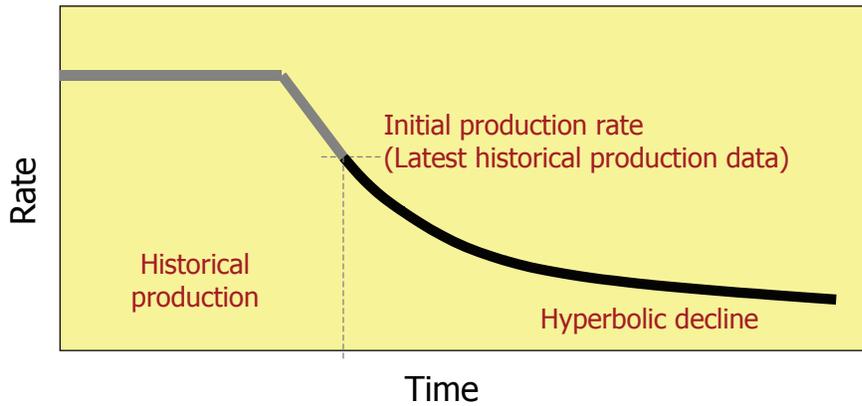
Source: U.S. Energy Information Administration, Energy Analysis, Office of Petroleum, Gas, and Biofuels Analysis

**Figure 3-4. Production Profile for Producing Fields - Constant Production Case**



Source: ICF Consulting

**Figure 3-5. Production Profile for Producing Fields - Declining Production Case**



Source: ICF Consulting

**Table 3-9. Production Profile Data for Oil & Gas Producing Fields**

Region	Crude Oil						Natural Gas					
	FSC 2 - 10			FSC 11 - 17			FSC 2 - 10			FSC 11 - 17		
	Ramp-up (years)	At Peak (years)	Initial Decline Rate	Ramp-up (years)	At Peak (years)	Initial Decline Rate	Ramp-up (years)	At Peak (years)	Initial Decline Rate	Ramp-up (years)	At Peak (years)	Initial Decline Rate
Shallow GOM	2	2	0.15	3	3	0.10	2	1	0.20	3	2	0.10
Deep GOM	2	2	0.20	2	3	0.15	2	2	0.25	3	2	0.20
Atlantic	2	2	0.20	3	3	0.20	2	1	0.25	3	2	0.20
Pacific	2	2	0.10	3	2	0.10	2	1	0.20	3	2	0.20

FSC = Field Size Class  
Source: ICF Consulting

## Generation of Supply Curves

As mentioned earlier, the OOGSS does not determine the actual volume of crude oil and nonassociated natural gas produced in a given projection year but rather provides the parameters for the short-term supply functions used to determine regional supply and demand market equilibration. For each year,  $t$ , and offshore region,  $r$ , the OGSM calculates the stock of proved reserves at the beginning of year  $t+1$  and the expected production-to-reserves (PR) ratio for year  $t+1$  as follows.

The volume of proved reserves in any year is calculated as

$$\text{RESOFF}_{r,k,t+1} = \text{RESOFF}_{r,k,t} - \text{PRDOFF}_{r,k,t} + \text{NRDOFF}_{r,k,t} + \text{REVOFF}_{r,k,t} \quad (3-17)$$

where

RESOFF	=	beginning- of-year reserves
PRDOFF	=	production
NRDOFF	=	new reserve discoveries
REVOFF	=	reserve extensions, revisions, and adjustments
$r$	=	region (1=Atlantic, 2=Pacific, 3=GOM)
$k$	=	fuel type (1=oil; 2=nonassociated gas)
$t$	=	year.

Expected production,  $\text{EXPRDOFF}$ , is the sum of the field level production determined in the undiscovered fields component, the discovered, undeveloped fields component, and the producing field component. The volume of crude oil production (including lease condensate),  $\text{PRDOFF}$ , passed to the PMM is equal to  $\text{EXPRDOFF}$ . Nonassociated natural gas production in year  $t$  is the market equilibrated volume passed to the OGSM from the NGTDM.

Reserves are added through new field discoveries as well as delineation and developmental drilling. Each newly discovered field not only adds proved reserves but also a much larger amount of inferred reserves. The allocation between proved and inferred reserves is based on historical reserves growth statistics provided by the Minerals Management Service. Specifically,

$$\text{NRDOFF}_{r,k,t} = \text{NFDISC}_{r,k,t-1} * \left( \frac{1}{\text{RSVGRO}_k} \right) \quad (3-18)$$

$$\text{NIRDOFF}_{r,k,t} = \text{NFDISC}_{r,k,t-1} * \left( 1 - \frac{1}{\text{RSVGRO}_k} \right) \quad (3-19)$$

where

NRDOFF	=	new reserve discovery
NIRDOFF	=	new inferred reserve additions
NFDISC	=	new field discoveries
RSVGRO	=	reserves growth factor (8.2738 for oil and 5.9612 for gas)
$r$	=	region (1=Atlantic, 2=Pacific, 3=GOM)
$k$	=	fuel type (1=oil; 2=gas)

t = year.

Reserves are converted from inferred to proved with the drilling of other exploratory (or delineation) wells and developmental wells. Since the expected offshore PR ratio is assumed to remain constant at the last historical value, the reserves needed to support the total expected production,  $EXPRDOFF$ , can be calculated by dividing  $EXPRDOFF$  by the PR ratio. Solving Equation 3-1 for  $REVOFF_{r,k,t}$  and writing

gives

$$REVOFF_{r,k,t} = \frac{EXPRDOFF_{r,k,t+1}}{PR_{r,k}} + PRDOFF_{r,k,t} - RESOFF_{r,k,t} - NRDOFF_{r,k,t} \quad (3-20)$$

The remaining proved reserves, inferred reserves, and undiscovered resources are tracked throughout the projection period to ensure that production from offshore sources does not exceed the assumed resource base. Field level associated-dissolved gas is summed to the regional level and passed to the NGTDM.

### Advanced Technology Impacts

Advances in technology for the various activities associated with crude oil and natural gas exploration, development, and production can have a profound impact on the costs associated with these activities. The OOGSS has been designed to give due consideration to the effect of advances in technology that may occur in the future. The specific technology levers and values are presented in Table 3-10.

**Table 3-10. Offshore Exploration and Production Technology Levers**

Technology Lever	Total Improvement (percent)	Number of Years
Exploration success rates	30	30
Delay to commence first exploration and between exploration	15	30
Exploration & development drilling costs	30	30
Operating cost	30	30
Time to construct production facility	15	30
Production facility construction costs	30	30
Initial constant production rate	15	30
Decline rate	0	30

Source: ICF Consulting

## Appendix 3.A. Offshore Data Inventory

VARIABLES				
Variable Name		Description	Unit	Classification
Code	Text			
ADVLTXOFF	PRODTAX	Offshore ad valorem tax rates	Fraction	4 Lower 48 offshore subregions; Fuel (oil, gas)
CPRDOFF	COPRD	Offshore coproduct rate	Fraction	4 Lower 48 offshore subregions; Fuel (oil, gas)
CUMDISC	DiscoveredFields	Cumulative number of dicovered offshore fields	NA	Offshore evaluation unit: Field size class
CUMNFW	CumNFW	Cumulative number of new fields wildcats drilled	NA	Offshore evaluation unit: Field size class
CURPRROFF	omega	Offshore initial P/R ratios	Fraction	4 Lower 48 offshore subregions; Fuel (oil, gas)
CURRESOFF	R	Offshore initial reserves	MMB BCF	4 Lower 48 offshore subregions; Fuel (oil, gas)
DECLOFF	--	Offshore decline rates	Fraction	4 Lower 48 offshore subregions; Fuel (oil, gas)
DEVLCOFF	DevelopmentDrillingCost	Development drilling cost	\$ per well	Offshore evaluation unit
DRILLOFF	DRILL	Offshore drilling cost	1987\$	4 Lower 48 offshore subregions
DRYOFF	DRY	Offshore dry hole cost	1987\$	Class (exploratory, developmental); 4 Lower 48 offshore subregions
DVWELLOFF	--	Offshore development project drilling schedules	wells per year	4 Lower 48 offshore subregions; Fuel (oil, gas)
ELASTOFF	--	Offshore production elasticity values	Fraction	4 Lower 48 offshore subregions
EXPLCOST	ExplorationDrillingCosts	Exploration well drilling cost	\$ per wells	Offshore evaluation unit
EXWELLOFF	--	Offshore exploratory project drilling schedules	wells per year	4 Lower 48 offshore subregions
FLOWOFF	--	Offshore flow rates	bls, MCF per year	4 Lower 48 offshore subregions; Fuel (oil, gas)
FRMINOFF	FRMIN	Offshore minimum exploratory well finding rate	MMB BCF per well	4 Lower 48 offshore subregions; Fuel (oil, gas)
FR1OFF	FR1	Offshore new field wildcat well finding rate	MMB BCF per well	4 Lower 48 offshore subregions; Fuel (oil, gas)
FR2OFF	FR3	Offshore developmental well finding rate	MMB BCF per well	4 Lower 48 offshore subregions; Fuel (oil, gas)
FR3OFF	FR2	Offshore other exploratory well finding rate	MMB BCF per well	4 Lower 48 offshore subregions; Fuel (oil, gas)
HISTPRROFF	--	Offshore historical P/R ratios	fraction	4 Lower 48 offshore subregions; Fuel (oil, gas)
HISTRESOFF	--	Offshore historical beginning-of-year reserves	MMB BCF	4 Lower 48 offshore subregions; Fuel (oil, gas)
INFRSVOFF	I	Offshore inferred reserves	MMB BCF	4 Lower 48 offshore subregions; Fuel (oil, gas)
KAPFRCOFF	EXKAP	Offshore drill costs that are tangible & must be depreciated	fraction	Class (exploratory, developmental)
KAPSPNDOFF	KAP	Offshore other capital expenditures	1987\$	Class (exploratory, developmental); 4 Lower 48 offshore subregions
LEASOFF	EQUIP	Offshore lease equipment cost	1987\$ per project	Class (exploratory, developmental); 4 Lower 48 offshore subregions
NDEVWLS	DevelopmentWells	Number of development wells drilled	NA	Offshore evaluation unit
NFWCOSTOFF	COSTEXP	Offshore new field wildcat cost	1987\$	Class (exploratory, developmental); 4 Lower 48 offshore subregions

VARIABLES				
Variable Name		Description	Unit	Classification
Code	Text			
NFWELLOFF	--	Offshore exploratory and developmental project drilling schedules	wells per project per year	Class (exploratory, developmental); r=1
NIRDOFF	NIRDOFF	Offshore new inferred reserves	Oil-MMB per well Gas-BCF per well	Offshore region; Offshore fuel(oil,gas)
NRDOFF	NRDOFF	Offshore new reserve discoveries	Oil-MMB per well Gas-BCF per well	Offshore region; Offshore fuel(oil,gas)
OPEROFF	OPCOST	Offshore operating cost	1987\$ per well per year	Class (exploratory, developmental); 4 Lower 48 offshore subregions
OPRCOST	OperatingCost	Operating cost	\$ per well	Offshore evaluation unit
PFCOST	StructureCost	Offshore production facility cost	\$ per structure	Offshore evaluation unit
PRJOFF	N	Offshore project life	Years	Fuel (oil, gas)
RCPRDOFF	M	Offshore recovery period intangible & tangible drill cost	Years	Lower 48 Offshore
RESOFF	RESOFF	Offshore reserves	Oil-MMB per well Gas-BCF per well	Offshore region; Offshore fuel(oil,gas)
REVOFF	REVOFF	Offshore reserve revisions	Oil-MMB per well Gas-BCF per well	Offshore region; Offshore fuel(oil,gas)
SC	Γ	Search coefficient for discovery model	Fraction	Offshore evaluation unit: Field size class
SEVTXOFF	PRODTAX	Offshore severance tax rates	fraction	4 Lower 48 offshore subregions; Fuel (oil, gas)
SROFF	SR	Offshore drilling success rates	fraction	Class (exploratory, developmental); 4 Lower 48 offshore subregions; Fuel (oil, gas)
STTXOFF	STRT	State tax rates	fraction	4 Lower 48 offshore subregions
TECHOFF	TECH	Offshore technology factors applied to costs	fraction	Lower 48 Offshore
TRANSOFF	TRANS	Offshore expected transportation costs	NA	4 Lower 48 offshore subregions; Fuel (oil, gas)
UNRESOFF	Q	Offshore undiscovered resources	MMB BCF	4 Lower 48 offshore subregions; Fuel (oil, gas)
WDCFOFFIRKLAG	--	1989 offshore exploration & development weighted DCFs	1987\$	Class (exploratory, developmental); 4 Lower 48 offshore subregions; Fuel (oil, gas)
WDCFOFFIRLAG	--	1989 offshore regional exploration & development weighted DCFs	1987\$	Class (exploratory, developmental); 4 Lower 48 offshore subregions;
WDCFOFFLAG	--	1989 offshore exploration & development weighted DCFs	1987\$	Class (exploratory, developmental)
WELLAGOFF	WELLSOFF	1989 offshore wells drilled	Wells per year	Class (exploratory, developmental); 4 Lower 48 offshore subregions; Fuel (oil, gas)
XDCKAPOFF	XDCKAP	Offshore intangible drill costs that must be depreciated	fraction	NA

PARAMETERS		
Parameter	Description	Value
nREG	Region ID (1: CENTRAL & WESTERN GOM; 2: EASTERN GOM; 3: ATLANTIC; 4: PACIFIC)	4
nPA	Planning Area ID (1: WESTERN GOM; 2: CENTRAL GOM; 3: EASTERN GOM; 4: NORTH ATLANTIC; 5: MID ATLANTIC; 6: SOUTH ATLANTIC; 7: FLORIDA STRAITS; 8: PACIFIC; NORTHWEST; 9: CENTRAL CALIFORNIA; 10: SANTA BARBARA - VENTURA BASIN; 11: LOS ANGELES BASIN; 12: INNER BORDERLAND; 13: OUTER BORDERLAND)	13
ntEU	Total number of evaluation units (43)	43
nMaxEU	Maximum number of EU in a PA (6)	6
TOTFLD	Total number of evaluation units	3600
nANN	Total number of announce discoveries	127

PARAMETERS		
Parameter	Description	Value
nPRD	Total number of producing fields	1132
nRIGTYP	Rig Type ( 1: JACK-UP 0-1500; 2: JACK-UP 0-1500 (Deep Drilling); 3: SUBMERSIBLE 0-1500; 4: SEMI-SUBMERSIBLE 1500-5000; 5: SEMI-SUBMERSIBLE 5000-7500; 6: SEMI-SUBMERSIBLE 7500-10000; 7: DRILL SHIP 5000-7500; 8: DRILL SHIP 7500-10000)	8
nPFTYP	Production facility type (1: FIXED PLATFORM (FP); 2: COMPLIANT TOWER (CT); 3: TENSION LEG PLATFORM (TLP); 4: FLOATING PRODUCTION SYSTEM (FPS); 5: SPAR; 6: FLOATING PRODUCTION STORAGE & OFFLOADING (FPSO); 7: SUBSEA SYSTEM (SS))	7
nPFWDR	Production facility water depth range (1: 0 - 656 FEET; 2: 656 - 2625 FEET; 3: 2625 - 5249 FEET; 4: 5249 - 7874 FEET; 5: 7874 - 9000 FEET)	5
NSLTIdx	Number of platform slot data points	8
NPFWD	Number of production facility water depth data points	15
NPLTDD	Number of platform water depth data points	17
NOPFWD	Number of other production facility water depth data points	11
NCSTWD	Number of water depth data points for production facility costs	39
NDRLWD	Number of water depth data points for well costs	15
NWLDEP	Number of well depth data points	30
TRNPPLNCSTNDIAM	Number of pipeline diameter data points	19
MAXFIELDS	Maximum number of fields for a project/prospect	10
nMAXPRJ	Maximum number of projects to evaluate per year	500
PRJLIFE	Maximum project life in years	10

INPUT DATA			
Variable	Description	Unit	Source
ann_EU	Announced discoveries - Evaluation unit name	-	PGBA
ann_FAC	Announced discoveries - Type of production facility	-	BOEMRE
ann_FN	Announced discoveries - Field name	-	PGBA
ann_FSC	Announced discoveries - Field size class	integer	BOEMRE
ann_OG	Announced discoveries - fuel type	-	BOEMRE
ann_PRDSTYR	Announced discoveries - Start year of production	integer	BOEMRE
ann_WD	Announced discoveries - Water depth	feet	BOEMRE
ann_WL	Announced discoveries - Number of wells	integer	BOEMRE
ann_YRDISC	Announced discoveries - Year of discovery	integer	BOEMRE
beg_rsva	AD gas reserves	bcf	calculated in model
BOEtoMcf	BOE to Mcf conversion	Mcf/BOE	ICF
chgDriCstOil	Change of Drilling Costs as a Function of Oil Prices	fraction	ICF
chgOpCstOil	Change of Operating Costs as a Function of Oil Prices	fraction	ICF
chgPFCstOil	Change of Production facility Costs as a Function of Oil Prices	fraction	ICF
cndYld	Condensate yield by PA, EU	Bbl/mmcf	BOEMRE
cstCap	Cost of capital	percent	BOEMRE
dDpth	Drilling depth by PA, EU, FSC	feet	BOEMRE
deprSch	Depreciation schedule (8 year schedule)	fraction	BOEMRE
devCmplCst	Completion costs by region, completion type (1=Single, 2=Dual), water depth range (1=0-3000Ft, 2=>3000Ft), drilling depth index	million 2003 dollars	BOEMRE
devDriCst	Mean development well drilling costs by region, water depth index, drilling depth index	million 2003 dollars	BOEMRE
devDriDly24	Maximum number of development wells drilled from a 24-slot PF by drilling depth index	Wells/PF/year	ICF
devDriDlyOth	Maximum number of development wells drilled for other PF by PF type, water depth index	Wells/field/year	ICF

INPUT DATA			
Variable	Description	Unit	Source
devOprCst	Operating costs by region, water depth range (1=0-3000Ft, 2=>3000Ft), drilling depth index	2003 \$/well/year	BOEMRE
devTangFrc	Development Wells Tangible Fraction	fraction	ICF
dNRR	Number of discovered producing fields by PA, EU, FSC	integer	BOEMRE
Drillcap	Drilling Capacity	wells/year/rig	ICF
duNRR	Number of discovered/undeveloped fields by PA, EU, FSC	integer	ICF
EUID	Evaluation unit ID	integer	ICF
EUname	Names of evaluation units by PA	integer	ICF
EUPA	Evaluation unit to planning area x-walk by EU_Total	integer	ICF
exp1stDly	Delay before commencing first exploration by PA, EU	number of years	ICF
exp2ndDly	Total time (Years) to explore and appraise a field by PA, EU	number of years	ICF
expDrlCst	Mean Exploratory Well Costs by region, water depth index, drilling depth index	million 2003 dollars	BOEMRE
expDrlDays	Drilling days/well by rig type	number of days/well	ICF
expSucRate	Exploration success rate by PA, EU, FSC	fraction	ICF
ExpTangFrc	Exploration and Delineation Wells Tangible Fraction	fraction	ICF
fedTaxRate	Federal Tax Rate	percent	ICF
fldExpRate	Maximum Field Exploration Rate	percent	ICF
gasprice	Gas wellhead price by region	2003\$/mcf	NGTDM
gasSevTaxPrd	Gas production severance tax	2003\$/mcf	ICF
gasSevTaxRate	Gas severance tax rate	percent	ICF
GOprop	Gas proportion of hydrocarbon resource by PA, EU	fraction	ICF
GOR	Gas-to-Oil ratio (Scf/Bbl) by PA, EU	Scf/Bbl	ICF
GORCutOff	GOR cutoff for oil/gas field determination	-	ICF
gRGCGF	Gas Cumulative Growth Factor (CGF) for gas reserve growth calculation by year index	-	BOEMRE
levDelWls	Exploration drilling technology (reduces number of delineation wells to justify development)	percent	PGBA
levDrlCst	Drilling costs R&D impact (reduces exploration and development drilling costs)	percent	PGBA
levExpDly	Pricing impact on drilling delays (reduces delays to commence first exploration and between exploration)	percent	PGBA
levExpSucRate	Seismic technology (increase exploration success rate)	percent	PGBA
levOprCst	Operating costs R&D impact (reduces operating costs)	percent	PGBA
levPfCst	Production facility cost R&D impact (reduces production facility construction costs)	percent	PGBA
levPfDly	Production facility design, fabrication and installation technology (reduces time to construct production facility)	percent	PGBA
levPrdPerf1	Completion technology 1 (increases initial constant production facility)	percent	PGBA
levPrdPerf2	Completion technology 2 (reduces decile rates)	percent	PGBA
nDelWls	Number of delineation wells to justify a production facility by PA, EU, FSC	integer	ICF
nDevWls	Maximum number of development wells by PA, EU, FSC	integer	ICF
nEU	Number of evaluation units in each PA	integer	ICF
nmEU	Names of evaluation units by PA	-	ICF
nmPA	Names of planning areas by PA	-	ICF
nmPF	Name of production facility and subsea-system by PF type index	-	ICF
nmReg	Names of regions by region	-	ICF
ndiroff	Additions to inferred reserves by region and fuel type	oil: MBbbls; gas: Bcf	calculated in model
nrdoff	New reserve discoveries by region and fuel type	oil: Mbbls; gas: Bcf	calculated in model
nRigs	Number of rigs by rig type	integer	ICF

INPUT DATA			
Variable	Description	Unit	Source
nRigWlsCap	Number of well drilling capacity (Wells/Rig)	wells/rig	ICF
nRigWlsUtl	Number of wells drilled (Wells/Rig)	wells/rig	ICF
nSlT	Number of slots by # of slots index	integer	ICF
oilPrcCstTbl	Oil price for cost tables	2003\$/Bbl	ICF
oilprice	Oil wellhead price by region	2003\$/Bbl	PMM
oilSevTaxPrd	Oil production severance tax	2003\$/Bbl	ICF
oilSevTaxRate	Oil severance tax rate	percent	ICF
oRGC GF	Oil Cumulative Growth Factor (CGF) for oil reserve growth calculation by year index	fraction	BOEMRE
paid	Planning area ID	integer	ICF
PAname	Names of planning areas by PA	-	ICF
pfBldDly1	Delay for production facility design, fabrication, and installation (by water depth index, PF type index, # of slots index (0 for non platform))	number of years	ICF
pfBldDly2	Delay between production facility construction by water depth index	number of years	ICF
pfCst	Mean Production Facility Costs in by region, PF type, water depth index, # of slots index (0 for non-platform)	million 2003 \$	BOEMRE
pfCstFrc	Production facility cost fraction matrix by year index, year index	fraction	ICF
pfMaxNFld	Maximum number of fields in a project by project option	integer	ICF
pfMaxNWls	Maximum number of wells sharing a flowline by project option	integer	ICF
pfMinNFld	Minimum number of fields in a project by project option	integer	ICF
pfOptFlg	Production facility option flag by water depth range index, FSC	-	ICF
pfTangFrc	Production Facility Tangible Fraction	fraction	ICF
pfTypFlg	Production facility type flag by water depth range index, PF type index	-	ICF
platform	Flag for platform production facility	-	ICF
prd_DEPTH	Producing fields - Total drilling depth	feet	BOEMRE
prd_EU	Producing fields - Evaluation unit name	-	ICF
prd_FLAG	Producing fields - Production decline flag	-	ICF
prd_FN	Producing fields - Field name	-	BOEMRE
prd_ID	Producing fields - BOEMRE field ID	-	BOEMRE
prd_OG	Producing fields - Fuel type	-	BOEMRE
prd_YRDISC	Producing fields - Year of discovery	year	BOEMRE
prdGasDecRatei	Initial gas decline rate by PA, EU, FSC range index	fraction/year	ICF
prdGasHyp	Gas hyperbolic decline coefficient by PA, EU, FSC range index	fraction	ICF
prdOilDecRatei	Initial oil decline rate by PA, EU,	fraction/year	ICF
prdOilHyp	Oil hyperbolic decline coefficient by PA, EU, FSC range index	fraction	ICF
prdDYrPeakGas	Years at peak production for gas by PA, EU, FSC, range index	number of years	ICF
prdDYrPeakOil	Years at peak production for oil by PA, EU, FSC, range index	number of years	ICF
prdDYrRampUpGas	Years to ramp up for gas production by PA, EU, FSC range index	number of years	ICF
prdDYrRampUpOil	Years to ramp up for oil production by PA, EU, FSC range index	number of years	ICF
prdGasDecRatei	Initial gas decline rate by PA, EU	fraction/year	ICF
prdGasFrc	Fraction of gas produced before decline by PA, EU	fraction	ICF
prdGasHyp	Gas hyperbolic decline coefficient by PA, EU	fraction	ICF
prdGasRatei	Initial gas production (Mcf/Day/Well) by PA, EU	Mcf/day/well	ICF
PR	Expected production to reserves ratio by fuel typ	fraction	PGBA
prdoff	Expected production by fuel type	oil:MBbls; gas: Bcf	calculated in model
prdOilDecRatei	Initial oil decline rate by PA, EU	fraction/year	ICF
prdOilFrc	Fraction of oil produced before decline by PA, EU	fraction	ICF

INPUT DATA			
Variable	Description	Unit	Source
prdOilHyp	Oil hyperbolic decline coefficient by PA, EU	fraction	ICF
prdOilRatei	Initial oil production (Bbl/Day/Well) by PA, EU	Bbl/day/well	ICF
prod	Producing fields - annual production by fuel type	oil:MBbls; gas:Mmcf	BOEMRE
prod_asg	AD gas production	bcf	calculated in model
revoff	Extensions, revisions, and adjustments by fuel type	oil:MBbls; gas:Bcf	
rigBldRatMax	Maximum Rig Build Rate by rig type	percent	ICF
rigIncrMin	Minimum Rig Increment by rig type	integer	ICF
RigUtil	Number of wells drilled	wells/rig	ICF
rigUtilTarget	Target Rig Utilization by rig type	percent	ICF
royRateD	Royalty rate for discovered fields by PA, EU, FSC	fraction	BOEMRE
royRateU	Royalty rate for undiscovered fields by PA, EU, FSC	fraction	BOEMRE
stTaxRate	Federal Tax Rate by PA, EU	percent	ICF
trnFlowLineLen	Flowline length by PA, EU	Miles/prospect	ICF
trnPpDiam	Oil pipeline diameter by PA, EU	inches	ICF
trnPplnCst	Pipeline cost by region, pipe diameter index, water depth index	million 2003 \$/mile	BOEMRE
trnTrfGas	Gas pipeline tariff (\$/Mcf) by PA, EU	2003 \$/Bbl	ICF
trnTrfOil	Oil pipeline tariff (\$/Bbl) by PA, EU	2003 \$/Bbl	ICF
uNRR	Number of undiscovered fields by PA, EU, FSC	integer	calculated in model
vMax	Maximum MMBOE of FSC	MMBOE	BOEMRE
vMean	Geometric mean MMBOE of FSC	MMBOE	BOEMRE
vMin	Minimum MMBOE of FSC	MMBOE	BOEMRE
wDpth	Water depth by PA, EU, FSC	feet	BOEMRE
yrAvl	Year lease available by PA, EU	year	ICF
yrCstTbl	Year of cost tables	year	ICF

Sources: BOEMRE = Bureau of Ocean Energy Management, Regulation, and Enforcement (formerly the Minerals Management Service); ICF = ICF Consulting; PGBA = EIA, Office of Petroleum, Gas, and Biofuels Analysis

## 4. Alaska Oil and Gas Supply Submodule

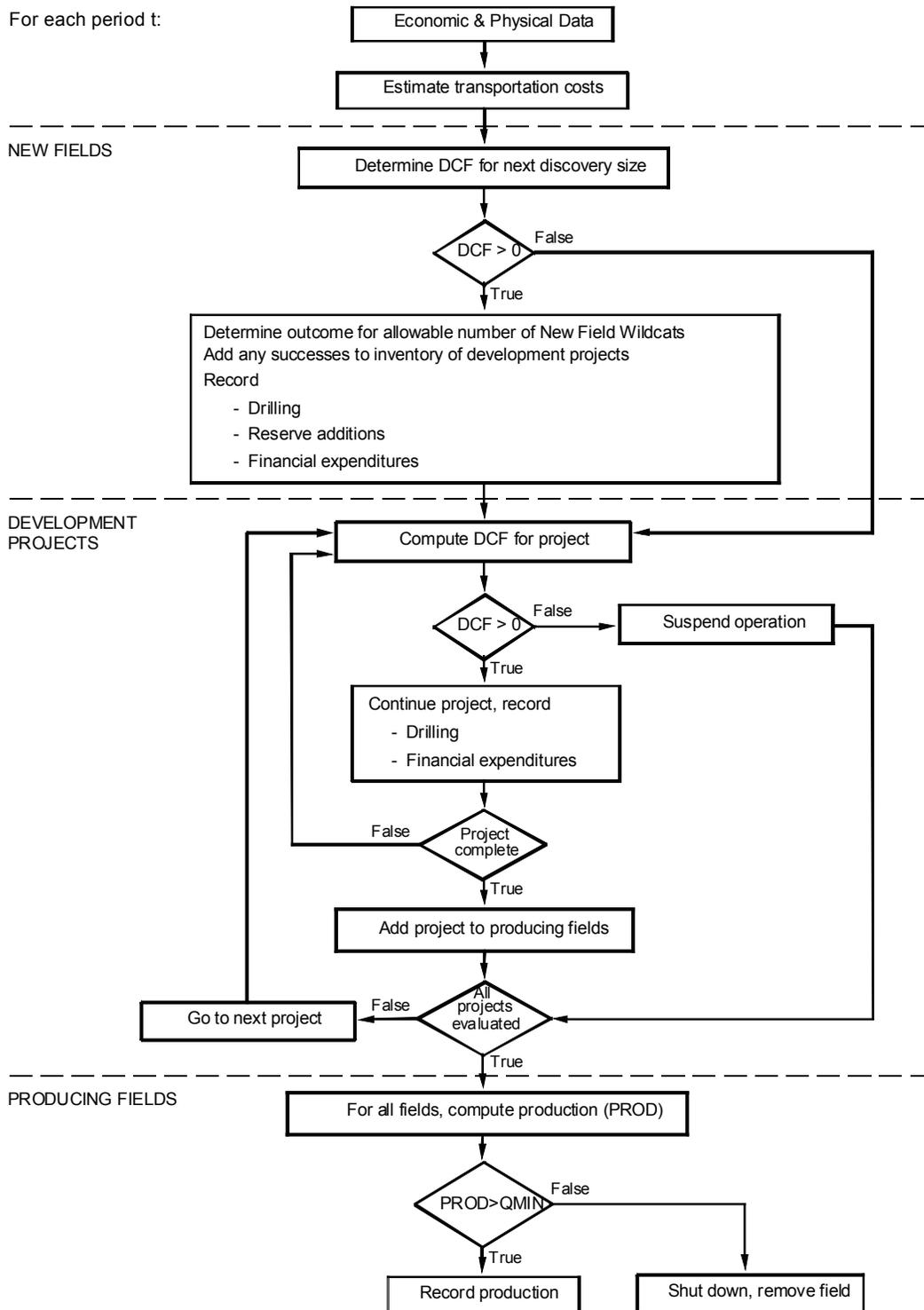
This section describes the structure for the Alaska Oil and Gas Supply Submodule (AOGSS). The AOGSS is designed to project field-specific oil production from the Onshore North Slope, Offshore North Slope, and Other Alaska areas (primarily the Cook Inlet area). The North Slope region encompasses the National Petroleum Reserve Alaska in the west, the State Lands in the middle, and the Arctic National Wildlife Refuge area in the east. This section provides an overview of the basic modeling approach, including a discussion of the discounted cash flow (DCF) method.

Alaska natural gas production is not projected by the AOGSS, but by Natural Gas Transmission and Distribution Module (NGTDM). The NGTDM projects Alaska gas consumption and whether an Alaska gas pipeline is projected to be built to carry Alaska North Slope gas into Canada and U.S. gas markets. As of January 1, 2009, Alaska was estimated to have 7.7 trillion cubic feet of proved reserves, 24.8 trillion cubic feet of inferred resources at existing fields (also known as field appreciation), and 257.5 trillion cubic feet of undiscovered resources, excluding the Arctic National Wildlife Refuge undiscovered gas resources. Over the long term, Alaska natural gas production is determined by and constrained by local consumption and by the capacity of a gas pipeline that might be built to serve Canada and U.S. lower-48 markets. The proven and inferred gas resources alone (i.e. 32.5 trillion cubic feet), plus known but undeveloped resources, are sufficient to satisfy at least 20 years of Alaska gas consumption and gas pipeline throughput. Moreover, large deposits of natural gas have been discovered (e.g., Point Thomson) but remain undeveloped due to a lack of access to gas consumption markets. Because Alaska natural gas production is best determined by projecting Alaska gas consumption and whether a gas pipeline is put into operation, the AOGSS does not attempt to project new gas field discoveries and their development or the declining production from existing fields.

### AOGSS Overview

The AOGSS solely focuses on projecting the exploration and development of undiscovered oil resources, primarily with respect to the oil resources expected to be found onshore and offshore in North Alaska. The AOGSS is divided into three components: new field discoveries, development projects, and producing fields (Figure 4-1). Transportation costs are used in conjunction with the crude oil price to Southern California refineries to calculate an estimated wellhead (netback) oil price. A discounted cash flow (DCF) calculation is used to determine the economic viability of Alaskan drilling and production activities. Oil field investment decisions are modeled on the basis of discrete projects. The exploration, discovery, and development of new oil fields depend on the expected exploration success rate and new field profitability. Production is determined on the basis of assumed drilling schedules and production profiles for new fields and developmental projects, along with historical production patterns and announced plans for currently producing fields.

**Figure 4-1. Flowchart of the Alaska Oil and Gas Supply Submodule**



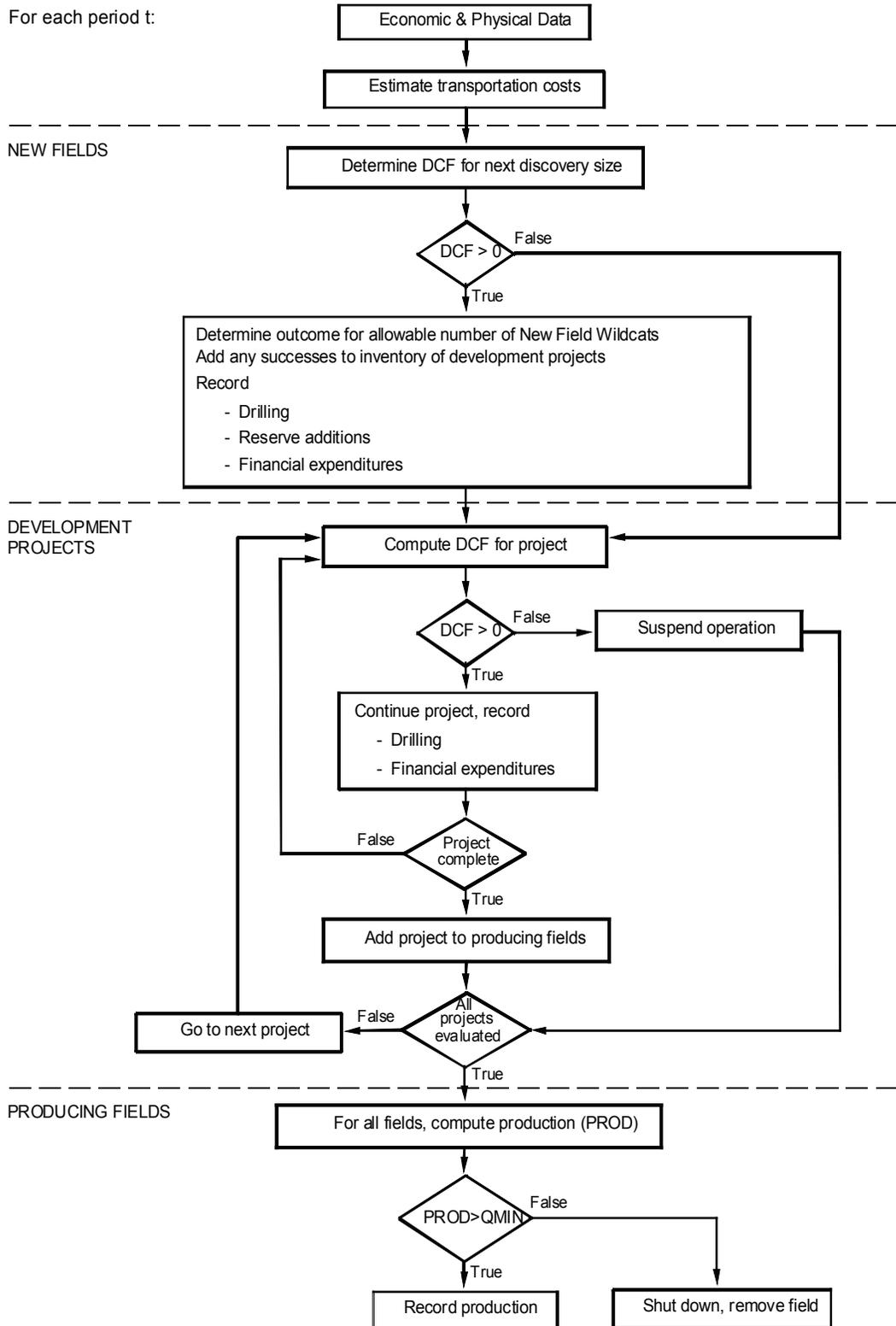
## **Calculation of Costs**

Costs differ within the model for successful wells and dry holes. Costs are categorized functionally within the model as

- Drilling costs,
- Lease equipment costs, and
- Operating costs (including production facilities and general and administrative costs).

All costs in the model incorporate the estimated impact of environmental compliance. Environmental regulations that preclude a supply activity outright are reflected in other adjustments to the model. For example, environmental regulations that preclude drilling in certain locations within a region are modeled by reducing the recoverable resource estimates for that region.

Each cost function includes a variable that reflects the cost savings associated with technological improvements. As a result of technological improvements, average costs decline in real terms



relative to what they would otherwise be. The degree of technological improvement is a user specified option in the model. The equations used to estimate costs are similar to those used for the lower 48 but include cost elements that are specific to Alaska. For example, lease equipment includes gravel pads and ice roads.

### ***Drilling Costs***

Drilling costs are the expenditures incurred for drilling both successful wells and dry holes, and for equipping successful wells through the "Christmas tree," the valves and fittings assembled at the top of a well to control the fluid flow. Elements included in drilling costs are labor, material, supplies and direct overhead for site preparation, road building, erecting and dismantling derricks and drilling rigs, drilling, running and cementing casing, machinery, tool changes, and rentals. Drilling costs for exploratory wells include costs of support equipment such as ice pads. Lease equipment required for production is included as a separate cost calculation and covers equipment installed on the lease downstream from the Christmas tree.

The average cost of drilling a well in any field located within region r in year t is given by:

$$\text{DRILLCOST}_{i,r,k,t} = \text{DRILLCOST}_{i,r,k,T_b} * (1 - \text{TECH1})^{*(t - T_b)} \quad (4-1)$$

where

- i = well class (exploratory=1, developmental=2)
- r = region (Offshore North Slope = 1, Onshore North Slope = 2, Cook Inlet = 3)
- k = fuel type (oil=1, gas=2 - but not used)
- t = forecast year
- DRILLCOST = drilling costs
- T<sub>b</sub> = base year of the forecast
- TECH1 = annual decline in drilling costs due to improved technology.

The above function specifies that drilling costs decline at the annual rate specified by TECH1. Drilling costs are not modeled as a function of the drilling rig activity level as they are in the Onshore Lower 48 methodology. Drilling rigs and equipment are designed specifically for the harsh Arctic weather conditions. Once drilling rigs are moved up to Alaska and reconfigured for Arctic conditions, they typically remain in Alaska. Company drilling programs in Alaska are planned to operate at a relatively constant level of activity because of the limited number of drilling rigs and equipment available for use. Most Alaska oil rig activity pertains to drilling in-fill wells intended to slow the rate of production decline in the largest Alaska oil fields.

For the *Annual Energy Outlook 2011*, Alaska onshore and offshore drilling and completion costs were updated based on the American Petroleum Institute's (API), *2007 Joint Association Survey on Drilling Costs*, dated December 2008. Based on these API drilling and completion costs and earlier work performed by Advanced Resources International, Inc. in 2002, the following oil well drilling and completion costs were incorporated into the AOGSS database (Table 4.1).

**Table 4.1**  
**AOGSS Oil Well Drilling and Completion Costs**  
**By Location and Category**  
**In millions of 2007 dollars**

	New Field Wildcat Wells	New Exploration Wells	Developmental Wells
In millions of 2007 dollars			
<b>Offshore North Slope</b>	206	103	98
<b>Onshore North Slope</b>	150	75	57
<b>South Alaska</b>	73	59	37
In millions of 1990 dollars			
<b>Offshore North Slope</b>	140	70	67
<b>Onshore North Slope</b>	102	51	39
<b>South Alaska</b>	50	40	25

Table 1 provides both 1990 and 2007 well drilling and completion cost data because the former are used within the context of calculating AOGSS discounted cash flows, while the latter are comparable to the current price environment.

***Lease Equipment Costs***

Lease equipment costs include the cost of all equipment extending beyond the Christmas tree, directly used to obtain production from a developed lease. Costs include: producing equipment, the gathering system, processing equipment (e.g., oil/gas/water separation), and production related infrastructure such as gravel pads. Producing equipment costs include tubing, pumping equipment. Gathering system costs consist of flowlines and manifolds. The lease equipment cost estimate for a new oil well is given by:

$$EQUIP_{r,k,t} = EQUIP_{r,k,t} * (1 - TECH2)^{t-T_b} \tag{4-2}$$

where

- r = region (Offshore North Slope = 1, Onshore North Slope = 2, Cook Inlet = 3)
- k = fuel type (oil=1, gas=2 – not used)
- t = forecast year
- EQUIP = lease equipment costs
- T<sub>b</sub> = base year of the forecast
- TECH2 = annual decline in lease equipment costs due to improved technology.

***Operating Costs***

EIA operating cost data, which are reported on a per well basis for each region, include three main categories of costs: normal daily operations, surface maintenance, and subsurface maintenance. Normal daily operations are further broken down into supervision and overhead, labor, chemicals, fuel, water, and supplies. Surface maintenance accounts for all labor and materials necessary to keep the service equipment functioning efficiently and safely. Costs of

stationary facilities, such as roads, also are included. Subsurface maintenance refers to the repair and services required to keep the downhole equipment functioning efficiently.

The estimated operating cost curve is:

$$\text{OPCOST}_{r,k,t} = \text{OPCOST}_{r,k,t} * (1 - \text{TECH2})^{t - T_b} \quad (4-3)$$

where

r	=	region (Offshore North Slope = 1, Onshore North Slope = 2, Cook Inlet = 3)
k	=	fuel type (oil=1, gas=2 – not used)
t	=	forecast year
OPCOST	=	operating cost
T <sub>b</sub>	=	base year of the forecast
TECH3	=	annual decline in operating costs due to improved technology.

Drilling costs, lease equipment costs, and operating costs are integral components of the following discounted cash flow analysis. These costs are assumed to be uniform across all fields within each of the three Alaskan regions.

### ***Treatment of Costs in the Model for Income Tax Purposes***

All costs are treated for income tax purposes as either expensed or capitalized. The tax treatment in the DCF reflects the applicable provisions for oil producers. The DCF assumptions are consistent with standard accounting methods and with assumptions used in similar modeling efforts. The following assumptions, reflecting current tax law, are used in the calculation of costs.

- All dry-hole costs are expensed.
- A portion of drilling costs for successful wells is expensed. The specific split between expensing and amortization is based on the tax code.
- Operating costs are expensed.
- All remaining successful field development costs are capitalized.
- The depletion allowance for tax purposes is not included in the model, because the current regulatory limitations for invoking this tax advantage are so restrictive as to be insignificant in the aggregate for future drilling decisions.

- Successful versus dry-hole cost estimates are based on historical success rates of successful versus dry-hole footage.
- Lease equipment for existing wells is in place before the first forecast year of the model.

## Discounted Cash Flow Analysis

A discounted cash flow (DCF) calculation is used to determine the profitability of oil projects.<sup>1</sup> A positive DCF is necessary to initiate the development of a discovered oil field. With all else being equal, large oil fields are more profitable to develop than small and mid-size fields. In Alaska, where developing new oil fields is quite expensive, particularly in the Arctic, the profitable development of small and mid-size oil fields is generally contingent on the pre-existence of infrastructure that was paid for by the development of a nearby large field. Consequently, AOGSS assumes that the largest oil fields will be developed first, followed by the development of ever smaller oil fields. Whether these oil fields are developed, regardless of their size, is projected on the basis of the profitability index, which is measured as the ratio of the expected discounted cash flow to expected capital costs for a potential project.

A key variable in the DCF calculation is the oil transportation cost to southern California refineries. Transportation costs for Alaskan oil include both pipeline and tanker shipment costs. The oil transportation cost directly affects the expected revenues from the production of a field as follows:<sup>2</sup>

$$REV_{f,t} = Q_{f,t} * (MP_t - TRANS_t) \quad (4-4)$$

where

f	=	field
t	=	year
REV	=	expected revenues
Q	=	expected production volumes
MP	=	market price in the lower 48 states
TRANS	=	transportation cost.

The expected discounted cash flow associated with a potential oil project in field f at time t is given by

$$DCF_{f,t} = (PVREV - PVROY - PVDRILLCOST - PVEQUIP - TRANSCAP - PVOPCOST - PVPRODTAX - PVSIT - PVFIT)_{f,t} \quad (4-5)$$

where,

PVREV	=	present value of expected revenues
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<sup>1</sup>See Appendix 3.A at the end of this chapter for a detailed discussion of the DCF methodology.

<sup>2</sup>This formulation assumes oil production only. It can be easily expanded to incorporate the sale of natural gas.

PVROY	=	present value of expected royalty payments
PVDRILLCOST	=	present value of all exploratory and developmental drilling expenditures
PVEQUIP	=	present value of expected lease equipment costs
TRANSCAP	=	cost of incremental transportation capacity
PVOPCOST	=	present value of operating costs
PVPRODTAX	=	present value of expected production taxes (ad valorem and severance taxes)
PVSIT	=	present value of expected state corporate income taxes
PVFIT	=	present value of expected federal corporate income taxes

The expected capital costs for the proposed field f located in region r are:

$$\text{COST}_{f,t} = (\text{PVEXPCOST} + \text{PVDEVCOST} + \text{PVEQUIP} + \text{TRANSCAP})_{f,t} \quad (4-6)$$

where

PVEXPCOST	=	present value exploratory drilling costs
PVDEVCOST	=	present value developmental drilling costs
PVEQUIP	=	present value lease equipment costs
TRANSCAP	=	cost of incremental transportation capacity

The profitability indicator from developing the proposed field is therefore

$$\text{PROF}_{f,t} = \frac{\text{DCF}_{f,t}}{\text{COST}_{f,t}} \quad (4-7)$$

The model assumes that field with the highest positive PROF in time t is eligible for exploratory drilling in the same year. The profitability indices for Alaska also are passed to the basic framework module of the OGSM.

### **New Field Discovery**

Development of estimated recoverable resources, which are expected to be in currently undiscovered fields, depends on the schedule for the conversion of resources from unproved to reserve status. The conversion of resources into field reserves requires both a successful new field wildcat well and a positive discounted cash flow of the costs relative to the revenues. The discovery procedure can be determined endogenously, based on exogenously determined data. The procedure requires the following exogenously determined data:

- new field wildcat success rate,
- any restrictions on the timing of drilling,
- the distribution of technically recoverable field sizes within each region.

The endogenous procedure generates:

- the new field wildcat wells drilled in any year,
- the set of individual fields to be discovered, specified with respect to size and location (relative to the 3 Alaska regions, i.e., offshore North Slope, onshore North Slope, and South-Central Alaska),
- an order for the discovery sequence, and
- a schedule for the discovery sequence.

The new field discovery procedure relies on the U.S. Geological Survey (USGS) and Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) respective estimates of onshore and offshore technically recoverable oil resources as translated into the expected field size distribution of undiscovered fields. These onshore and offshore field size distributions are used to determine the field size and order of discovery in the AOGSS exploration and discovery process. Thus, the AOGSS oil field discovery process is consistent with the expected geology with respect to expected aggregate resource base and the relative frequency of field sizes.

AOGSS assumes that the largest fields in a region are found first, followed by successively smaller fields. This assumption is based on the following observations: 1) the largest volume fields typically encompass the greatest areal extent, thereby raising the probability of finding a large field relative to finding a smaller field, 2) seismic technology is sophisticated enough to be able to determine the location of the largest geologic structures that might possibly hold oil, 3) producers have a financial incentive to develop the largest fields first both because of their higher inherent rate of return and because the largest fields can pay for the development of expensive infrastructure that affords the opportunity to develop the smaller fields using that same infrastructure, and 4) historically, North Slope and Cook Inlet field development has generally progressed from largest field to smallest field.

Starting with the AEO2011, onshore and offshore North Slope new field wildcat drilling activity is a function of West Texas Intermediate crude oil prices from 1977 through 2008, expressed in 2008 dollars. The new field wildcat exploration function was statistically estimated based on West Texas Intermediate crude oil prices from 1977 through 2008 and on exploration well drilling data obtained from the Alaska Oil and Gas Conservation Commission (AOGCC) data files for the same period.<sup>3</sup> The North Slope wildcat exploration drilling parameters were estimated using ordinary least squares methodology.

$$NAK\_NFW_t = (0.13856 * IT\_WOP_t) + 3.77 \quad (4-8)$$

where

$$\begin{aligned} t &= \text{year} \\ NAK\_NFW_t &= \text{North Slope Alaska field wildcat exploration wells} \\ IT\_WOP_t &= \text{World oil price in 2008 dollars} \end{aligned}$$

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<sup>3</sup> A number of alternative functional formulations were tested (e.g., using Alaska crude oil prices, lagged oil prices, etc.), yet none of the alternative formations resulted in statistically more significant relationships.

The summary statistics for the statistical estimation are as follows:

Dependent variable: NSEXPLORE  
 Current sample: 1 to 32  
 Number of observations: 32

Mean of dep. var. = 9.81250	LM het. test = .064580 [.799]
Std. dev. of dep. var. = 4.41725	Durbin-Watson = 2.04186 [<.594]
Sum of squared residuals = 347.747	Jarque-Bera test = .319848 [.852]
Variance of residuals = 11.5916	Ramsey's RESET2 = .637229E-04 [.994]
Std. error of regression = 3.40464	F (zero slopes) = 22.1824 [.000]
R-squared = .425094	Schwarz B.I.C. = 87.0436
Adjusted R-squared = .405930	Log likelihood = -83.5778

Variable	Estimated Coefficient	Standard Error	t-statistic	P-value
C	3.77029	1.41706	2.66065	[.012]
WTIPRICE	.138559	.029419	4.70982	[.000]

Because very few offshore North Slope wells have been drilled since 1977, within AOGSS, the total number of exploration wells drilled on the North Slope are shared between the onshore and offshore regions, with the wells being predominantly drilled onshore in the early years of the projections with progressively more wells drilled offshore, such that after 20 years 50 percent of the exploration wells are drilled onshore and 50 percent are drilled offshore.

Based on the AOGCC data for 1977 through 2008, the drilling of South-Central Alaska new field wildcat exploration wells was statistically unrelated to oil prices. On average, 3 exploration wells per year were drilled in South-Central Alaska over the 1977 through 2008 timeframe, regardless of prevailing oil prices. This result probably stems from the fact that most of the South-Central Alaska drilling activity is focused on natural gas rather than oil, and that natural gas prices are determined by the Regulatory Commission of Alaska rather than being “market driven.” Consequently, AOGSS specifies that 3 exploration wells are drilled each year.

The execution of the above procedure can be modified to reflect restrictions on the timing of discovery for particular fields. Restrictions may be warranted for enhancements such as delays necessary for technological development needed prior to the recovery of relatively small accumulations or heavy oil deposits. State and Federal lease sale schedules could also restrict the earliest possible date for beginning the development of certain fields. This refinement is implemented by declaring a start date for possible exploration. For example, AOGSS specifies that if Federal leasing in the Arctic National Wildlife Refuge were permitted in 2011, then the earliest possible date at which an ANWR field could begin oil production would be in 2021.<sup>4</sup> Another example is the wide-scale development of the West Sak field that is being delayed until a technology can be developed that will enable the heavy, viscous crude oil of that field to be economically extracted.

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<sup>4</sup>The earliest ANWR field is assumed to go into production 10 years after the first projection year; so the first field comes on line in 2020 for the *Annual Energy Outlook 2010* projections. See also *Analysis of Crude Oil Production in the Arctic National Wildlife Refuge*, EIA, SR/OIAF/2008-03, (May 2008).

## Development Projects

Development projects are those projects in which a successful new field wildcat has been drilled. As with the new field discovery process, the DCF calculation plays an important role in the timing of development and exploration of these multi-year projects.

Each model year, the DCF is calculated for each potential development project. Initially, the model assumes a drilling schedule determined by the user or by some set of specified rules. However, if the DCF for a given project is negative, then development of this project is suspended in the year in which the negative DCF occurs. The DCF for each project is evaluated in subsequent years for a positive value. The model assumes that development would resume when a positive DCF value is calculated.

Production from developing projects follows the generalized production profile developed for and described in previous work conducted by DOE staff.<sup>5</sup> The specific assumptions used in this work are as follows:

- a 2- to 4-year build-up period from initial production to the peak production rate,
- the peak production rate is sustained for 3 to 8 years, and
- after peak production, the production rate declines by 12 to 15 percent per year.

The production algorithm build-up and peak-rate period are based on the expected size of the undiscovered field, with larger fields having longer build-up and peak-rate periods than the smaller fields. The field production decline rates are also determined by the field size.

The pace of development and the ultimate number of wells drilled for a particular field is based on the historical field-level profile adjusted for field size and other characteristics of the field (e.g. API gravity.)

After all exploratory and developmental wells have been drilled for a given project, development of the project is complete. For this version of the AOGSS, no constraint is placed on the number of exploratory or developmental wells that can be drilled for any project. All completed projects are added to the inventory of producing fields.

Development fields include fields that have already been discovered but have not begun production. These fields include, for example, a series of expansion fields in both the Prudhoe Bay area, the National Petroleum Reserve - Alaska (NPR), and for various offshore fields. For these fields, the starting date of production and their production rates were not determined by the discovery process outlined above, but are based on public announcements by the company(s) developing those fields.

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<sup>5</sup> *Potential Oil Production from the Coastal Plain of the Arctic National Wildlife Refuge: Updated Assessment*, EIA (May 2000) and *Alaska Oil and Gas - Energy Wealth of Vanishing Opportunity?*, DOE/ID/0570-H1 (January 1991).

## Producing Fields

Oil production from fields producing as of the initial projection year (e.g., Prudhoe Bay, Kuparuk, Lisburne, Endicott, and Milne Point) are based on historical production patterns, remaining estimated recovery, and announced development plans. The production decline rates of these fields are periodically recalibrated based on recent field-specific production rates.

Natural gas production from the North Slope for sale to end-use markets depends on the construction of a pipeline to transport natural gas to lower 48 markets.<sup>6</sup> North Slope natural gas production is determined by the carrying capacity of a natural gas pipeline to the lower 48.<sup>7</sup> The Prudhoe Bay Field is the largest known deposit of North Slope gas (24.5 Tcf)<sup>8</sup> and currently all of the gas produced from this field is re-injected to maximize oil production. Total known North Slope gas resources equal 35.4 Tcf.<sup>9</sup> Furthermore, the undiscovered onshore central North Slope and NPRA technically recoverable natural gas resource base are respectively estimated to be 33.3 Tcf<sup>10</sup> and 52.8 Tcf.<sup>11</sup> Collectively, these North Slope natural gas reserves and resources equal 121.5 Tcf, which would satisfy the 1.64 Tcf per year gas requirements of an Alaska gas pipeline for almost 75 years, well after the end of the *Annual Energy Outlook* projections. Consequently, North Slope natural gas resources, both discovered and undiscovered, are more than ample to supply natural gas to an Alaska gas pipeline during the *Annual Energy Outlook* projection period.

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<sup>6</sup>Initial natural gas production from the North Slope for Lower 48 markets is affected by a delay reflecting a reasonable period for construction. Details of how this decision is made in NEMS are included in the Natural Gas Transmission and Distribution Module documentation.

<sup>7</sup> The determination of whether an Alaska gas pipeline is economically feasible is calculated within the Natural Gas Transmission and Distribution Model.

<sup>8</sup> *Alaska Oil and Gas Report 2009*, Alaska Department of Natural Resources, Division of Oil and Gas, Table I.I, page 8.

<sup>9</sup> *Ibid.*

<sup>10</sup> U.S. Geological Survey, *Oil and Gas Assessment of Central North Slope, Alaska, 2005*, Fact Sheet 2005-3043, April 2005, page 2 table – mean estimate total.

<sup>11</sup> U.S. Geological Survey, *2010 Updated Assessment of Undiscovered Oil and Gas Resources of the National Petroleum Reserve in Alaska (NPRA)*, Fact Sheet 2010-3102, October 2010, Table 1 – mean estimate total, page 4.

## Appendix 4.A. Alaskan Data Inventory

Variable Name		Description	Unit	Classification	Source
Code	Text				
ANGTSMAX	--	ANGTS maximum flow	BCF/D	Alaska	NPC
ANGTSPRC	--	Minimum economic price for ANGTS start up	1987\$/MCF	Alaska	NPC
ANGTSRES	--	ANGTS reserves	BCF	Alaska	NPC
ANGTSYR	--	Earliest start year for ANGTS flow	Year	NA	NPC
DECLPRO	--	Alaska decline rates for currently producing fields	Fraction	Field	OPNGBA
DEV_AK	--	Alaska drilling schedule for developmental wells	Wells per year	3 Alaska regions; Fuel (oil, gas)	OPNGBA
DRILLAK	DRILL	Alaska drilling cost (not including new field wildcats)	1990\$/well	Class (exploratory, developmental); 3 Alaska regions; Fuel (oil, gas)	OPNGBA
DRLNFWAK	--	Alaska drilling cost of a new field wildcat	1990\$/well	3 Alaska regions; Fuel (oil, gas)	OPNGBA
DRYAK	DRY	Alaska dry hole cost	1990\$/hole	Class (exploratory, developmental); 3 Alaska regions; Fuel (oil, gas)	OPNGBA
EQUIPAK	EQUIP	Alaska lease equipment cost	1990\$/well	Class (exploratory, developmental); 3 Alaska regions; Fuel (oil, gas)	USGS
EXP_AK	--	Alaska drilling schedule for other exploratory wells	wells per year	3 Alaska regions	OPNGBA
FACILAK	--	Alaska facility cost (oil field)	1990\$/bls	Field size class	USGS
FSZCOAK	--	Alaska oil field size distributions	MMB	3 Alaska regions	USGS
FSZNGAK	--	Alaska gas field size distributions	BCF	3 Alaska regions	USGS
HISTPRDCO	--	Alaska historical crude oil production	MB/D	Field	AOGCC
KAPFRCAK	EXKAP	Alaska drill costs that are tangible & must be depreciated	fraction	Alaska	U.S. Tax Code
MAXPRO	--	Alaska maximum crude oil production	MB/D	Field	Announced Plans
NAK_NFW	--	Number of new field wildcat wells drilling in Northern AK	wells per year	NA	OPNGBA
NFW_AK	--	Alaska drilling schedule for new field wildcats	wells	NA	OPNGBA
PRJAK	n	Alaska oil project life	Years	Fuel (oil, gas)	OPNGBA
PROYR	--	Start year for known fields in Alaska	Year	Field	Announced Plans

Variable Name		Description	Unit	Classification	Source
Code	Text				
RCPRDAK	m	Alaska recovery period of intangible & tangible drill cost	Years	Alaska	U.S. Tax Code
RECRES	--	Alaska crude oil resources for known fields	MMB	Field	<i>OFE, Alaska Oil and Gas - Energy Wealth or Vanishing Opportunity</i>
ROYRT	ROYRT	Alaska royalty rate	fraction	Alaska	USGS
SEVTXAK	PRODTAX	Alaska severance tax rates	fraction	Alaska	USGS
SRAK	SR	Alaska drilling success rates	fraction	Alaska	OPNGBA
STTXAK	STRT	Alaska state tax rate	fraction	Alaska	USGS
TECHAK	TECH	Alaska technology factors	fraction	Alaska	OPNGBA
TRANSAK	TRANS	Alaska transportation cost	1990\$	3 Alaska regions; Fuel (oil, gas)	OPNGBA
XDCKAPAK	XDCKAP	Alaska intangible drill costs that must be depreciated	fraction	Alaska	U.S. Tax Code

Source: National Petroleum Council (NPC), EIA Office of Petroleum, Natural Gas, & Biofuels Analysis (OPNGBA), United States Geologic Survey (USGS), Alaska Oil and Gas Conservation Commission (AOGCC)

## 5. Oil Shale Supply Submodule

Oil shale rock contains a hydrocarbon known as kerogen,<sup>12</sup> which can be processed into a synthetic crude oil (syncrude) by heating the rock. During the 1970s and early 1980s, petroleum companies conducted extensive research, often with the assistance of public funding, into the mining of oil shale rock and the chemical conversion of the kerogen into syncrude. The technologies and processes developed during that period are well understood and well documented with extensive technical data on demonstration plant costs and operational parameters, which were published in the professional literature. The oil shale supply submodule in OGSM relies extensively on this published technical data for providing the cost and operating parameters employed to model the “typical” oil shale syncrude production facility.

In the 1970s and 1980s, two engineering approaches to creating the oil shale syncrude were envisioned. In one approach, which the majority of the oil companies pursued, the producer mines the oil shale rock in underground mines. A surface facility then retorts the rock to create bitumen, which is then further processed into syncrude. Occidental Petroleum Corp. pursued the other approach known as “modified in-situ,” in which some of the oil shale rock is mined in underground mines, while the remaining underground rock is “rubbilized” using explosives to create large caverns filled with oil shale rock. The rubbilized oil shale rock is then set on fire to heat the kerogen and convert it into bitumen, with the bitumen being pumped to the surface for further processing into syncrude. The modified in-situ approach was not widely pursued because the conversion of kerogen into bitumen could not be controlled with any precision and because the leaching of underground bitumen and other petroleum compounds might contaminate underground aquifers.

When oil prices dropped below \$15 per barrel in the mid-1990s, demonstrating an abundance of conventional oil supply, oil shale petroleum production became untenable and project sponsors canceled their oil shale research and commercialization programs. Consequently, no commercial-scale oil shale production facilities were ever built or operated. Thus, the technical and economic feasibility of oil shale petroleum production remains untested and unproven.

In 1997, Shell Oil Company started testing a completely in-situ oil shale process, in which the oil shale rock is directly heated underground using electrical resistance heater wells, while petroleum products<sup>13</sup> are produced from separate production wells. The fully in-situ process has significant environmental and cost benefits relative to the other two approaches. The environmental benefits are lower water usage, no waste rock disposal, and the absence of hydrocarbon leaching from surface waste piles. As an example of the potential environmental impact on surface retorting, an industry using 25 gallons per ton oil shale rock to produce 2 million barrels per day would generate about 1.2 billion tons of waste rock per year, which is about 11 percent more than the weight of all the coal mined in the United States in 2010. Other advantages of the in-situ process include: 1) access to deeper oil shale resources, 2) greater oil and gas generated per acre because the process uses multiple oil shale seams within the resource column rather than just a single seam, and 3) direct production of petroleum products rather than

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<sup>12</sup> Kerogen is a solid organic compound, which is also found in coal.

<sup>13</sup> Approximately, 30 percent naphtha, 30 percent jet fuel, 30 percent diesel, and 10 percent residual fuel oil.

a synthetic crude oil that requires more refinery processing. Lower production costs are expected for the in-situ approach because massive volumes of rock would not be moved, and because the drilling of heater wells, production wells, and freeze-wall wells can be done in a modular fashion, which allows for a streamlined manufacturing-like process. Personnel safety would be greater and accident liability lower. Moreover, the in-situ process reduces the capital risk, because it involves building self-contained modular production units that can be multiplied to reach a desired total production level. Although the technical and economic feasibility of the in-situ approach has not been commercially demonstrated, there is already a substantial body of evidence from field tests conducted by Shell Oil Co. that the in-situ process is technologically feasible.<sup>14</sup> The current Shell field research program is expected to conclude around the 2014 through 2017 timeframe with the construction of a small scale demonstration plant expected to begin shortly thereafter. The Oil Shale Supply Submodule (OSSS) assumes that the first commercial size oil shale plant cannot be built prior to 2017.

Given the inherent cost and environmental benefits of the in-situ approach, a number of other companies, such as Chevron and ExxonMobil are testing alternative in-situ oil shale techniques. Although small-scale mining and surface retorting of oil shale is currently being developed, by companies such as Red Leaf Resources, the large scale production of oil shale will most likely use the in-situ process. However, because in-situ oil shale projects have never been built, and because companies developing the in-situ process have not publicly released detailed technical parameters and cost estimates, the cost and operational parameters of such in-situ facilities is unknown. Consequently, the Oil Shale Supply Submodule (OSSS) relies on the project parameters and costs associated with the underground mining and surface retorting approach that were designed during the 1970s and 1980s. In this context, the underground mining and surface retorting facility parameters and costs are meant to be a surrogate for the in-situ oil shale facility that is more likely to be built. Although the in-situ process is expected to result in a lower cost oil shale product, this lower cost is somewhat mitigated by the fact that the underground mining and surface retorting processes developed in the 1970s and 1980s did not envision the strict environmental regulations that prevail today, and therefore embody an environmental compliance cost structure that is lower than what would be incurred today by a large-scale underground mining and surface retorting facility. Also, the high expected cost structure of the underground mining/surface retorting facility constrains the initiation of oil shale project production, which should be viewed as a more conservative approach to simulating the market penetration of in-situ oil projects. On the other hand, OSSS oil shale facility costs are reduced by 1 percent per year to reflect technological progress, especially with respect to the improvement of an in-situ oil shale process. Finally, public opposition to building any type of oil shale facility is likely to be great, regardless of the fact that the in-situ process is expected to be more environmentally benign than the predecessor technologies; the cost of building an in-situ oil shale facility is therefore likely to be considerably greater than would be determined strictly by the engineering parameters of such a facility.<sup>15</sup>

The Oil Shale Supply Submodule (OSSS) only represents economic decision making. In the absence of any existing commercial oil shale projects, it was impossible to determine the

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<sup>14</sup> See “Shell’s In-situ Conversion Process,” a presentation by Harold Vinegar at the Colorado Energy Research Institute’s 26th Oil Shale Symposium held on October 16 – 18, 2006 in Boulder, Colorado.

<sup>15</sup> Project delays due to public opposition can significantly increase project costs and reduce project rates of return.

potential environmental constraints and costs of producing oil on a large scale. Given the considerable technical and economic uncertainty of an oil shale industry based on an in-situ technology, and the infeasibility of the large-scale implementation of an underground mining/surface retorting technology, the oil shale syncrude production projected by the OSSS should be considered highly uncertain.

Given this uncertainty, the construction of commercial oil shale projects is constrained by a linear market penetration algorithm that restricts the oil production rate, which, at best, can reach a maximum of 2 million barrels per day by the end of a 40-year period after commercial oil shale facilities are deemed to be technologically feasible (starting in 2017). Whether domestic oil shale production actually reaches 2 million barrels per day at the end of the 40-year period depends on the relative profitability of oil shale facilities. If oil prices are too low to recover the weighted average cost of capital, no new facilities are built. However, if oil prices are sufficiently high to recover the cost of capital, then the rate of market penetration rises in direct proportion to facility profitability. So as oil prices rise and oil shale facility profitability increases, the model assumes that oil shale facilities are built in greater numbers, as dictated by the market penetration algorithm.

The 2 million barrel per day production limit is based on an assessment of what is feasible given both the oil shale resource base and potential environmental constraints.<sup>16</sup> The 40-year minimum market penetration timeframe is based on the observation that "...an oil shale production level of 1 million barrels per day is probably more than 20 years in the future..."<sup>17</sup> with a linear ramp-up to 2 million barrels per day equating to a 40-year minimum.

The actual rate of market penetration in the OSSS largely depends on projected oil prices, with low prices resulting in low rates of market penetration, and with the maximum penetration rate only occurring under high oil prices that result in high facility profitability. The development history of the Canadian oil sands industry is an analogous situation. The first commercial Canadian oil sands facility began operations in 1967; the second project started operation in 1978; and the third project initiated production in 2003.<sup>18</sup> So even though the Canadian oil sands resource base is vast, it took over 30 years before a significant number of new projects were announced. This slow penetration rate, however, was largely caused by both the low world oil prices that persisted from the mid-1980s through the 1990s and the lower cost of developing conventional crude oil supply.<sup>19</sup> The rise in oil prices that began in 2003 caused 17 new oil sands projects to be announced by year-end 2007.<sup>20</sup> Oil prices subsequently peaked in July 2008,

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<sup>16</sup> See U.S. Department of Energy, "Strategic Significance of America's Oil Shale Resource," March 2004, Volume I, page 23 – which speaks of an "aggressive goal" of 2 million barrels per day by 2020; and Volume II, page 7 – which concludes that the water resources in the Upper Colorado River Basin are "more than enough to support a 2 million barrel/day oil shale industry..."

<sup>17</sup> Source: RAND Corporation, "Oil Shale Development in the United States – Prospects and Policy Issues," MG-414, 2005, Summary page xi.

<sup>18</sup> The owner/operator for each of the 3 initial oil sands projects were respectively Suncor, Syncrude, and Shell Canada.

<sup>19</sup> The first Canadian commercial oil sands facility started operations in 1967. It took 30 years later until the mid to late 1990s for a building boom of Canadian oil sands facilities to materialize. Source: Suncor Energy, Inc. internet website at [www.suncor.com](http://www.suncor.com), under "our business," under "oil sands."

<sup>20</sup> Source: Alberta Employment, Immigration, and Industry, "Alberta Oil Sands Industry Update," December 2007, Table 1, pages 17 – 21.

and declined significantly, such that a number of these new projects were put on hold at that time.

Extensive oil shale resources exist in the United States both in eastern Appalachian black shales and western Green River Formation shales. Almost all of the domestic high-grade oil shale deposits with 25 gallons or more of petroleum per ton of rock are located in the Green River Formation, which is situated in Northwest Colorado (Piceance Basin), Northeast Utah (Uinta Basin), and Southwest Wyoming. It has been estimated that over 400 billion barrels of syncrude potential exists in Green River Formation deposits that would yield at least 30 gallons of syncrude per ton of rock in zones at least 100 feet thick.<sup>21</sup> Consequently, the Oil Shale Supply Submodule assumes that future oil shale syncrude production occurs exclusively in the Rocky Mountains within the 2035 time frame of the projections. Moreover, the immense size of the western oil shale resource base precluded the need for the submodule to explicitly track oil shale resource depletion through 2035.

For each projection year, the oil shale submodule calculates the net present cash flow of operating a commercial oil shale syncrude production facility, based on that future year's projected crude oil price. If the calculated discounted net present value of the cash flow exceeds zero, the submodule assumes that an oil shale syncrude facility would begin construction, so long as the construction of that facility is not precluded by the construction constraints specified by the market penetration algorithm. So the submodule contains two major decision points for determining whether an oil shale syncrude production facility is built in any particular year: first, whether the discounted net present value of a facility's cash flow exceeds zero; second, by a determination of the number of oil shale projects that can be initiated in that year, based on the maximum total oil shale production level that is permitted by the market penetration algorithm.

In any one year, many oil shale projects can be initiated, raising the projected production rates in multiples of the rate for the standard oil shale facility, which is assumed to be 50,000 barrels per day, per project.

## **Oil Shale Facility Cost and Operating Parameter Assumptions**

The oil shale supply submodule is based on underground mining and surface retorting technology and costs. During the late 1970s and early 1980s, when petroleum companies were building oil shale demonstration plants, almost all demonstration facilities employed this technology.<sup>22</sup> The facility parameter values and cost estimates in the OSSS are based on information reported for the Paraho Oil Shale Project, and which are inflated to constant 2004 dollars.<sup>23</sup> Oil shale rock mining costs are based on Western United States underground coal mining costs, which would be representative of the cost of mining oil shale rock,<sup>24</sup> because coal

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<sup>21</sup> Source: Culbertson, W. J. and Pitman, J. K. "Oil Shale" in *United States Mineral Resources*, USGS Professional Paper 820, Probst and Pratt, eds. P 497-503, 1973.

<sup>22</sup> Out of the many demonstration projects in the 1970s only Occidental Petroleum tested a modified in-situ approach which used caved-in mining areas to perform underground retorting of the kerogen.

<sup>23</sup> Source: Noyes Data Corporation, *Oil Shale Technical Data Handbook*, edited by Perry Nowacki, Park Ridge, New Jersey, 1981, pages 89-97.

<sup>24</sup> Based on the coal mining cost per ton data provided in coal company 2004 annual reports, particularly those of

mining techniques and technology would be employed to mine oil shale rock. However, the OSSS assumes that oil shale production costs fall at a rate of 1 percent per year, starting in 2005, to reflect the role of technological progress in reducing production costs. This cost reduction assumption results in oil shale production costs being 26 percent lower in 2035 relative to the initial 2004 cost structure.

Although the Paraho cost structure might seem unrealistic, given that the application of the in-situ process is more likely than the application of the underground mining/surface retorting process, the Paraho cost structure is well documented, while there is no detailed public information regarding the expected cost of the in-situ process. Even though the in-situ process might be cheaper per barrel of output than the Paraho process, this should be weighted against the following facts 1) oil and gas drilling costs have increased dramatically since 2005, somewhat narrowing that cost difference, and 2) the Paraho costs were determined at a time when environmental requirements were considerably less stringent. Consequently, the environmental costs that an energy production project would incur today are considerably more than what was envisioned in the late-1970s and early-1980s. It should also be noted that the Paraho process produces about the same volumes of oil and natural gas as the in-situ process does, and requires about the same electricity consumption as the in-situ process. Finally, to the degree that the Paraho process costs reported here are greater than the in-situ costs, the use of the Paraho cost structure provides a more conservative facility cost assessment, which is warranted for a completely new technology.

Another implicit assumption in the OSSS is that the natural gas produced by the facility is sold to other parties, transported offsite, and priced at prevailing regional wellhead natural gas prices. Similarly, the electricity consumed on site is purchased from the local power grid at prevailing industrial prices. Both the natural gas produced and the electricity consumed are valued in the Net Present Value calculations at their respective regional prices, which are determined elsewhere in the NEMS. Although the oil shale facility owner has the option to use the natural gas produced on-site to generate electricity for on-site consumption, building a separate on-site/offsite power generation decision process within OSSS would unduly complicate the OSSS logic structure and would not necessarily provide a more accurate portrayal of what might actually occur in the future.<sup>25</sup> Moreover, this treatment of natural gas and electricity prices automatically takes into consideration any embedded carbon dioxide emission costs associated with a particular NEMS scenario, because a carbon emissions allowance cost is embedded in the regional natural gas and electricity prices and costs.

### ***OSSS Oil Shale Facility Configuration and Costs***

The OSSS facility parameters and costs are based on those reported for the Paraho Oil Shale

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Arch Coal, Inc, CONSOL Energy Inc, and Massey Energy Company. Reported underground mining costs per ton range for \$14.50 per ton to \$27.50 per ton. The high cost figures largely reflect higher union wage rates, than the low cost figures reflect non-union wage rates. Because most of the Western underground mines are currently non-union, the cost used in OSSS was pegged to the lower end of the cost range. For example, the \$14.50 per ton cost represents Arch Coal's average western underground mining cost.

<sup>25</sup> The Colorado/Utah/Wyoming region has relatively low electric power generation costs due to 1) the low cost of mining Powder River Basin subbituminous coal, and 2) the low cost of existing electricity generation equipment, which is inherently lower than new generation equipment due cost inflation and facility depreciation.

project. Because the Paraho Oil Shale Project costs were reported in 1976 dollars, the OSSS costs were inflated to constant 2004 dollar values. Similarly, the OSSS converts NEMS oil prices, natural gas prices, electricity costs, and carbon dioxide costs into constant 2004 dollars, so that all facility net present value calculations are done in constant 2004 dollars. Based on the Paraho Oil Shale Project configuration, OSSS oil shale facility parameters and costs are listed in Table 5-1, along the OSSS variable names. For the *Annual Energy Outlook 2009* and subsequent *Outlooks*, oil shale facility construction costs were increased by 50 percent to represent the world-wide increase in steel and other metal prices since the OSSS was initially designed. For the *Annual Energy Outlook 2011*, the oil shale facility plant size was reduced from 100,000 barrels per day to 50,000 barrels per day, based on discussions with industry representatives who believe that the smaller configuration was more likely for in-situ projects because this size captures most of the economies of scale, while also reducing project risk.

**Table 5-1. OSSS Oil Shale Facility Configuration and Cost Parameters**

Facility Parameters	OSSS Variable Name	Parameter Value
Facility project size	OS_PROJ_SIZE	50,000 barrels per day
Oil shale syncrude per ton of rock	OS_GAL_TON	30 gallons
Plant conversion efficiency	OS_CONV_EFF	90 percent
Average facility capacity factor	OS_CAP_FACTOR	90 percent per year
Facility lifetime	OS_PRJ_LIFE	20 years
Facility construction time	OS_PRJ_CONST	3 year
Surface facility capital costs	OS_PLANT_INVEST	\$2.4 billion (2004 dollars)
Surface facility operating costs	OS_PLANT_OPER_CST	\$200 million per year (2004 dollars)
Underground mining costs	OS_MINE_CST_TON	\$17.50 per ton (2004 dollars)
Royalty rate	OS_ROYALTY_RATE	12.5 percent of syncrude value
Carbon Dioxide Emissions Rate	OS_CO2EMISS	150 metric tons per 50,000 bbl/day of production <sup>26</sup>

The construction lead time for oil shale facilities is assumed to be 3 years, which is less than the 5-year construction time estimates developed for the Paraho Project. The shorter construction period is based on the fact that the drilling of shallow in-situ heating and production wells can be accomplished much more quickly than the erection of a surface retorting facility. Because it is not clear when during the year a new plant will begin operation and achieve full productive capacity, OSSS assumes that production in the first full year will be at half its rated output and that full capacity will be achieved in the second year of operation.

To mimic the fact that an industry's costs decline over time due to technological progress, better management techniques, and so on, the OSSS initializes the oil shale facility costs in the year 2005 at the values shown above (i.e., surface facility construction and operating costs, and underground mining costs). After 2005, these costs are reduced by 1 percent per year through 2035, which is consistent with the rate of technological progress witnessed in the petroleum industry over the last few decades.

<sup>26</sup> Based on the average of the Fischer Assays determined for four oil shale rock samples of varying kerogen content. Op. cit. Noyes Data Corporation, Table 3.8, page 20.

### ***OSSS Oil Shale Facility Electricity Consumption and Natural Gas Production Parameters***

Based on the Paraho Oil Shale Project parameters, Table 5-2 provides the level of annual gas production and annual electricity consumption for a 50,000 barrel per day, operating at 100 percent capacity utilization for a full calendar year.<sup>27</sup>

**Table 5-2. OSSS Oil Shale Facility Electricity Consumption and Natural Gas Production Parameters and Their Prices and Costs**

<b>Facility Parameters</b>	<b>OSSS Variable Name</b>	<b>Parameter Value</b>
Natural gas production	OS_GAS_PROD	16.1 billion cubic feet per year
Wellhead gas sales price	OS_GAS_PRICE	Dollars per Mcf (2004 dollars)
Electricity consumption	OS_ELEC_CONSUMP	0.83 billion kilowatt-hours per year
Electricity consumption price	OS_ELEC_PRICE	Dollars per kilowatt-hour (2004 dollars)

### ***Project Yearly Cash Flow Calculations***

The OSSS first calculates the annual revenues minus expenditures, including income taxes and depreciation expenses, which is then discounted to a net present value. In those future years in which the net present value exceeds zero, a new oil shale facility can begin construction, subject to the timing constraints outlined below.

The discounted cash flow algorithm is calculated for a 23 year period, composed of 3 years for construction and 20 years for a plant's operating life. During the first 3 years of the 23-year period, only plant construction costs are considered with the facility investment cost being evenly apportioned across the 3 years. In the fourth year, the plant goes into partial operation, and produces 50 percent of the rated output. In the fifth year, revenues and operating expenses are assumed to ramp up to the full-production values, based on a 90 percent capacity factor that allows for potential production outages. During years 4 through 23, total revenues equal oil production revenues plus natural gas production revenues.<sup>28</sup>

Discounted cash flow oil and natural gas revenues are calculated based on prevailing oil and natural gas prices projected for that future year. In other words, the OSSS assumes that the economic analysis undertaken by potential project sponsors is solely based on the prevailing price of oil and natural gas at that time in the future and is not based either on historical price trends or future expected prices. Similarly, industrial electricity consumption costs are also based on the prevailing price of electricity for industrial consumers in that region at that future time.

As noted earlier, during a plant's first year of operation (year 4), both revenues and costs are half the values calculated for year 5 through year 23.

<sup>27</sup> Op. cit. Noyes Data Corporation, pages 89-97.

<sup>28</sup> Natural gas production revenues result from the fact that significant volumes of natural gas are produced when the kerogen is retorted in the surface facilities. See prior table regarding the volume of natural gas produced for a 50,000 barrel per day oil shale syncrude facility.

Oil revenues are calculated for each year in the discounted cash flow as follows:

$$\text{OIL\_REVENUE}_t = \text{OIT\_WOP}_t * (1.083 / 0.732) * \text{OS\_PRJ\_SIZE} * \text{OS\_CAP\_FACTOR} * 365 \quad (5-8)$$

where

$\text{OIT\_WOP}_t$	=	World oil price at time t in 1987 dollars
$(1.083 / 0.732)$	=	GDP chain-type price deflators to convert 1987 dollars into 2004 dollars
$\text{OS\_PROJ\_PRJ\_SIZE}$	=	Facility project size in barrels per day
$\text{OS\_CAP\_FACTOR}$	=	Facility capacity factor
365	=	Days per year.

Natural gas revenues are calculated for each year in the discounted cash flow as follows:

$$\text{GAS\_REVENUE}_t = \text{OS\_GAS\_PROD} * \text{OGPRCL48}_t * 1.083 / 0.732 * \text{OS\_CAP\_FACTOR}, \quad (5-9)$$

where

$\text{OS\_GAS\_PROD}$	=	Annual natural gas production for 50,000 barrel per day facility
$\text{OGPRCL48}_t$	=	Natural gas price in Rocky Mtn. at time t in 1987 dollars
$(1.083 / 0.732)$	=	GDP chain-type price deflators to convert 1987 dollars into 2004 dollars
$\text{OS\_CAP\_FACTOR}$	=	Facility capacity factor.

Electricity consumption costs are calculated for each year in the discounted cash flow as follows:

$$\text{ELECT\_COST}_t = \text{OS\_ELEC\_CONSUMP} * \text{PELIN}_t * (1.083 / .732) * 0.003412 * \text{OS\_CAP\_FACTOR} \quad (5-10)$$

where

$\text{OS\_ELEC\_CONSUMP}$	=	Annual electricity consumption for 50,000 barrel per day facility
$\text{PELIN}_t$	=	Electricity price Colorado/Utah/Wyoming at time t
$(1.083 / .732)$	=	GNP chain-type price deflators to convert 1987 dollars into 2004 dollars
$\text{OS\_CAP\_FACTOR}$	=	Facility capacity factor.

The carbon dioxide emission tax rate per metric ton is calculated as follows:

$$\text{OS\_EMETAX}_t = \text{EMETAX}_t(1) * 1000.0 * (12.0 / 44.0) * (1.083 / .732) \quad (5-11)$$

where,

EMETAX <sub>t</sub> (1)	=	Carbon emissions allowance price/tax per kilogram at time t
1,000	=	Convert kilograms to metric tonnes
(12.0 / 44.0)	=	Atomic weight of carbon divided by atomic weight of carbon dioxide
(1.083 / .732)	=	GNP chain-type price deflators to convert 1987 dollars into 2004 dollars.

Annual carbon dioxide emission costs per plant are calculated as follows:

$$\text{CO2\_COST}_t = \text{OS\_EMETAX}_t * \text{OS\_CO2EMISS} * 365 * \text{OS\_CAP\_FACTOR} \quad (5-12)$$

where

OS_EMETAX <sub>t</sub>	=	Carbon emissions allowance price/tax per metric tonne at time t in 2004 dollars
OS_CO2EMISS	=	Carbon dioxide emissions in metric tonnes per day
365	=	Days per year
OS_CAP_FACTOR	=	Facility capacity factor

In any given year, pre-tax project cash flow is:

$$\text{PRETAX\_CASH\_FLOW}_t = \text{TOT\_REVENUE}_t - \text{TOTAL\_COST}_t \quad (5-13)$$

where

TOT_REVENUE <sub>t</sub>	=	Total project revenues at time t
TOT_COST <sub>t</sub>	=	Total project costs at time t.

Total project revenues are calculated as follows:

$$\text{TOT\_REVENUE}_t = \text{OIL\_REVENUE}_t + \text{GAS\_REVENUE}_t \quad (5-14)$$

Total project costs are calculated as follows:

$$\begin{aligned} \text{TOT\_COST}_t = & \text{OS\_PLANT\_OPER\_CST} + \text{ROYALTY}_t + \text{PRJ\_MINE\_CST} \\ & + \text{ELEC\_COST}_t + \text{CO2\_COST}_t + \text{INVEST}_t \end{aligned} \quad (5-15)$$

where

OS_PLANT_OPER_CST	=	Annual plant operating costs per year
ROYALTY <sub>t</sub>	=	Annual royalty costs at time t
PRJ_MINE_COST	=	Annual plant mining costs
ELEC_COST <sub>t</sub>	=	Annual electricity costs at time t
CO2_COST <sub>t</sub>	=	Annual carbon dioxide emissions costs at time t
INVEST <sub>t</sub>	=	Annual surface facility investment costs.

While the plant is under construction (years 1 through 3) only INVEST has a positive value, while the other four cost elements equal zero. When the plant goes into operation (years 4 through 23), the capital costs (INVEST) are zero, while the other five operating costs take on positive values. The annual investment cost for the three years of construction is calculated as follows, under the assumption that the construction costs are evenly spread over the 3-year construction period:

$$INVEST = OS\_PLANT\_INVEST / OS\_PRJ\_CONST \quad (5-16)$$

where the variables are defined as in Table 5-1. Because the plant output is composed of both oil and natural gas, the annual royalty cost (ROYALTY) is calculated by applying the royalty rate to total revenues, as follows:

$$ROYALTY_t = OS\_ROYALTY\_RATE * TOT\_REVENUE_t \quad (5-17)$$

Annual project mining costs are calculated as the mining cost per barrel of syncrude multiplied by the number of barrels produced, as follows:

$$PRJ\_MINE\_COST = OS\_MINE\_CST\_TON * \frac{42}{OS\_GALLON\_TON * OS\_CONV\_EFF} * OS\_PROJ\_SIZE * OS\_CAP\_FACTOR * 365 \quad (5-18)$$

where

$$\begin{aligned} 42 &= \text{gallons per barrel} \\ 365 &= \text{days per year.} \end{aligned}$$

After the plant goes into operation and after a pre-tax cash flow is calculated, then a post-tax cash flow has to be calculated based on income taxes and depreciation tax credits. When the prevailing world oil price is sufficiently high and the pre-tax cash flow is positive, then the following post-tax cash flow is calculated as

$$CASH\_FLOW_t = (PRETAX\_CASH\_FLOW_t * (1 - OS\_CORP\_TAX\_RATE)) + (OS\_CORP\_TAX\_RATE * OS\_PLANT\_INVEST / OS\_PRJ\_LIFE) \quad (5-19)$$

The above depreciation tax credit calculation assumes straight-line depreciation over the operating life of the investment (OS\_PRJ\_LIFE).

### ***Discount Rate Financial Parameters***

The discounted cash flow algorithm uses the following financial parameters to determine the discount rate used in calculating the net present value of the discounted cash flow.

**Table 5-3. Discount Rate Financial Parameters**

<b>Financial Parameters</b>	<b>OSSS Variable Name</b>	<b>Parameter Value</b>
Corporate income tax rate	OS_CORP_TAX_RATE	38 percent
Equity share of total facility capital	OS_EQUITY_SHARE	60 percent
Facility equity beta	OS_EQUITY_VOL	1.8
Expected market risk premium	OS_EQUITY_PREMIUM	6.5 percent
Facility debt risk premium	OS_DEBT_PREMIUM	0.5 percent

The corporate equity beta (OS\_EQUITY\_VOL) is the project risk beta, not a firm's volatility of stock returns relative to the stock market's volatility. Because of the technology and construction uncertainties associated with oil shale plants, the project's equity holder's risk is expected to be somewhat greater than the average industry firm beta. The median beta for oil and gas field exploration service firms is about 1.65. Because a project's equity holders' investment risk level is higher, the facility equity beta assumed for oil shale projects is 1.8.

The expected market risk premium (OS\_EQUITY\_PREMIUM), which is 6.5 percent, is the expected return on market (S&P 500) over the rate of 10-year Treasury note (risk-free rate). A Monte Carlo simulation methodology was used to estimate the expected market return.

Oil shale project bond ratings are expected to be in the Ba-rating range. Since the NEMS macroeconomic module endogenously determines the industrial Baa bond rates for the forecasting period, the cost of debt rates are different in each year. The debt premium (OS\_DEBT\_PREMIUM) adjusts the bond rating for the project from the Baa to the Ba range, which is assumed to be constant at the average historical differential over the forecasting period.

### ***Discount Rate Calculation***

A seminal parameter used in the calculation of the net present value of the cash flow is the discount rate. The calculation of the discount rate used in the oil shale submodule is consistent with the way the discount rate is calculated through the National Energy Modeling System. The discount rate equals the post-tax weighted average cost of capital, which is calculated in the OSSS as follows:

$$\begin{aligned}
\text{OS\_DISCOUNT\_RATE}_t = & ((1 - \text{OS\_EQUITY\_SHARE}) * (\text{MC\_RMCORPBAA}_t / 100 + \\
& \text{OS\_DEBT\_PREMIUM})) * (1 - \text{OS\_CORP\_TAX\_RATE}) + \\
& (\text{OS\_EQUITY\_SHARE} * ((\text{OS\_EQUITY\_PREMIUM} * \\
& \text{OS\_EQUITY\_VOL}) + \text{MC\_RMGFCM\_10NS}_t / 100))
\end{aligned} \tag{5-20}$$

where

OS_EQUITY_SHARE	=	Equity share of total facility capital
MC_RMCORPBAA <sub>t</sub> / 100	=	BAA corporate bond rate
OS_DEBT_PREMIUM	=	Facility debt risk premium
OS_CORP_TAX_RATE	=	Corporate income tax rate
OS_EQUITY_PREMIUM	=	Expected market risk premium
OS_EQUITY_VOL	=	Facility equity volatility beta
MC_RMGFCM_10NS <sub>t</sub> / 100	=	10-year Treasury note rate.

In calculating the facility's cost of equity, the equity risk premium (which is a product of the expected market premium and the facility equity beta, is added to a "risk-free" rate of return, which is considered to be the 10-year Treasury note rate.

The nominal discount rate is translated into a constant, real discount rate using the following formula:

$$\text{OS\_DISCOUNT\_RATE}_t = ((1.0 + \text{OS\_DISCOUNT\_RATE}_t) / (1.0 + \text{INFL}_t)) - 1.0 \tag{5-21}$$

where

$$\text{INFL}_t = \text{Inflation rate at time } t.$$

### ***Net Present Value Discounted Cash Flow Calculation***

So far a potential project's yearly cash flows have been calculated along with the appropriate discount rate. Using these calculated quantities, the net present value of the yearly cash flow values is calculated as follows:

$$\text{NET\_CASH\_FLOW}_{t-1} = \sum_{t=1}^{\text{OS\_PRJ\_LIFE} + \text{OS\_PRJ\_CONST}} \left[ \text{CASH\_FLOW}_t * \left[ \frac{1}{1 + \text{OS\_DISCOUNT\_RATE}_t} \right]^t \right] \tag{5-22}$$

If the net present value of the projected cash flows exceeds zero, then the potential oil shale facility is considered to be economic and begins construction, so long as this facility construction does not violate the construction timing constraints detailed below.

### ***Oil Shale Facility Market Penetration Algorithm***

As noted in the introduction, there is no empirical basis for determining how rapidly new oil shale facilities would be built, once the OSSS determines that surface-retorting oil shale facilities are economically viable, because no full-scale commercial facilities have ever been constructed. However, there are three primary constraints to oil shale facility construction. First, the construction of an oil shale facility cannot be undertaken until the in-situ technology has been sufficiently developed and tested to be deemed ready for its application to commercial size projects (i.e., 50,000 barrels per day). Second, oil shale facility construction is constrained by the maximum oil shale production limit. Third, oil shale production volumes cannot reach the maximum oil shale production limit any earlier than 40 years after the in-situ technology has been deemed to be feasible and available for commercial size facilities. Table 5-4 summarizes the primary market penetration parameters in the OSSS.

**Table 5-4. Market Penetration Parameters**

<b>Market Penetration Parameters</b>	<b>OSSS Variable Name</b>	<b>Parameter Value</b>
Earliest Facility Construction Start Date	OS_START_YR	2017
Maximum Oil Shale Production	OS_MAX_PROD	2 million barrels per year
Minimum Years to Reach Full Market Penetration	OS_PENETRATE_YR	40

Shell’s in-situ oil shale RD&D program is considered to be the most advanced, having begun in 1997. Shell is most likely to be the first party to build and operate a commercial scale oil shale production facility. Based on conversations between Shell personnel and EIA personnel, Shell is likely to conclude its field experiments, which test the various components of a commercial facility sometime during the 2014 through 2017 timeframe. Consequently, the earliest likely initiation of a full-scale commercial plant would be 2017.<sup>29</sup>

As discussed earlier, a 2 million barrel per day oil shale production level at the end of 40-year market penetration period is considered to be reasonable and feasible based on the size of the resource base and the volume and availability of water needed to develop those resources. The actual rate of market penetration in the OSSS, however, is ultimately determined by the projected profitability of oil shale projects. At a minimum, oil and natural gas prices must be sufficiently high to produce a facility revenue stream (i.e., discounted cash flow) that covers all capital and operating costs, including the weighted average cost of capital. When the discounted cash flow exceeds zero (0), then the market penetration algorithm allows oil shale facility construction to commence.

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<sup>29</sup> Op. cit. EIA/OIAF/OGD memorandum entitled, “Oil Shale Project Size and Production Ramp-Up,” and based on public information and private conversations subsequent to the development of that memorandum.

When project discounted cash flow is greater than zero, the relative project profitability is calculated as follows:

$$OS\_PROFIT_t = DCF_t / OS\_PLANT\_INVEST \quad (5-23)$$

where

$$DCF_t = \text{Project discounted cash flow at time } t$$

$$OS\_PLANT\_INVEST = \text{Project capital investment}$$

OS\_PROFIT is an index of an oil project's expected profitability. The expectation is that, as OS\_PROFIT increases, the relative financial attractiveness of producing oil shale also increases.

The level of oil shale facility construction that is permitted in any year depends on the maximum oil shale production that is permitted by the following market penetration algorithm:

$$MAX\_PROD_t = OS\_MAX\_PROD * (OS\_PROFIT_t / (1 + OS\_PROFIT_t)) * ((T - (OS\_START\_YR - 1989)) / OS\_PENETRATE\_YR) \quad (5-24)$$

where,

OS_MAX_PROD	=	Maximum oil shale production limit
OS_PROFIT_t	=	Relative oil shale project profitability at time t
T	=	Time t
OS_START_YR	=	First year that an oil shale facility can be built
OS_PENETRATE_YR	=	Minimum number of years during which the maximum oil shale production can be achieved.

The OS\_PROFIT portion of the market penetration algorithm (5-24) rapidly increases market penetration as the DCF numerator of OS\_PROFIT increases. However, as OS\_PROFIT continues to increase, the rate of increase in market penetration slows as (OS\_PROFIT / (1 + OS\_PROFIT)) asymptotically approaches one (1.0). As this term approaches 1.0, the algorithm's ability to build more oil shale plants is ultimately constrained by OS\_MAX\_PROD term, regardless of how financially attractive the construction of new oil shale facilities might be. This formulation also prevents MAX\_PROD from exceeding OS\_MAX\_PROD.

The second portion of the market penetration algorithm specifies that market penetration increases linearly over the number of years specified by OS\_PENETRATE\_YR. As noted earlier OS\_PENETRATE\_YR specifies the minimum number of years over which the oil shale industry can achieve maximum penetration. The maximum number of years required to achieve full penetration is dictated by the speed at which the OS\_PROFIT portion of the equation approaches one (1.0). If OS\_PROFIT remains low, then it is possible that MAX\_PROD never comes close to reaching the OS\_MAX\_PROD value.

The number of new oil shale facilities that start construction in any particular year is specified by the following equation:

(5-25)

$$\text{OS\_PLANTS\_NEW}_t = \text{INT}((\text{MAX\_PROD}_t - (\text{OS\_PLANTS}_t * \text{OS\_PRJ\_SIZE} * \text{OS\_CAP\_FACTOR})) / (\text{OS\_PRJ\_SIZE} * \text{OS\_CAP\_FACTOR}))$$

where

MAX_PROD <sub>t</sub>	=	Maximum oil shale production at time t
OS_PLANT <sub>t</sub>	=	Number of existing oil shale plants at time t
OS_PRJ_SIZE	=	Standard oil shale plant size in barrels per day
OS_CAP_FACTOR	=	Annual capacity factor of an oil shale plant in percent per year.

The first portion of the above formula specifies the incremental production capacity that can be built in any year, based on the number of plants already in existence. The latter portion of the equation determines the integer number of new plants that can be initiated in that year, based on the expected annual production rate of an oil shale plant.

Because oil shale production is highly uncertain, not only from a technological and economic perspective, but also from an environmental perspective, an upper limit to oil shale production is assumed within the OSSS. The upper limit on oil shale production is 2 million barrels per day, which is equivalent to 44 facilities of 50,000 barrels per day operating at a 90 percent capacity factor. So the algorithm allows enough plants to be built to fully reach the oil shale production limit, based on the expected plant capacity factor. As noted earlier, the oil shale market penetration algorithm is also limited by the earliest commercial plant construction date, which is assumed to be no earlier than 2017.

While the OSSS costs and performance profiles are based on technologies evaluated in the 1970's and early 1980's, the complete absence of any current commercial-scale oil shale production makes its future economic development highly uncertain. If the technological, environmental, and economic hurdles are as high or higher than those experienced during the 1970's, then the prospects for oil shale development would remain weak throughout the projections. However, technological progress can alter the economic and environmental landscape in unanticipated ways. For example, if an in-situ oil shale process were to be demonstrated to be both technically feasible and commercially profitable, then the prospects for an oil shale industry would improve significantly, and add vast economically recoverable oil resources in the United States and possibly elsewhere in the world.

# Appendix A. Discounted Cash Flow Algorithm

## Introduction

The basic DCF methodology used in the Oil and Gas Supply Module (OGSM) is applied for a broad range of oil or natural gas projects, including single well projects or multiple well projects within a field. It is designed to capture the effects of multi-year capital investments (e.g., offshore platforms). The expected discounted cash flow value associated with exploration and/or development of a project with oil or gas as the primary fuel in a given region evaluated in year T may be presented in a stylized form (Equation A-1).

$$\text{DCF}_T = (\text{PVTREV} - \text{PVROY} - \text{PVPRODTAX} - \text{PVDRILLCOST} - \text{PVEQUIP} - \text{PVKAP} - \text{PVOPCOST} - \text{PVABANDON} - \text{PVSIT} - \text{PVFIT})_T \quad (\text{A-1})$$

where

T	=	year of evaluation
PVTREV	=	present value of expected total revenues
PVROY	=	present value of expected royalty payments
PVPRODTAX	=	present value of expected production taxes (ad valorem and severance taxes)
PVDRILLCOST	=	present value of expected exploratory and developmental drilling expenditures
PVEQUIP	=	present value of expected lease equipment costs
PVKAP	=	present value of other expected capital costs (i.e., gravel pads and offshore platforms)
PVOPCOST	=	present value of expected operating costs
PVABANDON	=	present value of expected abandonment costs
PVSIT	=	present value of expected state corporate income taxes
PVFIT	=	present value of expected federal corporate income taxes.

Costs are assumed constant over the investment life but vary across both region and primary fuel type. This assumption can be changed readily if required by the user. Relevant tax provisions also are assumed unchanged over the life of the investment. Operating losses incurred in the initial investment period are carried forward and used against revenues generated by the project in later years.

The following sections describe each component of the DCF calculation. Each variable of Equation A.1 is discussed starting with the expected revenue and royalty payments, followed by the expected costs, and lastly the expected tax payments.

## Present Value of Expected Revenues, Royalty Payments, and Production Taxes

Revenues from an oil or gas project are generated from the production and sale of both the primary fuel as well as any co-products. The present value of expected revenues measured at the wellhead from the production of a representative project is defined as the summation of yearly expected net wellhead price<sup>1</sup>

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<sup>1</sup>The DCF methodology accommodates price expectations that are myopic, adaptive, or perfect. The default is myopic expectations, so prices are assumed to be constant throughout the economic evaluation period.

times expected production<sup>2</sup> discounted at an assumed rate. The discount rate used to evaluate private investment projects typically represents a weighted average cost of capital (WACC), i.e., a weighted average of both the cost of debt and the cost of equity.

Fundamentally, the formula for the WACC is straightforward.

$$\text{WACC} = \frac{D}{D+E} * R_D * (1-t) + \frac{E}{D+E} * R_E \quad (\text{A-2})$$

where D = market value of debt, E = market value of equity, t = corporate tax rate, R<sub>D</sub> = cost of debt, and R<sub>E</sub> = cost of equity. Because the drilling projects being evaluated are long term in nature, the values for all variables in the WACC formula are long run averages.

The WACC calculated using the formula given above is a nominal one. The real value can be calculated by

$$\text{disc} = \frac{(1 + \text{WACC})}{(1 + \pi_e)} - 1 \quad (\text{A-3})$$

where  $\pi_e$  = expected inflation rate. The expected rate of inflation over the forecasting period is measured as the average annual rate of change in the U.S. GDP deflator over the forecasting period using the forecasts of the GDP deflator from the Macro Module (MC\_JPGDP).

The present value of expected revenue for either the primary fuel or its co-product is calculated as follows:

$$\text{PVREV}_{T,k} = \sum_{t=T}^{T+n} \left[ Q_{t,k} * \lambda * P_{t,k} * \left[ \frac{1}{1 + \text{disc}} \right]^{t-T} \right], \lambda = \begin{cases} 1 & \text{if primary fuel} \\ \text{COPRD} & \text{if secondary fuel} \end{cases} \quad (\text{A-4})$$

where,

- k = fuel type (oil or natural gas)
- T = time period
- n = number of years in the evaluation period
- disc = discount rate
- Q = expected production volumes
- P = expected net wellhead price
- COPRD = co-product factor.<sup>3</sup>

Net wellhead price is equal to the market price minus any transportation costs. Market prices for oil and gas are defined as follows: the price at the receiving refinery for oil, the first purchase price for onshore natural gas, the price at the coastline for offshore natural gas, and the price at the Canadian border for Alaskan gas.

<sup>2</sup>Expected production is determined outside the DCF subroutine. The determination of expected production is described in Chapter 3.

<sup>3</sup>The OGSMD determines coproduct production as proportional to the primary product production. COPRD is the ratio of units of coproduct per unit of primary product.

The present value of the total expected revenue generated from the representative project is

$$PVTREV_T = PVREV_{T,1} + PVREV_{T,2} \quad (A-5)$$

where

$$\begin{aligned} PVREV_{T,1} &= \text{present value of expected revenues generated from the primary fuel} \\ PVREV_{T,2} &= \text{present value of expected revenues generated from the secondary fuel.} \end{aligned}$$

### **Present Value of Expected Royalty Payments**

The present value of expected royalty payments (PVROY) is simply a percentage of expected revenue and is equal to

$$PVROY_T = ROYRT_1 * PVREV_{T,1} + ROYRT_2 * PVREV_{T,2} \quad (A-6)$$

where

$$ROYRT = \text{royalty rate, expressed as a fraction of gross revenues.}$$

### **Present Value of Expected Production Taxes**

Production taxes consist of ad valorem and severance taxes. The present value of expected production tax is given by

$$\begin{aligned} PVPRODTAX_T = & PRREV_{T,1} * (1 - ROYRT_1) * PRDTAX_1 + PVREV_{T,2} \\ & * (1 - ROYRT_2) * PRODTAX_2 \end{aligned} \quad (A-7)$$

where

$$PRODTAX = \text{production tax rate.}$$

PVPRODTAX is computed as net of royalty payments because the investment analysis is conducted from the point of view of the operating firm in the field. Net production tax payments represent the burden on the firm because the owner of the mineral rights generally is liable for his/her share of these taxes.

### **Present Value of Expected Costs**

Costs are classified within the OGSM as drilling costs, lease equipment costs, other capital costs, operating costs (including production facilities and general/administrative costs), and abandonment costs. These costs differ among successful exploratory wells, successful developmental wells, and dry holes. The present value calculations of the expected costs are computed in a similar manner as PVREV (i.e., costs are discounted at an assumed rate and then summed across the evaluation period).

### **Present Value of Expected Drilling Costs**

Drilling costs represent the expenditures for drilling successful wells or dry holes and for equipping successful wells through the Christmas tree installation.<sup>4</sup> Elements included in drilling costs are labor,

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<sup>4</sup>The Christmas tree refers to the valves and fittings assembled at the top of a well to control the fluid flow.

material, supplies and direct overhead for site preparation, road building, erecting and dismantling derricks and drilling rigs, drilling, running and cementing casing, machinery, tool changes, and rentals. The present value of expected drilling costs is given by

$$\begin{aligned}
 \text{PVDRILLCOST}_T = \sum_{t=T}^{T+n} & \left[ \left[ \text{COSTEXP}_T * \text{SR}_1 * \text{NUMEXP}_t + \text{COSTDEV}_T * \text{SR}_2 * \text{NUMDEV}_t \right. \right. \\
 & + \text{COSTDRY}_{T,1} * (1 - \text{SR}_1) * \text{NUMEXP}_t \\
 & \left. \left. + \text{COSTDRY}_{T,2} * (1 - \text{SR}_2) * \text{NUMDEV}_t \right] * \left( \frac{1}{1 + \text{disc}} \right)^{t-T} \right] \quad (\text{A-8})
 \end{aligned}$$

where

COSTEXP	=	drilling cost for a successful exploratory well
SR	=	success rate (1=exploratory, 2=developmental)
COSTDEV	=	drilling cost for a successful developmental well
COSTDRY	=	drilling cost for a dry hole (1=exploratory, 2=developmental).
NUMEXP	=	number of exploratory wells drilled in a given period
NUMDEV	=	number of developmental wells drilled in a given period.

The number and schedule of wells drilled for an oil or gas project are supplied as part of the assumed production profile. This is based on historical drilling activities.

### **Present Value of Expected Lease Equipment Costs**

Lease equipment costs include the cost of all equipment extending beyond the Christmas tree, directly used to obtain production from a drilled lease. Three categories of costs are included: producing equipment, the gathering system, and processing equipment. Producing equipment costs include tubing, rods, and pumping equipment. Gathering system costs consist of flowlines and manifolds. Processing equipment costs account for the facilities utilized by successful wells.

The present value of expected lease equipment cost is

$$\text{PVEQUIP}_T = \sum_{t=T}^{T+n} \left[ \text{EQUIP}_t * (\text{SR}_1 * \text{NUMEXP}_t + \text{SR}_2 * \text{NUMDEV}_t) * \left[ \frac{1}{1 + \text{disc}} \right]^{t-T} \right] \quad (\text{A-9})$$

where

EQUIP	=	lease equipment costs per well.
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### ***Present Value of Other Expected Capital Costs***

Other major capital expenditures include the cost of gravel pads in Alaska, and offshore platforms. These costs are exclusive of lease equipment costs. The present value of other expected capital costs is calculated as

$$\text{PVKAP}_T = \sum_{t=T}^{T+n} \left[ \text{KAP}_t * \left[ \frac{1}{1 + \text{disc}} \right]^{t-T} \right] \quad (\text{A-10})$$

where

KAP = other major capital expenditures, exclusive of lease equipment.

### Present Value of Expected Operating Costs

Operating costs include three main categories of costs: normal daily operations, surface maintenance, and subsurface maintenance. Normal daily operations are further broken down into supervision and overhead, labor, chemicals, fuel, water, and supplies. Surface maintenance accounts for all labor and materials necessary to keep the service equipment functioning efficiently and safely. Costs of stationary facilities, such as roads, also are included. Subsurface maintenance refers to the repair and services required to keep the downhole equipment functioning efficiently.

Total operating cost in time  $t$  is calculated by multiplying the cost of operating a well by the number of producing wells in time  $t$ . Therefore, the present value of expected operating costs is as follows:

$$PVOPCOST_T = \sum_{t=T}^{T+n} \left[ OPCOST_t * \sum_{k=1}^t [SR_1 * NUMEXP_k + SR_2 * NUMDEV_k] * \left( \frac{1}{1 + disc} \right)^{t-T} \right] \quad (A-11)$$

where

OPCOST = operating costs per well.

### Present Value of Expected Abandonment Costs

Producing facilities are eventually abandoned and the cost associated with equipment removal and site restoration is defined as

$$PVABANDON_T = \sum_{t=T}^{T+n} \left[ COSTABN_t * \left[ \frac{1}{1 + disc} \right]^{t-T} \right] \quad (A-12)$$

where

COSTABN = abandonment costs.

Drilling costs, lease equipment costs, operating costs, abandonment costs, and other capital costs incurred in each individual year of the evaluation period are integral components of the following determination of State and Federal corporate income tax liability.

### Present Value of Expected Income Taxes

An important aspect of the DCF calculation concerns the tax treatment. All expenditures are divided into depletable,<sup>5</sup> depreciable, or expensed costs according to current tax laws. All dry hole and operating costs are expensed. Lease costs (i.e., lease acquisition and geological and geophysical costs) are capitalized and then amortized at the same rate at which the reserves are extracted (cost depletion). Drilling costs are split between tangible costs (depreciable) and intangible drilling costs (IDC's) (expensed). IDC's include

<sup>5</sup>The DCF methodology does not include lease acquisition or geological & geophysical expenditures because they are not relevant to the incremental drilling decision.

wages, fuel, transportation, supplies, site preparation, development, and repairs. Depreciable costs are amortized in accord with schedules established under the Modified Accelerated Cost Recovery System (MACRS).

Key changes in the tax provisions under the tax legislation of 1988 include the following:

- ! Windfall Profits Tax on oil was repealed,
- ! Investment Tax Credits were eliminated, and
- ! Depreciation schedules shifted to a Modified Accelerated Cost Recovery System.

Tax provisions vary with type of producer (major, large independent, or small independent) as shown in Table A-1. A major oil company is one that has integrated operations from exploration and development through refining or distribution to end users. An independent is any oil and gas producer or owner of an interest in oil and gas property not involved in integrated operations. Small independent producers are those with less than 1,000 barrels per day of production (oil and gas equivalent). The present DCF methodology reflects the tax treatment provided by current tax laws for large independent producers.

The resulting present value of expected taxable income (PVTAXBASE) is given by:

$$\begin{aligned}
 \text{PVTAXBASE}_T = \sum_{t=T}^{T+n} \left[ (\text{TREV}_t - \text{ROY}_t - \text{PRODTAX}_t - \text{OPCOST}_t - \text{ABANDON}_t - \text{XIDC}_t \right. \\
 \left. - \text{AIDC}_t - \text{DEPREC}_t - \text{DHC}_t) * \left( \frac{1}{1 + \text{disc}} \right)^{t-T} \right] \quad (\text{A-13})
 \end{aligned}$$

where

T	=	year of evaluation
t	=	time period
n	=	number of years in the evaluation period
TREV	=	expected revenues
ROY	=	expected royalty payments
PRODTAX	=	expected production tax payments
OPCOST	=	expected operating costs
ABANDON	=	expected abandonment costs
XIDC	=	expected expensed intangible drilling costs
AIDC	=	expected amortized intangible drilling costs <sup>6</sup>
DEPREC	=	expected depreciable tangible drilling, lease equipment costs, and other capital expenditures
DHC	=	expected dry hole costs
disc	=	expected discount rate.

TREV<sub>t</sub>, ROY<sub>t</sub>, PRODTAX<sub>t</sub>, OPCOST<sub>t</sub>, and ABANDON<sub>t</sub> are the undiscounted individual year values. The following sections describe the treatment of expensed and amortized costs for the purpose of determining corporate income tax liability at the State and Federal level.

<sup>6</sup>This variable is included only for completeness. For large independent producers, all intangible drilling costs are expensed.

## Expected Expensed Costs

Expensed costs are intangible drilling costs, dry hole costs, operating costs, and abandonment costs. Expensed costs and taxes (including royalties) are deductible from taxable income.

### *Expected Intangible Drilling Costs*

For large independent producers, all intangible drilling costs are expensed. However, this is not true across the producer category (as shown in Table A-1). In order to maintain analytic flexibility with respect to changes in tax provisions, the variable XDCKAP (representing the portion of intangible drilling costs that must be depreciated) is included.

**Table A-1. Tax Treatment in Oil and Gas Production by Category of Company Under Current Tax Legislation**

Costs by Tax Treatment	Majors	Large Independents	Small Independents
Depletable Costs	<b>Cost Depletion</b>  G&G <sup>a</sup> Lease Acquisition	<b>Cost Depletion<sup>b</sup></b>  G&G Lease Acquisition	<b>Maximum of Percentage or Cost Depletion</b>  G&G Lease Acquisition
Depreciable Costs	<b>MACRS<sup>c</sup></b>  Lease Acquisition Other Capital Expenditures Successful Well Drilling Costs Other than IDC=s  <b>5-year SLM<sup>d</sup></b>  20 percent of IDC=s	<b>MACRS</b>  Lease Acquisition Other Capital Expenditures Successful Well Drilling Costs Other than IDC=s	<b>MACRS</b>  Lease Acquisition Other Capital Expenditures Successful Well Drilling Costs Other than IDC=s
Expensed Costs	Dry Hole Costs  80 percent of IDC's  Operating Costs	Dry Hole Costs  80 percent of IDC's  Operating Costs	Dry Hole Costs  80 percent of IDC's  Operating Costs

<sup>a</sup>Geological and geophysical.

<sup>b</sup>Applicable to marginal project evaluation; first 1,000 barrels per day depletable under percentage depletion.

<sup>c</sup>Modified Accelerated Cost Recovery System; the period of recovery for depreciable costs will vary depending on the type of depreciable asset.

<sup>d</sup>Straight Line Method.

Expected expensed IDC's are defined as follows:

$$\begin{aligned}
 \text{XIDC}_t = & \text{COSTEXP}_T * (1 - \text{EXKAP}) * (1 - \text{XDCKAP}) * \text{SR}_1 * \text{NUMEXP}_t \\
 & + \text{COSTDEV}_T * (1 - \text{DVKAP}) * (1 - \text{XDCKAP}) * \text{SR}_2 * \text{NUMDEV}_t
 \end{aligned}
 \tag{A-14}$$

where

COSTEXP	=	drilling cost for a successful exploratory well
EXKAP	=	fraction of exploratory drilling costs that are tangible and must be depreciated
XDCKAP	=	fraction of intangible drilling costs that must be depreciated <sup>7</sup>
SR	=	success rate (1=exploratory, 2=developmental)
NUMEXP	=	number of exploratory wells
COSTDEV	=	drilling cost for a successful developmental well
DVKAP	=	fraction of developmental drilling costs that are tangible and must be depreciated
NUMDEV	=	number of developmental wells.

If only a portion of IDC's are expensed (as is the case for major producers), the remaining IDC's must be depreciated. The model assumes that these costs are recovered at a rate of 10 percent in the first year, 20 percent annually for four years, and 10 percent in the sixth year; this method of estimating the costs is referred to as the 5-year Straight Line Method (SLM) with half-year convention. If depreciable costs accrue when fewer than 6 years remain in the life of the project, the recovered costs are estimated using a simple straight line method over the remaining period.

Thus, the value of expected depreciable IDC's is represented by

$$\begin{aligned}
 AIDC_t = \sum_{j=\beta}^t & \left[ (COSTEXP_T * (1 - EXKAP) * XDCKAP * SR_1 * NUMEXP_j \right. \\
 & + COSTDEV_T * (1 - DVKAP) * XDCKAP * SR_2 * NUMDEV_j) \\
 & \left. * DEP IDC_t * \left( \frac{1}{1 + infl} \right)^{t-j} * \left( \frac{1}{1 + disc} \right)^{t-j} \right] \quad (A-15)
 \end{aligned}$$

$$\beta = \begin{cases} T & \text{for } t \leq T + m - 1 \\ t - m + 1 & \text{for } t > T + m - 1 \end{cases}$$

where,

j	=	year of recovery
β	=	index for write-off schedule
DEPIDC	=	for t # n+T-m, 5-year SLM recovery schedule with half year convention; otherwise, 1/(n+T-t) in each period
infl	=	expected inflation rate <sup>8</sup>
disc	=	expected discount rate
m	=	number of years in standard recovery period.

AIDC will equal zero by default since the DCF methodology reflects the tax treatment pertaining to large independent producers.

<sup>7</sup>The fraction of intangible drilling costs that must be depreciated is set to zero as a default to conform with the tax perspective of a large independent firm.

<sup>8</sup>The write-off schedule for the 5-year SLM give recovered amounts in nominal dollars. Therefore, recovered costs are adjusted for expected inflation to give an amount in expected constant dollars since the DCF calculation is based on constant dollar values for all other variables.

**Expected Dry Hole Costs**

All dry hole costs are expensed. Expected dry hole costs are defined as

$$DHC_t = COSTDRY_{T,1} * (1 - SR_1) * NUMEXP_t + COSTDRY_{T,2} * (1 - SR_2) * NUMDEV_t \quad (A-16)$$

where

COSTDRY = drilling cost for a dry hole (1=exploratory, 2=developmental).

Total expensed costs in any year equals the sum of XIDC<sub>t</sub>, OPCOST<sub>t</sub>, ABANDON<sub>t</sub>, and DHC<sub>t</sub>.

**Expected Depreciable Tangible Drilling Costs, Lease Equipment Costs and Other Capital Expenditures**

Amortization of depreciable costs, excluding capitalized IDC's, conforms to the Modified Accelerated

**Table A-2. MACRS Schedules**  
(Percent)

Year	3-year Recovery Period	5-year Recovery Period	7-year Recovery Period	10-year Recovery Period	15-year Recovery Period	20-year Recovery Period
1	33.33	20.00	14.29	10.00	5.00	3.750
2	44.45	32.00	24.49	18.00	9.50	7.219
3	14.81	19.20	17.49	14.40	8.55	6.677
4	7.41	11.52	12.49	11.52	7.70	6.177
5		11.52	8.93	9.22	6.93	5.713
6		5.76	8.92	7.37	6.23	5.285
7			8.93	6.55	5.90	4.888
8			4.46	6.55	5.90	4.522
9				6.56	5.91	4.462
10				6.55	5.90	4.461
11				3.28	5.91	4.462
12					5.90	4.461
13					5.91	4.462
14					5.90	4.461
15					5.91	4.462
16					2.95	4.461
17						4.462
18						4.461
19						4.462
20						4.461
21						2.231

Source: U.S. Master Tax Guide.

Cost Recovery System (MACRS) schedules. The schedules under differing recovery periods appear in Table A-2. The particular period of recovery for depreciable costs will conform to the specifications of the tax code. These recovery schedules are based on the declining balance method with half year convention. If depreciable costs accrue when fewer years remain in the life of the project than would allow for cost recovery over the standard period, then costs are recovered using a straight line method over the remaining period.

The expected tangible drilling costs, lease equipment costs, and other capital expenditures is defined as

$$\begin{aligned}
 \text{DEPREC}_t = \sum_{j=\beta}^t & \left[ \left[ (\text{COSTEXP}_T * \text{EXKAP} + \text{EQUIP}_T) * \text{SR}_1 * \text{NUMEXP}_j \right. \right. \\
 & \left. \left. + (\text{COSTDEV}_T * \text{DVKAP} + \text{EQUIP}_T) * \text{SR}_2 * \text{NUMDEV}_j + \text{KAP}_j \right] \right. \\
 & \left. * \text{DEP}_{t-j+1} * \left( \frac{1}{1 + \text{infl}} \right)^{t-j} * \left( \frac{1}{1 + \text{disc}} \right)^{t-j} \right] \quad (\text{A-17})
 \end{aligned}$$

$$\beta = \begin{cases} T & \text{for } t \leq T + m - 1 \\ t - m + 1 & \text{for } t > T + m - 1 \end{cases}$$

where

j	=	year of recovery
β	=	index for write-off schedule
m	=	number of years in standard recovery period
COSTEXP	=	drilling cost for a successful exploratory well
EXKAP	=	fraction of exploratory drilling costs that are tangible and must be depreciated
EQUIP	=	lease equipment costs per well
SR	=	success rate (1=exploratory, 2=developmental)
NUMEXP	=	number of exploratory wells
COSTDEV	=	drilling cost for a successful developmental well
DVKAP	=	fraction of developmental drilling costs that are tangible and must be depreciated
NUMDEV	=	number of developmental wells drilled in a given period
KAP	=	major capital expenditures such as gravel pads in Alaska or offshore platforms, exclusive of lease equipment
DEP	=	for t ≠ n+T-m, MACRS with half year convention; otherwise, 1/(n+T-t) in each period
infl	=	expected inflation rate <sup>9</sup>
disc	=	expected discount rate.

## Present Value of Expected State and Federal Income Taxes

The present value of expected state corporate income tax is determined by

$$\text{PVSIT}_T = \text{PVTAXBASE}_T * \text{STRT} \quad (\text{A-18})$$

where

PVTAXBASE	=	present value of expected taxable income (Equation A.14)
STRT	=	state income tax rate.

<sup>9</sup>Each of the write-off schedules give recovered amounts in nominal dollars. Therefore, recovered costs are adjusted for expected inflation to give an amount in expected constant dollars since the DCF calculation is based on constant dollar values for all other variables.

The present value of expected federal corporate income tax is calculated using the following equation:

$$PVFIT_T = PVTAXBASE_T * (1 - STRT) * FDRT \quad (A-19)$$

where

FDRT = federal corporate income tax rate.

## Summary

The discounted cash flow calculation is a useful tool for evaluating the expected profit or loss from an oil or gas project. The calculation reflects the time value of money and provides a good basis for assessing and comparing projects with different degrees of profitability. The timing of a project's cash inflows and outflows has a direct affect on the profitability of the project. As a result, close attention has been given to the tax provisions as they apply to costs.

The discounted cash flow is used in each submodule of the OGSM to determine the economic viability of oil and gas projects. Various types of oil and gas projects are evaluated using the proposed DCF calculation, including single well projects and multi-year investment projects. Revenues generated from the production and sale of co-products also are taken into account.

The DCF routine requires important assumptions, such as assumed costs and tax provisions. Drilling costs, lease equipment costs, operating costs, and other capital costs are integral components of the discounted cash flow analysis. The default tax provisions applied to the costs follow those used by independent producers. Also, the decision to invest does not reflect a firm's comprehensive tax plan that achieves aggregate tax benefits that would not accrue to the particular project under consideration.

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## Appendix C. Model Abstract

1. Model Name  
Oil and Gas Supply Module
2. Acronym  
OGSM
3. Description  
OGSM projects the following aspects of the crude oil and natural gas supply industry:
  - production
  - reserves
  - drilling activity
  - natural gas imports and exports
4. Purpose  
OGSM is used by the Oil and Gas Division in the Office of Integrated Analysis and Forecasting as an analytic aid to support preparation of projections of reserves and production of crude oil and natural gas at the regional and national level. The annual projections and associated analyses appear in the *Annual Energy Outlook* (DOE/EIA-0383) of the U.S. Energy Information Administration. The projections also are provided as a service to other branches of the U.S. Department of Energy, the Federal Government, and non-Federal public and private institutions concerned with the crude oil and natural gas industry.
5. Date of Last Update  
2010
6. Part of Another Model  
National Energy Modeling System (NEMS)
7. Model Interface References  
Coal Module  
Electricity Module  
Industrial Module  
International Module  
Natural Gas Transportation and Distribution Model (NGTDM)  
Macroeconomic Module  
Petroleum Market Module (PMM)
8. Official Model Representative  
Office: Integrating Analysis and Forecasting  
Division: Oil and Gas Analysis  
Model Contact: Dana Van Wagener  
Telephone: (202) 586-4725
9. Documentation Reference  
U.S. Department of Energy. 2009. *Documentation of the Oil and Gas Supply Module (OGSM)*, DOE/EIA-M063, U.S. Energy Information Administration, Washington, DC.

10. Archive Media and Installation Manual  
NEMS2010

11. Energy Systems Described

The OGSM projects oil and natural gas production activities for six onshore and three offshore regions as well as three Alaskan regions. Exploratory and developmental drilling activities are treated separately, with exploratory drilling further differentiated as new field wildcats or other exploratory wells. New field wildcats are those wells drilled for a new field on a structure or in an environment never before productive. Other exploratory wells are those drilled in already productive locations. Development wells are primarily within or near proven areas and can result in extensions or revisions. Exploration yields new additions to the stock of reserves, and development determines the rate of production from the stock of known reserves.

12. Coverage

Geographic: Six Lower 48 onshore supply regions, three Lower 48 offshore regions, and three Alaskan regions.

Time Units/Frequency: Annually 1990 through 2035

Product(s): Crude oil and natural gas

Economic Sector(s): Oil and gas field production activities

13. Model Features

Model Structure: Modular, containing four major components

- Onshore Lower 48 Oil and Gas Supply Submodule
- Offshore Oil and Gas Supply Submodule
- Alaska Oil and Gas Supply Submodule
- Oil Shale Supply Submodule

Modeling Technique: The OGSM is a hybrid econometric/discovery process model. Drilling activities in the United States are projected using the estimated discounted cash flow that measures the expected present value profits for the proposed effort and other key economic variables.

Special Features: Can run stand-alone or within the NEMS. Integrated NEMS runs employ short-term natural gas supply functions for efficient market equilibration.

14. Non-DOE Input Data

- Alaskan Oil and Gas Field Size Distributions - U.S. Geological Survey
- Alaska Facility Cost By Oil Field Size - U.S. Geological Survey
- Alaska Operating cost - U.S. Geological Survey
- Basin Differential Prices - Natural Gas Week, Washington, DC
- State Corporate Tax Rate - Commerce Clearing House, Inc. *State Tax Guide*
- State Severance Tax Rate - Commerce Clearing House, Inc. *State Tax Guide*
- Federal Corporate Tax Rate, Royalty Rate - U.S. Tax Code
- Onshore Drilling Costs - (1.) American Petroleum Institute. *Joint Association Survey of Drilling Costs (1970-2008)*, Washington, D.C.; (2.) Additional unconventional gas recovery drilling and operating cost data from operating companies
- Offshore Technically Recoverable Oil and Gas Undiscovered Resources - Department of Interior. Minerals Management Service (Correspondence from Gulf of Mexico and Pacific OCS regional offices)
- Offshore Exploration, Drilling, Platform, and Production Costs - Department of Interior. Minerals Management Service (Correspondence from Gulf of Mexico and Pacific OCS regional offices)
- Canadian Wells drilled - Canadian Association of Petroleum Producers. *Statistical Handbook*.

- Canadian Recoverable Resource Base - National Energy Board. *Canada's Conventional Natural Gas Resources: A Status Report*, Canada, April 2004.
- Canadian Reserves - Canadian Association of Petroleum Producers. *Statistical Handbook*.
- Unconventional Gas Resource Data - (1) USGS *1995 National Assessment of United States Oil and Natural Gas Resources*; (2) Additional unconventional gas data from operating companies
- Unconventional Gas Technology Parameters - (1) Advanced Resources International Internal studies; (2) Data gathered from operating companies

#### 15. DOE Input Data

- Onshore Lease Equipment Cost – U.S. Energy Information Administration. *Costs and Indexes for Domestic Oil and Gas Field Equipment and Production Operations (1980 - 2008)*, DOE/EIA-0815(80-08)
- Onshore Operating Cost – U.S. Energy Information Administration. *Costs and Indexes for Domestic Oil and Gas Field Equipment and Production Operations (1980 - 2008)*, DOE/EIA-0815(80-08)
- Emissions Factors – U.S. Energy Information Administration
- Oil and Gas Well Initial Flow Rates – U.S. Energy Information Administration, Office of Oil and Gas
- Wells Drilled – U.S. Energy Information Administration, Office of Oil and Gas
- Expected Recovery of Oil and Gas Per Well – U.S. Energy Information Administration, Office of Oil and Gas
- Oil and Gas Reserves – U.S. Energy Information Administration. *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, (1977-2009)*, DOE/EIA-0216(77-09)

#### 16. Computing Environment

- Hardware Used: PC
- Operating System: Windows 95/Windows NT/Windows XP
- Language/Software Used: FORTRAN
- Memory Requirement: Unknown
- Storage Requirement: Unknown
- Estimated Run Time: 287 seconds

#### 17. Reviews conducted

- Independent Expert Review of the Offshore Oil and Gas Supply Submodule - Turkey Ertekin from Pennsylvania State University; Bob Speir of Innovation and Information Consultants, Inc.; and Harry Vidas of Energy and Environmental Analysis , Inc., June 2004
- Independent Expert Review of the Annual Energy Outlook 2003 - Cutler J. Cleveland and Robert K. Kaufmann of the Center for Energy and Environmental Studies, Boston University; and Harry Vidas of Energy and Environmental Analysis, Inc., June-July 2003
- Independent Expert Reviews, Model Quality Audit; Unconventional Gas Recovery Supply Submodule - Presentations to Mara Dean (DOE/FE - Pittsburgh) and Ray Boswell (DOE/FE - Morgantown), April 1998 and DOE/FE (Washington, DC)

#### 18. Status of Evaluation Efforts

Not applicable

#### 19. Bibliography

See Appendix B of this document.



## Appendix D. Output Inventory

Variable Name	Description	Unit	Classification	Passed To Module
OGANGTSMX	Maximum natural gas flow through ANGTS	BCF	NA	NGTDM
OGCCAPRD	Coalbed Methane production from CCAP		17 OGSM/NGTDM regions	NGTDM
OGCOPRD	Crude production by oil category	MMbbl/day	10 OGSM reporting regions	Industrial
OGCOPRDGOM	Gulf of Mexico crude oil production	MMbbl/day	Shallow and deep water regions	Industrial
OGCOWHP	Crude wellhead price by oil category	87\$/bbl	10 OGSM reporting regions	Industrial
OGCNQPRD	Canadian production of oil and gas	oil: MMB gas: BCF	Fuel (oil, gas)	NGTDM
OGCNPPRD	Canadian price of oil and gas	oil: 87\$/ bbl gas: 87\$/ BCF	Fuel (oil, gas)	NGTDM
OGCORSV	Crude reserves by oil category	Bbbl	5 crude production categories	Industrial
OGCRDSHR	Crude oil shares by OGSM region and crude type	percent	7 OLOGSS regions	PMM
OGDNGPRD	Dry gas production	BCF	57 Lower 48 onshore & 6 Lower 48 offshore districts	PMM
OGELSCO	Oil production elasticity	fraction	6 Lower 48 onshore & 3 Lower 48 offshore regions	PMM
OGELSHALE	Electricity consumed	Trillion Btu	NA	Industrial
OGELSNQOF	Offshore nonassociated dry gas production elasticity	fraction	3 Lower 48 offshore regions	NGTDM
OGELSNQON	Onshore nonassociated dry gas production elasticity	fraction	17 OGSM/NGTDM regions	NGTDM
OGEORFTDRL	Total footage drilled from CO2 projects	feet	7 OLOGSS regions 13 CO2 sources	Industrial
OGEORINJWLS	Number of injector wells from CO2 projects	wells	7 OLOGSS regions 13 CO2 sources	Industrial
OGEORNEWWLS	Number of new wells drilled from CO2 projects	wells	7 OLOGSS regions 13 CO2 sources	Industrial
OGEORPRD	EOR production from CO2 projects	Mbbl	7 OLOGSS regions 13 CO2 sources	Industrial
OGEORPRDWLS	Number of producing wells from CO2 projects	wells	7 OLOGSS regions 13 CO2 sources	Industrial
OGEOYAD	Unproved Associated-Dissolved gas resources	TCF	6 Lower 48 onshore regions	Industrial
OGEOYRSVON	Lower 48 Onshore proved reserves by gas category	TCF	6 Lower 48 onshore regions 5 gas categories	Industrial
OGEOYINF	Inferred oil and conventional NA gas reserves	Oil: Bbbl Gas: TCF	6 Lower 48 onshore & 3 Lower 48 offshore regions	Industrial

Variable Name	Description	Unit	Classification	Passed To Module
OGEOYRSV	Proved Crude oil and natural gas reserves	Oil: Bbbl Gas: TCF	6 Lower 48 onshore & 3 Lower 48 offshore regions	Industrial
OGEOYUGR	Technically recoverable unconventional gas resources	TCF	6 Lower 48 onshore & 3 Lower 48 offshore regions	Industrial
OGEOYURR	Undiscovered technically recoverable oil and conventional NA gas resources	Oil: Bbbl Gas: TCF	6 Lower 48 onshore & 3 Lower 48 offshore regions	Industrial
OGGROWFAC	Factor to reflect expected future cons growth		NA	NGTDM
OGJOBS			NA	Macro
OGNGLAK	Natural Gas Liquids from Alaska	Mbbl/day	NA	PMM
OGNGPRD	Natural Gas production by gas category	TCF	10 OGSM reporting regions	Industrial
OGNGPRDGOM	Gulf of Mexico Natural Gas production	TCF	Shallow and deep water regions	Industrial
OGNGRSV	Natural gas reserves by gas category	TCF	12 oil and gas categories	Industrial
OGNGWHP	Natural gas wellhead price by gas category	87\$/MCF	10 OGSM reporting regions	Industrial
OGNOWELL	Wells completed	wells	NA	Industrial
OGPCRWHP	Crude average wellhead price	87\$/bbl	NA	Industrial
OGPNGEXP	NG export price by border	87\$/MCF	26 Natural Gas border crossings	NGTDM
OGPNGWHP	Natural gas average wellhead price	87\$/MCF	NA	Industrial
OGPPNGIMP	NG import price by border	87\$/MCF	26 Natural Gas border crossings	NGTDM
OGPRCEXP	Adjusted price to reflect different expectation		NA	NGTDM
OGPRCOAK	Alaskan crude oil production	Mbbl	3 Alaska regions	NGTDM
OGPRDADOF	Offshore AD gas production	BCF	3 Lower 48 offshore regions	NGTDM
OGPRDADON	Onshore AD gas production	BCF	17 OGSM/NGTDM regions	NGTDM
OGPRDUGR	Lower 48 unconventional natural gas production	BCF	6 Lower 48 regions and 3 unconventional gas types	NGTDM
OGPRRCAN	Canadian P/R ratio	fraction	Fuels (oil, gas)	NGTDM
OGPRRCO	Oil P/R ratio	fraction	6 Lower 48 onshore & 3 Lower 48 offshore regions	PMM
OGPRRNGOF	Offshore nonassociated dry gas P/R ratio	fraction	3 Lower 48 offshore regions	NGTDM
OGPRRNGON	Onshore nonassociated dry gas P/R ratio	fraction	17 OGSM/NGTDM regions	NGTDM
OGQANGTS	Gas flow at U.S. border from ANGTS	BCF	NA	NGTDM
OGQCRREP	Crude production by oil category	MMbbl	5 crude production categories	PMM
OGQCRRSV	Crude reserves	Bbbl	NA	Industrial
OGQNGEXP	Natural gas exports	BCF	6 US/Canada & 3 US/Mexico border crossings	NGTDM

Variable Name	Description	Unit	Classification	Passed To Module
OGQNGIMP	Natural gas imports	BCF	3 US/Mexico border crossings; 4 LNG terminals	NGTDM
OGQNGREP	Natural gas production by gas category	TCF	12 oil and gas categories	NGTDM
OGQNGRSV	Natural gas reserves	TCF	NA	Industrial
OGRADNGOF	Non Associated dry gas reserve additions, offshore	BCF	3 Lower 48 offshore regions	NGTDM
OGRADNGON	Non Associated dry gas reserve additions, onshore	BCF	17 OGSM/NGTDM regions	NGTDM
OGRESCAN	Canadian end-of-year reserves	oil: MMB gas: BCF	Fuel (oil, gas)	NGTDM
OGRESO	Oil reserves	MMB	6 Lower 48 onshore & 3 Lower 48 offshore regions	PMM
OGRESNGOF	Offshore nonassociated dry gas reserves	BCF	3 Lower 48 offshore regions	NGTDM
OGRESNGON	Onshore nonassociated dry gas reserves	BCF	17 OGSM/NGTDM regions	NGTDM
OGSHALENG	Gas produced	BCF	NA	NGTDM
OGTAXPREM	Canadian tax premium	oil: MMB gas: BCF	Fuel (oil, gas)	NGTDM
OGTECHON	Technology factors	BCF	3 cost categories, 6 fuel types	Industrial
OGWPTDM	Natural Gas wellhead price	87\$/MCF	17 OGSM/NGTDM regions	NGTDM