RECENT DEVELOPMENTS IN THE GAS SYSTEM ANALYSIS MODEL (GSAM)

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ABSTRACT

The Gas System Analysis Model (GSAM) is a modular, reservoir-based model of the North American natural gas market, developed by ICF Kaiser Inc., under the sponsorship of the U.S. Department of Energy. A major improvement of GSAM over previous models is its ability to build the gas supply curves from the "bottom up", based on its input database of over 16,000 gas reservoirs. This feature allows one to examine changes in technology or market factors and see their effect on individual reservoirs. In this way GSAM is free from assuming certain functional forms for the supply curves. These generated supply curves are then brought together with demand-side and market-based constraints into an integrating linear program that models the flows of gas in the North American pipeline network. The result is a set of equilibrium gas quantities and prices as well as the resultant flows. The approach used in GSAM provides a tool for policy and program analysis.

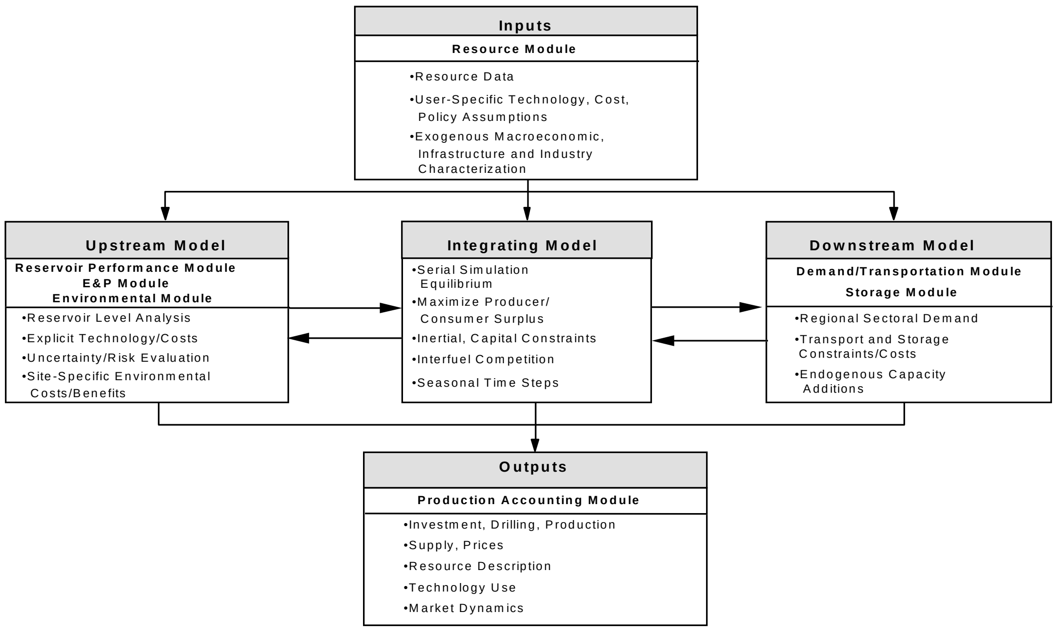
INTRODUCTION

The U. S. Department of Energy (DOE) Office of Fossil Energy is responsible for developing and demonstrating technologies that improve the cost and effectiveness of finding, developing, and producing natural gas in the U. S. In order to identify and evaluate the impacts associated with alternative research and development opportunities, DOE sponsored the development, performed by ICF Kaiser Inc., of the Gas Systems Analysis Model (GSAM). GSAM is a sophisticated, comprehensive analytical system that models the entire natural gas market system in North America, from reservoir to burner tip.

GSAM was developed to simulate the application of specific technologies in individual reservoirs, each characterized in terms of its specific geologic and fluid properties and current development status. Over 16,000 reservoirs in the U. S. and Canada can be individually evaluated within the constraints imposed by existing market infrastructure and market conditions. A major improvement over existing models, GSAM has the capability of building gas supply curves from the "bottom up," based on the technological alternatives that could be applied to each of the thousands of reservoirs in the U. S. and Canada.

The consistent evaluation of gas supply and demand under alternative economic, technology, regulatory, and policy conditions is the main objective of this modeling system, which is designed to be fully consistent with operator decision-making procedures. Its modular design provides flexibility in developing and completing detailed resource assessments. Figure 1 shows the general structure and logic flow of GSAM.

Figure 1
Structure of the Gas Systems Analysis Model (GSAM)



MODEL DESCRIPTION

GSAM has been designed to fully assess, both regionally and nationally, the benefits and costs associated with the flow of gas from the reservoir to various end-users. It can be used to evaluate the potential of alternative R&D strategies to increase natural gas extraction efficiency and/or reduce costs. Many existing models are already designed to evaluate various aspects of natural gas recovery at the level of an individual well. The uniqueness of the system lies in its simultaneous evaluation of R&D strategy in a market context, with the benefits of technology advances measured in terms of both commercial and technical success.

Required Inputs

Reservoir Data. In GSAM, each reservoir is explicitly characterized by rock and fluid properties, depth, pressure, and temperature, as well as resource type, play, location, and current development status. These data, plus carefully selected defaults when required, are used to evaluate the productivity and costs of each reservoir for a set of alternative technologies and policy scenarios.

By being able to evaluate known reservoirs, GSAM’s comprehensive characterization of the base resource provides a credible basis for numerous and varied policy analyses. After examination of several publicly available databases, NRG Associates' (NRG) *Significant Oil and Gas Fields Database* was determined to be the best reservoir database available to accomplish the goal.

The NRG database is a reservoir-level database for both the known and undeveloped natural gas resources and has sufficient coverage of necessary data elements to do a volumetric calculation of OGIP. It also contains sufficient data to perform analyses on different resource types, different regions, and other levels of disaggregation.

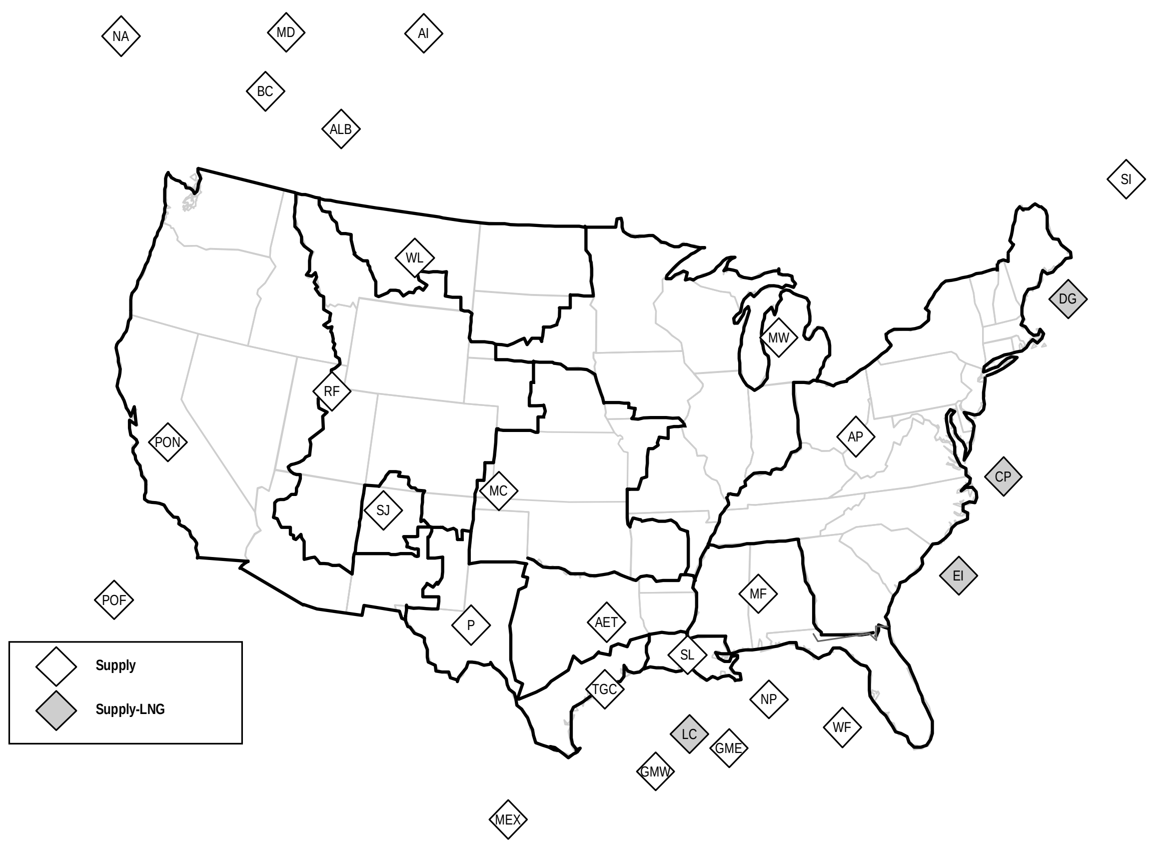
Each of the reservoirs has detailed information on the location of the reservoir, allowing the allocation of reservoirs into the regions (Figure 2). Producing regions are allocated in the system according to their geologic characteristics. Each reservoir is also assigned to a geologic play.

The plays are defined to approximate specific exploration concepts and to indicate groups of reservoirs susceptible to similar development strategies. The U.S. play definitions in the NRG database have been compared with and correspond closely to the plays defined by the USGS in its national resource assessments.

The undiscovered gas resource database in the system is more theoretical in nature than the known resource database. The undiscovered resource database in model was compiled using existing estimates of the undiscovered gas resource in the United States.

Other Input Data. Other information is needed to fully evaluate a gas reservoir's productivity and economics relative to other investments. Various capital and associated operating and maintenance (O&M) costs must be estimated as a function of specified technologies, location, and producing characteristics. Information on regional or national trends in drilling and completion costs, dry hole costs, and gas processing and waste disposal costs, along with other gas industry factors, is incorporated to reflect the dynamics of evolving capital and energy markets. Additional data on local, state, and federal tax structures, depletion, depreciation, and royalties, as they relate to gas producers and reservoir location and types, are used to provide fully costed reservoir evaluations on a project-specific discounted cashflow basis.

Figure 2
Supply Regions for the Gas Systems Analysis Model (GSAM)



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Current and advanced technology performance and cost assumptions and various policy conditions are defined as user-specified parameters. GSAM evaluates the evolution of decision parameters in response to constantly changing procedures and technologies as they are developed, tested, and implemented by operators in the field and as the character of the remaining resource base changes. It has been designed to directly evaluate and quantify the impacts of changing technology or policy conditions on the domestic gas system. It must therefore provide a flexible method for changing technology and policy conditions through user-specified input. This capability has been carefully designed into the various modules.

Finally, macroeconomic variables, infrastructure constraints and costs, and gas industry characterizations are required to fully represent the market within which investment decisions are made. These market parameters strongly affect the model's simulation of investments in new gas supplies, as well as end-use gas demand, by imposing realistic limits on regional supplies and inter-regional transportation volumes. These downstream factors are derived from historic industry practices and adjusted for fundamental changes in industry structure and recent regulations.

Analytical Modules of GSAM

The six main analytical modules, each of which can be run in a stand-alone mode, are as follows:

- **Resource Module -** transforms raw resource and reservoir data into fully characterized, reservoir level databases. The module operates using several routines that evaluate available information and estimate missing data elements based on reasonable engineering and geologic default parameters.
- **Reservoir Performance Module -** estimates annual production volumes and costs associated with development of each known or potential producing natural gas reservoir characterized by the Resource Module.
- **Storage Reservoir Performance Module -** estimates working gas, base gas, delieverability, injectivity and associated economics of storage reservoirs.
- **Exploration and Production Module -** evaluates the exploration, development and production of the natural gas resource base over time as a function of contemporary market conditions and technology, economic, and policy assumptions. Gas prices can be exogenously input or calculated based on analysis using the Demand and Integrating Model.
- **Demand and Integrating Module -** evaluates demand for gas by region, sector, and season as a function of gas prices, population growth, economic activity, interfuel competition, and other regional and national factors. Creates input files for operating the linear program to balance supply and demand across a nationwide transportation network linking supply and demand region.
- **Production Accounting Module -** converts output from other modules to provide a full accounting of all exploration, drilling, completion, operations, and upstream activities. Output provides details on annual gas production, gross revenues, taxes, investments, operating costs, and operating profits.

Figure 3
Major Components of the Gas Systems Analysis Model (GSAM)

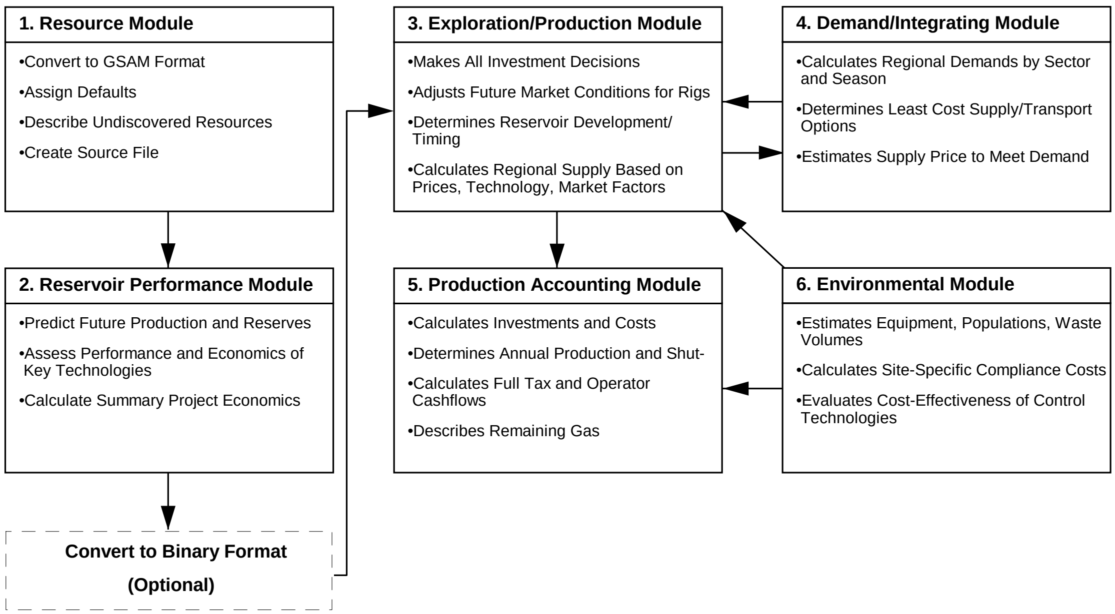


Figure 3 provides a schematic overview of the major analytical components. Each of these major components is summarized below.

Resource Module

The resource and data module converts resource data into reservoir-specific information in a format that the Reservoir Performance Module can use. All available raw resource data are incorporated into the Resource Module to be processed, analyzed, and validated into full reservoir descriptions. The module consists of more than simple screens, instead using the distribution of properties within plays to confirm information and estimate missing data. The full characterization of known producing, discovered but undeveloped, and undiscovered reservoirs in the United States and Canada draws on resource assessments available from various private and public sources.

Additional segments of these modules check for data consistency among reservoirs within plays by size and depth. This evaluation allows data default values to be determined and appropriately incorporated where reservoir data are inconsistent or missing. The completed reservoir descriptions are stored in one database for undiscovered/undeveloped reservoirs and another database for reservoirs for which initial development and significant production have occurred.

Undiscovered plays are split into two categories: hypothetical plays (plays with no current known reservoirs) and currently producing plays. For hypothetical plays, an analogous play in the model's database is identified and the characteristics of the analog play are used to describe the hypothetical play. Currently producing plays were matched to at least one play code in the database.

For each type of matching play, the same general methodology is used to estimate recoverable resource. In each play, a recoverable resource per reservoir is calculated for each reservoir size class in the play. A logarithmic function is then used to determine the relationship between the number of reservoirs in each size class within a play. The total recoverable resource in each play is determined by multiplying the number of reservoirs by the recoverable resource per reservoir in each size class and summing the recoverable resource across size classes for each play. The number of reservoirs is adjusted (while maintaining the mathematical relationship) until the recoverable resource in the database closely matches the resource reported by USGS. For hypothetical plays, since there are no known reservoirs, the U.S. recoverable resource is matched to the USGS estimate.

The play approach to exploration evaluation provides a comprehensive assessment of the resource at a level of detail appropriate to the system's analytical requirements. Because the model considers the full cost and potential of exploration activities nation-wide, a play-based approach (White 1981) is ideal for undiscovered resource assessments. Reservoir characteristics for undiscovered reservoirs are determined from average properties in known reservoirs described in the play. Using this relationship, the largest possible size class in that play is determined and the number of reservoirs is adjusted until the recoverable resource for the play matches the USGS estimate.

Reservoir Performance Module

The Reservoir Performance Module develops reservoir production response estimates and summary project economics based on the reservoir data output from the Resource Module and input on technology specifications, regional costs, state and federal tax requirements, and other assumptions. The production response estimates and project economics are subsequently used by other modules of GSAM.

The Reservoir Performance Module estimates initial production and conducts economic analyses that are used later in the Upstream Model to sequence natural gas resource development. This module incorporates type curve models that transform discrete reservoir properties and technology assumptions into a characterization of reservoir development and production profiles and ultimate gas recovery. These estimates are evaluated using appropriate costs and economic values to determine discounted net cashflows and project profitability.

Central to the module is a series of type curves. These type curves estimate gas production from various reservoir settings based on average reservoir properties. The type curve estimation has the capability to analyze individual, uniquely described pay grades in each reservoir under a variety of development options (including conventional, infill drilling, and restimulation), providing production and pressure estimates for the entire life of each reservoir.

A total of six explicit type-curve models have been developed for the North American Natural Gas Analysis System:

- ❑ Conventional radial flow - single and dual porosity
- ❑ Linear flow (fracture stimulated or horizontal wells) - single and dual porosity
- ❑ Water drive
- ❑ Unconventional resources (wet and dry shales, and wet and dry coals).

These type curves are explicitly designed to evaluate the performance and economic impacts of various technologies on future gas production. This is accomplished in the models by direct variation of parameters related to the exploration, drilling, completion, reservoir characterization, and production characteristics of individual reservoirs. These type curves were developed to characterize the explicit impact on well performance and costs of alternative technology scenarios, individually or in selected combinations.

Individual investments and operating processes are uniquely assessed in the model to determine their cost to operators:

- ❑ Based on published sources at level of well, reservoir, prospect
- ❑ Adjusted/verified by vendor quotes for known costs
- ❑ Scaled up to reservoir/prospect
- ❑ Based on regional, rate/depth specific values, where appropriate
- ❑ Use commercial costs, not R&D level costs
- ❑ Are technology-specific
- ❑ Can be adjusted for market conditions.

The models characterize the capital and operating costs of finding and developing natural gas reserves as a function of location, technology used, and production performance. The models also contain routines for state income and production taxes, depreciation, depletion, and amortization schedules, and Federal income tax parameters.

Tax and policy assumptions characterize the impact on natural gas E&P activities and project economics of alternative public sector tax, leasing, regulatory, capital and other potential policies directly or indirectly affecting natural gas development.

Exploration and Production Module

Operator decision-making for upstream investments is performed in five individual modules for exploration, initial reservoir development, production, additional development, and additional sources (LNG and associated gas). These modules evaluate preprocessed, project-specific production and financial summary data from the Reservoir Performance Module against user-specified decision criteria for contemporary market conditions.

The module ultimately determines the production from available reservoirs at projected gas price tracks. Again, the modules consider options from the viewpoint of the operator, deciding whether to implement or defer various investment opportunities. For example, the additional development module evaluates investment options for infill drilling or recompletion of initial development wells to maintain reservoir deliverability.

The evaluations are all based on reservoir specific calculations and consider the direct and secondary impacts of changing technology on future production, costs, and reservoir access.

Exploration Module. The Exploration Module completes economic evaluation of drilling new field wildcats in undiscovered reservoirs of various plays if expected value of full cost discovery is greater than long term wellhead prices provided by the Integrating Model. Some adjustment may have to be made to the expected value of exploration to represent the long term need to replace reserves, even when prices are low.

The method incorporates a characterization of remaining prospects (as for White's geological model) based on empirical and subjective data on known reservoirs in each play. It replaces the Monte Carlo sampling scheme (as in White's exploration model) with an algebraic representation of testing prospects as a function of geophysical measurement accuracy and regional interpretations. The exploration model evaluates the full cost economics of drilling a series of prospects.

Based on the size, shape, and other detectable properties, as well as the probability of finding a reservoir based on its proportional area, the model estimates an expected net present value for a successful exploratory well. In traditional exploration models, one-time improvements in exploration technology usually result in permanent improvements in exploration efficiency. ICF Kaiser’s approach reflects the reality that an improvement in technology that more accurately detects reservoirs of a certain size or trap type is only effective until the pool of those types of newly detectable reservoirs is depleted.

Initial Reservoir Development Module. The Initial Reservoir Development Module develops reservoirs already discovered, but not yet developed, if the minimum required price on a sunk cost basis is lower than the expected wellhead price. The analysis in this segment is fully based on sunk exploration costs. Individual reservoirs that have been discovered as a result of previous exploration activities are analyzed to determine when operators would develop them. The evaluation considers the performance and economic evaluation completed in the Reservoir Performance Module for primary development to "normal" well spacing. Based on the timing of the development decision, technology conditions are also adjusted. Contemporary market conditions and tax structures are also considered in all development decisions.

Additional Development Module. The Additional Development Module incrementally develops reservoirs that have already been developed by conventional practices. The decision process in this module, however, is at the pay grade level. Once developed to "normal" spacing, segments of the reservoir can be identified for exploitation using incremental development options. Two additional development decisions are possible: (1) infill drilling to some "close" spacing, and (2) re-stimulation of existing wells. These decisions are made based on an engineering evaluation of the status of wells at the time such incremental development is possible, relative to available technology and contemporary wellhead prices.

As with initial development decisions, this module adjusts all parameters to the situation at the time of an operator's decision. Incremental economics are considered, ensuring that the additional development being analyzed offers an economic gain over continued operation of the reservoir under initial development status. Also, technology considerations are independently evaluated in the module based on the market penetration at the time of the additional development investment.

Developed Reservoir Production Module. The Developed Reservoir Production Module produces or curtails wells producing from reservoirs that have completed initial development. This includes reservoirs already developed and on production as well as reservoirs developed over time. The module evaluates annual reservoir and pay grade production and evaluates annual shut-in decisions based on operating costs, royalties, and taxes on that production relative to available wellhead prices provided by the Demand and Integrating Model or the user. Production is shut-in when total costs exceed total revenue from a well or pay grade.

Production from these wells may be curtailed for several years if wellhead prices are falling but later rise. Once prices increase to a point where revenues exceed total cost of operations, production can be reestablished. However, pay grades and wells are assumed abandoned after a shut-in period of three years.

Demand and Integrating Module

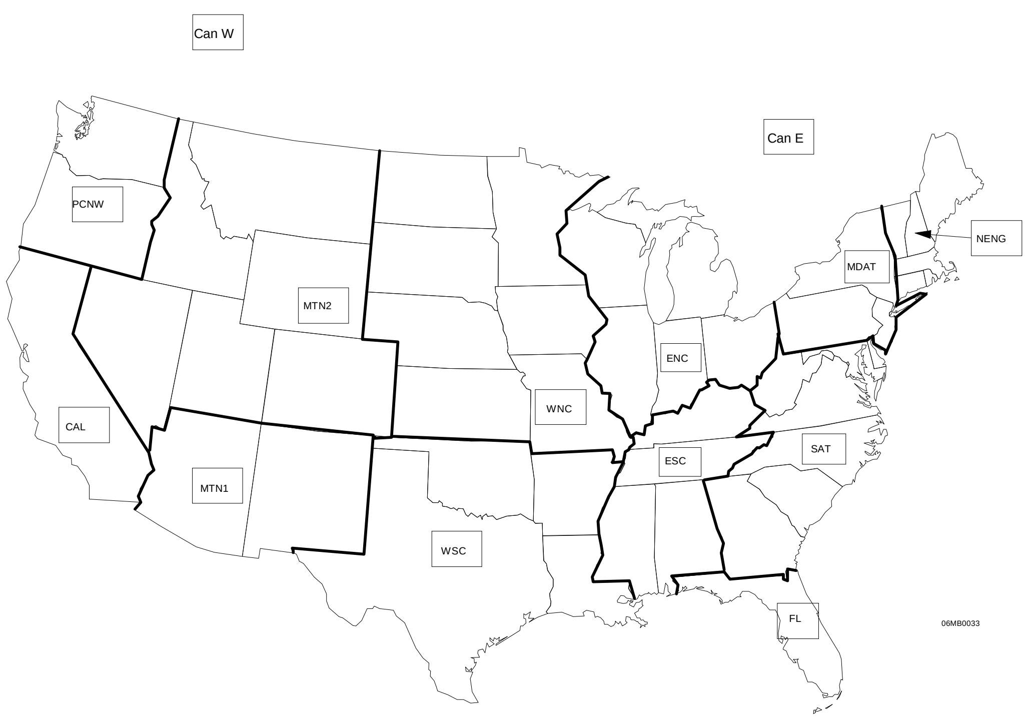
The downstream components characterize the transportation and end use market segments of the natural gas industry in sufficient detail to represent the dynamics of market supply and demand interaction and price formation. The structure is designed to allow users to assess benefits of gas supply research and development initiatives in light of operational, demand, and ultimate supply price impacts. In addition, the downstream model allows the user to assess the implications of changes in downstream policies on supply-related activities. The downstream model has the following major characteristics:

Regional Demand. Gas demand is presented in fourteen regions or nodes. These are based on the nine major census bureau regions, subdivided in several cases to provide additional detail. The demand remains used in the model are illustrated in Figure 4.

Sectoral Demand. Within each region, gas demand is represented in four end use sectors: residential, commercial, industrial, and electric generation. Both industrial and electric generation are further subdivided into market segments based on alternative fuel use in order to simulate gas and oil competition. The model simulates competition between gas and distillate, low-sulfur residual fuel oil and high-sulfur residual fuel oil. In addition, the electric generation component includes a sub-model for estimating the level of gas-fired generation capacity and generation that would occur at different price levels for natural gas.

Seasonality of Demand. Gas demand is represented in two seasons: a 151 day winter period and a 214 day summer period. During summer, storage becomes a demand sector; in winter, storage is treated as "local" supply source, much like an alternative fuel, for meeting demand.

Figure 4
Demand Regions in GSAM



Transmission. The model's transmission network consists of 74 links. The links connect gas supply nodes with other supply nodes and ultimately with gas demand nodes. Each link is characterized by maximum capacity, fixed costs, variable costs, and fuel. The model endogenously expands capacity on links when economically justified. Distribution costs are treated as a margin added onto the delivered city gate gas cost.

The downstream model operates by generating gas demand curves for each region. The transportation network integrates the gas demand curves with the gas supply curves by means of a linear program that minimizes the total cost of meeting demand, inclusive of transmission and gas costs.

The underlying assumptions concerning the existing structure, future expansion, and general operation of the downstream gas market which the model is designed to represent fall into three categories:

- ❑ Supply/demand equilibrium
- ❑ Regional pricing
- ❑ End use pricing.

The model assumes that the gas market is workably competitive and that gas prices will adjust upward or downward to balance supply and demand, consistent with economic theory. In today's highly integrated marketplace, producers now have multiple opportunities to reach markets, and buyers now have multiple routes by which to purchase and transport gas.

The model is structured to reflect the competitive nature of the market and to find the price that will bring gas supply and demand into equilibrium.

The model is designed to represent a key feature of today's market -- that is, the fact that the marginal users of gas have seen the average margin charged to them decline relative to other customers since they have several alternative fuel sources. Where these users can be kept on the gas system and still make a contribution to fixed costs, regulators have allowed the margins to shrink. Thus, the cost to the marginal user will tend towards the wellhead price plus the variable costs of transportation. In the winter, the marginal user will tend to see a full cost of transportation. The model represents this by allowing marginal customer groups -- industrial boilers and electric generators -- to buy gas based on variable costs. Other customer groups see a price with full fixed and variable costs, including distribution margins.

The integrating module uses results from the Demand Module and Exploration and Production Module to equilibrate annual gas prices and sales volumes over the entire period of analysis. The regional assessment of supply and demand is reconciled to determine inter-regional gas flows and resulting regional gas prices, from wellhead to end-use. Linear programming techniques solve for gas price and sales volumes against physical capacities and economic constraints among and within the 26 supply regions, 14 demand regions, and over 74 transportation links.

Production Accounting Module

The Production and Accounting Module provides summary output on details not reported elsewhere in the modeling system. It has been designed to answer key policy and planning questions and provide comprehensive output on the results of model analyses. This module is designed to construct final analytical results based solely on data and assumptions developed used in the other modules.

The Production Accounting Module consists of a series of routines that read and sort output files from the Exploration and Production Module and the Reservoir Performance Module. The purpose is to conduct a final accounting of production, revenues, taxes and royalties, operating costs, and investments once drilling decisions have been evaluated and timed. The analytical structure is consistent with the economic evaluation methods developed for the Reservoir Performance Module.

ACCOMPLISHMENTS

During the past year a number of enhancements were implemented in GSAM. These enhancements are grouped in following topics.

Gas Supply

- A characterization of the Western Canadian Sedimentary Basin was included as part of the resource base. NRG database was used for developed gas resource and Canadian Geological Survey (CGS) for undiscovered and undeveloped gas resource.
- The reservoirs were grouped according to USGS and CGS play definition.
- An explicit characterization of the unconventional resource was developed.
- A separate module was developed for estimating the cost of gas processing based on reservoir-specific gas composition.
- Associated gas production is estimated based on output from Crude Oil Policy Model (COPM).

Gas Storage

- A separate storage reservoir performance model (SRPM) was developed which operates on reservoir level.
- SRPM applies upstream model processing (both technical and economic processing) to existing as well as potential storage reservoirs (388 existing and 145 potential future storage reservoirs based on various screening criteria).
- A 50% annual utilization of working gas capacity for reservoirs is assumed with an annual decline of 5.2% per year in deliverability.

Environmental

- An environmental module was developed to estimate the costs of regulatory compliance.

Demand/Transportation

- Pipeline tariff and regional demand data were updated.
- The transportation network was expanded to include Canada and Mexican imports/exports.
- Pipeline descriptions and routed were revised and expanded.
- Pipeline risks were incorporated into costs.
- SO_2 allowance for coal was incorporated.

APPLICATIONS

GSAM has been applied to address a number of research and development and policy needs of the Department of Energy (DOE), and for the U.S. Environmental Protection Agency (EPA). An application of the upstream model of GSAM is the study of technology impacts on Natural Gas Supply. GSAM's upstream model has been utilized to determine the potential benefits of federal research and development programs on natural gas supply. Three separate cases were analyzed in this exercise. The three cases analyzed are:

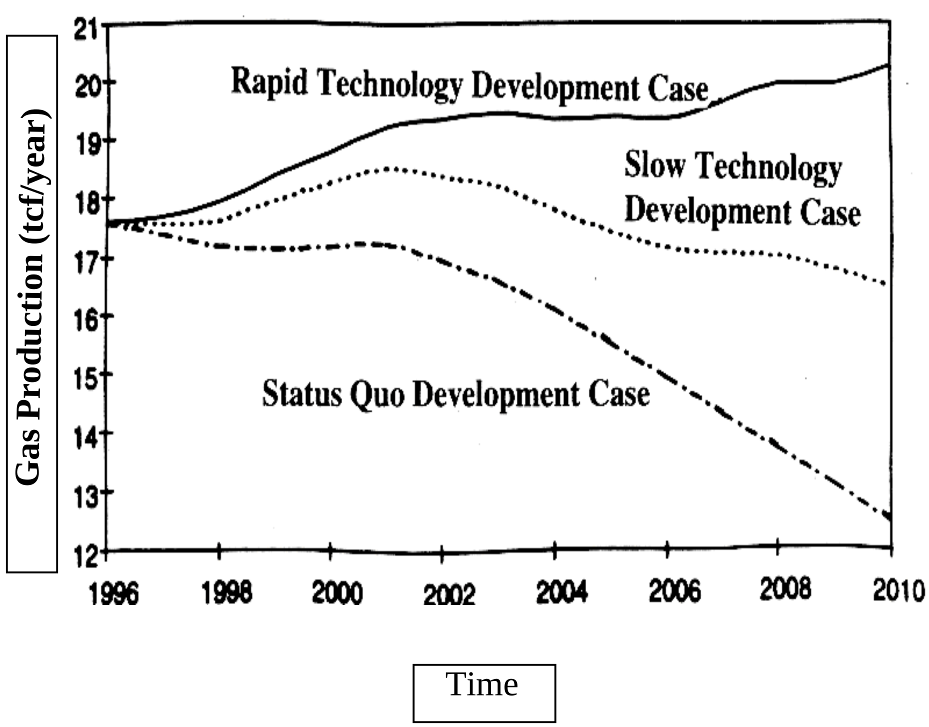
Rapid Technology Development Case. In this case GSAM was utilized to generate natural gas supply estimates assuming more aggressive levels of successful research in the areas of better drilling, completion and stimulation technologies, reservoir characterization, reduced operating and investment costs, increased operating efficiency, and lower environmental compliance costs. This could possibly correspond to a case consistent with continued federal support for gas industry R& D.

Slow Technology Case. This case assumes that technology development occurs at a substantially slower pace, like that which could result if massive budget cuts in federal R&D programs occur.

Status Quo Technology Case. This case assumes that there are no technology improvements in the natural gas industry after 1996. Hence, this exercise models technology in an "as is" situation.

These cases cover the three extreme cases with the Status Quo Case serving as a benchmark for the other two. Figure 5 shows the plot of U.S. natural gas production for these three cases. Domestic natural gas supply (associated and non-associated) could be increased by about 3.9 trillion cubic feet (TCF) per year for Rapid Technology Case by 2010. The U.S. gas production decreases sharply in the Status Quo Case, as indicated, resulting in annual supplies of around 12.5 TCF/year in 2010 compared to 20.4 TCF/year in the Rapid Technology Case. The Slow Technology Case produces 16.5 TCF/year in 2010.

Figure 5
U.S Gas Production Versus Time as Predicted by GSAM



FUTURE WORK

This current work is a continuation of the on-going effort to develop, test, utilize, and refine a comprehensive gas system to address program planning and policy alternatives at the regional and national levels. The development of GSAM continues with three tasks:

(1) Development of a graphical display interface for GSAM output.

(2) Incorporation of new analytical methodologies that will reduce the run-time.

(3) Modify GSAM modules to convert the system to a more user-friendly Windows based environment for input, evaluations, and output.

ACKNOWLEDGMENTS

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