Development of a Natural Gas Systems Analysis Model (GSAM)

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT.....	iv
I. INTRODUCTION.....	1
A. Research Objective	1
B. Background.....	1
C. Report Structure	2
II. RESEARCH METHODOLOGY.....	3
A. Overview	3
B. Design Philosophy.....	4
C. Methodology Overview and System Capabilities	5
1. GSAM Model Methodology	7
2. Demand and Integrating Module Methodology	13
3. GSAM Outputs.....	16
III. RESEARCH RESULTS AND ONGOING ACTIVITIES.....	17
A. Review Workshop.....	17
1. Background	17
2. Recommendations	18
B. Gas Storage.....	27
1. Background	27
2. Results.....	28
3. Conclusions and Remaining Work.....	36
C. Testing and Validation	36
1. Background	36
2. Results.....	40
3. Conclusions and Remaining Work.....	46
D. Updated Upstream/Downstream Data and Models.....	47
1. Background	47
2. Results.....	47
3. Conclusions and Remaining Work.....	52
E. Gas Processing.....	53
1. Background	53
2. Research Results	54
3. Conclusions and Remaining Work.....	57
F. Environmental Module Design and Development.....	57
1. Background	57
2. Research Completed.....	61

TABLE OF CONTENTS
(CONTINUED)

	<u>Page</u>
G. Royalty Relief	61
1. Background	62
2. Results	64
3. Conclusions and Remaining Work.....	66
H. Reduce GSAM Run Time	66
1. Background	66
2. Results	66
3. Conclusions and Remaining Work.....	69
I. Windows Interfaces	73
1. Background	73
2. Results	73
3. Conclusions and Remaining Work.....	76
IV. CONCLUSION	91

TABLE OF CONTENTS

(CONTINUED)

LIST OF FIGURES

	<u>Page</u>
Figure II-1 GSAM Structure	6
Figure II-2 GSAM Market Logic Flow	8
Figure II-3 GSAM Upstream Model Flowchart.....	8
Figure II-4 Major Components of the ICF Gas Modeling System.....	12
Figure II-5 Analysis of Natural Gas Resources by GSAM Analytical Modules and Databases	12
Figure II-6 GSAM Demand Model Flowchart.....	14
Figure II-7 GSAM Transportation and Supply/Demand Region Map.....	15
Figure III-1 Effect of Reservoir Thickness on a Conventional Radial Flow Reservoir	41
Figure III-2 Effect of Well Spacing on a Conventional Radial Flow Reservoir	41
Figure III-3 Overview of EM Structure and Data Flows.....	59
Figure III-4 MASP at Current Costs.....	63
Figure III-5 The Computation of Equilibrium Gas Supply Prices and Quantities	67
Figure III-6 Sample Supply Curve.....	70
Figure III-7 Tabular Display of Link-Based Data	74
Figure III-8 Graphical Display of Link Flows.....	75
Figure III-9 Network Display of Link Flows.....	75
Figure III-10 The GSAM Network.....	76
Figure III-11 Sample GSAM Output Display in Graphic Form.....	78
Figure III-12 An Application of GIS to Show GSAM Outputs in Creating Price-Supply Curves.....	83
Figure III-13 Representative Mapping Screen for Selecting Output Variables to be Displayed	84

LIST OF TABLES

Table II-1 GSAM Supply Model Components	10
Table III-1 Extraction Rates for Storage Gas, Bcf	31
Table III-2 Extraction Rates for Storage Gas, Bcf	34
Table III-3 Summary Of New Storage Facilities.....	35
Table III-4 Type Curve Analysis for Testing and Validation	37
Table III-5 Scenario Summary	39
Table III-6 Summary of Cost Assumptions.....	55
Table III-7 Comparison of Resource Estimates (Tcf).....	57
Table III-8 Net Effects of the Incentives at \$2.00/Mcf	65
Table III-9 Net Costs and Royalties by State	65
Table III-10 Actual Computing Times for One Typical Equilibrium Iteration.....	68

ABSTRACT

North American natural gas markets have changed dramatically over the past decade. A competitive, cost-conscious production, transportation, and distribution system has emerged from the highly regulated transportation wellhead pricing structure of the 1980's. Technology advances have played an important role in the evolution of the gas industry, a role likely to expand substantially as alternative fuel price competition and a maturing natural gas resource base force operators to maximize efficiency. Finally, significant changes continue in regional gas demand patterns, industry practices, and infrastructure needs. As the complexity of the gas system grows so does the need to evaluate and plan for alternative future resource, technology, and market scenarios.

Traditional gas modeling systems focused solely on the econometric aspects of gas marketing. These systems, developed to assess a regulated industry at a high level of aggregation, rely on simple representation of complex and evolving systems, thereby precluding insight into how the industry will change over time. Credible evaluations of specific policy initiatives and research activities require a different approach. Also, the mounting pressure on energy producers from environmental compliance activities requires development of analysis that incorporates relevant geologic, engineering, and project economic details. The objective of policy, research and development (R&D), and market analysis is to integrate fundamental understanding of natural gas resources, technology, and markets to fully describe the potential of the gas resource under alternative future scenarios.

This report summarizes work over the past twelve months on DOE Contract DE-AC21-92MC28138, Development of a Natural Gas Systems Analysis Model (GSAM). The products developed under this project directly support the Federal Energy Technology Center (FETC) in carrying out its natural gas R&D mission.

The objective of GSAM development is to create a comprehensive, non-proprietary, microcomputer model of the North American natural gas system. GSAM explicitly evaluates the key components of the system, including the resource base, exploration and development practices, extraction technology performance and costs, project economics, transportation costs and restrictions, storage, and end-use. The primary focus is the detailed characterization of the resource base at the reservoir and sub-reservoir level. This disaggregation allows direct evaluation of alternative extraction technologies based on discretely estimated, individual well productivity, required investments, and associated operating costs. GSAM's design allows users to evaluate complex interactions of current and alternative future technology and policy initiatives as they directly impact the gas market.

GSAM development has been ongoing for the past five years. Key activities completed during the past year include:

- Analyzed the effects of a royalty relief policy for marginal wells;
- Studied the impacts of advanced gas processing technology on natural gas supplies and updated the gas processing module in GSAM;
- Modified GSAM to gain an understanding of the market for natural gas storage in order to provide for rigorous evaluation of federal R&D opportunities in storage technologies; we also added a new Storage Reservoir Performance Module and made suitable changes to the integrating linear program. This allows GSAM to thoroughly assess impacts of technology on storage utilization and the market impacts of storage on future gas prices which could in return affect E&P technology application;
- Updated upstream and downstream databases;
- Enhanced and updated the resource databases for U.S. and Canada for both discovered and undiscovered resources;
- Tested and validated GSAM's inputs and outputs to verify their soundness;
- Conducted two Peer Review Workshops (one devoted to performance and economic model and data issues, the other focusing on environmental matters) collecting comments and suggestions from a panel of experts from government, industry, and academia;
- Decreased GSAM run time by a combination of software and hardware changes; and
- Performed initial development of a GSAM Windows interface.

I. INTRODUCTION

This report reviews the goals, work plan, and accomplishments of research under the Department of Energy (DOE) contract DE-AC21-92MC28138, Development of a Natural Gas Systems Analysis Model (GSAM). The work has been under way for five years, since June 22, 1992. Work previously performed under this contract included review of existing and emerging technologies and critique of other available models. ICF also completed the final design of the model, developed and tested the databases, entered various engineering and cost modules, and updated market model interfaces, developed a metrics analysis of the FETC natural gas R&D program, and conducted initial training on modeling methodology.

This report provides an overview of the activities to date and schedule for future testing, validation, and authorized enhancements. Its goal is to inform DOE managers of progress in model development and to provide a road map for ongoing and future research.

A. RESEARCH OBJECTIVE

The objective of this research effort is to create a comprehensive, non-proprietary, microcomputer model of the North American natural gas market. GSAM is designed to explicitly evaluate components of the natural gas system, including the entire in-place gas resource base, exploration and development technologies, extraction technology and performance parameters, transportation and storage factors, and end-use issues. The system can be used to evaluate alternative research and development (R&D) activities and strategies under the direction of FETC. GSAM can now provide the analytical capability to estimate the impacts of federal energy, tax, and environmental policy initiatives on domestic gas potential.

B. BACKGROUND

The domestic gas market has undergone dramatic economic and technical evolution in the past decade. This change in the way business is conducted has significant implications for the extraction potential of the natural gas resource, due to both upstream supply considerations and downstream demand requirements. DOE's natural gas research must address these new market realities.

The expanded design of GSAM, including environmental analysis capabilities and a more complete resource description, also meets important strategic objectives identified by DOE. To be

utilized in today's market, technology advances must be environmentally sound and prudent. Also, more R&D is being focused directly on environmental damage mitigation. As regulations become more complex, interrelated, and cumbersome, the analysis of environmental policy and R&D activities will increase in importance. GSAM will be ready to assist DOE managers in program focusing and review.

DOE's Natural Gas Strategic Plan requires that R&D activities be evaluated for their ability to provide adequate supplies of reasonably priced gas. GSAM provides the capability to assess potential and ongoing R&D projects using a full fuel cycle, cost-benefit approach. This method provides realistic, market-based assessments of benefits and costs of alternative or related technology advances. It can estimate both technical and commercial successes, quantifying the potential benefits to the market, as well as to other related research. GSAM, therefore, represents an integration of research activities and a method for planning and prioritizing efforts to maximize benefits and minimize costs.

C. REPORT STRUCTURE

This annual report summarizes the purpose, work, and results of research activities during the period of performance, July 1, 1996 to June 30, 1997. Section II describes the research methodology, including how it has progressed as DOE's strategic direction has shifted, and as new findings have focused model development efforts. Section III provides a discussion and summary of research activities for the major task assignments on which work has been done during the reporting period. Lastly, in Section IV, we summarize the work accomplished during this past year and the work we anticipate doing in the future on GSAM.

II. RESEARCH METHODOLOGY

A. OVERVIEW

The primary purpose of GSAM is to provide credible, valid empirical support to FETC R&D program planning and policy assessment. This role has become increasingly important as DNGOI and other government and industry initiatives call for more detailed analysis of alternative strategies. GSAM development is being coordinated to ensure that the highest quality product possible is delivered in a timely manner. In addition, consistent review and input from FETC has been sought to maximize future DOE use of GSAM's capabilities.

Where appropriate, GSAM development adapted and consolidated many existing analysis models. Significant efforts were committed in order to define the analytical needs, assess what models and data are currently available, and develop logical, cost-effective methods to convert and link various elements into an integrated design. The focus of GSAM development, however, has not been limited to currently defined needs and analytical requirements, nor has the system been narrowly defined to address a confined set of conditions. Rather, the models, databases, reports, and input procedures have been developed to assure maximum flexibility.

Environmental compliance costs are expected to increasingly influence operator decision-making. Costs associated with land management, drilling waste disposal, emission controls, and underground injection control (UIC) are a function of the regulatory requirements imposed at various levels. GSAM has been enhanced to analyze the direct cost of environmental compliance on future investments and operating costs as a function of the restrictions imposed, the unique location of the reservoir, and the general operating conditions. The expanded analytical capability to determine increases in compliance costs as a function of the regulatory scenario imposed on operators in various regions has been fully developed. This capability has been added to all modules of GSAM.

Data development efforts have resulted in the creation of a comprehensive database of non-associated gas reservoirs for analysis in GSAM. This included the licensing and incorporation of NRG Associates' Significant Oil and Gas Field of the United States and The Significant Oil and Gas Pools of Canada databases, the evaluation and description of the undiscovered resource based on the U.S. Geologic Survey assessment and Canadian Geology Survey reports, and the addition and calibration of reservoir characterization for Appalachia and some offshore regions. The result has been the rapid development of a data source that has been used in support of the DOE program.

GSAM development has also been planned and designed to be timely and responsive. Development was significantly accelerated to provide analytical capabilities to assist DOE in planning new initiatives. Also, the final methodology developed and discussed below was selected because of the speed and flexibility it provided in completing this research.

B. DESIGN PHILOSOPHY

The design foundation of GSAM constructed to prevent obsolescence and provide for ongoing enhancements. GSAM has been developed in discrete modules that are linked, but can be validated and used on a stand-alone basis. This design feature was selected to ensure easy updating and enhancing of the system as new information and procedures become available. Additionally, GSAM uses a series of component databases, each specifically designed to allow separate updates as new data become available. The database structures have been generated to ensure consistency between different segments. Source documentation for all data elements has also been completed

Because the analyses needed for a full GSAM run are so complex, GSAM incorporates various modules that perform the computer intensive resource and reservoir-level modeling prior to the user-initiated GSAM run. Based on expected future analysis needs, alternative scenarios (e.g., various R&D, tax, or market strategies) can be modeled using the GSAM Reservoir Performance Module. This allows the user to quickly analyze multiple technology, policy, or tax situations and store results for future use. This potentially reduces GSAM run-times by more than 80 percent in evaluations of multiple R&D in policy strategies. The preprocessor (Reservoir Performance Module) output data are configured to accommodate changes in market conditions that would require new analysis in traditional models. The full explanation of these concepts is described in the Model Development Topical Report.

GSAM models the upstream natural gas system at the level at which operators make investment and technology selection decisions: the individual prospect or reservoir. Each component of the upstream evaluation methodology accommodates this level of detail:

- The *resource base* is characterized as individual reservoirs with average effective reservoir properties and, for known reservoirs, complete drilling and production histories. These units are further subdivided where appropriate to reflect intra-reservoir heterogeneities.
- *Engineering costs* and investment requirements are derived based on region, depth, and operating conditions of each zone.
- *Technology* is characterized in terms reservoir performance (flow rates and ultimate recovery) and cost parameters that are associated with applying a group of technologies in the specified reservoir setting.

- *Production modeling* accounts for unique interactions of geology, technology, and operating practices that influence gas recovery rate and ultimate volume for individual wells and reservoirs.
- *Project economics* are evaluated on an industry-standard after-tax pro-forma basis for both full and incremental project bases. The cost for a project is set at the level of the commonly used authorization for expenditure evaluated under explicit timing and amounts of capital, operating and tax costs, and revenue streams.
- *Decision-making* incorporates the inherent uncertainties and inefficiencies in technology performance and gas markets.

The components of GSAM can evaluate the inherent uncertainties in resource characterization, technology application, reservoir performance, market economics, and operator decision-making. Two important benefits of including explicit risk analysis in GSAM are to provide insights into the value of better information and to estimate the range of possible outcomes of current or proposed policies under alternative resource, technology, or market scenarios.

Analysis of downstream issues such as gas demand, transmission, storage, imports, additional gas sources, pipeline capacity additions, and interfuel competition which can directly offset upstream operations, are aggregated to the regional level. The GSAM Integrating Model uses a linear programming algorithm to balance demand in various regions based on available supplies. The model then estimates future gas price tracks by region in order to balance supply and demand while maximizing discounted total surplus. The model also estimates future expansion of gas transportation and storage capacities across the pipeline network. This market dynamic model is a key component of the assessment of future technology applications. It allows analyses to directly consider the market impact on future gas prices, and therefore project economics of recovery operations.

C. *METHODOLOGY OVERVIEW AND SYSTEM CAPABILITIES*

The domestic gas market is an integrated, commodity-based system of supply, transportation, and demand. Regulatory changes have dramatically altered the once highly regulated gas industry. Demand and supply of gas are influenced and limited by market conditions and regional boundaries established by the existing infrastructure. GSAM has been designed and developed to fully assess, both regionally and nationally, the benefits and costs associated with the flow of gas from the reservoir to various end-users. Figure II-1 provides a schematic overview of GSAM's major analytical components. Each of these GSAM components is summarized below.

The domestic gas resource is large, diverse, and widely dispersed, both geologically and geographically. E&P efforts encompass a broad range of activities and technologies. Many of these are explicitly designed for the specific characteristics of particular prospects or resources. Each is designed to improve the producibility and economics of the domestic natural gas resource. To fully meet its objective and assist DOE R&D managers, GSAM must consistently address both conventional and unconventional gas resources and the many processes used to find, extract, and process natural gas for sale.

To maximize both validity and credibility, GSAM's methodology evaluates each activity as an investment opportunity at the appropriate unit of analysis. Exploration is evaluated on a fully risked prospect basis. For exploration to be conducted, the expected value of the next discovery must exceed

Figure II-1
GSAM Structure

the full cost of finding hydrocarbons (including dry holes) and ultimately developing and producing the potential discovered reservoir(s). Once a reservoir has been discovered, development and production from that reservoir must generate expected revenues to cover the investments, operating costs, and risks of development. Each investment decision is approached from the view point of an operator determining if the investment is warranted. These evaluations integrate detailed information on reservoir geology, technology applications, productivity, costs, and market prices — the same information an operator uses in the field to select projects. Additionally, transportation and demand decisions are modeled from the viewpoint of the appropriate decision-maker, each attempting to maximize fully-risked profit in a market context.

GSAM integrates these discrete decisions into a market framework. Investment decisions are evaluated based on contemporary market conditions (e.g., capital and rig availability, wellhead prices) consistent with the supply and demand of gas and the availability of infrastructure in various regions. E&P activity that creates market imbalances (e.g., excess supply in a given region) must cover not only the direct extraction costs but the additional costs of transporting the gas to its end-user. Based on aggregate activities in various supply and demand regions, GSAM equilibrates regional markets and prices over the forecast period. Figure II-2 displays a simple overview of GSAM's market balancing approach. The downstream model also explicitly addresses seasonal demand fluctuations that influence gas infrastructure, storage, and utilization capacity and investment decisions.

1. GSAM Model Methodology

The consistent evaluation of gas supply, demand, and transportation under alternative economic, technology, and regulatory conditions is a key objective of GSAM development. Figure II-3 provides a detailed view the logic flow of the Model. The integrated, modular design of data and analytical procedures maximizes flexibility in organizing, designing, implementing, and completing analyses. This structure also allows efficient model/data maintenance and enhancements in response to priorities derived from initial GSAM analyses and evolving gas R&D program direction.

Figure II-2
GSAM Market Logic Flow

Figure II-3
GSAM Upstream Model Flowchart

The remainder of this section provides an overview of the entire model. GSAM is grouped into the following modules:

- **Resource Module.** Translates reservoir properties into a prescribed GSAM data structure characterizing the North American gas resource base including existing and potential new storage projects. A parallel source database documents the origin or derivation of each data element;
- **Reservoir Performance Module.** Estimates future production from each gas reservoir based on the unique reservoir properties and technology conditions being considered. Performs summary economic analyses to provide a basis for analyzing investment alternatives;
- **Storage Reservoir Performance Module.** Characterizes storage reservoirs to predict both gas deliverability and injectivity, and associated economics;
- **Exploration and Production Module.** Simulates the exploration decisions and development schedules for individual reservoirs as a function of price and market constraints. Computes annual gas production for each reservoir and aggregates this production to the play, regional, and/or national level;
- **Production and Accounting Module.** Calculates annual gas production, gross revenue, taxes, investments, operating costs, and operating profits, in addition to other pro-forma activities;
- **Demand Module.** Calculates the seasonal demand for gas in the residential, commercial, industrial, and electrical power generation sectors in distinct demand regions.
- **Integrating Module.** Balances supply, demand, and storage of gas in each North American region, and calculates market equilibrium prices and quantities.

Table II-1 provides descriptions of the individual modules and databases that comprise the entire Upstream Model.

The normal process of operating GSAM is shown in Figure II-4. The GSAM design and development also emphasizes the importance of proper accounting of resources by describing, quantifying, and evaluating the remaining domestic gas resource after production by selected technologies. The modular design provides an easy tracking capability within the model to monitor how technology is influencing gas recovery from various resource segments (Figure II-5). The Remaining Resource Database provides a balanced, accountable description of gas remaining to be recovered in various reservoir settings. These resources are targets for more aggressive R&D to overcome key physical or economic barriers to production. A key feature of GSAM is its ability to describe resources in terms of gas-in-place. Past reliance on recoverable gas as a unit of analysis has confounded the estimation of the impact of technology on reserve growth and recovery efficiency.

Table II-1
GSAM Supply Model Components

1. Natural Gas Resource Data - Contains raw data on reservoir location rock and fluid properties, production, reserves, and development history.

2. Resource Module - Generates explicit and complete reservoir descriptions for known and undiscovered/undeveloped resources. Estimates characteristics and numbers of undiscovered reservoirs and the characteristics of known reservoirs (including, as appropriate, those reservoirs of record that are not explicitly identified in the database). Assigns individual reservoirs to fields and plays based on available information. Implements defaults as needed to pass complete reservoir descriptions to the Undiscovered/Undeveloped and Developed Resource Databases.

3. Undiscovered/Undeveloped Resource Database - Comprehensive database that characterizes the numbers and properties of typical reservoirs of each field size class for each identified natural gas play. This database describes about 1,000 typical undiscovered reservoirs (100 significant gas plays with 10 size classes per play).

4. Developed Resource Database - Same format as the Undiscovered/Undeveloped Resource Database, but includes data on current development/production status to define alternative future development options. This database includes an additional elements to account for associated dissolved gas in each region and any missing resource not accounted for in the raw data.

5. Undiscovered/Undeveloped Resource Evaluation Module - Estimates well recovery and economics for initial reservoir development (to "wide spacing") by size class and play under alternative technology and cost assumptions. Explicitly evaluates the effects of reservoir heterogeneity on production potential and economics. Estimates impact by evaluating three wells characterized by a distribution of those reservoir properties that affect storage and deliverability or other reservoir engineering components. The property distributions can be defined for each play type. Production profiles for initial development wells are stored for use in the analysis modules. Minimum acceptable supply prices for exploration, development, continued development, and continued operation are calculated and required elements stored for use in decision analysis.

6. Developed Resource Evaluation Module - Evaluates known reservoirs to determine current development status and estimates potential for additional drilling, reserve addition, and production options. All reservoirs evaluated are either already developed to wide spacing, partially infilled, or approaching abandonment. Reservoirs are characterized based on current development status and incremental economics to continue current production and evaluate all possible additional development options. Fully characterized reservoirs are passed to the Developed Reservoir Bank.

7. Undiscovered Reservoir Bank - Contains information on all reservoirs not yet discovered or delineated by a new field wildcat well. Economic evaluation results, including required gas price to initiate exploration and development, and data on cost to continue development and production (in the event of decreased gas price), are contained in the file.

8. New Reservoir Bank - Contains all reservoirs discovered by the Exploration Module, including reservoirs that will be discovered by infield wildcats (new reservoirs in old fields). The file also contains economic analysis results including capital, drilling, sunk cost-basis required wellhead gas prices, indices to typical reservoir production profiles, and other data used to select newly discovered reservoirs for initial development. Reservoirs discovered by new field wildcats are aggregated in the bank by size class and play (roughly a 13 size class by 1,000 play matrix). In each model time period, successful new field wildcats "deposit" reservoirs to the bank and some portion of recently discovered reservoirs are "withdrawn" (i.e., developed).

9. Developed Reservoir Bank - Identical in structure to the Undiscovered and New Reservoir Banks. Provides development status of all known reservoirs and indicates the potential production and economics for alternative additional development options. Unlike the New Reservoir Bank that has "deposits" from the exploration module, Developed Reservoirs are only "deposited" once, at the beginning of the GSAM run. However, they are "withdrawn" rather rapidly since this bank feeds the Developed Reservoir Production Module, which implements ongoing development plans, and are then passed to the Additional Development Module.

Table II-1
GSAM Supply Model Components (continued)

10. Technology/Cost/Geology Assumptions - Represents user-specified or default technology performance assumptions, regional/resource-specific cost data, and geological assumptions on intrareservoir property distributions. Intrareservoir property distributions are specified based on geological appraisals of typical reservoirs in several generic play "types" (to be defined, but broadly based on lithology, depositional environment, or other gross factors that would significantly influence well-to-well distribution of reservoir properties). The technology assumptions used impact both the preprocessing modules, as well as the Exploration, Initial Development, Known Production, and Additional Development Modules. Technology advances can be modeled as either improved performance, reflected in higher volumes of gas production as predicted from type-curve analysis, improved economics, accelerated production, enhanced application over time (market penetration or decreased costs), or any combination.

11. Exploration Module - Estimates the distribution of reservoir size classes discovered by successful new field wildcats (NFW). The efficiency of exploration adopts traditional exploration modeling concepts as well as new, technology-dependent ones. Success is modeled as the relative proportions of reservoirs discovered in various size classes for each successful NFW. The distribution across size classes is based on remaining reserves in each class, aggregate volume/area as a proportion of each size class in a drilling area (prospects in several plays are usually tested in the same drilling program), and the ability of exploration technology to characterize those parameters that are size- or volume-related. The outputs of the modules are the composite (expected value) finding rate for the next successful NFW, the minimum wellhead gas price required to initiate exploration (including lease costs and dry holes), and the proportion of fields discovered in each size class. The Exploration Module "drills" NFW's in response to price signals and capital and drilling constraints issued by the Integrating Model. Exploration Module data outputs are passed to the New Reservoir Bank.

12. Initial Reservoir Development Module - "Develops" reservoirs in the New Reservoir Bank in response to price, demand, and constraint signals from the Integrating Model. Includes "suboptimization" algorithms to reflect imperfect demand and price signals as well as investment evaluation criteria other than minimum required price (e.g., reserve replacement, production maximization, differing utility functions, corporate distribution of investment opportunities). This module also handles major GSAM bookkeeping functions of vintaging production, capital expenses, and drilling

13. Additional Development Module - Estimates the capital, drilling, reserve addition, production, and required price for two development options in all known and newly discovered fields that have already been drilled to wide spacing: (1) infill (one drill-down only) and (2) recompletion of existing wells. Development options are based on data supplied by the Developed and Undiscovered/Undeveloped Resource Evaluation Modules. Since the combination of changing wellhead gas prices, technology availability, and reservoir depletion continuously alter development option economics, options are evaluated and characterized so that results of these evaluations can be adjusted without rerunning the reservoir and cost modules. This module implicitly contains an "additional reservoir development bank" that is similar in format and operation to the New and Undeveloped Reservoir Banks, but indicates as available only those development options that are technically feasible and economic at the appropriate time. Finally, as for other development modules in GSAM, no optimization of infill options is anticipated for a given reservoir. A reservoir is infilled if it is preferred relative to other currently available options for that reservoir, eliminating the consideration of a currently economic reservoir "waiting" for advanced technology or higher prices.

14. Developed Reservoir Production Module - "Completes" the current development phase of reservoirs in the Developed Reservoir Bank in response to price, demand, and constraint signals from the Integrating Model. Determines appropriate levels of production from existing wells, and the future production profile to the point where additional development can take place. Provides for curtailment of current production in producing reservoirs if wellhead gas prices decrease or operating costs increase.

15. Other Gas Sources Module - Contains data and analytical modules on LNG, synthetics, associated gas and other potentially important or emerging sources of gas.

16. Remaining Resource Database - Repository for unproduced gas resource. Data on resource and marginal costs of next producible increment of gas for each identified reservoir are stored for future analysis. Provides full accounting of remaining gas resource by type (undiscovered, discovered/undeveloped, developed/uncontacted, contacted/uneconomic). Can be assessed during model run for quality control reasons or for further analysis (e.g., abandonments, evolving research targets, etc.).

Figure II-4
Major Components of the ICF Gas Modeling System

Figure II-5
Analysis of Natural Gas Resources by GSAM Analytical Modules and Databases

GSAM's modeling methodology provides a comprehensive evaluation of the natural gas resource and key E&P issues by making major analytical advances in scope of analysis units, full volumetric accounting for gas resources, and efficient preprocessing that allows for more extensive analysis than is now possible. However, these assessments will not be complete without further analysis and integration to determine how the market for natural gas impacts technology commercialization and reservoir profitability. The following sections describe how GSAM analyses can be integrated into the full-system gas market.

2. Demand and Integrating Module Methodology

Traditional technology appraisal methods which estimate the impact of new technology on selected resources are inadequate to derive the full benefits of R&D. The GSAM methodology goes beyond evaluating gas supplies to explicitly modeling the full impact of technology and policy changes on the timing and magnitude of technology commercialization. Natural gas cost reductions due to improved technology may have limited value if they fail to stimulate production to meet market demand. Despite lower costs of producing specific segments of the resource, these supplies may ultimately be higher in cost to the end-user. To correctly and completely evaluate the market impact of various competing technologies and policies, GSAM includes a comprehensive model of the downstream (gas demand) segment. Figure II-6 displays the logic and data flow of GSAM's current end use demand model.

Analysis of demand for natural gas includes regional assessment of consumption by sector. The GSAM methodology uses existing models of residential, commercial, industrial, and electric utility requirements for gas to determine demand within the demand regions. The end-use projections rely on user-specified macroeconomic parameters (e.g., population, economic growth, and other factors) that directly influence the overall demand for natural gas. Inter-fuel competition is also explicitly analyzed within GSAM. End-users in the industrial and utility sectors have substantial fuel switching capacity, capable of using natural gas, oil, or coal as needed. GSAM explicitly analyzes the future impact of inter-fuel competition on regional and sectoral demand.

The Demand and Integrating modules provide the breadth and depth of evaluation consistent with the role of GSAM in E&P policy and R&D planning and evaluation. The regional equilibration of supply and demand is accomplished to provide realistic estimates of North American gas market performance.

Figure II-6
GSAM Demand Model Flowchart

GSAM explicitly evaluates gas transportation and storage which are among the most important issues targeted by DOE's DNGOI. The ability of existing infrastructure to cost-effectively move gas to market is modeled by GSAM as transport links between supply and demand regions. In addition, the integrated approach provides for the evaluation of adding capacity or new service pipelines when market limitations and economics dictate, accounting for seasonal demand fluctuations and storage and other peaking options. The explicit evaluation of seasonality provides FETC a unique opportunity to evaluate storage reservoir performance, the need for additional capacity, and alternative strategies to merely developing more storage reservoirs.

The Integrating Module equilibrates annual gas prices and sales volumes over a multi-year period. The regional assessments of supply and demand must be reconciled to determine inter-regional gas flows and resulting regional gas prices. GSAM uses a linear programming technique to equilibrate

gas price and volumes against physical capacity and economic constraints among and within supply regions, demand regions, and over transport links (Figure II-7).

The Demand and Integrating Modules also perform important accounting and equilibration of investments and available infrastructure, observing existing and probable future constraints. Similar to the Upstream and Downstream Models that provide input to it, the Integrating Module approaches decisions from an investor's viewpoint. It attempts to balance supply and demand in each region by the least-cost strategy that balances (fully risked) producer or consumer surplus, as appropriate. Figure II-7 shows the transportation infrastructure currently used in GSAM to estimate supply and demand balance.

Figure II-7
GSAM Transportation and Supply/Demand Region Map

3. GSAM Outputs

The results from the Integrating Module provide a verifiable and credible basis to forecast future gas supplies and prices, based on user-specified E&P technology and policy assumptions. However, it also captures the resulting market events that are likely to impact demand for gas. The reports generated from this integrated market evaluation provides valuable insight into strategies for maximizing the current and future value of the domestic gas resource.

GSAM output is designed and formatted for flexible use in post-processing and extended analysis. Tabular reports are structured to allow direct export for use by spreadsheets, databases, and graphics software. The output formats for the various modules ensure easy compatibility with other systems models and databases. Current research is designing a detailed graphical user interface (GUI) to display and analyze results of GSAM runs.

GSAM output includes significant detail on production, consumption, technology use, resource status, and gas price by region over time. Additional economic variables detailing operator-view economic pro forma, as well as public sector benefit analysis, are also available from GSAM reports in the Production Accounting Module. The modular design provides the user with capabilities to focus analyses on items of interest and, by varying input or output options, create special application reports for use in further analysis. Additional information and flexible report formats are available to determine reservoir-specific production and economic summaries, regional, state or resource output, and national summaries.

Potentially most important and relevant to DOE are the GSAM summary outputs of technology-related variables. Technology summaries, including the number, types, costs, and benefits of various applications, are provided in standard reports. Technology market penetration and applicability in various regions or specific reservoir settings can be derived from these standard reports.

Quality control indicators are also included in all GSAM output. Internal consistency and external congruity provide users with assurance of data and model validity and plausibility. The level of disaggregation in GSAM provides the potential to generate output in formats similar to other, more aggregate models for direct comparison.

III. RESEARCH RESULTS AND ONGOING ACTIVITIES

GSAM research over the past year has substantially enhanced the accuracy, credibility, and comprehensiveness of the system. Ongoing work seeks to complete the transformation of GSAM into a viable analysis system for future DOE planning. This section documents the recent results and continuing efforts for GSAM development.

A. REVIEW WORKSHOP

1. Background

As part of its contract with FETC, ICF hosted two GSAM Review Workshops. The first one, held in Fairfax, Virginia, took place on February 5-6, 1997, and covered all aspects of GSAM, except for environmental topics. The second meeting, devoted to environmental aspects of GSAM, was held in Dallas, Texas on March 6, 1997. The participants at these meetings included experts in natural gas modeling from the government, the private sector, and academia.

The suggested improvements in the data, models, assumptions, and analytical processes of GSAM were based on critical review of the individual components of the model. Industry experts assessed the input data, key assumptions, technical and the economic procedures for processing all information and assumptions, and the format and content of output, much of which is used by other modules to complete a full GSAM assessment. This review was predicated on a familiarity with the full GSAM structure and principal uses of the analytical system by DOE.

The recommendations by the industry experts generated from these workshops can be grouped into the following categories:

- Reservoir data and modeling improvements;
- Exploration and production modeling and methodology improvements;
- GSAM system improvements and documentation;
- Demand, storage and integrating modeling improvements; and
- Environmental modeling improvements.

The GSAM Workshop provided important feedback from key industry and government experts in the areas of natural gas and oil exploration, production, and utilization. The sessions improved the understanding of the needs and concerns of both DOE and industry participants. The comments from the participants, when incorporated into GSAM, will allow FETC to further refine the capabilities of the

model to better serve key stakeholders. Upon approval from FETC, the full expansion of GSAM, consistent with recommendations of the GSAM Workshop panel, will provide a highly credible data source, analysis tool, and planning standard for DOE managers. The system will also provide the domestic gas industry with a publicly available tool for use in resource assessment and R&D evaluation.

2. Recommendations

Reservoir Data and Modeling Improvements

Industry experts made several recommendations for improving natural gas reservoir data and modeling. The data improvements include the addition of reservoir pressure data, the addition of more comprehensive data on Appalachian reservoirs, the addition of a better characterization of the undiscovered resource base, and the addition of a more comprehensive offshore Gulf of Mexico database. The reservoir modeling improvements include adding an ability to analyze stacked reservoirs and to better characterize the growth of discovered reserves over time.

Exploration and Production Model and Methodology Improvements

The work in this area complements the data development discussed above and allows the new and existing reservoir data to be fully utilized in improved GSAM assessment methods. Specific improvements include: updating and documenting input parameters, developing improved user interfaces, developing consistency in logic with oil E&P modeling, and expanding project selection criteria and constraints.

GSAM System Improvements and Documentation

The recent and proposed changes to various components of GSAM can improve the reliability and analytical capabilities of the model. In order to fully utilize these new assets, it is imperative that FETC maintain the overall system and its related documentation. Based on the work discussed in other sections and the direct recommendations of the GSAM industry experts, documentation and system enhancements are needed.

Procedures and Policies for GSAM Updates and Maintenance

It was determined that GSAM could be improved by documenting the methods, procedures, data sources, and recommended schedules to check, update, and verify input. Also, one should develop a comprehensive outline of what models and interfaces would need to be altered when new data become available. In addition, one should identify sources of data to be used to determine model input parameters whenever possible.

Compare GSAM Forecasts with Other Agencies' Forecasts

A variety of agencies, regional organizations, and professional groups provide estimates of future potential energy requirements or supplies. The assessments range in scope and type from national studies to focused local estimates, and from detailed, economically derived production estimates to generalized resource potential. Many of these are directly or indirectly comparable to key GSAM inputs or outputs. As GSAM is updated, it was suggested that one should compare key inputs, procedures, and findings with those from the EIA, USGS, the Gas Research Institute and the Potential Gas Committee.

Complete Additional Testing and Review

Once the entire GSAM system has been updated, it was recommended that the revised databases, modules, interfaces, and overall system be completely retested, validated, calibrated, and reviewed, consistent with previous research and the results documented appropriately.

Demand Module Improvements

The industry experts recognized a need to update and strengthen the downstream modeling in GSAM in order to enhance GSAM's ability to analyze key market issues. As a result, the industry experts made the following recommendations for improving the downstream modules of GSAM.

Provide for a More Detailed Characterization of the Forces Which Determine Natural Gas Demand

The industry experts recommended that the model incorporate interfuel competition (in the residential and commercial sectors) in projecting the demand for gas. They felt that this was important in order to properly simulate the affects of electric utility deregulation. With increased deregulation of the electric industry and the eventual lower electricity prices anticipated, gas demand for space heating and other heating loads will see increasing competitive pressure from electricity in the residential and commercial sectors.

Allow for the interregional transmission of electric power

The industry experts recommended that the GSAM be modified to incorporate a methodology that allows for the movement of electric power between regions. At present the GSAM Demand Module assumes that all of the power used in a demand region is generated in that region. This is important since a realistic evaluation of the impacts of electric industry deregulation will also require recognition that electricity can be moved among demand regions.

Incorporate turnover in capital stock to model lag time fuel switching

GSAM currently models only short term fuel switching. The industry experts recommended that a mathematical characterization should be developed to incorporate the lag times that are involved in fuel switching due to turnover in capital stock. Modifying GSAM to complement instantaneous fuel switching with gradual changes as suggested by the industry experts could substantially improve the simulation of market forces and their impacts on gas supply needs.

Annual Forecasting

Since the initial development of GSAM focused on the supply side of the industry, a more reduced form model of the downstream side was developed for integrated runs. At that time, it was decided to model the downstream industry in five year intervals. The industry experts recommended a more detailed modeling of the downstream industry. They suggested that to better characterize the downstream side of the market, the Demand, Integrating, and Storage Modules should be modified to operate on a yearly basis.

Improve the Storage Module of GSAM

Gas storage is an important component of the natural gas industry. With the move towards less regulation in the electric power industry, gas storage will become even more critical. Gas fired electric power plants will require reliable high capacity sources of gas available on short notice. High deliverability storage can fill that need. Technology can play an important role in creating a gas supply that is responsive to the electric utility power plant needs. Technology can increase the deliverability of existing storage and make economically attractive the development of new storage fields. The industry experts felt that storage is an important component of GSAM and should be enhanced to improve GSAM's ability to model future storage needs in a changing natural gas marketplace. In addition, peak shaving needs can only be captured by modeling multiple seasons. The future role of LNG in the marketplace will likely depend on future needs of peak shaving. Therefore, it is necessary for GSAM to have a peak season to adequately capture the role for LNG. In this regard, the industry experts made several recommendations which are described below.

Expand GSAM to Four Seasons

The two-season structure of the current GSAM Demand Module is adequate for simulating the effects that seasonal price changes have on seasonal gas demands and the effects that the total annual demand has on gas supply. However, two seasons do not adequately simulate the decisions that the gas industry must make regarding the capacity tradeoffs for pipelines, gas storage and peak shaving. With

only two seasons, the calculations for using and adding storage capacity versus pipeline capacity favor pipeline capacity, and peaking capacity is never found to be economic. The problem is that the average demand levels of two seasons fail to capture the dramatic short-term demands for gas that occur in cold winter periods. One way to address this problem is by adding two additional short-term seasons to the GSAM Demand Module. A three-day to five-day highest demand season is required to simulate peak shaving economics. The next highest demand season will need to be in the range of from 30 to 60 days to capture economic demand for high deliverability underground storage for either winter loads or electric power plant high demands. The final two seasons will be used for longer term seasonal storage withdrawals and for the warm weather storage injection period. Properly designed, these four seasons will greatly improve the ability of GSAM to realistically forecast the demands for peaking, underground storage, and pipeline capacity.

Reduce Natural Gas Storage Deliverability Decline Rates

Industry experience indicates that the current storage reservoir deliverability decline rate of five percent per year is too high. Workshop industry experts indicate that well workover and infill drilling activities are being used to reduce the actual annual deliverability decline rate to less than five percent. ICF will investigate the appropriate deliverability decline rate to use by contacting industry experts and conducting a literature search. The Storage Module will be modified to reduce the existing deliverability decline rate appropriately.

Increase Well Workover Cycle Time

Industry experience also indicates that maintenance of acceptable storage facility deliverability rates requires storage well workovers on about a five-year cycle, rather than the two-year cycle currently used in the GSAM Storage Module. It was mentioned that the Storage Module should be modified to increase the elapsed time between well workovers accordingly.

Use a Lower Bound on Storage Reservoir Use

Under a given scenario tested by GSAM, if a storage facility's operation is found to be uneconomic, the storage facility is completely unused in that time period. Industry experience indicates that a more realistic simulation of gas storage use would result if some minimum storage facility gas withdrawals and injections are required. The industry experts advocated modifying the Storage Module by adding a lower bound on the use of each storage facility.

Improve Reservoir Characterization of Existing Storage Reservoirs

The lack of adequate reservoir data for existing gas storage facilities in Appalachia resulted in a GSAM Storage Module design that does not allow investigation of the impacts that advanced technologies will have on the deliverability of existing storage reservoirs. The improved deliverability of existing storage to satisfy current gas industry needs is increasingly important. The industry experts suggested that GSAM be modified to allow for improvements in deliverability for existing storage.

Improve the Integrating Module of GSAM

The Integrating Module of GSAM takes the supply curves generated from the Exploration & Production Module, and the demand and storage information from their respective modules, and balances supply of and demand for natural gas. This equilibration is done for each region (supply/demand/other) as well as for each time period and season. A linear programming formulation, based on the concept of maximizing total surplus (consumer surplus plus producer surplus), is employed to compute equilibrium prices and quantities of gas, as well as the storage levels and resulting flows in the gas pipeline network. The industry experts made several recommendations for modifying the logic in order to more accurately simulate the real world.

Relax the "Perfect Foresight" Assumption

At present, the integrating linear program seeks to optimize decisions over all regions, years and seasons simultaneously. This approach is one of "perfect foresight" since the model is able to consider the entire time horizon. As was pointed out in the GSAM Workshop, this approach probably leads to the model "over-optimizing". It was re-commented that the model only look ahead a specified number of years (one year or five years for example), to better simulate actual behavior in the marketplace. The results and decisions would then be passed on to the next set of years.

Use Individual Regional Supply Curves

At present, even though individual regional supply curves are generated in the Exploration Production Module, a composite *national* supply curve is used in the integrating linear program. The composite national curve is then apportioned to the basins to generate a pseudo-regional supply curve. This approach can result in roundoff errors due to the imprecise nature of the apportioning. It was agreed that use of individual regional supply curves in the integrating LP would be preferred.

Incorporate the Effects of a Deregulated Gas Market on Increased Competition

It was determined that the Integrating Module should add aspects of the deregulated gas market to improve its modeling capability. Examples of these improvements include modifying distributor margins so that they can vary over time, and allowing the transportation model to include margin discounting in summer months for both pipeline and distributor transportation services.

Environmental Module Improvements

The workshop included a brief overview of GSAM as context for the structure and function of the EM. The discussion of the EM focused on the structure and approach, followed by application of the structure to two specific issue examples — control of hazardous air pollutants from gas exploration and production (E&P) operations and drilling waste management. Based on these presentations, the reviewers made some suggestions for improvements to the EM. The key recommendations of the reviewers are summarized below.

Recommendations

The recommendations made by the reviewers fall into three general categories:

- Coverage/level of reporting issues
- Data improvements
- Miscellaneous suggestions/improvements.

Each of these areas is discussed in more detail below.

1. Coverage/Level of Reporting

Several recommendations to address current limitations or enhance capabilities were made in this area, as described briefly below.

- **Reservoir Level Specificity.** There was some discussion among the reviewers about whether calculations at the reservoir level were more detailed than necessary. Use of play-level data may be adequate to capture the level of diversity, as well as providing a more manageable number of data inputs to GSAM. Aggregation to field level data may be another option. It is not clear whether a play or field level approach is feasible, but the reviewers felt that it may be worth investigating.
- **State or Congressional District Reporting.** Regardless of whether data are estimated at the reservoir or play level, the reviewers felt that it would be valuable for results to be reported at the state or Congressional district level. Given that one of the primary uses of this system (by DOE or industry) would be to provide information to public policy debates, the ability to

focus on the impacts in specific areas of interest to participants in the debate would be useful.

- Explicit Representation of Gas Plants. The need to explicitly address natural gas processing plants was clear from the discussion among reviewers. These plants, with their larger-sized equipment, are likely to be a primary target of upcoming regulations. Moreover, it is important when examining the effect of regulations to understand where gas is processed in the field and where it is sent to a gas plant for processing, since this affects the type and size of equipment at field locations.
- Layering of Reservoirs. Use of reservoir-level data to estimate field equipment and facilities can cause double-counting where reservoirs are layered in the subsurface (i.e., are produced using common surface facilities). While reviewers recognize that this may be difficult to address, without identifying these layered reservoirs and using their combined flow to estimate surface equipment/facilities, overstatement of the capacity and/or number of particular facilities or pieces of equipment could result.
- Access Issues. The reviewers discussed the need to be able to set certain areas (e.g., those on federal lands, certain areas of the OCS) off limits to exploration or to show that more stringent requirements applied in certain areas. This is fairly straightforward to accomplish and the reviewers recommended that it be implemented.

2. Data Improvements

Data quality and availability was recognized as the biggest limitation of the EM. The reviewers had numerous comments about the data currently used in the EM (although it was generally agreed to be the best available) and suggestions for improving the data upon which the EM is based, as described below.

- Group to Prioritize Data Needs. Through the discussion among reviewers it was clear that the potential volume of data to feed into the EM is huge. The reviewers recommended establishing a specific Work Group with the responsibility to identify data needs, set priorities, review quality control protocols, etc. To avoid getting lost in the details, this group could help to apply the 80/20 rule, focusing on the items that are expected to have the most value across upcoming environmental issues. This group should have representation from DOE and industry, possibly EPA and states.
- API Survey Data. API is conducting a nationwide survey of the equipment (tanks, dehydrators, compressors, pits, etc.) located at oil and gas fields and natural gas processing plants. When it becomes publicly available, the data from API's survey should represent an improvement over the existing (old) data and the current need to assume a constant size for glycol dehydrators, compressors, etc. The reviewers recommended incorporating these data as soon as they are available. This would include changing the current method of assuming a constant dehydrator or compressor size to sampling from a size distribution or another methods to link the largest units to the highest volume sites.
- API Tank Emissions Method. The reviewers recommended that the current AP-42 method for calculating air emissions from tanks be replaced with the new estimation methodology

developed by API and presented at the recent SPE/EPA Environmental Conference. The AP-42 method understates emission levels.

- Better Characterization of Air Emissions and Sources. While one of the existing segments of the EM examines emissions of hazardous air pollutants, several reviewers mentioned the need to understand emissions of other pollutants (e.g., NO_x) as well. This would include characterizing both the equipment that generates emissions and the level of emissions from that equipment. This recommendation is being driven by the possible impact of NO_x emission limits on future activity in the Green River Basin.
- Offshore Platforms, Other Offshore Data. Offshore operations, particularly deep water areas, will be the focus of much industry activity over the next few years. The reviewers felt that it was important that adequate data be available to characterize offshore platforms and operations so that these issues can be analyzed using the EM.
- Distance to Population Centers. For several upcoming regulatory issues, the reviewers felt that it would be helpful to incorporate either data on the population in the area surrounding the reservoir or data on the distance from the field to an urban area. Data on the latter should be available from API's survey. Data on the former is being developed by ICF under contract to API. Mark Rubin (API) indicated a willingness to make these data available to DOE for inclusion in the database for the EM.
- Locations of NORM Occurrence. The reviewers felt that the approach used in the EM could be particularly useful for an issue like NORM, so they suggested that any available data on NORM occurrence (by field, county, or other entity) be incorporated into the EM database.
- Downstream Environmental Data. Some of the reviewers suggested that data should be collected to facilitate analysis of certain downstream issues, such as refining (when the EM is expanded to oil), transportation right-of-ways, etc. Upcoming regulations may address gathering lines and pipelines in "sensitive" areas, so data to address these may also be useful. It was noted that environmental regulations on gas storage operations are also being ignored and that this limits full evaluation of the cost of gas storage.
- Drilling Waste Volume Data. Reviewers noted that something appeared to be wrong with the data value used for waste volume from air drilling (all solids, no liquid). They recommended that these data be reviewed and updated as appropriate.

3. Miscellaneous Suggestions/Improvements

The reviewers also had suggestions or recommended improvements in several other areas as described below. Some of these included changes to the GSAM model itself, as well as the EM.

- Current Environmental Costs. One reviewer questioned whether there was adequate understanding of current environmental costs. The reviewer went on to question whether the costs for new regulations were truly incremental. Moreover, it was felt that where DOE initiatives are aimed at reducing current compliance costs, a better understanding of current costs is required. As a result of this discussion, it was recommended that the current costs used in DOE's oil and gas models be examined to separate out (to the extent practical) current environmental compliance costs.

- Annual versus Longer-Term Decision-Making. GSAM incorporates incremental environmental compliance costs in its annual decision-making about whether to develop a reservoir. When regulations are being input over several years, this can conceivably create a situation where a reservoir is economic to develop in one year, but has to be shut-in or development curtailed a couple of years later due to new environmental requirements. The reviewers recommended that a method be developed whereby costs over the next several years could be considered before development decisions are made. While this implies perfect foresight (something avoided elsewhere in GSAM), it is not unreasonable to expect that, for environmental requirements that are often under development for several years, producers have a good idea what is coming and might make investment decisions accordingly.
- Translate EM from Spreadsheets to Program. The reviewers felt that the EM had reached a stage in its development where it should be moved from a series of spreadsheets to a programming language compatible with the other DOE models.
- Consideration of State Initiatives. DOE has traditionally focused primarily on environmental requirements at the federal level. A couple of reviewers suggested that an expanded focus to encompass more state level initiatives (in the EM and other DOE work) could be beneficial since the E&P industry is regulated mostly at the state level.
- Addressing Long Term Liability. The perception of long-term liability associated with certain actions can affect environmental compliance decision-making. While the reviewers had no specific suggestions for how this should be considered in the EM, they mentioned it as an area meriting further investigation.
- Additional Seasons in Storage/Demand Module. The EM reviewers echoed a recommendation received from the GSAM reviewers that two seasons does not allow adequate representation of market dynamics. They concurred with the recommendation (from the earlier GSAM workshop) to add more seasons to GSAM.

Conclusions

The reviewers felt that the EM is a valuable tool for contributing to public policy debates over the impact of future regulations. Industry representatives were interested in the broader application of a tool such as this to demonstrate the impact of regulatory requirements on the E&P industry (both oil and gas). While they had numerous suggestions for improvements to the data, the reviewers felt that the EM makes excellent use of currently available data to characterize operations and show the impact of changes in regulations on those operations. The basic structure of the EM was felt to be adequate to address a range of environmental issues.

The suggested improvements to the Environmental Module of GSAM will be further analyzed, evaluated and discussed with key DOE managers. DOE will determine the priorities for addressing these recommendations, determining whether they should be implemented in an improved version of the EM. To assist DOE in establishing these priorities, reviewers were asked to assign a high, medium, or low priority to each of the recommendations summarized above. These individual priorities have been

provided to DOE separately for review and evaluation. Future workshops will be conducted, as determined by DOE, to review changes and suggest additional improvements to the EM. The goal of this process is to make the EM an effective tool for evaluating regulatory changes and new technologies to provide input to public policy debates and DOE's environmental R&D planning.

B. GAS STORAGE

1. Background

New opportunities have been created for underground gas storage as a result of recent regulatory developments in the energy industry. The Federal Energy Regulatory Commission (FERC) Order 636 changed the economics of gas storage nationwide. Pipelines have been required to "unbundle" their various services so that pipeline users can select only what they need from among the transportation, storage, balancing and the other traditional pipeline services. At the same time, the shift from Modified Fixed Variable (MFV) rate design to Straight Fixed Variable (SFV) rate design has increased the costs of pipeline capacity relative to storage and peak shaving options. Finally, the secondary market in pipeline and storage services created by Order 636 gives potential gas users more flexibility in assembling combinations of gas delivery services to create reliable gas deliverability. In response to Order 636, the last two years have seen an explosion in proposals for gas storage projects.

Another major development affecting the demand for storage is the restructuring of the electric power industry. This trend began with the passage of the Public Utilities Regulatory Policies Act (PURPA) which allowed non-electric generators, or qualifying facilities, to provide electric power to electric utilities. Since 1978 substantial amounts of cogeneration and independent power capacity have come on line. Repeal of the Fuel Use Act enabled this capacity to be built with efficient gas-fired turbine technologies. The Energy Policy Act of 1992 and newly proposed FERC regulations will further the break-up of the electric power industry into independent generators and distribution utilities. The fuel of choice for most cogeneration and independent power has been, and probably will continue to be, natural gas. Since many of these units are load following units (peaking or intermediate), as opposed to baseload units, they use gas unevenly over time. In regions where electric power demand is greatest in the summer for air conditioning, this uneven usage could eventually decrease the need for storage.

ICF recently completed a project to modify GSAM to gain an understanding of the market for natural gas storage in order to eventually provide for rigorous evaluation of federal R&D opportunities in storage technologies. The project was divided into six tasks. Tasks 1, 3, and 5 were the analytical assignments and tasks 2, 4, and 6 were the written reports for the three analytical tasks. The analytical

assignments are identified as follows. Task 1 defines the storage market, including identification of existing and proposed storage facilities and their costs, development of an analytical basis for comparing the economics of gas storage with its competitors, and preliminary identification of where additional storage may be required. Task 3 required the development of a database and screening criteria for existing and potential storage reservoirs and modification of GSAM to evaluate the effects of technology changes on storage reservoirs in much the same way as on production reservoirs. Task 5 evaluated a range of alternative storage technologies under varying market conditions.

The primary objectives of this project were:

- (1) To identify market areas and end-use sectors where new natural gas underground storage capacity can be economically employed;
- (2) To develop a storage evaluation system that will provide the analytical tool to evaluate storage requirements under alternate economic, technology, and market conditions; and
- (3) To analyze the economic and technical feasibility of alternatives to conventional gas storage.

2. Results

Task 1

The major findings of the work in Task 1 are outlined in this section. Because storage services are often provided by capacity in different regions and numerous parties are involved in the development and use of storage, identifying the gas storage needs for a strictly end-user perspective and on a region-by-region basis is infeasible. The gas storage market, along with the entire gas industry, is undergoing major changes that affect investment decisions. Examples of these changes include:

- Pipeline rate design changes that have raised fixed pipeline costs, making storage generally more attractive than in the past;
- Pipeline rate design changes, rate discounting, and excess capacity in some regions which have made summer transportation rates less expensive;
- Gas pipeline companies are no longer the primary sources of storage services since Local Distribution Companies (LDCs) and gas marketers now control much of the storage capacity; and
- Surplus storage capacity appears to be available in the East North Central region.

The value of storage depends on the way it is used and the gas supply alternatives against which storage competes. Storage use varies from the conventional seasonal cycle of withdrawal during cold weather and refill during warmer months, to the intra-daily cycles that an electric utility may need during summer and winter. The gaseous supply alternatives to storage are pipeline capacity and peak shaving

supplies (liquefied natural gas and propane mixed with air). Gas also competes with fuel oils in the industrial and electric generation sectors where some facilities are dual-fueled.

The costs of the gas supply alternatives depend primarily on the number of days per year the gas delivery is needed. For periods over half of a year, pipeline capacity will be the least costly choice. For the very short term — roughly one to ten days per year — peak shaving supplies will typically be the least expensive in areas distant from gas production. The costs of storage fall between those of pipeline capacity and peak shaving — from a few days to possibly 150 days in areas distant from gas production.

Existing gas storage service costs vary widely, depending on both the type of storage and when the facility was completed. Typically, the least costly storage is that developed in depleted gas and oil reservoirs, where some existing subsurface and surface facilities may be used and pipeline connections may be available. The highest cost facilities are mined caverns in salt formations, where deliverabilities are highest and cycling times are shortest. In between these cost levels are those for storage facilities using aquifers. Under cost of service rate regulation, the storage charges for older, largely amortized storage facilities of the same type are always much less costly than for newer facilities. This historical downward trend in rates for storage will probably not be seen for those storage facilities that are now being allowed by the Federal Energy Regulatory Commission to charge "market based" rates.

Gas demand growth forecasts and recent regulatory changes have appeared to increase the demand for storage for several regions of the U.S. The growth in unbalanced seasonal demand from the residential and commercial sectors is expected to be greatest in the South Atlantic, West South Central, California, and combined Middle Atlantic/New England regions. Examples of the complications that prevent these areas from increasing storage capacity are: 1) except for West Virginia, the South Atlantic has no known storage reservoir sites near the major population areas and the transportation distance from storage in Louisiana and Mississippi to this region typically makes storage an uneconomic alternative to pipeline capacity; 2) the short distances from gas production to demand areas makes pipeline capacity a tough competitor for storage in the West South Central region; 3) California has a surplus of pipeline capacity from Canadian and U.S. supply areas that should compete favorably with any new storage capacity; and 4) the lack of geology favorable to gas storage in New England makes this region dependent on other regions, such as the Middle Atlantic, for storage service.

Existing and potential gas storage capacities in the East North Central, Middle Atlantic, and the South Atlantic (West Virginia) regions are capable of meeting storage needs in several other market regions. The location of economic gas storage capacity for use in a given demand region will depend on

the cost of the storage service, the costs of gas transportation to the storage region, and the cost of gas transportation from the storage region to the demand region, compared with these same costs for storage in another region.

In 1994 there were 375 gas storage facilities in the U.S., with working gas capacities totaling 3,695 billion cubic feet and deliverability rates totaling nearly 68 billion cubic feet per day. These facilities included depleted gas and oil reservoirs, aquifers, and salt caverns. Proposed new facilities of the same three types total 81 projects with 495 billion cubic feet of working gas capacity and about 21 billion cubic feet per day of deliverability.

The deliverability of the proposed storage projects will be substantially higher than for the existing facilities. The planned projects would add about 13 percent to working gas capacity and nearly 31 percent to deliverability. This increased deliverability trend is in response to higher values being placed on high deliverability storage to take advantage of gas price volatility (attempts to buy low and sell high) and to be more competitive with peak shaving supplies.

In addition to conventional seasonal storage for reducing the cost of winter supplies, gas is stored today for short-term peak supplies (in high deliverability facilities), to balance gas volumes that shippers place into pipelines with the amounts they take out (to avoid paying imbalance penalties), to hedge against price changes, to speculate on price changes, and to provide emergency supply services (by marketers and pipelines).

In the past, the principal investors in storage facilities were the gas companies — mostly pipelines (or their subsidiaries) and LDCs. The primary subscribers to the storage service were the LDCs which needed storage to minimize their costs of winter supplies for serving the temperature sensitive loads of residential and commercial customers. Today, investors in new storage facilities are more apt to be marketers who are expanding the supply services they offer and entrepreneurs who develop storage to sell the service. In addition to the LDCs, storage service subscribers are now more likely to include industrial consumers and gas marketers.

The new players in gas storage and their varying reasons for investing and using this service tend to complicate simulation of the decision making process that is required for developing the economics of storage compared to its alternatives.

Task 3

The gas storage module for GSAM was tested in four supply/demand and technology scenarios that provided insights on how economic and technological changes could affect the demand for gas storage capacity. In other words, an attempt was made to examine potential requirements for gas storage that account for several possible futures in the North American gas market. A Base Case, that represents the status quo, was used as a benchmark against the other three cases. The Low Demand and High Demand Cases differ from the Base Case in the amount of gas demand growth they experience for fueling electric power generation. In the Low Demand Case, coal wins the competition with gas for this growth sector. In the High Demand Case, gas wins the competition for power generation fuel. In the Technology Case, aggressive advancements are assumed in technology for both exploration and production and storage reservoirs. The major findings from these tests are outlined in this section.

Among the four scenarios tested, the greatest use of storage as measured by annual gas extraction rates occurs in the Technology Case. For this case total U.S. gas extraction declines from 1,185 Bcf in the year 2000 to 854 Bcf in 2010. The Base Case uses the least amount of storage of 1,077 to 765 Bcf between the years 2000 and 2010. Table III-1 summarizes the total U.S. forecast gas extraction rates for each of the four cases. In all cases, the use of storage declines by 26 to 29 percent between 2000 and 2010. This decline in storage utilization occurs because most of the growth in gas demand is for power generation rather than for the temperature-sensitive residential and commercial loads that improve the economics for gas storage.

Table III-1
Extraction Rates for Storage Gas, Bcf

	<u>2000</u>	<u>2005</u>	<u>2010</u>
Base Case	1,077	905	765
Low Demand Case	1,144	1,013	843
High Demand Case	1,098	931	776
Technology Case	1,185	1,050	854

The number of new gas storage reservoirs developed varies from four in the Base Case to 11 in the Technology Case. Only four demand regions are projected to add new storage capacity in any of the cases analyzed, the East North Central, West South Central, Mountain South, and California. In the Low

Demand Case, eight new storage facilities are forecast as required in the U.S., while in the High Demand Case, the projection is for development of six new storage facilities.

In addition to selecting reservoirs for development as new storage facilities, the Integrating Module also selects which of the existing storage facilities are economic to use. Annual utilization of existing storage capacity varied widely among the regions and the scenarios tested. The higher utilization rates are in the Middle Atlantic, South Atlantic, East South Central and California regions. These rates varied from 90 to 100 percent utilization. The lower utilization rates appeared in the East North Central, West North Central, and Pacific Northwest regions. The utilization rates among these latter four regions varied from zero to 60 percent. These results indicate that in the Middle Atlantic, South Atlantic, East South Central, and California regions, the reservoir deliverability received per unit of service cost is better with most of the existing storage facilities than it would be with new facilities. On the other hand, these results indicate that the East North Central, West North Central, and Pacific Northwest regions, probably have more storage capacity than the market demands. In the case of the East North Central region and California, these results indicate that some existing storage facilities are not as economic as new facilities, because these two regions are among the four regions where new facilities are forecast to be developed.

The existing storage facilities selected for use by the storage module also change with the scenario analyzed. For example, in the Base Case, 13 of the 23 existing storage facilities in the Mountain North region were selected for use. In the Low Demand Case, one additional storage facility was selected for use, bringing the total to 14 active storage facilities in the Mountain North region. Considering all regions, the Low Demand Case had 10 existing storage reservoirs scattered among four regions added to the Base Case total. In the High Demand and Technology Cases, several existing storage facilities were added to the Base Case roster and several were deleted. In the High Demand Case, the larger decline in storage demand resulted in deletion of three storage reservoirs that were used in the Base Case. In the Technology Case, the single reservoir deletion from the list of existing storage reservoirs used in the Base Case indicates that the more aggressive technology advancements assumed for this scenario has improved the economics of using some reservoirs relative to others. In other words, some of the idle reservoirs of the Base Case are more susceptible to technology improvements than those used in the Base Case.

The High Demand Case requires less gas storage capacity because essentially all of the gas demand increase over the Base Case occurs in the power generation sector. This added load takes the place of storage because gas use for generation is typically a summer load that reduces the seasonality of

demand, making better year-round use of pipeline capacity. The Low Demand Case has less electric generation demand and has greater seasonal swings in gas demand, improving the economics for storage.

Substantial pipeline capacity is added to transport gas from the Gulf of Mexico West to Texas Gulf Coast and from the Mid-Continent to Mountain North regions in all four scenarios. Other significant pipeline capacity additions are projected from the San Juan to Mountain North and from the Permian to San Juan. The regions receiving gas through these expansions are not included in regions projected to need gas storage because in these instances pipeline capacity was determined to be more economic than storage.

Prices for the gas storage service used in the four scenarios vary widely within each storage region and among the four scenarios tested. Prices, based on company tariff rates for existing facilities and reservoir development cost estimates for new storage facilities, vary from as little as \$0.17 to as much as \$1.63 per Mcf stored. The lower prices are typically for older facilities that had lower investments for facility development and for the base gas.

Because GSAM is structured to recognize only two seasons and the winter season is 151 days long, the economic advantage of gas storage is understated in this study. Since there is no recognition of the higher winter demand that typically occurs for shorter periods, the full advantage of both peak shaving and shorter-cycle storage cannot be determined. As structured now, gas pipeline capacity is justified over 151 days of constant demand. This constant demand can be an average of 151 days that have peak gas demands several times the average demand. Since pipeline capacity rarely can be justified for the gas demands of the coldest ten to 30 days of winter, this average winter load is unrealistic.

Despite the understatement of the demand for gas storage, this study does support anecdotal information from the trade press and from contacts with storage operators that storage capacity is overbuilt in several regions. Regions where additional storage capacity will be required are identified. The differences in the need for storage have been determined, depending on whether or not gas wins in the competition with coal for the power generation market and on the level of technology advancement assumed.

Task 5

The gas storage module for GSAM was used to test two comparison cases involving four supply/demand and technology scenarios.

In the first comparison, aggressive technology advancement assumptions were added to a Base Case, creating a Technology Case. The Base Case represents essentially the status quo in gas markets and evolutionary technology advancement. In this comparison, the Technology Case resulted in more use of storage, lower cost storage, and improved storage performance. In the second comparison, the same aggressive technology advancement assumptions were added to a High Demand Case, creating a High Demand Technology Case. The High Demand Case differs from the Base Case in the amount of gas demand growth experienced, primarily for fueling electric power generation. In the High Demand Case, gas wins the future competition with coal for increasing shares of power generation fuel. As in the first comparison, the addition of improved technology results in more use of storage, lower cost storage, and improved storage performance. In both of the higher technology cases, aggressive advancements are assumed in technology for both exploration and production and for storage reservoirs. The major findings from testing these four scenarios are listed below.

Among the four scenarios tested, the larger use of storage as measured by annual gas extraction rates occurs in the Technology Case, wherein total U.S. gas extraction declines from 1,185 Bcf in the year 2000 to 854 Bcf in 2010. The Base Case uses the least amount of storage at 1,077 to 765 Bcf between the years 2000 and 2010. In both of the case comparisons, the addition of aggressive technology increases the need for storage, as shown in Table III-2.

Table III-2
Extraction Rates for Storage Gas, Bcf

Comparison Cases	<u>2000</u>	<u>2005</u>	<u>2010</u>
Base Case	1,077	905	765
Technology Case	1,185	1,050	854
High Demand Case	1,098	931	776
High Demand/Tech Case	1,173	1,021	831

In all four cases, the use of storage declines by 28 to 29 percent between 2000 and 2010. There are two reasons for this decline in storage utilization: 1) most of the growth in gas demand is for power generation where storage economics are disadvantaged rather than for the temperature-sensitive residential and commercial loads that improve the economics for gas storage and 2) gas deliverability from storage reservoirs is assumed to decline at five percent per year.

The number of new gas storage reservoirs developed varies from four in the Base Case to 11 in the Technology Case. Only four demand regions are projected to add new storage capacity in any of the cases analyzed, the East North Central, West South Central, Mountain South, and California. As in the case of total storage capacity utilized, the two higher technology cases resulted in more demand for new storage capacity. Table III-3 summarizes the numbers of new storage facilities selected for the two comparisons.

Table III-3
Summary Of New Storage Facilities

Region	Base Case	Technology Case	High Demand Case	High Demand Tech Case
East North Central	1	2	1	1
West South Central	1	2	3	2
Mountain South	0	5	0	3
California	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>
Totals	4	11	6	8

The High Demand Technology Case shows the combined effects of the High Demand and Technology Cases. The number of new storage facilities added in the High Demand Technology Case are lower than in the Technology Case because of the increased power generation load that goes with the High Demand assumptions. This added load takes the place of storage because gas use for generation is typically a summer load that reduces the seasonality of demand, making better year-round use of pipeline capacity. However, two more new storage facilities are added in the High Demand Technology Case compared to the High Demand Case.

Typically, the impact on a potential storage reservoir from adding aggressive technology advancement to a given scenario: 1) raises the volume of working gas available in the reservoir, 2) increases reservoir deliverability, 3) raises the levelized investment cost, and 4) lowers the total fixed costs. These changes are observed in both of the comparisons made wherein improved technology assumptions were added to the Base and High Demand Cases.

Substantial pipeline capacity is added to transport gas from the Mountain North to Mid-Continent, Gulf of Mexico West to Texas Gulf Coast, and from the Mountain North to San Juan regions in all four scenarios. Other significant pipeline capacity additions are projected from Alberta to Canada East and into the U.S. Northeast in all four scenarios and from the San Juan to the Permian in the two higher technology cases. Significantly, the two higher technology cases projected less demand for

additional capacity on TransCanada Pipelines than the Base and High Demand Cases. This increased U.S. gas supply at lower prices, reducing dependence on Canadian imports. The regions receiving gas through these pipeline expansions are not included in regions projected to need gas storage because in these instances pipeline capacity was determined to be more economic than storage.

Prices for the gas storage service used in the four scenarios vary widely within each storage region and among the four scenarios tested. Prices, based on company tariff rates for existing facilities and reservoir development cost estimates for new storage facilities, vary from as little as \$0.11 to \$1.63 per Mcf stored. The lower prices are typically for older facilities that had lower investments for facility development and for the cushion gas.

3. Conclusions and Remaining Work

At the recent GSAM Review Workshop February 5-6, 1997, the reviewers suggested a variety of improvements that would make the storage model more comprehensive and therefore useful in subsequent analyses. The specific recommendations for storage can be found in the Peer Review section of this report.

C. TESTING AND VALIDATION

1. Background

As part of the ongoing efforts directed towards development of GSAM, testing and validation activities were undertaken for FETC. This involved significant engineering, geologic, economic, and full systems checks to satisfy reasonable concerns about accuracy, precision and consistency of the GSAM analytical procedures and results.

This process is an important part of the overall model development, and helps in the verification of proper functioning of the various modules of GSAM, the interfaces between the modules, and the overall model itself. For each of the modules considered, the testing and validation process consisted of a series of simulation runs where input parameters were varied over a reasonable range of possibilities, and the evaluation of the results and their sensitivities to the variation of the parameters involved. Tests were planned for the upstream and downstream modules, including the Reservoir Performance Module, the Exploration and Production Module, the Storage Module, and the Demand and Integrating Module.

Reservoir Performance Module

In testing the Reservoir Performance Module, a broad range of reservoir and performance parameters were evaluated. Each sub-module is dedicated to a particular type-curve computational analysis, relating to conventional radial flow, conventional linear flow, dual porosity radial flow, dual porosity linear flow, conventional water drive, or unconventional coal and shale reservoirs. Each was subjected to this testing and validation process. The range of values for the different parameters involved in the testing and validation of the type curve computations are given in Table III-4 below:

Table III-4
Type Curve Analysis for Testing and Validation

	Module	Permeability (MD Ft)	Porosity (%)	Well Spacing (Acres)	System Pressure (PSIA)	Skin (Dimensionless)
Conventional	1	1 to 50	10 to 30	80 to 640	300 to 1000	-1 to 8
Tight	2	0.001 to 0.1	-	40 to 320	100 to 1000	-6 to 4
Natural Fractured	4	0.01 to 0.20	-	40 to 320	100 to 1000	-6 to 4
Waterdrive	5	50 to 4000	2 to 150	80 to 640	100 to 1000	2 to 5
Coal/Shale *	6	50 to 750	-	10 to 160	-	1 to 50

Since the Reservoir Performance Module is also responsible for project-level economic feasibility evaluations, calculations to determine the minimum acceptable gas price for each individual reservoir in the GSAM database were also performed. The testing and validation, therefore, encompassed assessment of the impacts on the Reservoir Performance Module, including evaluation of the selected reservoirs over a variety of economic, policy and regulatory regimes. These scenarios could include variations in the prices received for the required initial investments in drilling, facilities, stimulation treatments, or operating costs, variation in production taxes, state income taxes, federal income taxes, or depreciation schedules. The results were checked by scrutinizing the various project pro-forma files generated by the Reservoir Performance Module, as well as by comparing the results with spreadsheet calculations.

Exploration and Production Module

The Exploration and Production Module was calibrated using two alternative undiscovered resource descriptions (the bank files) with different combinations of fields, reservoirs, and geologic

plays. Inputs to the Exploration and Production Module were generated using the Reservoir Performance Module. Individual input bank files represent unique development technology scenarios, various policy alternatives, and/or environmental requirements and regulatory constraints. The two input bank files used for the testing and validation process provide easily predictable and analyzable calibration runs.

Exploration technology was evaluated under three separate technology levels, random or blanket exploration drilling, current technology to eliminate drilling for smaller reservoirs due to better geologic or geophysical understanding, and perfect knowledge of reservoir size distribution. Results from the random and current technology cases were tested and compared against the historic activities of drilling levels, reserve additions, and gas resource discoveries.

The development activities predicted by the module were tested in a manner consistent with exploration activities, using the results and output for the two undiscovered resource data sets (bank files). Testing included sensitivity to variation in gas price forecasts on the timing of the development of various reservoirs in diverse regions. Additionally, the algorithms were tested for adjusting base costs as utilized in the Reservoir Performance Module to future costs based on market conditions. Additional development activities, including infill drilling and recompleting of existing wells, were checked using the results from the other segments of GSAM. The E&P Module was also validated by testing and comparing the relative economic attractiveness of infill drilling or recompletion options, including the appropriate evaluation of acceleration economics. Testing also included verification of drilling cost adjustment methods and reservoir bank file accuracy as it reflects additional development productivity and project economics.

Storage Module

Four cases were tested to determine the effects on storage demand that result from changes in economic and technology scenarios. A Base Case, using the *status quo* for supply, demand, and price parameters, provided the benchmark against which the other three cases were compared. Four of the Base Case assumptions were common to all four of the scenarios. They were: 1) gas continues to be exported from the U.S. to Mexico, 2) gas from Sable Island, Nova Scotia begins flowing into New England by 1995, 3) the Northern Border Pipeline capacity expansion of 700 million cubic feet per day is in service between 2000 and 2005, and 4) there are no major changes in environmental regulations through the forecast period to 2010. Two scenarios were tested that dealt with economic changes from the Base Case. They were a Low Demand Case and a High Demand Case. The fourth scenario tested, the Technology Case, assumed that E&P technology advanced aggressively for both producing reservoirs and storage

reservoirs, reducing the cost of finding, producing, and storing gas, primarily through improved well completion designs and practices. Descriptions of these four scenarios are summarized in Table III-5 below:

**Table III-5
Scenario Summary**

Base Case	Low Demand Case	High Demand Case	Technology Case
Current electric market for gas	Coal use increases in electric market	Gas use increases in electric market	Current electric market for gas
Evolutionary E&P technology	Evolutionary E&P technology	Evolutionary E&P technology	Aggressive E&P technology for producing & storage reservoirs
Current environmental rules	Current environmental rules	Current environmental rules	Current environmental rules
Expand Northern Border	Expand Northern Border	Expand Northern Border	Expand Northern Border
Add Sable Island pipeline	Add Sable Island pipeline	Add Sable Island pipeline	Add Sable Island pipeline
Export gas to Mexico	Export gas to Mexico	Export gas to Mexico	Export gas to Mexico

Demand and Integrating Modules

The Demand and Integrating Modules were tested by adjusting various factors in the pipeline network, as well as relevant demand and supply figures. In particular, the tests included:

- (1) Restricted pipeline construction;
- (2) Reduced cost pipeline construction;
- (3) Restricted supply (limited exploration), normal demand;
- (4) Normal supply, restricted demand (heavy coal use); and
- (5) Normal supply, high demand (restricted coal use).

While the first two sets of changes were adopted for all of the links in the network, the remaining tests were applied on a regional basis to evaluate the impacts on price, regional production, and exploration and production activities. The particular tests that were performed include:

- (1) High demand in New England, low in Mid-West, normal supply;
- (2) Low demand in Mid-West, normal elsewhere, normal supply;
- (3) High demand in Mid-West, normal elsewhere, normal supply;
- (4) High California Demand, normal elsewhere, high Rockies supply; and
- (5) Low California Demand, normal elsewhere, low Rockies supply.

2. Results

Reservoir Performance Module

The results of the evaluation indicate that the Reservoir Performance Module of GSAM is predicting production and pressure response consistently with engineering routines and equations used and the key reservoir and drilling and completion techniques considered. Better reservoir properties in terms of thicker net pays, larger drainage areas, higher permeabilities and porosities, and larger tubing installations, lead to higher initial production rates and generally larger volumes of total gas recovered.

For conventional reservoirs, thicker reservoirs lead to higher initial production rates, but the rates decline faster than for thinner reservoirs (see Figures III-1 and III-2). Improved well-spacing, permeability, and porosity also substantially increase production rates and ultimate recoveries, but not always the percent of original gas-in-place extracted. In the more productive reservoir settings, tubing size can limit initial production capacity and control early rates. System pressure changes do not significantly alter productive potential, but lower inlet pressures can decrease abandonment pressure and improve ultimate recovery.

For tight gas reservoirs, thicker reservoirs yield more gas production, but tubing size and fracture length are more important factors in reservoir production. Fracture conductivity has a minimal effect on reservoir performance, but fracture skin is a key variable. For naturally fractured reservoirs, thicker reservoirs yield more production, but skin and tubing size have the largest overall impact on production. As with the other resource types, thickness of the reservoir is a key production attribute, but less than in conventional reservoirs. The spacing and permeability of natural fractures are also key variables impacting reservoir performance in dual porosity-permeability zones.

In water drive reservoirs, the larger the aquifer, the higher the production rate is until water breakthrough (coning) occurs. However, the stronger or larger the aquifer is, the higher the abandonment pressure and therefore the lower the overall recovery. This is a key aspect of producing a waterdrive reservoir. Higher production rates, either through lower restrictions in primary wells or by infill drilling, provides the opportunity to out-produce the water encroachment and can have a marked positive impact on ultimate recovery. Lower permeability slows water encroachment and limits pressure support. This allows more gas to be produced by lowering the abandonment pressure. However, production decline can set in earlier, limiting production rates and the ability to out-produce the water.

Figure III-1
Effect of Reservoir Thickness on a Conventional Radial Flow Reservoir

Figure III-2
Effect of Well Spacing on a Conventional Radial Flow Reservoir

For dry coal bed methane reservoirs, lower skin values lead to better production, but for wet coal bed methane reservoirs, skin values have very little effect on productivity. Coal and shale properties, particularly gas content per ton, are the most significant determinants of productivity and recovery. This characterization of the resource is consistent with the development history of the coalbed methane and devonian shale resources. Generally, the productivity of the resource is locally specific and highly dependent on the properties of the gas bearing matrix.

Storage Module

As described in the background section, there were four scenarios under which the storage module was tested in conjunction with the Demand and Integrating Modules: a Base Case, a Low Demand Case, a High Demand Case, and an Advanced Technology Case (for both production and storage reservoirs). All of the cases assume that only 50 percent of the working gas capacity for each active gas storage reservoir is utilized in a year. Although the future average annual capacity utilization of gas storage reservoirs is unknown, an initial assumption of 70 percent utilization resulted in essentially no new storage capacity being developed. Even at the 50 percent level for storage capacity utilization, many existing storage reservoirs are not chosen for operation by the storage module. The operation of the integrating linear program for finding optimal solutions to balancing supply and demand and the seasonal construction of GSAM both contribute to the low level of storage demand found in the four cases investigated. Although the results of the four test scenarios are not considered to be precise regarding the demand for storage, for the reasons described above, they do support the conventional wisdom that storage capacity is in surplus in some parts of the U.S.

In all four scenarios, the demand for gas storage declines over the forecast period. There are two reasons for this decline. First is the model assumption that storage reservoir deliverability declines by five percent each year. For those reservoirs that have lower deliverabilities, this decline sometimes means that the working gas available for withdrawal cannot all be extracted in the 151-day winter period. Thus, depending on their maximum gas extraction rates, the volume that can be withdrawn from individual reservoirs tends to decline unevenly during the 1995 to 2010 forecast period. The demand for new storage facility development is inadequate to make up for these annual losses in withdrawal capacity. As explained earlier, the demand for new storage would likely be much larger if the GSAM winter season were structured to deal with shorter peak demands rather than just a single average winter demand. The second reason for the decline in storage use is that most of the gas demand increases forecast are for electric power generation, rather than for temperature sensitive residential and commercial loads. With

these seasonal loads making up a smaller part of total gas demand, the economic need for storage is reduced.

In the process of optimizing gas supply to meet growing demand, GSAM found that the efficient approach to increased gas deliveries was a mixture of adding gas storage capacity and more gas pipeline capacity. The following table shows where pipeline expansions occur, when the expansions began, and how much pipeline capacity was demanded by the year 2010, for the four cases analyzed. By far the larger expansions were needed from the Gulf of Mexico West to the Texas Gulf Coast and from the Mid-Continent to the Mountain North region, for all four scenarios. Also there was a major expansion on TransCanada Pipelines from Alberta to Canada East for the High Demand Case.

The number of new gas storage facilities selected by the Demand and Integrating Modules for use between 2000 and 2010 varies from four for the Base Case to 11 for the Technology Case. All of the new storage facilities are forecast to start up in the year 2000. The Demand and Integrating Modules select new reservoirs in only four regions for the four scenarios tested. Thus, of the 12 U.S. demand regions in GSAM, eight require no new storage capacity under any of the scenarios analyzed. The only region that has new storage capacity added in all four cases analyzed is California. The Technology and Low Demand Cases require the most new storage facilities at 11 and 8 reservoirs, respectively.

Across the four cases studied, the projected utilization of existing working gas capacity in the ten regions that have underground storage facilities varies from zero to 100 percent. As an example, neither of the two storage facilities in the Pacific Northwest region are selected for use. In the Base, High Demand and Technology Cases, gas demand growth in the Pacific Northwest is projected to be handled by additional pipeline capacity from the Rockies Foreland supply area. In the Low Demand Case, neither storage or new pipeline capacity are required for the Pacific Northwest. At the other extreme, the only existing storage reservoir in the Mountain South states of New Mexico and Arizona is always used. Similarly, in the Middle Atlantic and South Atlantic regions, storage capacity utilization varies from 97 to 100 percent in the four cases studied. In the other six regions storage capacity utilization ranges from 12 to 91 percent.

The GSAM net U.S. gas supply forecasts that support the storage demand results of this study vary from a low of 19,278 Bcf in the Low Demand Case for the year 1995 to a high of 25,708 Bcf for the year 2010 in the High Demand Case. These supply figures include U.S. gas production and peak shaving volumes, but exclude imports. Between 1995 and 2010 gas imports from Canada continue to grow as they have in recent years. By 2010 Canadian gas supply to the U.S. in the Base Case grows by 15

percent, reaching 3,245 Bcf. In the Low Demand Case the 2010 total is 2,948 Bcf, an increase from 1995 of less than five percent. Even less Canadian gas is needed to meet U.S. demand by 2010 in the Technology Case, as U.S. supply costs are lowered and domestic supply increases. In the Technology Case, the growth in Canadian gas imports from 1995 is only a little over one percent, reaching 2,827 Bcf in 2010.

Demand and Integrating Modules

The Demand and Integrating Modules were tested by varying the levels of demand and supply in various regions, as well as the link costs and pipeline expansion constraints. Often, since the pipeline network is comprised of many interdependent components, a change in one area, such as increasing a region's demand level, will have an effect on other areas. The model will capture not only the first order effects--demand in one region increasing means that prices in that region will go up, for example-- but also other effects due to the interdependence of regions and links in the network.

The following tests were performed on the Demand and Integrating Module:

- (1) Restricted pipeline case, only existing pipeline available in the network, no pipeline expansion;
- (2) Decreased pipeline costs case, the levelized investment costs were decreased by 20%;
- (3) Higher residential demand for New England and lower residential demand for the Midwest (East North Central and West North Central) than the base case;
- (4) Lower residential demand for the Midwest than the base case;
- (5) Higher residential demand for the Midwest than the base case;
- (6) Lower Rockies supply and lower California demand than the base case; and
- (7) Higher Rockies supply and higher California demand than the base case.

In the first test, the effect on the entire network of not allowing new pipeline expansion was measured. By the year 2010, under the base case in which new pipeline is allowed to come on line, over all the links, there is 361.762 Tcf/year of capacity. In the restricted case, this figure declines to only 354.271 Tcf/year, a net loss of some 7.491 Tcf/year of capacity. An in-depth examination of these numbers reveals that for some links, there is no actual change in the optimal capacity of the pipeline as chosen by the model. This occurs since under the less restrictive base case, no new pipeline would have been activated for these links. However, for certain links, there is a sharp difference between the optimal capacities chosen by the model under the two cases.

When pipeline expansion is not allowed, the amount of gas that can flow along the network should decrease, or possibly in some regions remain the same. In aggregate, this conclusion was validated in the GSAM runs. When there is less capacity to transport gas, the prices to the end-users should rise reflecting the lack of efficient, cost effective pipelines.

In the second test, the investment costs for new pipeline were decreased by 20%. This reduction in costs was relatively minor in that the supply and demand values were essentially the same as the base case. For example, in 2010, total supplies for the base case were 31.93 Tcf and under the reduced costs case this figure was 31.99 Tcf. The wellhead and wholesale prices also did not change dramatically, with the maximum average price difference between the two cases for the years 2000, 2005, and 2010 being \$0.01 for supply prices and \$0.04 for wholesale prices.

The reduction in investment costs did affect eight of the 74 links. In particular, versus the base case, the model selected different capacities for these links, and in most cases it was an increase in the pipeline capacity. As one might expect, the 20% reduction in levelized investment costs did not affect each link in the same way. In particular, for those pipelines with larger levelized investment costs, a 20% drop results in an overall decrease to the system which is larger than for those links with smaller costs. Since the integrating linear program is making its investment and operating decisions based on overall system costs, this 20% decline should favor those links with larger costs.

In the third set of tests, the residential demand for New England was increased and the residential demand for the Midwest (East North Central and West North Central) was lowered. These changes were for the years 2000, 2005, and 2010. For New England, GSAM determines how this additional customer demand would be satisfied most cost effectively. In the GSAM integrating linear program, the customer demand at a node is one of seven "levers" that can be adjusted. The sum of the entries for arrows leading in should equal the sum of the entries for arrows leading out when supply and demand are balanced. For the New England node, the model selected to decrease the net flow or transport of gas as the most cost effective approach.

For the Midwest, the decrease in customer demand is constructed by adjusting the net flow in to the nodes for ENC and WNC. As well, there are smaller changes in the storage and interruption levels. The reduced net flow of ENC (flow in to ENC -flow out from ENC) accounts for most of the drop in demand.

The total flow in to ENC in the year 2010 dropped by 396.2 Bcf (from 5251.8 to 4855.6). The East North Central region can receive gas shipments from supply nodes as well as other demand nodes. In particular, Appalachia (APP), Alberta (ALB), Mid-west (MW), and Arkla-East Texas (AET) are the production sites that transport gas to the demand nodes ENC, East South Central (ESC), and West North Central (WNC). All else being equal, GSAM decreases the flow along those links which are the least cost effective in its optimization calculations. Taking the wellhead price plus the transportation cost for the supply nodes and the citygate or wholesale price plus the transportation cost for the demand nodes, we see that GSAM does in fact achieve these ends.

In the next two tests, the residential demand for ENC and WNC was lowered and raised above that of the Base Case, with no other changes. The changed demand in the Midwest produces a series of adjustments that ultimately lead to an increase in the production in Appalachia. In Step 1, demand increases in the Midwest under the three scenarios considered (low demand, base case, high demand). Since the price of gas in ENC rises from low demand to base case to the high demand scenario, less (or the same amount of) gas should leave from ENC to go to other nodes. This observation was validated in the output. Namely, the flow from ENC to Canada East and Mid-Atlantic stayed the same but the flow from ENC to Appalachia decreased, reflecting, all things being equal, the higher prices in ENC. This decrease in flow from ENC to Appalachia constitutes Step three of the adjustment process. In the fourth and last step, Appalachia, unable to receive as much gas from ENC in the high demand case as it had in the other two, increased its production to make up for the shortfall.

3. Conclusions and Remaining Work

During the past year, GSAM was subjected to a broad range of tests, validations, and calibration work. These comprehensive tests ranged from individual performance parameter validation in a select group of well defined reservoirs to complete testing of all components of GSAM in series validation (ensuring changes in the Resource Module correctly and consistently impact reservoir production costs, economics, exploration and production decisions, and accounting functions in various segments of the model).

The results of these tests indicate that individual modules are functioning correctly and that interfaces are structured correctly. The results of efforts have identified areas for additional development work that should be considered by FETC. However, the results indicate that GSAM can be used for required analysis and to generate accurate results.

The testing and validation effort provided the framework for the GSAM Review Meeting.

At the current time, the testing and validation is nearly complete, and ICF anticipates full completion in the near future.

D. *UPDATED UPSTREAM/DOWNSTREAM DATA AND MODELS*

1. Background

As part of GSAM's continuing development, ICF has updated various cost equations and input data used in the upstream and downstream models. In what follows, we report on these recent modifications and developments. The general theme has been to use more up-to-date data, from respected sources, and both expand and update our current system.

2. Results

Update of Drilling and Completion Costs

The Reservoir Performance Module of GSAM calculates drilling and completion costs based on the reservoir depth. For each supply region, a third-order equation is used to estimate these costs given a certain depth. In order to keep GSAM current, these equations were recently updated using more recent data.

GSAM's drilling and completion costs were based on "1995 Drilling Costs," published by the Joint Association Survey (JAS). This report provides 1995 United States drilling cost data on a state and sub-state basis. The data, which include number of wells, total footage drilled, and total drilling costs, are reported for 10 different well-depth intervals within each state/region.

For each GSAM supply region and well-depth interval, the JAS data were aggregated to compile the following statistics:

- Average number of wells
- Average well-depth
- Drilling cost per well

In deriving reasonable drilling costs, one needs to take into account the wellhead price of natural gas. According to the Natural Gas Annual, the average wellhead price in the United States for 1995 was \$1.55/Mcf.

In GSAM, the Reservoir Performance Module operates assuming a wellhead price of \$2.00/Mcf and thus, in using the JAS cost data, an adjustment was needed. The factor for adjusting the drilling costs was 1.099, calculated using the following equation:

$$\text{factor} = 1 / (1 + \text{weight} * ((\text{oldprice} - \text{newprice}) / \text{newprice}))$$

$$1.099 = 1 / (1 + 0.40 * ((1.55 - 2.00) / 2.00))$$

The above equation came from a National Petroleum Council study. The 0.40 factor, which weights the change in drilling costs due to a price change, is applied only for drilling costs.

Once the data were adjusted using the above factor, drilling costs were regressed against average well-depths, weighting each entry by the average number of wells. Regression analyses produced third-order equations of the following form for each GSAM supply region:

$$\text{drilling cost} = A_0 + A_1 * \text{well-depth} + A_2 * (\text{well-depth})^2 + A_3 * (\text{well-depth})^3$$

The A_0 term in the equation represents the fixed cost of drilling a well at any depth and varies greatly from region to region. At low depths (the first two thousand feet, on average) drilling costs increase rapidly, but then flatten out considerably. At deep depths, drilling costs rise again, showing that every extra foot drilled is more and more costly.

Because of bad or insufficient data, some regions did not have a valid equation formulated. In these cases, and for the two Canadian regions, an equation from an appropriate surrogate region was used in its place.

The new information was formatted, verified, and tested in the Reservoir Performance, Exploration and Production, and Production Accounting Modules of GSAM.

Update of Operating and Maintenance Costs

The operating and maintenance costs in GSAM are calculated based on fixed costs, flow rate and well-depth. In the past, separate equations existed for only a few regions, with the remaining regions using a general equation. In order to expand on this, updated data were collected and separate equations were computed for more regions. In addition, the existing equations were updated using the more recent data.

The source for updating GSAM's operating costs was the "Costs and Indices for Domestic Oil and Gas Field Equipment and Production Operations 1992 through 1995" (EIA, 1995). This publication reported 1995 direct annual operating costs per well for six United States regions by flow rate and by well depth. The six regions in the report were West Texas, South Texas, South Louisiana, North Louisiana, Mid-Continent, and Rocky Mountains.

Because the Reservoir Performance Module of GSAM operates with a \$2/Mcf wellhead price, the operating costs had to be multiplied by an adjustment factor. This factor was different for each region, varying on the 1995 basin price. It was calculated using the following equation:

$$\text{factor} = 1 / (1 + \text{weight} * ((\text{oldprice} - \text{newprice}) / \text{newprice}))$$

$$\text{factor} = 1 / (1 + 0.20 * ((\text{oldprice} - 2.00) / 2.00))$$

The above equation came from a National Petroleum Council study. The 0.20 factor, which weights the change in drilling costs due to a price change, is applied only for operating costs. Different types of costs will have different weighting factors.

Once the operating costs were adjusted, a seventh "average region" was created by aggregating the data of all six regions. For each of the seven regions, operating costs were then regressed against flow rate and well-depth. Results of the regression analyses produced equations of the following form for each region:

$$\text{operating and maintenance costs} = A_0 + A_1 * (\text{flow}) + A_2 * (\text{well-depth})$$

The A_0 term in the equation represents the fixed cost of operating a well with any flow rate at any depth. The flow rate coefficient (A_1) was relatively constant across all regions at 0.005, so that value was used for all GSAM supply regions.

Since there were only six regions with data, many GSAM regions had to use the "average region" equation or, where appropriate, an equation from a similar region. This, however, was an improvement over the previous model, which used only four separate equations.

Updates to the Resource Module

To better model the available resource, ICF continues to update and modify the Resource Module, databases, default algorithms, and data evaluation methods used in GSAM. The following explains the recent revisions and adjustments made to GSAM's Resource Module.

Update of NRG Data

The Resource Module of GSAM, which uses data from NRG Associates, now implements the latest available U.S. database -- "The Significant Oil and Gas Fields of the United States Database (10th Update)". The database, similar in structure to the original database, now contains 1993 production and reserves data (instead of 1992), additional reservoirs added during the year, and new data elements contained in various NRG files, and other minor modifications. The newer database contains more reservoirs than before, giving it a better coverage and description of the U.S. resource.

Update of USGS Data

The undiscovered database, which uses USGS resource estimates, was reworked using the latest data. The "1996 National Assessment of United States Oil and Gas Resources -- Results, Methodology, and Supporting Data" from USGS gives resource estimates for U.S. basins. These estimates were used to recalculate and remodel the undiscovered reservoirs in GSAM. In addition, the resource characteristics were updated based on the new NRG data as well as additional descriptive items provided in the USGS and MMS assessments.

Update of Canadian Associated Gas Forecast

A forecast for Canadian associated and dissolved natural gas (A/D gas) was regenerated. This is important because GSAM currently does not explicitly model A/D gas in Canada, although the volumes of gas produced from crude oil wells impacts natural gas markets and prices throughout North America. The updated Canadian A/D gas forecast was created using the NRG Associates Canadian database 1993 values for crude oil production and A/D gas were noted. The assumption was then made that A/D gas production is directly proportional to crude oil production, converting to a gas-oil ratio (GOR) for all crude oil reservoirs. NRG's A/D gas production was divided by its crude oil production to arrive at an average GOR. This factor was then applied to EIA's Annual Energy Outlook (AEO) crude oil forecast for Canada through 2015. The result was an associated and dissolved natural gas forecast through the year 2015. The forecast was then extended to 2020 by applying the decline rate from 2014-2015 to the remaining years. This new A/D gas volume for Canadian producing regions (Alberta and British

Columbia) are currently used in GSAM E&P and Integrating runs to estimate gas prices and overall production rates in these key gas sales regions.

Update of Thickness Equations

The calculation of the thickness of undiscovered reservoirs was regenerated, in order to give a more accurate estimate. Previously, the net pay for all undiscovered reservoirs was calculated based on the field size class (FSC), as displayed in the following equation:

$$netpay = 5 \times (\sqrt{2})^{(FSC-1)}$$

This equation, while valid, was recalculated on a play basis, in order to better estimate the volume of each reservoir. Regression analyses were performed for each play, resulting in a different equation for each play. The equations had the same form as before, but were now play-specific. The base thickness (T) and incremental thickness factor (ITF) changed for each play, resulting in equations of the following form:

$$netpay = T \times (ITF)^{(FSC-1)}$$

This change in thickness better reflects the play characteristics and allows the reservoir area to be calculated for each field size class based on other reservoir properties.

Update of Well Calculations

The well coverage in the NRG database is not extensive. The well counts also are determined from various NRG files depending on the region or state reporting requirements, and the prevailing field rules. Therefore, equations exist in the Resource Module to revise well counts when regional totals are lower than actuals. These equations and defaults were updated and compared to well data from the Joint Association Survey (JAS) and the Independent Petroleum Association of America (IPAA). The code for checking and calculating well counts was modified and reformulated in order to calibrate results with the JAS and IPAA. These changes were minor and sometimes region-specific, but resulted in an overall more accurate well count.

Update Module Software

The various software packages that constitute the Resource Module were checked for accuracy and consistency. Tests found minor coding mistakes that were corrected. These corrections were not major and did not significantly change the resource characteristics, but did improve the accuracy of

GSAM data and analyses. For example, a small number of reservoirs (approximately 20) were being assigned to incorrect USGS plays. This was corrected and slightly changed the resource of a few regions. Other changes were even less substantial and sometimes did not even change the output. In these cases, duplicated code, or code that was deemed unnecessary, were removed. This cleaning-up process helped by improving the documentation of the code and allows future changes, such as the ones addressed above, to be implemented more easily.

3. Conclusions and Remaining Work

Update of Demand Data

In GSAM, natural gas demand is calculated from input files which contain, among other things, base demand values for each of the four sectors: residential, commercial, industrial, and electric utility. The following explains ICF's methodology for updating these input files so that the demand estimates matched other sources.

In the residential and commercial sectors, GSAM includes input files that contain a base demand forecast with an associated base price track for each region. These demand values are merely base numbers and are adjusted in the model for different price tracks. In order to calibrate, GSAM's 1995 gas demand in the residential and commercial sectors was compared to associated values in the Natural Gas Monthly (for the United States) and the Canadian Gas Association (for Canada). In addition, the base prices in the input files are currently being adjusted to calibrate with these sources. This is not a one-step process since changes in any one GSAM region may affect other regions. Also, demand changes with each price track.

In the industrial sector, GSAM includes an input file that contains a base energy forecast for each region with different factors detailing how much of this energy is available. These percentages give how much of the forecasted energy is interruptible, how much can be used for oil and gas consumption, and how much is available for each fuel type. GSAM's industrial demand is being calibrated against the Natural Gas Monthly (for United States regions in 1995), the GRI (for United States regions beyond 1995), and the Canadian Gas Association (for Canadian regions). The percentages discussed above are being modified so as to match the demands with these data sources.

The electric utility sector demand is also being calibrated with the same sources mentioned above. This is an ongoing process that is more complicated than the other sectors. First, total electricity demand was adjusted to account for imports and exports. Since GSAM does not model imports and exports across regions, the electricity demand had to be adjusted. For each region, imports had to be

subtracted from the demand and exports had to be added. The imports and exports data came from the Energy Information Administration (EIA). Next, the capacities for each fuel type were adjusted to match those from the EIA. Now that this is complete, electric utility demand is currently being calibrated with the NGA and CGA by adjusting the maximum utilization rates for each fuel type. These utilization rates give the percentage of capacity that is available for each fuel type. Raising or lowering these numbers will raise or lower electricity utility demand.

As mentioned, calibrating the demand model is ongoing. Since GSAM integrates its supply and demand models -- each model feeds into the other until a convergence between supply and demand is met -- it is not enough to calibrate against one price track. The prices are constantly changing during a model run, therefore changing the demand. So, in order to calibrate the demand model, many runs must be made with varying

Conclusions

During the past year, ICF revised and updated the Resource Module, prepared data and methodology documentation, and completed quality control and validation work for key resource data and software. This work improved the accuracy and operating procedures of GSAM. This work was also critical to the successful completion of the GSAM Review meeting.

As new data becomes available and key elements are added or updated, GSAM data and modules should be updated as well. This will ensure the system accurately reflects the diversity of the resource and the key elements of the FETC R&D target resources.

E. GAS PROCESSING

1. Background

ICF Kaiser has a study in progress to analyze the impact of advanced gas processing technology on natural gas supplies. As part of the study, ICF has examined the impacts that improved technology might have on the costs of processing sub-quality gas. The costs of purifying gas containing hydrogen sulfide (H₂S), carbon dioxide (CO₂) and nitrogen (N₂) will be analyzed for inlet streams that contain just one of these impurities, as well as for streams containing more than one.

Also as part of this study, ICF has characterized the potential resource base of sub-quality natural gas. Sub-quality gas is typically defined as natural gas containing greater than 2% carbon dioxide, greater than 4% nitrogen, or combined nitrogen and carbon dioxide greater than 4%. As technology

advances, these sub-quality reserves will become less and less expensive to process, thus increasing the potential supply of natural gas.

The next step of this study is to run the Exploration and Production Module of GSAM under varying cost scenarios in order to determine the impact that advanced gas processing technology will have on natural gas production.

2. Research Results

Cost Impact of Advanced Technology Findings

The current state of gas processing costs and technology is documented in the Gas Research Institute's topical report "Business Characteristics of the Natural Gas Conditioning Industry." This report describes the basic process flows for a number of technologies. Included in these descriptions are issues which must be considered in choosing a specific technology (i.e. plant flowrate, impurity level, presence of other impurities, etc.), generalizations of costs and cost drivers. For some technologies, the report also gives capital and operating cost curves, from which equations can be derived to estimate costs at other flowrates and compositions. Conventional technologies considered at this detailed level include diethanolamine (DEA) treatment (removes H_2S , CO_2), claus sulfur recovery (H_2S), direct conversion of H_2S to sulfur (removes H_2S) and cryogenic nitrogen removal (removes N_2).

Several "advanced" technology options were examined as part of ICF's study as potentially cost reducing processes. These options include membrane separation, bioprocessing, new solvent development, the use of a non-aqueous complexing agent and liquid redox. Each of these options is in the research and development stage, and have the potential to come on line within the next five to ten years.

Membranes that will separate CO_2 and N_2 from natural gas are being developed by Sandia National Laboratories and Membrane Technology Research (MTR). Membranes generally fall into one of two categories, high flux or high selectivity. High flux membranes have the capability to purify a large amount of gas, but in the process, they also lose a significant amount of gas. High selectivity membranes separate the components much better, but they cannot pass as great a volume of gas as high flux membranes.

Bioprocessing (being developed by ARCTECH) involves the use of microbes in the purification of natural gas. The gas is pumped into a bioreactor, where microbes degrade the impurities (primarily H_2S) and transform them into benign products (i.e. elemental sulfur). This technology is generally for

low flowrates. The liquid redox process developed by Dr. Rai at Texas A&M University is actually the standard Lo-Cat process, except it uses microbes to more effectively and efficiently regenerate the catalyst.

When placed in contact with natural gas at high pressure, physical solvents extract CO₂ and H₂S from the gas as the system moves toward a state of equilibrium. This means that the solvent has a high solubility for the impurity, so the impurity would "rather" be dissolved in the solvent than in the gas. The impurity rich solvent is separated from the clean gas and sent to a flash vessel, where the temperature and/or pressure are changed, and the solvent releases the impurity for further processing (if necessary). The Institute of Gas Technology, in cooperation with a German engineering firm, has developed N-Formyl Morpholine (NFM), a new physical solvent that has improved properties over traditional solvents. NFM is a nontoxic chemical that pulls more impurities out of the gas stream than conventional solvents, and it has a lower vapor pressure, which leads to less solvent loss.

The non-aqueous complexing agent being developed by SRI International works in much the same way that the physical solvents work, except under high pressure they chemically bind to nitrogen (physical solvents don't actually bind to the impurity - the impurity dissolves in the solvent). The complexing agent is then separated from the gas stream, the pressure is reduced, and it releases the nitrogen.

Advanced technology has the potential to reduce gas processing costs between 20 to 50% (see Table III-6 for cost assumptions). The costs of processing impurities are dependent primarily on the capacity of the plant, the throughput of gas, and on the concentration level of the impurity.

Table III-6
Summary of Cost Assumptions

Process Stream	Capital Cost Reduction	Operating Cost Reduction
Nitrogen	20%	20%
Nitrogen	50%	50%
CO ₂ , H ₂ S	35%	35%

Because of the lack of hard data for these processes, and the sensitivity of processing costs to variables such as impurity concentration and flowrate, it is difficult to precisely compare the processes. Another factor that effects cost estimates is the assumptions that each individual company has made in

calculating their process costs. Efforts were made to minimize the effects of varying assumptions, but it was not always possible to determine the basis for some estimates. Because of these uncertainties, recommendations are made on a judgmental basis, rather than a direct comparison of available data.

ICF recommends that analyses of processing technology include the impact of CO₂ and H₂S processing costs being reduced by 35%. This is because of the optimistic projections of the developers of these new technologies. Because it is difficult to determine the effect new technologies will have on the cost of processing nitrogen rich gas, it is recommended that two scenarios be examined - one in which costs are reduced by 20% and one in which costs are reduced by 50%.

Resource Characterization Findings

Using the NRG database, ICF predicts 2.8 million Bcf of methane in place. Two other reports predict around 600,000 Bcf of reserves (GRI's "Business Characteristics of the Natural Gas Conditioning Industry" [prepared by Pervin & Gertz, GRI-93/0342], and DOE's "Utilization of Low Quality Natural Gas, A Current Assessment" [DOE/MC/27346-3517]). Because all methane in place is not recoverable, the discrepancy in these numbers largely is due to recovery factors for gas resources. In order to put the original methane in place calculations on the same basis as the reserves from the other two studies, the GSAM resources were multiplied by the ratio of reserve additions to total resource in place (744/1446).

When compared to the reserves vs. impurity levels presented in the DOE study, ICF's calculations match very well for nitrogen. For CO₂, the overall amount of impure gas matches well, but there is more gas at the lower range of impure gas (2% - 3%) in the NRG database. From 3% to 7%, there is slightly less impure gas in the NRG database, and above that, they match well.

When compared to the GRI report on a regional basis, the NRG reserves match up very well. The NRG data is low for the Mid-West and Rockies Foreland in both the CO₂ and N₂ estimates. For the Mid-West, this is because the NRG database has low impurity levels for the gas. In the Rockies Foreland, it is because the NRG does not have as many gas reserves as the GRI estimates. The NRG estimate for carbon dioxide rich reserves in the Texas Gulf Coast is much higher than the GRI estimate. The reverse is true for the Gulf of Mexico. This is because the two studies have different regional boundaries. Table III-7 shows the estimated sub-quality reserves from each data source.

Table III-7
Comparison of Resource Estimates (Tcf)

	GRI	DOE	GSAM OGIP	GSAM Reserves¹
CO ₂ > 2%	184.2	191.1	334.6	172.2
N ₂ > 4%	51.8	67.5	106.8	55.0

¹ Equals OGIP multiplied by the factor 744 / 1446

ICF is in the final stages of a study to estimate the effects that improved gas processing technology will have on natural gas production. The first step of this study was to debug and improve the gas processing module within GSAM. In order to determine the most probable gas processing cost reductions due to improved technology, ICF examined DOE funded research projects that have the potential to come on line within the next decade. Work was subsequently done to refine the sub-quality gas resource base characterization that GSAM uses to calculate gas production over time. ICF is presently in the process of combining these efforts to predict the impact that research and its associated technology advances may have on future natural gas supplies.

3. Conclusions and Remaining Work

The next step of this study is to run the Exploration and Production Module of GSAM under varying cost scenarios in order to determine the impact that advanced gas processing technology will have on natural gas production. The costs of gas processing will be reduced according to the above table, and the improved resource characterization will be used in order to more accurately assess the impacts of technology on gas production. The final result of this study will show the potential supply increases that may result from gas processing research.

F. ENVIRONMENTAL MODULE DESIGN AND DEVELOPMENT

1. Background

Task Objective

The Environmental Module (EM) provides the capability to characterize the impact of changes in environmental regulations and advancements in waste control/mitigation technologies on industry operations, total gas reserves, industry employment, public sector revenues, and, where sufficient data exist, on the environment. This capability will assist DOE in many upcoming analyses of incremental

compliance cost impacts, technology evaluations and benefits assessments of different potential regulatory scenarios.

Development Approach

Locational, operational, and environmental data have been gathered and developed for different environmental issues related to the production of natural gas. Examples of these issues include produced water management, soil remediation of hydrocarbon contamination, and hazardous air pollutant controls. EM can be used to evaluate the impacts of a wide range of possible future environmental regulations on these and other wastes.

For each issue area, EM estimates the baseline volume of waste (prior to the consideration of any new compliance requirements) generated by E&P activities, reductions in waste volumes as a result of the application of waste management controls/practices, the incremental costs for the new compliance requirements and controls, and finally, the cost-effectiveness (e.g., dollars per unit reduction in waste volume) of the controls in meeting the environmental regulation. To arrive at a useful measure of cost-effectiveness, EM ultimately will include estimates that reflect the expected benefits of possible regulatory scenarios. The time frame for developing the benefit assessment work depends largely on the extent to which relevant data exist to support recent studies.

Module Design

The basic structure of the Environmental Module is shown in Figure III-3. EM is composed of several files that interact with other GSAM modules (e.g., the GSAM technology, cost, and economic routines) to develop cost impact, waste reduction, and cost-effectiveness estimates of possible future environmental regulatory or technology scenarios. A brief description of each file is provided below.

EM Activity Factor File: The Activity Factor File estimates the number of waste "sources" per reservoir producing waste that may be subject to future environmental regulatory requirements. Examples include existing and new production wells, glycol dehydrators, condensate storage tanks, compressors, and emergency and workover pits.

EM Base Waste File: Taking into account current waste management practices, baseline waste volumes are estimated for each source using data on reservoir characteristics (e.g., reservoir depth, composition of natural gas); environmental characteristics associated with the source's location (e.g., proximity to wetland, aquifer bottom depth); operator-specific characteristics (e.g., use of drilling muds, use of flares on dehydrator condensers); and unit waste (e.g., emissions) factors.

Figure III-3
Overview of EM Structure and Data Flows

EM Waste Management File: The Waste Management File characterizes the existing waste management practices currently used by industry. It also allows the user to specify the regulatory or technology scenario under consideration. For example, a new environmental requirement may be characterized by identifying the level of waste volume to be controlled (e.g., 95 percent control of hazardous air pollutant emissions) and/or the particular method of compliance (e.g., installation of liners on all emergency pits); when the requirement will become effective, and the geographic applicability (e.g., county, state, federal, onshore, offshore). Advances in technology that improve the efficiency of the control or reduce the capital and/or operating costs also could be specified.

EM Scenario Assessment File: This file performs a series of capital and operation and maintenance (O&M) unit cost calculations per waste source, per well, and per reservoir. These estimates reflect the incremental costs associated with complying with the specified regulatory or technology scenario. If the scenario does not specify the exact method of control, costs are calculated for the least-cost control option. This cost would then be passed to GSAM's technology, cost, and economic routines and combined with costs for other factor inputs to estimate the Minimum Acceptable Supply Price (MASP). For cases in which the implementation of a particular scenario would lead to controlling the waste stream rather than simply managing it, the reduction in waste can be estimated based on the efficiency of the control in preventing or mitigating waste volumes.

EM Post-Processor: In addition to providing GSAM with incremental environmental compliance cost estimates, EM generates output that characterizes the cost-effectiveness of a particular scenario over GSAM's forecast period of time.

For each simulation year, EM develops:

- Total incremental compliance costs;
- Baseline waste volumes and reduction in waste volumes, as applicable;
- The cost-effectiveness of the environmental regulation under consideration in reducing waste volumes.

Ultimately, EM could also include information on human health and environmental risks and other benefits assessment work to provide a comprehensive assessment of the risk-cost and benefit-cost trade-offs of future environmental requirements under consideration.

Through this reservoir-level approach, EM captures potentially significant variability in key factors (such as waste volume production, source and operator characteristics, and environmental-

specific factors) that ultimately might lead to the uneven distribution of marginal costs and benefits of compliance across sources. EM will substantially broaden system capabilities by providing key information to support environmental R&D activities, assessing the impacts of changing environmental requirements on gas supply and price, estimating the cost-effectiveness of future environmental regulations, and, identifying and prioritizing R&D activities aimed at reducing the costs for waste management controls.

2. Research Completed

Compliance Costs

Recent work has focused on designing a methodology for developing the compliance cost estimates using reservoir-level locational, operational and environmental data, and is ongoing.

To date, compliance cost estimates have been developed (in spreadsheet format) and validated for the following environmental issue areas: drilling waste management, hazardous air pollutant controls, and produced water management.

EM Workshop

A workshop was held on March 6, 1997 in Dallas to review the structure and approaches used in the Environmental Module of GSAM being developed by ICF Resources Inc. for FETC. The workshop was attended by representatives of industry and other federal agencies. A state representative was invited, but was unable to attend. The review committee members have expertise in various aspects of environmental requirements on the oil and gas exploration and production industry, including both regulatory and R&D perspectives. The goal of the workshop was to evaluate the utility of the Environmental Module (EM) against DOE's stated objectives (regulatory analysis and R&D planning) and to identify any improvements for increasing the efficiency or effectiveness of the EM in achieving those objectives. See the peer review section (Section A) for more details on the environmental workshop.

G. ROYALTY RELIEF

The Bureau of Land Management (BLM) and the Department of Energy contracted ICF Resources to evaluate the effects of royalty relief for marginal natural gas wells. ICF's analysis found no royalty relief scenario that was revenue neutral, and as prices increased, the cost of the incentives

increase dramatically. From the study, ICF concluded that a reduced royalty rate between 6.25 and 12.50 percent is preferable.

1. Background

Because of the rapid evolution of the domestic gas marketplace and because the characteristics of U.S. gas supplies are evolving, the U.S. must expand its sources of natural gas. Environmental pressures have increased the use of low emissions fuels and the need for larger gas provisions. The historical surplus of gas deliverability has ended, and open access transportation is changing the way gas gets to the market. New reserves are now coming from the development of identified resources, as opposed to coming from new discoveries, and future supplies will come from more challenging settings. In the expansion of the U.S.'s gas supplies, technology will play a key role, and lower costs will be needed to meet the new environmental challenges. The intent of federal royalty relief is to enable marginal wells to meet these challenges.

ICF analyzed a royalty relief policy using the Gas Systems Analysis Model. An objective in the design of GSAM was to enable the model to assess public sector issues that will impact the future of the natural gas industry. Examples of these issues include: royalty incentives, regulation, tax policy, market developments, market constraints, and international developments. GSAM provides a detailed and flexible model for policy and programmatic decisions through its ability to assess technology, supply, policy, and market dynamics.

GSAM is superior to the traditional upstream gas system models. The latter lacked certain key features that were required to meet DOE objectives in policy analysis. In these traditional models, the characterization of the gas resource base was inadequate. Technology performance representation was insufficient. Portrayal of economic decision-making was often inconsistent with true operator behavior, especially related to making technological choices. Finally, these models lacked comprehensive, consistent analysis of total resource and all technology and policy options. GSAM incorporates the analytical elements which the traditional models lacked, making it more consistent with DOE goals.

GSAM's database of over 10,000 known reservoirs in the U.S., in conjunction with the USGS play level analysis, was used to identify 70 plays that were considered to be on federal lands in significant quantities.

The 11 basins that were included were:

- Uinta-Piceance
- Paradox Basin
- San Juan Basin
- Powder River Basin
- Bighorn Basin
- Wind River Basin
- Wyoming Thrust Belt
- Southwestern Wyoming
- Denver Basin
- Las Animas Arch
- Raton Basin

Because these 70 plays have substantial leases on federal lands, they could be significantly impacted by the effects of federal royalty relief. GSAM provides economic evaluation of the impact of royalty relief policy through operator analysis at the reservoir level. In other words, economic decisions are incorporated into the reservoir performance module. A discounted cash flow model leads to the operator's decision. Decisions made at the reservoir level depend on the minimum acceptable supply price (MASP), that is, the price at which the discounted cash stream, the net present value (NPV), is equal to zero. If the market gas price is above the MASP, then the operator will decide to develop the reservoir (See Figure III-4). The reservoir decision file stores information to adjust the MASP to contemporary conditions. The discounted cash flow model contains current state and federal tax laws, full depreciation and depletion, and accommodates a variety of proposed tax/regulatory initiatives.

Figure III-4
MASP at Current Costs

Crucial to the royalty relief analysis is the Reservoir Performance Module. The Reservoir Performance Module contains costing algorithms developed to incorporate operational variables, such as: location, terrain, reservoir size, reservoir depth, reservoir pressure, gas and water production, and extraordinary operating conditions. These costs can be adjusted for market conditions, for example, a change in gas prices, a change in infrastructure utilization, or a change in technology application. Royalties are also included and are calculated simply by multiplying revenues by the royalty rate.

In addition to decision making at the reservoir level, GSAM also incorporates decision making into the exploration and production (E&P) module. Exploration prospects are ranked on a full cost, expected value basis. In addition, exploration activity is constrained by infrastructure capacity. The module also contains anticipated environmental compliance, exploration, development, operating, and gas processing costs. Development is evaluated on a sunk exploration cost basis, where options are evaluated in the context of current markets, stage of reservoir depletion, and available technology. Additional development is evaluated consistently and is constrained by infrastructure capacity, or rig availability. Estimates of future production are based on demonstrated reservoir deliverability, regulatory and market constraints, and future operating costs and conditions. Production can be curtailed if marginal cost exceeds revenue. After a specified curtailment period, the reservoir is abandoned.

2. Results

The GSAM analysis used several parameters to assess the impact of royalty relief. In the 72 runs of the model, three different wellhead prices were utilized: \$1.50/Mcf, \$2.00/Mcf, and \$2.50/Mcf. Four production cutoffs were employed: 60, 90, 120, and 150 Mcf per day per well. The royalty relief incentives were incorporated starting in 1997 and run for the full project life, with a cutoff in the year 2020. Three flat royalty rates were tested, 0%, 6.25%, and 12.5%. As a simple example, a royalty rate of 6.25% with a cutoff of 60 Mcf per day means that wells which produce less than 60 Mcf per day will receive a reduced royalty rate of 6.25%.

The analysis found that, in aggregate, none of the scenarios is revenue neutral. Further, a royalty rate between 6.25 and 12.50 percent is generally preferable, as larger incentives (greater royalty deductions) do not yield commensurate benefits in terms of reserves, production, or employment. Also, as prices increase, the cost of the incentive increases dramatically.

The net effects of two different relief rates under four cut-off levels, at a price of \$2.00, is summarized in Table III-8.

Table III-8
Net Effects of the Incentives at \$2.00/Mcf

	60 MCFD		90 MCFD		120 MCFD		150 MCFD	
	0%	6.25%	0%	6.25%	0%	6.25%	0%	6.25%
Cumulative Production Summary								
Conventional (BCF)	56	33	78	46	66	32	97	44
Tight (BCF)	85	25	-97	34	-72	39	190	6
Coalbed Methane (BCF)	97	36	210	127	243	141	290	162
Total (BCF)	238	94	191	207	237	212	577	212
Reserves Additions Summary								
Conventional (BCF)	8	5	15	18	3	9	25	18
Tight (BCF)	319	224	355	229	365	215	663	241
Coal (BCF)	70	42	202	159	260	182	327	205
Total (BCF)	397	271	572	406	628	406	1,015	464
Financial Summary								
Lost Royalties (B\$)	4.15	1.79	6.37	3.00	7.87	3.85	8.80	4.39
Net Cost to Government (Federal and State) (B\$)	2.76	1.39	4.22	2.03	5.19	2.46	5.69	2.79
Industry Job-Years Provided	1,459	682	1,222	1,299	1,504	1,318	3,357	1,341
Net Cost/Prod. (\$/MCF)	11.59	14.76	22.10	9.82	21.91	11.58	9.86	13.16

When looking at tax policy, GSAM produces an analysis of production as well as reserve additions, broken down by reservoir type. It also is able to assess the revenue impact on the federal government and the effect a royalty relief policy would have on industry employment.

GSAM's analysis was run on a national basis in order to account for the interaction of states having significant production on federal lands with other producing areas. Four states, New Mexico, Wyoming, Colorado, and Utah, are primarily represented in the analysis, as they account for over 90% of the gas produced in the U.S. from federal leases. The effects on these states are shown in Table III-9.

Table III-9
Net Costs and Royalties by State

Cut-off Royalty Rate Price	Net Costs (\$Billions)		Royalties (\$Billions)	
	60 Mcf/d	150Mcf/d	60Mcf/d	150Mcf/d
	6.25%	0%	6.25%	0%
	\$1.50/Mcf	\$2.50/Mcf	\$1.50/Mcf	\$2.50/Mcf
Colorado	0.011	-0.843	0.012	-1.361
Wyoming	0.017	-3.750	0.011	-5.793
Utah	-0.004	-0.611	0.002	-0.960
New Mexico	-0.126	-2.392	-0.061	-4.016

3. Conclusions and Remaining Work

Royalty relief policy will be continued to be analyzed by GSAM. Upcoming tasks involve integrating new data into the model and testing specific scenarios to find one which exhibits revenue neutrality.

H. *REDUCE GSAM RUN TIME*

1. Background

The complex nature of GSAM and the high level of detail required from its analyses have led to development of a modular system that is uniquely capable of evaluating future technology enhancements and policy alternatives for all of North America. However, each module, now that it has been developed, tested, and linked, can be made more efficient. This would allow significant reductions in the time required to complete GSAM evaluations. By simplifying the input and analysis methods used, the proposed work would also reduce the computing requirements of the system and provide users with more flexibility in every future GSAM analysis performed.

The benefits to DOE of reducing GSAM run times, through reduction in computing requirements in each module and simplified input structures, will allow future analyses to be completed faster, at a lower cost, and with significant more reliability. Also, the reduced run times will allow certain evaluations to be expanded to answer related policy and program planning questions that the current system could not provide in a timely fashion.

To date, ICF has successfully completed several tasks that have greatly sped up the run times for GSAM. These tasks have included a combination of software and hardware changes. In ongoing work, ICF is also looking into other software-related approaches to further bring down the running time. In what follows, we describe the completed work as well as the remaining tasks.

2. Results

Speeding Up Calculating Equilibrium Gas Prices and Quantities

Currently, in order to compute equilibrium gas prices and quantities, GSAM estimates both the supply and the demand sides of the gas market separately and then integrates them in a linear program (LP). The supply side of the market is handled in Exploration and Production module, which uses a data base of approximately 16,000 reservoirs to model the activities and decision-making involved in

extraction, treatment, and compression of North American natural gas resources. The demand side of the market for gas is based on forecasting demand levels by region, end-use sector, and time.

These independent forecasts of prices and quantities for both supply and demand are then incorporated in an integrating LP which seeks to maximize overall discounted total surplus subject to a variety of realistic constraints related to the natural gas distribution network. In this network, the nodes represent supply and/or demand regions and the arcs are the flows of natural gas between them.

The Integrating Module makes a comparison to see if the difference between the LP's estimate of equilibrium prices matches those determined by the Exploration and Production Module. If there is agreement, then the equilibrium process stops. Otherwise, updated gas prices are sent back to the Exploration and Production Module (via the file "gasprc.new") and another integrated iteration is attempted. Typically, ten integrated iterations are used to arrive at estimates of equilibrium prices and quantities. The basic scheme for this integrated process is shown in Figure III-5.

As can be seen from this diagram, the Exploration and Production Module generates valid (price, quantity) pairs via an updated gas price file. In essence, this model is dynamically producing points from a supply curve for each region and time period given an assumed technology and other factors. It is important to note that, due to the level of detail in GSAM E&P evaluations (16,000 reservoirs), the individual supply curves in various regions over time are not known in closed form, but must be generated "on the fly" via updated module runs. The contribution of the Demand and Integrating Modules is to generate new estimates of an equilibrium set of gas prices (via the file "gasprc.new") obtained from the integrating linear program. In a typical equilibrium or "integrated" run, the Exploration

Figure III-5
The Computation of Equilibrium Gas Supply Prices and Quantities

and Production Module is called four times to generate enough supply curve information to complete a market balancing calculation.

The steps in an integrated iteration with actual times listed for a run on a 90 Megahertz Pentium computer with 16 Megabytes of RAM using DOS are shown in Table III-10.

Table III-10
Actual Computing Times for One Typical Equilibrium Iteration

Step	Time in Minutes	% of Total Time
(1) Four calls to E&P (@47.5 minutes/call)	190.00	76.7 %
(2) Calculate forecasted demands and other LP data	0.45	0.2%
(3) Solve the integrated LP	57.00	23.0%
(4) Test for convergence and generate reports	0.28	0.1%
TOTAL	247.73	100.0%

Reduce Unnecessary Calls to the E&P Module

A first improvement was to reduce unnecessary calls to the E&P Module in generating the four supply price, quantity pairs for each integrated run. In particular, a price of \$0.10/Mcf was previously used (for each supply region and time period) as the first price (out of the four generated). The E&P Module then calculated the associated production quantities based on this price.

After the first GSAM integrated iteration, the associated production levels for this first price of \$0.10/Mcf would not change in subsequent iterations. Therefore, the modification was to eliminate this first call (at \$0.10/Mcf) for the second and later GSAM iterations. Instead, the associated production levels for the \$0.10/Mcf price were stored at iteration number one and then read back for subsequent iterations.

Increase Memory and CPU Speed

The second speedup enhancement was to allow more memory for the computer running GSAM. The E&P module calculations require a generous amount of random access memory (RAM) and we increased the default size from 16 megabytes to 128 megabytes. The decision to increase to this level of RAM was based on observing how much memory was requested by the system when the E&P module

was running. In addition, we increased the CPU speed to 200 Megahertz and switched from DOS to the Window NT (4.0) operating system.

As compared to the results in Table III-10, the impact of the proposed speedup was substantial. With the new configuration, one E&P call now takes approximately four minutes to run (as compared to 47.5 minutes as stated above). Combined with the reduction in unnecessary E&P calls at the \$0.10/Mcf price, we estimate that the new time for ten GSAM integrated runs to be about four hours compared to over 40 hours originally.

Remaining speedups for calculating equilibrium prices and quantities will focus on software and data base improvements; we describe these ongoing projects below.

3. Conclusions and Remaining Work

In what follows, we describe possible speedup projects that ICF will investigate.

Speeding Up the Exploration and Production Module

Approximate the Gas Supply Curves

If we knew the actual functional form of the supply curves (for a fixed region and time period), then calling the Exploration and Production Module to generate valid (price, quantity) values would be unnecessary and very significant computing time could be saved. As an illustration, suppose that the gas supply relationship were as follows (indices for the region and time period are omitted since we are assuming that the region and time period are fixed) ¹:

$$(1) \quad q(p) = \alpha e^{\beta p}$$

where $q(\cdot)$ is the supply quantity function, p is the supply price and α, β are positive constants to be determined. With $\alpha = 2, \beta = 0.5$, Figure III-6 is this supply curve.

¹ This model is for illustrative purposes, an actual supply curve approximation would no doubt be more complicated.

Figure III-6
Sample Supply Curve

When given a particular gas price p^* , the related gas quantity q^* would be immediately available via equation (1), thus bypassing the need for any additional calls to Exploration and Production Module. Of course, the resulting integrating LP would need to be modified suitably to handle this more compact form of the supply price-quantity relationship.

Since the explicit functional form is unknown, the model would need to generate reasonable approximations to it that also maintained a significant level of detail from E&P results. In the first case, this approximation is updated "on the fly" as the Integrating Module proceeds. In the second case, these approximations are done "off-line" so that the supply curve approximations are done ahead of time.

Improved Memory Management

At present, the current FORTRAN programs allocate the maximum amount of memory (as specified in various setup files) and do not relinquish this memory for the duration of the GSAM session. This is inefficient management of memory which appears to be a major cause for slowing down this module. Another potential speedup area is to rewrite the relevant portions of the E&P FORTRAN programs so that memory allocation is done under demand rather than statically and at a maximum level; this procedure will make the program run more efficiently.

Improve Input/Output Procedures

Another area that could be made more efficient and thus save computational time is the input and output of data from and to files. An improvement would be to "buffer" this procedure. That is to say, read and write blocks of data more efficiently than what is currently done in FORTRAN. In addition, certain output requirements could be simplified or eliminated during integrating procedures.

Reduce the Size of the Binary and Data Files

There are potential savings to be made in computing time if one is more efficient in the binary and data files in the E&P Module. In particular, , those reservoirs with a minimum acceptable selling price (MASP) greater than a certain level, for example \$10/Mcf, could be eliminated. The rationale would be that almost no market gas prices would make these reservoirs profitable, hence they should not be considered, thus reducing the size of relevant E&P input files. The overall effect would be to speed up calculations that used these associated files.

Speeding Up the Demand and Integrating Module

In this section we explore several approaches to speed up the LP solution time.

Improve Starting Points

At present, we are using a variation of the classical Simplex method developed by G. B. Dantzig (1947)² for solving the integrating linear program. This is an iterative method which, at each iteration improves the objective function while staying feasible to the given constraints. As is the case with most iterative approaches, the choice of the starting point is crucial.

In recent tests that we performed, we used several starting points to solve a typical integrating LP that GSAM would face. The proper choice of starting point dramatically affected the solution time. We propose to systematically investigate optimal starting points for the integrating LP to be able to automatically generate them given the GSAM problem data. This approach could be based on a careful examination of the actual structure of the LP and/or running various numerical tests.

Use Alternative Linear Programming Methods

The Simplex method for solving linear programs is a successful method that has been in use for some 50 years. Recently however, alternative strategies for solving linear programs have been developed,

² For background, see for example *Linear Programming and Extensions*, G.B. Dantzig, Princeton, New Jersey, Princeton University Press (1963).

tested, and published. One particularly successful avenue is the host of techniques called "Interior Point" methods. These methods have been shown to be very efficient on larger problems. In fact, in recent tests on GSAM's integrating LP, significant speedups were gained using an interior point approach. We plan to continue this investigation.

Decreasing Runtime for Reservoir Performance Evaluations

A critical feature of GSAM is its capability to evaluate large numbers of reservoirs based on their specific rock, fluid, geologic, and economic properties. This unique capability is also a drawback in that the time required to process the full database of over 16,000 reservoirs can be significant. By improving data flow and modifying the logic of the Reservoir Performance Module, evaluation time could be reduced substantially.

The most time-intensive aspect of the Reservoir Performance Module is the evaluation using specific type-curves. These dimensionless relationships between time and production levels are converted to specific volumes and timesteps based on individual reservoir properties. The analysis of evaluating a reservoir's production potential, checking material balance constraints, checking production system and user imposed constraints, and adjusting operating pressures throughout the reservoir system is complex. The entire procedure for an individual reservoir can be completed in a matter of seconds using available computing capability.

By altering the logic of the existing system, one can shorten the time required to complete analysis of individual reservoirs. First, the type-curve module of the Reservoir Performance Module would be enhanced to limit the need to evaluate each scenario for each paygrade, development, and technology option. The system would be modified to check inputs for the specific case being considered and only reevaluate a case/ timestep combination using the type curves if the production response would change. If inputs have not changed, the model would simply use the results previously stored and proceed to the next timestep, paygrade, or case, as appropriate.

In addition, GSAM's database currently contains information on reservoirs that do not directly impact the future production from a play or region. For example, initially undiscovered reservoirs that were found and developed by previous E&P activities are included in the database and evaluated in the Reservoir Performance Module. They are subsequently identified and eliminated from further analysis. However, their evaluation takes time. Another area of speedup is to identify and eliminate the analysis of any duplicate or unnecessary reservoirs in this module.

The proposed improvements in the Reservoir Performance Module could cut analysis time significantly for certain program and policy evaluations. For a technological specification, alternative policy scenario runs can be completed in GSAM in only a fraction of the time it takes otherwise. By also eliminating unneeded reservoirs, runtime can be further reduced. This enhancement could provide important benefits for future policy and program evaluations.

I. WINDOWS INTERFACES

1. Background

In its initial form, GSAM was designed to run under the MS-DOS operating system. Since GSAM development began, the Microsoft windows environments (Windows 3.1, Windows 95, and Windows NT) have become the preeminent operating systems for personal computers. ICF is currently in the process of converting GSAM to work in a Windows NT environment.

The development of a comprehensive windows interface will enhance the capabilities and user applications of GSAM. As a result, GSAM software could run more efficiently, be better understood by diverse users, and be more easily linked to other software packages.

The work plan is to develop both a front-end Windows interface—to facilitate the input and running of GSAM, as well as a back-end Windows interface—to assist in analysis of the output. In what follows, the achievements and planned work for both the front- and back-ends of the windows interface are described.

2. Results

To date, the majority of work related to the Windows version of GSAM (WGSAM) has been concentrated on development of the back-end geographical information system (GIS). In general, a GIS is an automatic system designed to support the capture, management, manipulation, analysis, modeling and display of spatially-referenced data for solving complex planning and management problems. As such, it acts as a large repository of data in the form of a database, which can return data and analysis back into the system for subsequent use.

The accomplishments to date include the connecting of GSAM output reports to mapping and other graphical software. In particular, the following sample windows demonstrate some of the achievements to date.

The information concerning the links in the transmission network have been read from a GSAM output file and inserted in tabular form as shown in Figure III-7.

The values from this table constitute the links in the GSAM network along with capacities and flows as determined from a model run. If the user wishes to see the data in another format, at present the software displays the results in graphic form or network form as depicted in Figures III-8 and III-9.

In addition to these visual displays, we have added the capability to view all or selected parts of the GSAM network. This will let the user examine particular demand nodes (triangles), supply nodes (circles), or pipelines (links connecting nodes). Figure III-10 is an example of the associated screen.

We are currently still developing many of the windows and capabilities to analyze the GSAM output in either map, graphic, or tabular form and describe some of the features that we may add in the sections below.

Figure III-7
Tabular Display of Link-Based Data

ORIGINNAME	DESTNAME	CAPACITY	L1FLOW	L2FLOW	ANNUALFLOW
East South Central	Appalachia	2361	0	0	0
North Alaska	Alberta	0	0	0	0
MacKenzie Delta	Alberta	0	0	0	0
Rockies Foreland	California	730	730	730	266.45
Pacific Onshore	California	0	679.43	624.24	236.18
Pacific Offshore	California	110	99.25	91.19	34.5
Mountain South	California	3078	2304.42	2892.52	966.97
Pacific Northwest	California	1831	1315.03	1027.11	418.37
Alberta	Canada-East	4053	3337.18	4053	1371.26
East North Central	Canada-East	2030	0	0	0
Alberta	Western Canada	0	1932.56	1573.86	628.62
Alberta	BC-Demand	0	0	0	0
Texas Gulf Coast	Arkia-East Texas	2527	0	2180.22	466.57
Mid-Continent	Arkia-East Texas	680	0	680	145.52
Norfolk	MAFLA Onshore	600	315.24	289.63	109.58
Gulf of Mexico-East	So-Louisiana	7004	3993.32	3309.73	1311.27
Texas Gulf Coast	So-Louisiana	2653	2653	2653	968.35
Lake Charles	So-Louisiana	700	0	0	0
Appalachia	East North Central	3232	0	237.27	50.78
Alberta	East North Central	2447	2447	2447	893.16
Mid-West	East North Central	0	521.94	479.55	181.44
Arkia-East Texas	East North Central	2540	2540	2540	927.1
East South Central	East North Central	5973	4386.41	3508.84	1413.24
West North Central	East North Central	4389	3290.43	0	496.85

Figure III-8
Graphical Display of Link Flows

Figure III-9
Network Display of Link Flows

Figure III-10
The GSAM Network

3. Conclusions and Remaining Work

Ongoing Work-Back End

Analysis of GSAM Cases

When using GSAM to evaluate the effects of various technologies or policy changes, it is helpful to save together the various inputs, outputs and assumptions. ICF proposes creating a dialog box that would allow the user to more easily accomplish this. This window could:

- (1) Ask for the name of the case to be saved,
- (2) Ask for confirmation on selected files to be saved (for example, advanced technology gasprc.a01, gsamrpt.a01, gsamsln.a01, etc.), with the current versions of these files used as defaults,
- (3) Allow for inserting a description field to document any assumptions/calculations relevant to the case in question,
- (4) Allow the user to call up a previously created case to run or modify input files from this case as a starting point for a new evaluation.

In this way, the difficult job of setting up scenarios to run would be made easier by using pieces of previously run cases, changing only those areas under consideration.

Automated Comparison of GSAM Cases

There is another window which could allow automatic comparison of GSAM cases. This window would open spreadsheet/graphics/database window to compare, for example, the output of the current run versus a particular base case. The user could see in tabular and/or graphic form the marginal effects of the case under consideration as compared to a previous benchmark. At present, this is not automatically available with GSAM.

Status Window

Another proposed feature is a GSAM status window which would allow the user to examine the progress of the software at any given time. In particular, such a dialog box could:

- (1) Display the particular module currently running;
- (2) Display how long this module and the entire GSAM model had been running;
- (3) Display the expected amount of time until completion for the module and for the entire GSAM model (based on similar runs);
- (4) Display the status of any errors or data inconsistencies encountered; and
- (5) Indicate whether certain outputs were beyond an acceptable range, and thus allow the user to rerun the module with different inputs.

This new feature could, for example, allow the user to stop a particular integrated run if the current error status, output values, or anticipated time until completion was not satisfactory. The incorporation of the GSAM status window will improve the user interface of GSAM, making it more acceptable to DOE stakeholders.

GSAM is a complex analytical tool that contains detailed data, diverse modeling capabilities, and is flexible in its reporting. While the comprehensive nature of the system is an asset to program planning and policy analysis, it also contributes to difficulties in utilizing and understanding the results for various analyses. The capability to display results in the form of graphics would enhance GSAM's value to DOE and broaden its application, appeal, and impact.

ICF will investigate and develop graphical displays for a variety of current GSAM reports using two different approaches. In the first approach, GSAM results will be displayed using Microsoft (MS) Office (MS Excel spreadsheet and/or MS Access database) as a platform. This approach offers the

advantage of using a standard, widely used software suite to quickly and efficiently process GSAM output. In the second approach, we will investigate and develop mapping displays of GSAM results using MAPINFO software as a platform. This alternative offers the capability to assist users in analyzing regional and national GSAM results in a more comprehensive manner, while maintaining compatibility with DOE systems used by the Energy Information Agency (EIA) and other offices.

The following sections first discuss the specific displays that could be developed using the MS Office platform for the various GSAM modules, including the Reservoir Performance, Exploration and Production, Production Accounting, and Demand and Integrating segments of the system. Remaining work on the mapping displays of GSAM results using MAPINFO is discussed in a separate section.

Microsoft Office Platform Graphical Displays

In many instances, the best way to begin analyzing the outputs from GSAM is to see them in a graphic format; consider the following plot used in analyzing the effect of various DOE technology programs on production (Figure III-11).

In a graphical environment, the user would have many options for plotting various outputs to better understand them, removing the time-consuming (and potentially error-prone) task of manually moving the data. In the current DOS version of GSAM, the user must manually move the outputs of the

Figure III-11
Sample GSAM Output Display in Graphic Form

model to other packages that handle graphics, spreadsheets, data bases, etc. Developing a graphical interface with Microsoft Excel, Microsoft Access, and other Microsoft Office products would enable the user to more easily analyze the detailed output from GSAM.

Reservoir Performance Module

The Reservoir Performance Module estimates future production for individual reservoirs based on the unique rock and fluid properties, setting, and technology conditions being considered. It develops reservoir production response estimates and summary project economics based on the reservoir data and input on technology specifications, regional costs, state and federal tax requirements, and other assumptions found in separate data files. The production response estimates and project economics are subsequently used by other modules of GSAM.

A desirable feature of the performance assessment step would be the capability to efficiently create cost-supply curves for individual GSAM supply regions, plays, resource types, or other user defined groups. The evaluation of cost-supply curves are most readily accomplished with graphs, plotting the cost on the vertical axis and the associated supply volume on the horizontal axis. This would allow economic analysis to consider how changes in gas price would affect supplies for various groupings of reservoirs.

The graphical cost-supply relationship for various Reservoir Performance cases would let the user gauge the effects of technology performance, changes in costs (either up or down), changes in environmental requirements, development enhancements, or other parameters on natural gas extraction potential as a function of price. It could also be used to display in-place volumes that are not impacted by the changes modeled. This could aid planners in quickly determining impacts of specific programs on segments of the natural gas resource. The addition of graphical capability to the GSAM Reservoir Performance module will speed interpretation of results, add to the existing quality control capabilities of the system, and limit some requirements for more complex, time-consuming analyses.

Exploration and Production Module

The 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 Modules. The E&P Module and outputs track and collate

capital, drilling, technology implementation, and production as they are affected by changing prices, rig availability, technology application, and environmental and other costs.

The E&P module creates the following five output files:

- (1) *prodsumm.out*;
- (2) *resvsumm.out*;
- (3) *suppsumm.out*;
- (4) *price.out* ; and
- (5) *decision.out*.

The file *prodsumm.out* contains information on reserves, production, wells drilled, and annual gas prices for the United States, Canada, each GSAM supply region, and each resource type. A graphical environment could allow the user to plot production, reserves, and number of wells drilled by GSAM region, by resource type, and for all regions taken together. The user would select the region(s), production, and reserves, while the number of wells drilled would be automatically displayed in graphic and/or tabular form.

The file *resvsumm.out* contains summary information on original gas in place (OGIP), resources discovered and developed during analysis, and reserve estimates for total, primary, and secondary (from infill-drilling or recompletions) operations. The proposed enhancements would allow an option to plot these entries as a function of time.

The file *suppsumm.out* contains production summary information for selected time intervals. The graphical results would provide pie charts and bar charts comparing and contrasting regional and resource impacts over time. This summary capability could provide important insights into how the effectiveness of programs and policies impact specific regions and resource types over time.

The files *price.out* and *decision.out* are passed over to the Production Accounting Module for final aggregation of the results at the selected technology and market conditions. Graphical summary of these files could provide additional quality control and summary interpretation of Exploration and Production Module results.

Demand and Integrating Modules

The Demand and Integrating Modules evaluate 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.

At present, there are three files that are output from the Demand and Integrating Modules:

- (1) *gasprc.ext*
- (2) *gsamsln.ext*
- (3) *gsamrpt.ext*.³

The first file contains estimates of equilibrium gas prices for each region and time period. An Excel spreadsheet with assorted macros could allow the user to compare gas prices across regions and observe the evolution of gas prices over time.

The *gsamsln.ext* file contains summary information on: supply by region over time, demand by region and sector over time, wellhead and end-use prices over time, and electricity generation capacity and utilization over time. Connecting these outputs to a spreadsheet/graphics/database package will allow the user to manipulate the data and graph key values more easily and quickly. This would entail creating a workbook in which the user would run previously set-up macros that ICF would have created. This capability would easily allow analysis of how the supply for a particular region, for example, might be growing over time given the GSAM technology and demand assumptions.

The last file, *gsamrpt.ext*, describes both the transportation capacities, seasonal flows, and storage utilization in the GSAM network. An Excel spreadsheet with macros could allow the user to easily compare, for example, transportation flow between regions and/or time periods in both tabular and graphic format.

The development of the proposed graphical interfaces for the Demand and Integrating Modules' reports would substantially improve the analytical capability of GSAM in evaluating various market impacts. By allowing comparison of supply, demand, transportation, and storage volumes, prices, costs, both over time for an individual case, and across multiple cases, the user's ability to quickly interpret the results will be enhanced. Improvements will also enhance the quality control and assurance of GSAM runs by providing easily comparable results for each model run.

³ The extension "ext" is generic, the actual extension is selected by the user in an associated batch file.

Storage Module

The storage module was developed under FETC contract DE-AC21-92MC28138 has been used to create storage reservoir specific parameters which are fed into the Demand and Integrating Modules of GSAM. For further information on the Storage Module, see section B.

Production Accounting Module

The 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, operating profits, as well as the number and type of wells drilled, jobs created or maintained, and quantities of by-products generated. This information is difficult to evaluate in output tables due to the large volume of data generated in each run. Also, the tabular output, while in a consistent format, is sometimes difficult to directly import into other software.

The Production Accounting Module generates four output files:

- (1) *nat.pro* (National Pro-Forma);
- (2) *region.pro* (Pro-Forma for all the GSAM Supply Regions);
- (3) *res.pro* (Pro-Forma for all the resource types selected); and
- (4) *region.prd* (Yearly production rates for all the GSAM Supply Regions).

The graphical environment would be capable of plotting yearly production rates for the entire nation, specified regions, or selected resource types as selected by the user. In addition, environmental costs, operating costs, and total investments could be plotted for various GSAM supply regions or specific resource types as selected by the user. The user would also be able to plot state taxes, federal taxes paid, and industry jobs created (or any other variable in the pro-forma output) as a function of time.

The addition of the graphical capability for each of the output files of the Production Accounting Module will enhance the results of GSAM evaluations. It will save considerable time in the managing and checking of results, adding to the quality of the analysis.

Mapping Graphical Displays

Currently GSAM's output files are ASCII files that must be independently imported and processed using other software packages for graphing/displaying. This process, while providing some versatility in the use and interpretation of model results, is not always efficient and has the potential for

human errors. A Graphical User Interface (GUI), which takes GSAM outputs and processes them for automatic screen displays (such as pie-charts, bar-charts, x-y plots) in a Geographical Information System format would enhance the capability of GSAM considerably. As mentioned above, some of this work has already been done.

In the following sections the potential application of a mapping system to display results for individual GSAM modules is discussed.

Reservoir Performance Module

The Reservoir Performance Module forecasts the technically recoverable natural gas production from individual reservoirs as well as the specific costs to develop and produce the reservoir. In addition, it also provides an estimate for the original gas in place (OGIP) and minimum supply price needed to initiate E&P activities in the reservoir under prescribed conditions. The proposed mapping system would be able to display the response of a particular gas reservoir at a given technology compared to other cases. In addition, the system would automatically show the price-supply curves for a region or for the entire United States based on the user's instructions. A typical display for the reservoir performance module is shown in Figure III-12.

The development of a comprehensive GIS package would further enhance the capabilities of

Figure III-12
An Application of GIS to Show GSAM Outputs in Creating Price-Supply Curves

GSAM's reservoir specific evaluations. It would provide users with additional flexibility and capability to analyze impacts of program or policy alternatives at an appropriate level of aggregation. It would also allow analysis of specific impacts without more complicated analyses that require the use of other GSAM modules. This enhancement in capabilities should make GSAM more valuable as a planning and analysis tool.

Exploration and Production Module

The exploration and production module provides the logic for all investment decisions concerning upstream activities in GSAM. Here, the proposed mapping system would allow display of the technology penetration, wells drilled by type, production, and reserves additions in aggregate or by resource type. It could also show similar output by play, region, or depth, if required.

The proposed system would also compare and contrast E&P activities for two or more policy or technology cases. This capability could be very useful in determining the incremental benefit of a particular policy on natural gas supply or industry activity. Currently the ASCII output files of GSAM are manipulated manually. This approach is not sophisticated and this proposed system can provide the results in a more transparent, directly useable manner. The relative impact of a policy might affect regions differently (in one region it might result in higher gas production while lowering production in another). A map showing this impact by color coding various changes would be very effective in evaluating/presenting results. A typical window from the exploration and production module is shown in Figure III-13.

Figure III-13
Representative Mapping Screen for Selecting Output Variables to be Displayed

Regional Map Selection

Year
1994
1995
1996

Exploration and Production Module Results

Production Summary
- By Region
- By Resource
- By Play

Well Summary
- Exploration Well

Development Wells
- Dry Well

Reserves Summary
- By Region

The development of an effective, efficient GIS interface for the E&P module of GSAM could improve reliability and utility of the results. By allowing users to specify the type of data, the level of aggregation, and the timeframe of interest, GSAM would become a better analytical tool. By providing a more efficient means of processing and evaluating results, the GIS could decrease evaluation time and lower the cost of various GSAM evaluations.

Demand and Integrating Modules

The Demand and Integrating Modules provide estimates of pipeline capacity expansions and seasonal flows, gas storage activities, and gas supply in a balanced supply-demand market condition. It also provides market-based gas prices at the wellhead and in various end-use markets based on the specific costs to extract and transport gas through the pipeline network.

The proposed mapping system can show which pipeline links are expanded or utilized for a specific demand region over time. It can also indicate, for a particular policy case, which pipeline systems and storage reservoirs respond to the policy change being analyzed. Hence, this system could be used as an effective planning tool in determining the effect of a policy on the complete gas market.

Production Accounting Module

This module performs the final economic evaluations and generates detailed cash flow pro-forma based on the specified model run. Various cash flow entries such as sales revenues, royalties, investment costs, operating costs, state taxes, federal income tax, and jobs required are calculated in this module. The output is routinely used by planners and analyst to determine costs and benefits of various alternatives. This detailed information, built from reservoir specific data, is critical to the utility of GSAM.

The proposed GIS would allow the individual line items from the Production Accounting Module to be summarized and displayed by reservoir, play, region, or state. In addition, a national cash flow pro-forma is also generated and could be displayed or summarized. This would allow users to see variations in regional impacts and the effect on specific plays or resources nationwide. Displaying final results graphically, and providing the capability to contrast impacts across cases will enhance user understanding of GSAM findings. This should reduce analytical errors and time requirements for evaluating GSAM results.

Ongoing Work-Front End

The windows interface front-end will have the following uses:

- To allow the user easier viewing and manipulation of the data files specific to each module;
- To verify the consistency and quality of these data in an interactive way, alerting the user to potential data errors; and
- To allow the user to run one or more modules in an easy way as well as check on the status of a run and possible errors encountered.

In what follows, we describe, for each module, ongoing projects for the windows front-end.

Reservoir Performance Module

The Reservoir Performance Module takes a set of database files which are formatted for use in GSAM. These files contain reservoir data for over 16,000 known and undiscovered reservoirs located in the U.S. and Canada. In a windows-based GSAM, these files could be password-protected to avoid having the user inadvertently modify or delete them.

In addition to the database files, other data and assumptions required to run the model (including technology specifications, regional production costs, state and federal tax requirements, etc.) are contained in the static data files with extension **.dat*. The user should be able to easily review and modify these files, if so required for the analysis. It is important to know before any GSAM run which input files are selected for the run. Before initiating the reservoir performance run, the modified windows version of GSAM would display the names of each of these files. For example, the file *tech.dat* specifies technology parameters for various resources. If the user clicks on this file name, the dialog box in WGSAM would let the user perform the following activities:

- (1) View the actual data with column headings;
- (2) Modify technology specific parameters such as proration, minimum system pressure, skin factors, fracture properties, tubing size, etc.;
- (3) Modify well information in specific regions;
- (4) Modify the technology parameters for two analysis cases (base and advanced, current and future, or for any two user-defined cases);
- (5) Check related values for internal consistency or alert the user to data conflicts;
- (6) Create a description field to the file to explain assumptions/calculations made; and
- (7) Select an alternate file name to save important scenario values.

In addition to allowing the user the flexibility of viewing/modifying the static files, WGSAM would have the capability of running the Reservoir Performance Module with and without the type curve model, similar to the current capability. WGSAM would prompt the user to select this option. If the "Run Type Curve" option is selected, WGSAM would invoke the type curves in calculating the technology-related parameters (such as production rates, pressures, etc.) This option also would allow calculation of a minimum acceptable supply price (MASP) for a given economic scenario. If the "Do Not Run Type Curve" option is selected, WGSAM would not load the type curves, but would still calculate the MASP for a given set of reservoir flow characteristics. This latter option runs more quickly than the former one.

In addition, WGSAM would determine if the model had all the necessary files to run the Reservoir Performance Module. Proper warning or error messages (fatal and/or non-fatal) would appear on the computer screen as the run proceeded. WGSAM would have the capability of terminating in case of fatal errors after creating a well documented log file, which could be viewed later to determine the cause of error.

Once the Reservoir Performance module run was complete, WGSAM would provide an option of moving and compressing the output files to appropriate directories for possible use by other modules of GSAM. WGSAM would have the capability of immediately creating the binary files needed by other GSAM modules (*undb.tcp*, *undb.bnk*, *disb.tcp*, and *disb.bnk*) in an appropriate directory, as well as any special environmental files, tax structure files, or technology files needed for future runs.

Exploration and Production Module

The E&P module can be run in two modes for a variety of technologies, costs, regional drilling capacities, tax and royalty rates, exploration risks, and environmental regulations. For estimating activity under a single established gas price track, the module is run one time with the specified price track file. For an integrating run, the E&P Module is run several times in conjunction with the Demand and Integrating Modules to establish a balanced supply gas price.

The user should be able to view/modify all of the E&P module input files and specify the type and structure of the evaluation. In the E&P Module window, these file names would be displayed and the user would pick the file to be modified. To illustrate what could be done with WGSAM, consider the file *dtec_pen.spc*. This file is set up to allow incremental penetration of development technology over the entire time frame being modeled for individual resource types. It includes technology penetration by year, the percentage of the resource available for technology application, and the relative cost (compared

to the assumptions in the Reservoir Performance Module) to implement the technology. If the user selected this, WGSAM would allow the user to perform the following activities:

- (1) View the technology penetration rates used in the file with column headings;
- (2) Modify technology penetration by resource type;
- (3) Modify relative cost of the technology by resource type;
- (4) Create a description field to the file to explain assumptions/calculations made; and
- (5) Select an alternate file name to save important scenario values.

In addition, the user would be prompted to pick a gas price file from a list of previously saved files.

Demand and Integrating Modules

The Demand and Integrating Modules take as input various static files and forecasts gas demands for the years selected by the user. These demand values are then used in the integrating linear program, which balances the gas prices and quantities between the supply and demand sides of the market. For each iteration of this integrating procedure, GSAM calls the E&P module several times to determine valid gas price, quantity pairs and then feeds this information into the LP.

One of the more important aspects of a WGSAM would be the ability to examine/modify the inputs to GSAM. In the D&I module of a windows-based GSAM, the user would be able to modify the various static input files.

ICF proposes allowing the user greater flexibility in modifying or viewing these files if desired. For example, if the user selects *link_nde.spc*, which contains link information, a dialog box would be created to perform the following activities:

- (1) View the actual data with column headings;
- (2) Modify individual values in an easy-to-use manner;
- (3) Apply percentage growth factors to certain selected costs or other values;
- (4) Create a description field to the file to explain assumptions/calculations made; and
- (5) Select an alternate file name to save important scenario values.

In addition to allowing an easy way to modify/view the static files, the windows version of GSAM that we propose would also allow the user flexibility in choosing the various settings when calling the E&P module. For example, at present, the user must stipulate a gas price file which contains a set of starting values; this is renamed by the program as "gasprc.new". We propose creating a dialog box

to allow the user more freedom in selecting and creating this file. In particular, this window would allow the user to:

- (1) View the existing choices for gas prices (from previous integrated runs);
- (2) Easily create a new gas price file either from scratch or using parts of existing files; and
- (3) Add a description field to the gas price file to describe particular assumptions/calculations made.

Similar dialog boxes would be created for other E&P inputs. At present, the user must also select the appropriate technology (advanced, base, etc.) to be used when the E&P module is called from within an integrated run. In certain situations, the user may want to create a new technology specification "on the fly" and the next dialog box would be able to do this. In particular, this window would allow the user to:

- (1) View the existing technology descriptions;
- (2) Create new technology descriptions to be tested from scratch or modify previous descriptions; and
- (3) Create a description field to describe particular assumptions/calculations made.

The current method of determining how long to run the Demand and Integrating Modules is to specify *a priori* a fixed number of iterations. In the windows version of GSAM, we would allow the user to both specify the maximum number of iterations to be attempted (before an equilibrium set of gas prices is determined) as well as other convergence criteria. Such convergence criteria might include a check to see if successive gas prices estimates were converging. The associated dialog box would thus query the user on the following items:

- (1) The maximum number of iterations to be tried;
- (2) The stopping criterion to be used, to be applied to all regions and time periods or just to specific regions or time periods; and
- (3) The possibility of examining the gas prices and other outputs after certain iterations before continuing on to the next iteration.

Production Accounting Module

The Production Accounting Module takes inputs from files created from a number of other GSAM modules, such as the Reservoir Performance Module and the E&P Module. WGSAM would make an internal consistency check between the files used by the Production Accounting Module and the files used by all other GSAM modules. In addition, the user would be allowed to view these files, but

would not be allowed to change the entries, because of the potential to introduce inconsistencies with the other sections of GSAM. In addition to the files transferred over from other GSAM modules, there is one input file (*output.opt*) which contains information about the format of the output files. The user should be capable of viewing and, if desired, changing the entries in this file. The user would have the following choices in *output.opt*:

- (1) Pro-forma entries for state, region, resource type or for the entire U.S.; and
- (2) Yearly production rates by region or state name.

The modification of the Production Accounting Module to a windows interface will ensure that runs are completed consistently and that appropriate, complete output is generated.

IV. CONCLUSION

The development of GSAM continues on track. A major event in the past year was the Peer Review Workshop, which provided GSAM with direction and increased focus. The reviewers who participated in the two-day workshop recommended several improvements. The recommendations cover an array of model data and methodology, including improvements to reservoir data and to the E&P, Demand, Integrating, and Storage Modules. Guidance on the design and implementation of the Environmental Module was also given.

Upon approval from FETC, work on the Environmental Module will continue as compliance cost estimates can be developed and the conclusions of the Peer Review Workshop are implemented. Like the Environmental Module, the Storage Module also received the attention of the Peer Review Workshop. The Module was completed in the past year, and can be modified, pending FETC approval, to the specifications of the workshop participants.

Overall GSAM testing was performed in the past year. In the effort to ensure the validity and long-term reliability of GSAM, the Reservoir Performance Module, the E&P Module, the Demand and Integrating Modules, and the Storage Module were all tested. The results of the tests were consistent with geologic and financial evidence, and provided conclusions that were intuitive and well-documented.

The nature of the databases which support GSAM is such that they must be frequently updated and scrutinized. In the model, upstream and downstream data were revised, including reservoir data, drilling and completion costs, O&M costs, and demand data. Providing GSAM with current data has increased its effectiveness and relevance.

GSAM is designed as a multi-function tool, able to provide analysis on a variety of issues, and can be especially useful in analyzing the impacts of public policy. In this regard, GSAM was used to study the effects on the public and private sectors of a royalty relief tax credit for marginal wells. The study is ongoing, and in the past year it produced results which demonstrate GSAM's applicability to a variety of scenarios.

The time to run GSAM, both in an integrated fashion as well as for the E&P Module by itself, has been greatly reduced. This was done through a combination of hardware improvements and streamlining the logic of the programs involved. Further speed-ups are possible and this is the subject of ongoing work.

Looking forward to the next year, bringing a windows interface to GSAM will be a top priority. Initial work has been completed, and the development of the interface is continuing. This will make the model more user-friendly and more widely applicable.