Development of a Natural Gas Systems Analysis Model (GSAM)

**Annual Report
January 1994 - January 1995**

July 1994

Work Performed Under Contract No.: DE-AC21-92MC28138

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
ICF Resources Incorporated
Fairfax, Virginia

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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 requires 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 futures.

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 Morgantown Energy Technology Center (METC) in carrying out its natural gas R&D mission.

Recent events have heightened the critical need for analytical systems to address key aspects of the gas R&D program. In December 1993, two reports issued by DOE strongly endorsed the technical approach applied by METC to develop GSAM. The *Domestic Natural Gas and Oil Initiative* (DNGOI) and Natural Gas Strategic Plan were issued by DOE to ensure the gas program is appropriately focused

on key activities to assist industry with minimum duplicative effort. The overall goal of the gas program is to improve the ability to supply, store, transport, distribute, and utilize gas in an economically efficient and environmentally beneficial manner. The DNGOI reinforces the critical role of gas in the U.S. energy equation by identifying strategic activities and actions to advance and disseminate technology and stimulate natural gas markets. GSAM is designed specifically to meet many of the analytical requirements resulting from these important initiatives.

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 two years. Research findings to date have focused the design work on critical data and model segments required to fully evaluate future market conditions. Recently, the contract was modified to include in the scope of work the development, testing, and integration of an environmental analysis module. This work is currently being planned in coordination with DOE's Metairie Site Office. The preliminary design was discussed at a recent meeting at METC to initiate activity under this new task. In addition, a modification has been proposed to develop a reservoir-level natural gas resource database for use in GSAM. This database is necessary to validate and calibrate the GSAM modeling components and integrated systems. This work is expected to begin shortly and provide the basis to complete GSAM by the end of the year. This accelerated completion is important for the analytical requirements likely to be forthcoming, consistent with actions under the DNGOI.

Key activities completed during the past year include:

- Conducted a comparative analysis of commercial reservoir databases
- Licensed and screened NRG Associates Significant Oil and Gas Fields of the United States reservoir database

- Developed and tested reduced form reservoir model production type curves
- Fully developed database structures for use in GSAM and linkage to other systems
- Developed a methodology for the exploration module
- Collected and updated upstream capital and operating cost parameters
- Completed initial integration of downstream/demand models
- Presented research results at METC Contractor Review Meeting
- Conducted other briefings for METC managers, including initiation of the GSAM Environmental Module
- Delivered draft topical reports on technology review, model review, and GSAM methodology.

The GSAM prototype is complete and systems integration, testing, and validation are underway. The next critical activity will be the examination of GSAM by a technical Review Committee in September 1994. This activity will require significant analysis of results from validation runs of individual modules across a range of conditions. This activity will be ongoing through November 1994, when the model will be installed at METC and GSAM training provided for METC staff.

GSAM development will be completed six months ahead of schedule to provide analytical capabilities in R&D planning and policy review in the coming year. Additional system enhancements may be beneficial to allow the system to quickly and thoroughly analyze the evolving domestic gas market. The GSAM Environmental Module development, integration, and testing is scheduled to be completed by June 1995. This enhancement, along with the full development of a comprehensive resource database, allows METC to significantly focus its natural gas R&D program, credibly respond to policy initiations, and provide the most valid and comprehensive assessments of the North American gas market available.

I. Introduction

This report reviews the goals, work plan, schedule, 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 underway for two years, since June 22, 1992. Work performed under this contract has included review of existing and emerging technologies, critique of other available models, final design of the model, development and initial testing of the databases, engineering and cost modules, and development of market model interfaces.

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 provide a roadmap for on-going and future research. The findings reported are consistent with the Project Review briefing presented on June 16, 1994 at Morgantown Energy Technology Center (METC).

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 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, once fully developed, tested, and validated, will be used to evaluate alternative research and development (R&D) activities and strategies under the direction of METC.

The goal is to provide the analytical capability to estimate the impacts of federal energy and environmental policy initiatives on domestic gas potential. The three-year project has been accelerated to provide a tested and validated GSAM later this year. Final development and testing is under way. The work was recently expanded to include the development of explicit environmental modeling capabilities. This work will be concluded within the original contract period.

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.

In December 1993, DOE published the *Domestic Natural Gas and Oil Initiative* (DNGOI) and Natural Gas Strategic Plan. These two documents contain important guidance on R&D direction to ensure that the gas program is appropriately focused on key activities of interest to improve the gas industry with minimum duplicative effort. The overall goal of the gas program, to improve the ability of the domestic gas market to supply, store, transport, distribute, and utilize gas in an economically efficient manner, must be met through strategic direction that appropriately reflects and accounts for market realities. The DNGOI recognizes the important role natural gas will play in the future. It lists strategic activities and specific actions focused on advancing and disseminating technology and stimulating markets related to natural gas. GSAM will provide analytical background and strategic planning capabilities needed to meet many of the DNGOI requirements. Without an analytical tool like GSAM, R&D activities cannot be appropriately ranked or focused on the most important aspects of natural gas extraction efforts or utilization considerations.

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 on-going R&D projects using a full fuel cycle, cost-benefit approach. This method will yield 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, June 22, 1993 to June 21, 1994. 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 four major task assignments on which work has been done during the reporting period. Section IV summarizes the results of the research efforts, including difficulties encountered and methods used to overcome them. Section V provides details about planned activities in the coming year. These include final GSAM integration and testing, resource data development, environmental module research, and review committee meeting work, each of which is discussed. Appendix A provides additional detail on the full research work plan and individual task activities for the entire project, including the recently approved and initiated environmental module.

The results of GSAM work over the past year and immediate plans for GSAM development were recently presented to DOE personnel at a meeting at METC. This meeting identified important aspects for the upcoming GSAM Review Committee meeting, scheduled for September, 1994. In addition, the meeting provided a forum for feedback on concerns about key design features and potential future uses. Appendix B is a complete presentation package from the meeting.

II. Research Methodology

A. Overview

The primary purpose of GSAM is to provide credible, valid empirical support to METC R&D program planning and policy assessment. This role has become increasingly important as DNGOI and other government and industry initiatives increasingly 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 METC 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 to 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 and future use of the system.

GSAM development has also been planned and designed to be timely and responsive. Development was significantly accelerated to provide analytical capabilities to assist METC 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 is to prevent obsolescence and provide for ongoing enhancements. GSAM is being developed in discrete modules that are linked but can be validated and used on a stand-alone basis. This design feature was selected to assure easy updating and enhancing of the system as new information and procedures become available. Additionally, GSAM will use a series

of component databases, each specifically designed to allow separate updates as new dates become available. The database structures have been generated to ensure consistency between different segments.

Because the analyses needed for a full GSAM run are so complex, GSAM incorporates a preprocessor module that performs the computer intensive 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 preprocessor. This allows the user to quickly analyze multiple technology, policy, or tax situations. This potentially reduces GSAM run-times by more than 80 percent in evaluations of multiple R&D in policy strategies. The preprocessor output data are configured to accommodate changes in market conditions that would require new analysis in traditional models. The full explanation of these concepts will be 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 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.
- *Technology* is characterized in terms of the explicit performance that affect gas contact, 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. Projects are costed 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.
- *Decisionmaking* incorporates the inherent uncertainties and inefficiencies in technology performance and gas markets.

Each component of GSAM will incorporate the capability to evaluate the inherent uncertainties in resource characterization, technology application, reservoir performance, market economics, and operator decisionmaking. 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 are aggregated to the regional level.

C. Research Plan

Design and development of a model of this complexity required a detailed research plan and corresponding management controls. For this project, we developed a research Work Breakdown Structure and integrated this into a critical path method (CPM) management plan. Appendix A contains the summary Work Breakdown Structure (WBS) developed for the research. The CPM work schedule is updated weekly and used to sequence and manage project activities.

Research over the past year was conducted in four distinct tasks (1) Review Technologies, (2) Review Models, (3) Develop GSAM Methodology, and (4) Design and Test Models. Details on each of these activities is summarized in the next section. Greater detail is provided in separate topical reports on each activity, the first three of which have already been delivered.

The recent modification to the contract to add the environmental module is still being planned. Based on initial review and input from DOE, the WBS for this module has been incorporated into the research plan, as shown in Appendix A and discussed in Section V.

ICF also recently responded to a request from METC with a proposal to develop and enhance a reservoir-level natural gas resource database. Once this modification is approved, the research plan, CPM, contract Management Plan, and Cost Plan will be modified and submitted for DOE approval. This will be completed within thirty days of approval of the proposed modification.

III. Research Activity and Findings

This section summarizes the research completed and preliminary findings during the reporting period just completed. Work was continued on four tasks of GSAM. Work under each of these tasks is described below. The integration of these individual research efforts is summarized in the next section and in the GSAM design task. Work under the recently approved and initiated environmental module has focused only on planning tasks and research for completion in the next reporting period.

A. Technology Review

Work under this task reviewed the status of exploration and technology (E&P) technologies and their applicability to conventional and unconventional gas resources. This included making specific recommendations regarding which technologies should be incorporated into and explicitly modeled in GSAM. Although GSAM also evaluates transportation and downstream technologies, the principal focus of this phase of GSAM development is on natural gas E&P technologies.

This task and the topical report summarizing the work provides a context for the initial GSAM technology characterization. A method of clustering technologies by both their use in the field as well as scope of required R&D was developed. This method allows DOE to estimate the impact of discrete segments of a research strategy, providing an analytical basis to make programmatic judgments about specific types of natural gas technologies.

1. Task Objective

The GSAM project scope encompasses both upstream and downstream gas market segments. The immediate priority for this model and technology review, however, is focused on the E&P sector, to which METC's primary gas research activities are directed. The objectives of the GSAM technology review were to:

- Classify and characterize natural gas E&P technologies.

- Define current technology applications and limitations and, whenever possible, anticipate future applications.
- Characterize the fundamental reservoir performance and economic parameters and the appropriate methods that could be used to model natural gas technologies.
- Examine the limitations of traditional technology modeling approaches.
- Propose guidelines and recommend approaches to account for and model natural gas technologies in GSAM.

The impact of technology on natural gas production costs and supply potential varies tremendously across the domestic resource base. Therefore, to derive the maximum analytical value, GSAM must evaluate technologies in a full systems context that considers variation in resource characteristics, reservoir development status, and project productivity and economics. For this reason, this review of natural gas technologies primarily focuses on how they can be represented to most effectively support METC gas R&D planning, implementation, and evaluation.

2. Assessment Approach

Because many technologies have similar or related impacts, this technology assessment first clustered technologies by their scope of application in the discovery, characterization, development, and extraction of gas resources. Technology categories were also specified to represent similar objectives or scope of R&D activities.

Although several approaches were evaluated to classify natural gas technologies, a two-tier method was selected. The first tier consists of five categories:

- Exploration
- Drilling
- Reservoir Characterization
- Completion and Stimulation
- Production Optimization and Processing

Each of these five major technology categories is further divided into subcategories, characterized by groups of technologies with similar impacts and R&D objectives. Table III-1 lists the proposed categories and subcategories of E&P technologies to be modeled in GSAM. For example, the drilling category is

Table III-1
Proposed GSAM Natural Gas E&P Technologies

Exploration

- Surveys - geophysical surveys, including gravity, magnetic and geochemical
- Exploration Seismic - deep investigation seismic, used prior to drilling of wells, that leads to identification of drilling prospects through structural or stratigraphic anomalies
- Regional Interpretation - geological modeling on a basin or play scale that predicts gross depositional trends

Drilling

- Drilling Structures - includes offshore platforms of various configurations, ice and gravel islands, alternative onshore site preparation methods, and special methods of access to sites, such as helicopter-delivered slimhole rigs
- Rigs - includes top drive, turbo drilling, rig automation
- Drillstring - included tubulars and bits, including coiled tubing, PDC bits, corrosion resistant drill pipe and casing, and high strength steel
- Fluids - includes air and alternative mud fluids
- Orientation - includes azimuth and inclination, such as for horizontal, deviated, or extended reach drilling
- MWD - included both measurement and directional control components

Reservoir Characterization

- Geologic Model - knowledge, data, or computer representation of intra-field or cross-wellbore interpretation of characteristics, continuity, and estimation of potential, including geostatistics using fractals or other stochastic techniques
- Measurement - includes developmental seismic (e.g., cross-borehole tomography, vertical seismic profiling), cased and open hole logs, coring, mechanical properties testing, well testing, and petrophysical analysis
- Reservoir Design and Analysis - models and interpretation that lead to optimal production for field development, drilling, completion, and stimulation (e.g., models for drilling, hydraulics selection, completion and stimulation design, and production optimization)

Completion and Stimulation

- Configuration - includes casing, packer, and tubing alternatives (e.g., slotted liner, gravel pack, open hole, cavity, and cased and perforated), as they affect production optimization and environmental compliance or risks
- Cementing - includes optimum cement composition and placement techniques for various physical and chemical environments, including horizontal wells, especially as related to mechanical integrity of wells
- Stimulation - included acidizing, hydraulic fracturing (i.e., design methods, proppants, fluids, and additives), and explosive and combustion fracturing

Production Optimization and Processing

- Production Optimization - includes regular and one-time interventions to optimize well or field economics, such as bottomhole fluids removal, subsurface and surface maintenance, recompletions, temporary curtailment, or abandonment
- Processing - includes separation, sweetening, dehydration, and compression on-lease

subdivided into six subcategories: drilling structures, rigs, drillstring components, fluids, orientation, and measurement while drilling (MWD). Each subcategory represents the collection of various individual tools, techniques, and practices that are applied in various reservoir settings. A total of 17 technology subcategories are considered. For purposes of technology modeling, however, all technologies in a subcategory have similar performance objectives and impacts on gas production, reserves, and costs for a given resource type. A subcategory would, collectively, be the focus of a more intensive R&D planning and evaluation.

The performance of each technology subcategory is characterized for six types of impacts:

- *Reservoir Performance.* Impact on the amount of gas contacted by a wellbore or stimulation, and its initial deliverability, production profile, and ultimate hydrocarbon recovery.
- *Cost.* Impact on required capital or operating costs.
- *Reservoir Access.* Impact on access to resources that were previously precluded from any E&P activity (i.e., overcome physical or regulatory constraints).
- *Technology Applicability.* Impact on operators' ability to effectively apply the technology to a given resource/setting.
- *Market Penetration.* Impact on the availability, commercialization, and ultimate market saturation of major technology improvements and their displacement of existing technologies.
- *Risk.* Impact of uncertainty associated with process performance, geologic characterization, or project economics.

3. Topical Report Summary

The topical report on this task expands on the methodology described above and defines a preliminary natural gas technology category-impact matrix to be used in GSAM model development. Each technology subcategory is characterized in terms of each of the six impact criteria defined above, including defining the parameters by which various impacts may be modeled in GSAM. The report also summarizes recommendations for an initial approach to model each subgroup of technologies within GSAM. Each cell of the detailed technology characterization matrix is described for each of the 17 technology

subcategories and six types of impacts. The matrix characterizes, in summary form, the possible impact of technology improvements against each criteria considered.

This report provides an initial framework for early model design and data configuration within GSAM to accurately assess technology changes over time. Further disaggregation of technology categories, impact types, and modeling procedures will evolve as model and database development continue and as METC needs dictate. However, the proposed GSAM approach provides DOE with state-of-the-art capability to evaluate strategies to accomplish its mission of maximizing environmentally acceptable production of the domestic gas resource.

B. Model Review

Many models exist that evaluate various aspects of natural gas production potential. The scope of these models tends to focus on unique features, such as an overall representation of the total U.S. natural gas system (e.g., market) or an explicit representation of potential reservoir performance given historical production performance and technology utilization, without consideration of its market context or underlying economic criteria. GSAM is being developed to simultaneously evaluate the impact of various combinations of technologies and energy policies across a diverse resource base. Evaluations within GSAM of alternative natural gas R&D strategies or policies are conducted in a market context, with the benefits of technology advances measured in terms of both commercial as well as technical success. Design and development of these model capabilities requires integration of data and modeling concepts from various sources, many components of which may already exist.

GSAM design requires a comprehensive characterization of natural gas technologies and the development of technology evaluation models. It is therefore appropriate to evaluate existing, publicly available natural gas models to determine their applicability within GSAM. Existing model features that are appropriate for GSAM will be incorporated as necessary. Overcoming analytical or data limitations common to many existing natural gas systems or reservoir models will be given special emphasis in the GSAM design.

1. Task Objective

Work under this task included a thorough review of existing gas models, as prescribed in the GSAM statement of work, to provide the context for the model design and development planning for GSAM. The approach to this evaluation was to review microcomputer-based, non-proprietary models of natural gas resources, technologies, and markets. Two types of models were evaluated:

- Natural gas systems models, which integrate supply, demand, and transportation components of the U.S. natural gas market system.
- Reservoir models, which estimate gas production volume and rate from a well or reservoir as a function of geological properties and applied technologies.

The objective of this task was to provide guidelines and recommendations as to how GSAM can incorporate the best features of existing natural gas systems, reservoir, and technology models. The scope of the report is to summarize selected model reviews and recommendations, the application of which will be more fully discussed in GSAM Topical Report 4 (GSAM Model Development).

2. Assessment Approach

A GSAM requirements analysis was conducted prior to reviewing models to define the appropriate modeling parameters, level of required analysis aggregation, required data accuracy, and analytical complexity to be represented in GSAM. Only with this information can existing models be evaluated as to their appropriateness for incorporation into GSAM. Also, the ongoing development of GSAM affects the timing and priorities for implementing various model features.

The first finding of this requirements analysis was that, given METC's focus on evaluating the impact of R&D on the performance of specific extraction technologies, the GSAM unit of analysis must be the individual reservoir or prospect well. This single analytical requirement makes almost all gas systems models inappropriate as a basis for direct use in GSAM. Existing systems models evaluate resources at a much higher level of aggregation and/or estimate the impacts of various technologies by statistical methods. The historical lack of a comprehensive natural gas reservoir database and the analytical complexity of simultaneously evaluating an array of extraction technologies has also precluded development of a systems model at this level of detail. Therefore, the systems model review focused on

those regularly used natural gas systems models whose results have been extensively published and for which documentation was available.

The second finding of the requirements analysis was that reservoir modeling of extraction technologies must be conducted on a consistent basis, evaluating the entire in-place gas resource, to allow METC to establish and modify R&D priorities. Reservoir-level models have been developed for almost every resource type, technology, and operating condition. However, these models differ widely in their analytical assumptions, data inputs, and level of detail. Therefore, the reservoir model review process emphasized "reduced form" reservoir models that shared a common analytical scope and level of detail. A reduced form model incorporates analytical simplification and less rigorous data requirements, providing the desired estimation of rates and volumes of gas recovery. Reservoir models were evaluated in terms of their consistency with currently accepted reservoir engineering theory, accuracy of reduced form model results against those generated by a simulator (where appropriate), comparability of the model results against field results (e.g., history match), and an evaluation against a full range of input parameters (i.e., testing the model's boundary limits or range of accuracy).

3. Topical Report Summary

The topical report submitted for this task summarizes the criteria used to evaluate the various types of models. It describes the capabilities and limitations of the models evaluated and their relevance to each of the major components of GSAM, focusing on the upstream model components. The report also reviews basic risk analysis concepts and recommends how best to apply them in GSAM. The potential linkages of other models with GSAM are described, focusing on downstream and other components. The conclusions drawn from these model reviews and the implications for GSAM design are summarized.

The topical report provides insights into important steps in GSAM design, validation, equilibration, and integration. The results and conclusions, including identification of linkage to other systems, will provide future reviewers and users with needed information to comprehensively use GSAM to study gas markets. This report will therefore provide important guideposts for ongoing GSAM model implementation.

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 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 III-1 provides a schematic overview of GSAM's major analytical components. Each of these five 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 proposed methodology evaluates each activity as investment opportunities 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 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 decisionmaker, each attempting to maximize fully-risked profit in a market context.

Figure III-1. GSAM Structure

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 III-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. Upstream Model Methodology

The consistent evaluation of gas supply under alternative economic, technology, and regulatory conditions is a key objective of GSAM. Figure III-3 provides a detailed view of the proposed framework of eight databases and eight analytical modules comprising the logic flow of the Upstream Model. The integrated, modular design of data and analytical procedures maximizes flexibility in organizing, designing,

Figure III-2. GSAM Market Logic Flow

Figure III-3. GSAM Upstream Model Flowchart

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implementing, and completing analyses. This proposed 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.

The remainder of this section provides an overview of the upstream model. The upstream model is grouped into four functions:

- *Resource Set Up.* Available resource, play, and reservoir data are transformed into fully characterized play-specific groups of known and undiscovered reservoirs.
- *Analytical Preprocessor.* All reservoirs are fully evaluated under all plausible alternative technology, economic, and development scenarios.
- *Current Resource Status.* Characterizes the current and potential productivity and economics of each reservoir.
- *Supply Analysis Segment.* In response to market signals generated by the GSAM Integrating Model, allocates exploration, development, and production activity over the forecast period.

Table III-2 provides descriptions of the individual modules and databases that comprise the entire Upstream Model.

The GSAM design also emphasizes the importance of proper accounting of resources by describing, quantifying, and evaluating the remaining domestic gas resource (Box 16) 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 III-4). The Remaining Resource Database will provide 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 will be 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.

GSAM's proposed upstream model methodology promises a comprehensive evaluation of the natural gas resource and key E&P issues by making major analytical advances in scope of analysis units,

Table III-2. 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, composite reservoir for each play representing all known reservoirs that are not identified in the database, most likely to be the smallest discovered reservoirs. These "pseudo-reservoirs" are needed to reconcile model results to booked reserve estimates and current/historic production 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 will be defined for each play type. Production profiles for initial development wells will be stored for use in the analysis modules. Minimum acceptable supply prices for exploration, development, continued development, and continued operation will be calculated and required elements stored for use.
6. **Developed Resource Evaluation Module** - Evaluates known reservoirs to determine current development status and estimate 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 10 size class by 100 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 III-2. GSAM Supply Model Overview (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 will be 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 will 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, lower costs or accelerated production, or some 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.
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 III-4. Analysis of Natural Gas Resources by GSAM Analytical Modules and Databases

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 will impact technology commercialization and reservoir profitability. The following sections describe how upstream analyses will be integrated into the full-system gas market.

2. Downstream Model Methodology

Traditional technology appraisal methods estimating the impact of new technology on selected resources are inadequate to derive the full benefits of R&D. The proposed 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 III-5 displays the logic and data flow of GSAM's proposed Demand Model.

Analysis of demand for natural gas will include regional assessment of consumption by sector. The proposed GSAM methodology uses existing models of residential, commercial, industrial, and electric utility requirements for gas to determine demand within 14 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 proposed downstream modeling methodology provides the breadth and depth of evaluation consistent with the role of GSAM in E&P policy and R&D planning and evaluation. The next section describes the regional equilibration of supply and demand to provide realistic estimates of North American gas market performance.

Figure III-5. GSAM Demand Model Flowchart

3. Integrating Model Methodology

GSAM explicitly evaluates gas transportation and storage, 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 71 transport links between supply and demand regions. In addition, the proposed methodology 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 METC a unique opportunity to evaluate storage reservoir performance, the need for additional capacity, and alternative strategies to merely developing more storage reservoirs.

The Integrating Model equilibrates annual gas prices and sales volumes over a 40 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 26 supply regions, 14 demand regions, and over 71 transport links (Figure III-6).

Figure III-6. GSAM Transportation and Supply/Demand Region Map

The Integrating Model also performs 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 Model 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.

4. GSAM Outputs

The results from the Integrating Model 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 will provide 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 will be structured to allow direct export for use by spreadsheets, databases, and graphics software. Lotus 1-2-3 data file formats will provide a basis for the design, which will be generic enough to allow translation to other formats. The proposed output formats ensure easy compatibility with other systems models and databases as well.

GSAM output will include 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, will also be derived from GSAM reports. Additional information and flexible report formats will be available at the user's discretion.

Potentially most important and relevant to DOE will be GSAM summary output of technology-related variables. Technology summaries, including the number, types, costs, and benefits of various applications, will be 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 will be included in all GSAM output. Internal consistency and external congruity will 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.

D. Model Development

1. Task Objective

This task is the culmination of all GSAM work to date and the dominant activity during this period of performance. Its objective is the development and testing of the individual modules that constitute GSAM. The importance of this task is reflected in the detailed documentation requirements as described in the contract. Work on this task began with the development of prototype modules. Much of the essential testing of the modules has been awaiting the availability of resource data and is now in full operation.

2. Development Approach

As the GSAM methodology was finalized for each segment, a prototype module was developed. The entire GSAM model is coded in FORTRAN. This provides for the quick development of prototypes that can be easily expanded or replaced completely, as necessary. These various prototypes were linked to provide an overall GSAM structure. As new information was obtained and new approaches to analysis developed, modules were replaced in enhanced updates. This modular approach has paid dividends in terms of time savings in design modification, testing, and overall model development.

The type curve modules that are the heart of GSAM's reservoir performance evaluation system, have been developed sequentially. The simpler pressure depletion, radial flow module was developed first to provide a working framework and starting point for other more complex settings. To date, five complete type curve modules have been delivered and individually tested and integrated. Final changes to the water drive module have been outlined based on initial testing. This module, along with the final coalbed methane and shale type curves, will be completed this summer. These final modules can be rapidly integrated into the existing system and again tested and validated with available data.

The exploration module has also been fully developed and is now being thoroughly tested. The final development of this segment of GSAM depended on availability of resource descriptive data. With the availability of NRG data, a comprehensive test database has been developed. It is expected that, similar to the type curves, this module will require minor adjustments after initial testing. This will be completed in July. Once the full undiscovered resource database is constructed under the proposed contract modification, final integration and calibration of the exploration process will be complete.

The full upstream model has been integrated and data links checked, modified as required, and confirmed. Most of the work remaining in this segment is in validating results and documenting procedures. This will be completed in accordance with the contract requirements for model documentation.

Work is underway to complete a comprehensive testing and validation plan for GSAM. This plan will serve as the outline for full model testing and validation under Task 5. This step is also critical to the successful completion of the Peer Review meeting. This plan will be provided along with the topical report on model development in July.

IV. Research Results

A. Results Achieved During Period of Performance

GSAM's highly disaggregated resource and technology characterization allows it to assess alternative federal natural gas R&D, tax, regulatory and environmental policy initiatives at a previously available level of detail. It will also be available to industry to support capacity planning and market analysis for various end-users and provide comprehensive gas industry environmental impact assessments.

As discussed above, the first task of the GSAM research was a thorough review of technologies and methods to characterize their performance. This activity required an improved understanding of existing practices in the areas of exploration, development, drilling, completion, production, and processing. In addition, research results provided a basis for estimating the likely impact of individual groups of technology advances on well productivity, costs, and/or associated risk for various resource types. The findings of this research were summarized in a technology matrix and explained in Topical Report 1.

ICF Resources has developed a working prototype of GSAM and is now calibrating the model and data. Relevant natural gas upstream, downstream, and market models were reviewed to identify appropriate analytic capabilities to incorporate into GSAM. We also reviewed commercial gas extraction technologies to better characterize performance and costs in terms of GSAM parameters. Models were also evaluated to determine appropriate methods and needs for linking to GSAM through modified input or output structure. Results of this research were reported in Draft Topical Report 2.

GSAM operates on a DOS platform and currently runs on a 486DX2/66 machine with 16 Mb of RAM and a 250 MB hard disk. The hardware requirements of GSAM will be reevaluated as part of the Peer Review to determine if any model changes are desirable. User manuals will be developed after completion of this review. A priority has been given to improving run time efficiency and minimizing data storage requirements.

Full GSAM methodology development was completed over the reporting period. The design of the databases, modules, and interfaces was finalized. Design specifications for the individual process and economics modules, quality control procedures, and databases were fully developed to provide a framework for final design and integration, which has proceeded rapidly and is nearing completion. Topical Report 3 summarizes the full research findings surrounding GSAM methodology development.

GSAM design, model development, and database structuring was also largely completed during the period. All individual modules have been developed and tested through a series of calibration runs. Final modifications to the type curve reduced form model for unconventional resources (coal and shale) have been initiated with a new approach based on previous findings. Current activities are focused on improving the speed, accuracy, input and output specification, and storage requirements of the overall system. This is proceeding concurrent with testing and systems validation. This activity will culminate in the preparation of Topical Report 4, GSAM Model Development. This report will provide the framework for briefing the Review Committee.

B. Research Difficulties and Methods Developed to Overcome Them

GSAM cannot be validated, calibrated, peer reviewed or used for DOE R&D planning or policy, however, until it has access to the validated reservoir level data for which it was designed. The core concept of GSAM was to build a modeling system that integrated geology, technology, economics, and markets. That capability is grounded in the ability to define the unique interactions between reservoir properties and explicit technologies on a disaggregated level. This capability addresses one of the most serious limitations of natural gas modeling that even the National Petroleum Council (NPC) could not overcome in its recent study of natural gas - the need for reservoir level resource data.

Data limitations have now been overcome. METC has licensed NRG Associates' significant Oil and Gas Fields of the United States databases. ICF has been given access to these data and has developed test reservoir databases to proceed with final design and testing of GSAM. A proposed contract modification to develop comprehensive resource descriptions over the summer and fall of 1994 will complete the process of overcoming data limitations. Work proposed under this modification will provide the level of detail and consistency required to fully test, validate, and calibrate GSAM.

V. Planned Research Activities

GSAM development is entering into a critical final year of testing and validation. Significant work remains to calibrate and fully document individual components and the Integrating Model. Additionally, recent modifications to the contract are being planned and scheduled for full implementation over the period from now until June 21, 1995. This section outlines the remaining work to complete GSAM: develop and integrate the environmental module, construct and test a comprehensive gas resource database, and complete a through technical review before a panel of industry and government experts.

A. Final Model Integration and Testing

As discussed above, work to fully integrate and test GSAM is currently ongoing and will be complete prior to a meeting of the Peer Review Panel. GSAM structure and design will be finalized with the completion of the individual upstream modules, the reservoir database developed using the NRG database, and the integration and interface with the downstream model complete. Testing and validation will involve a large number of sensitivity analyses over a broad range of market, technology, tax, and cost conditions. The goal is to ensure that the modules, each of which has been individually tested, are appropriately linked and calibrated.

This activity will be integrated with the resource data development discussed below, but will be undertaken prior to the Peer Review meeting, tentatively scheduled for September 15, 1994. The proposed structure of the review panel is also discussed below. Based on recommendations of the panel and various subcommittees, the final GSAM design will be modified and models enhanced. This approach is designed to produce a highly relevant system with maximum value to METC for strategic R&D planning, program evaluation, and policy evaluations.

B. Environmental Module

The kick-off meeting for activities to develop the Environmental Module of GSAM was held June 16, 1994 at METC. At this meeting ICF presented the initial design for the Environmental Module to

obtain DOE input. Plans for the development of the Environmental Module over the coming year were also discussed. The schedule for the Environmental Module is being driven, in part, by concurrent activities as part of GSAM development, including the planned review panel meeting in September.

The basic structure of the Environmental Module is shown in Figure V-1. The locational cross-reference file will serve an important function to translate data at various levels of aggregation to the reservoir level for use in GSAM analyses. The volume of environmental data that could potentially be included is large. ICF plans to work with DOE to establish priorities for data inclusion. The Environmental Module will supply data to the GSAM technology, cost, and economic routines, preprocessing the data for each reservoir and transferring information to GSAM in terms of dollars per well, dollars per foot, dollars per barrel of water produced, or dollars per thousand standard cubic feet (Mcf) of gas processed. Figure V-2 illustrates the data retrieval and processing procedure associated with the Environmental Module.

Figure V-1. Structure of GSAM Environmental Module

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Figure V-2. Data Retrieval/Processing Procedure

The 1992 study by the NPC of the *Potential for Natural Gas in the United States* included an evaluation of the potential impact of environmental regulations on gas supplies. ICF supported the NPC in this analysis, which relied primarily on regional variation in compliance costs. The NPC study provides an excellent basis for the initial testing and verification of the operations of the GSAM Environmental Module. Initially, the compliance cost data and assumptions used by the NPC will be input to the Environmental Module databases. GSAM will then be run using the same incremental compliance costs as used in the NPC analysis. The results will then be compared with those from the NPC study. Since the NPC study used the Hydrocarbon Model, which has some limitations that GSAM has been designed to overcome, the results from GSAM are unlikely to be identical, but they should be comparable. This initial test is scheduled to be completed by early September so that it can be presented to the peer review panel. Subsequently, data at a more disaggregated level (e.g., state, county) that can be used to develop more specific costs based on the NPC scenarios will be input to the database. Another run of GSAM using the more disaggregate level data can be compared with the initial run using the NPC costs. This

will provide a second test of the Environmental Module and begins to illustrate the benefit of using more disaggregate level data for analysis.

The development of the Environmental Module has been planned to provide a useful analytic tool for examining the impacts of incremental compliance costs on supply by mid-November. It should be able to address most types of requests that require the estimation of incremental compliance costs to assist DOE in any upcoming analyses. The technology evaluation and benefits assessment features of the Environmental Module are more complex and will be developed following the initial tests of the compliance cost calculations. Figure V-3 graphically displays the primary steps involved in the development of the Environmental Module.

Figure V-3. Approach to Environmental Module Development

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Figure V-4 shows the planned schedule for completion of these tasks.

Figure V-4. Planned Schedule for Completion

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At the kick-off meeting, it was agreed that ICF would prepare a list of available environmental settings, costing, and regulatory data that would serve as the basis for a meeting with DOE personnel in mid-July to discuss data priorities. The planned deliverables for the Environmental Module include:

- Addendum to Task 3 methodology development report
- Addendum to Task 4 model development report
- Addendum to Task 5 testing and validation report.

These reports will be prepared as each aspect of the Environmental Module is completed.

When complete, the Environmental Module will have the following primary capabilities designed to assist DOE:

- Incorporate site-specific incremental environmental costs and technology performance in a GSAM analysis to determine the impact of a regulatory or technology change on production, reserves, price, and costs.
- Estimate the benefits of a regulatory or technology change (in terms of wastes generated and potential risks posed) for comparison with costs of compliance and impacts found.
- Assess the benefits of various research projects in terms of achieving the same level of protection at a lower cost or achieving greater protection at the same cost.

The design of the Environmental Module is flexible enough that it can serve a range of other DOE analytical needs.

The expansion of GSAM to directly address environmental policy issues, consistent with the expansion of GSAM data to allow such detailed assessments, will substantially broaden system capabilities. This should enhance the future use and overall accuracy of GSAM in policy evaluations. Previous experience in analysis of domestic oil reservoirs has allowed this task to be quickly structured, planned, and will ultimately hasten and shorten data collection work.

C. Resource Data Development

METC recently proposed to fully develop the GSAM data structure by integrating all available data into a comprehensive resource database. This task is expected to be approved shortly and work started immediately thereafter to maximize the input prior to the GSAM Peer Review meeting. The modification requires close coordination and discussions with NRG Associates concerning the development and validation of their Significant Oil and Gas Fields of the United States Database. To speed up this work, ICF has proposed subcontracting a portion of the data development effort to NRG.

The proposed effort will produce a reservoir database and full documentation on data evaluation methods, data coverage, GSAM database format, default methods, and testing and validation procedures. This task is proposed to be completed over four months to coincide with the expected delivery of the GSAM system to METC. A work plan for the task will be submitted within two weeks of final task approval.

D. Review Committee Meeting and Follow-up

The final critical step in GSAM development and testing is critique and technical review by gas industry experts and DOE representatives. This peer review is critical to the technical acceptance of GSAM results and analytical conventions by industry. The proper selection of panelists, design of presentation packages, structure of the meeting, and follow-up actions will be planned and implemented over the next month. The Peer Review Committee Meeting is tentatively scheduled for September, 1994.

The review committee meeting structure will provide a thorough review of individual components of GSAM as well as calibration and validation of the integrated system. The following panel structure is currently being formulated:

GSAM PEER REVIEW COMMITTEE

Proposed Structure and Member Categories

Industry Review Panel (Up to 3 per Category)	DOE Advisors
<u>Category</u>	<u>Office</u>
Independent Producer	METC
Major Producer	OGPT
Pipeline Company	MSO
Association of Producers	BPO
Associations of Utilities	
Geologic Group	

The GSAM review committee will be charged with analyzing and critiquing the design, capabilities, and limitations of GSAM for achieving R&D objectives and analyzing R&D goals and results. Four sub-groups are proposed:

- Resource and Data Design
- Exploration Modeling
- Development and Production Modeling
- Downstream/Demand and Linkage

A two day meeting is planned to allow adequate time for reviewer questions and interaction. The agenda will include introduction and system description for the entire panel, individual, detailed sessions to discuss technical and analytical details of various GSAM component modules and databases, and a final wrap-up to discuss critical issues and priorities for modifications and additions to GSAM. A more detailed description of the review committee process will be included in the GSAM testing and validation plan which will be delivered to METC in July.

VI. Conclusions

GSAM development continues ahead of schedule with all major obstacles to final delivery now cleared. Three of the five required topical reports have been delivered in draft, with a fourth currently being prepared for delivery in July. Testing and validation has begun for all modules, and initial phases of system integration should be complete shortly. The next major activity is the design and implementation of the GSAM technical review. This will involve development of a comprehensive validation plan and design, preparation, and conduct of the GSAM Peer Review meeting. This gathering of industry experts and DOE advisors is scheduled for September.

The recent expansion of GSAM in the areas of environmental evaluation and the development of a comprehensive reservoir-level resource database will complement existing GSAM design and allow for more comprehensive evaluations of a range of R&D and policy alternatives. The initiation of these tasks will also now allow preliminary review of findings from the work by the GSAM Review committee.

Work planned for the final contract year will result in a complete analysis system, one that is thoroughly tested, validated, and calibrated. GSAM will then be the R&D planning tool needed by METC to comprehensively assess benefits of the gas program. The benefits of GSAM development will also accrue to both DOE and industry, as research is focused on the critical areas most affecting gas marketability. With this potential, the future of GSAM is an exciting and dynamic one.

Appendix A - GSAM Research Work Breakdown Structure

Research activities are planned using this WBS:

1 REVIEW TECHNOLOGIES

- 1.1 Establish technology selection criteria
- 1.2 Finalize technologies to evaluate with METC
- 1.3 Collect data on current technology applications and R&D in progress (literature search)
- 1.4 Contact operators and researchers for additional data
- 1.5 Tabulate technology performance data and map application locations
- 1.6 Characterize technologies as to SOA, limitations, potential, and set selection guidelines
- 1.7 Prepare topical report and brief METC personnel on technology review (Draft submitted)
- 1.8 Revise technology reviews and report as needed

2 REVIEW MODELS

- 2.1 Establish model evaluation criteria/objectives
- 2.2 Conduct METC review of models to be reviewed and evaluation criteria
- 2.3 Gather models/documentation/applications data
- 2.4 Evaluate models
- 2.5 Prepare topical report/briefing to METC personnel on models (Draft submitted)
- 2.6 Revise model reviews and report as needed

3 DEVELOP METHODOLOGY

- 3.1 Inventory and evaluate resource data by resource category
- 3.2 Evaluate model and data compatibility/usefulness
- 3.3 Refine GSAM concept
- 3.4 Finalize GSAM analysis/data requirements
- 3.5 Revise proposed approach and work plan as needed
- 3.6 Submit final development plan in topical report and briefing (Draft submitted)
- 3.7 Revise concept and/or plan as needed

4 DEVELOP MODELS

- 4.1 Supply Models
 - 4.1.1 Resource data
 - 4.1.2 Create reduced form reservoir models
 - 4.1.3 Create reduced form technology models
 - 4.1.4 Create engineering and costing models
 - 4.1.5 Incorporate uncertainty in supply models
 - 4.1.6 Validate models and set standards for integration (iterate as needed)
 - 4.1.7 Document reduced form models, data and validation results

- 4.1.8 Peer review component supply models and data
- 4.1.9 Revise supply data/models per peer review
- 4.2 Demand Models
 - 4.2.1 Demand data
 - 4.2.2 Create reduced form demand models
 - 4.2.3 Create engineering and costing models
 - 4.2.4 Incorporate uncertainty in demand models
 - 4.2.5 Validate models and set standards for integration (iterate as needed)
 - 4.2.6 Document reduced form models, data and validation results
 - 4.2.7 Peer review component demand models and data
 - 4.2.8 Revise demand data/models per peer review
- 4.3 Market Models
 - 4.3.1 Collect market/integration model data
 - 4.3.2 Develop market/integration model components
 - 4.3.3 Develop standards for supply/demand component linkage
 - 4.3.4 Incorporate uncertainty in market model
 - 4.3.5 Validate market model components and set standards for integration (iterate as needed)
 - 4.3.6 Document market model capabilities, data and, validation results
 - 4.3.7 Peer review market model
 - 4.3.8 Revise market model per peer review
- 4.4 System Integration
 - 4.4.1 Integrate model components
 - 4.4.2 Prepare GSAM benchmark runs
 - 4.4.3 Develop GSAM testing and validation plan
 - 4.4.4 Document integrated model capabilities and limitations

5 TEST AND VALIDATE

- 5.1 System validation
 - 5.1.1 Test against boundary conditions
 - 5.1.2 Compare to literature/other broad models/industrial forecasts
 - 5.1.3 Test adequacy of uncertainty treatment
 - 5.1.4 Validate adequacy of datasets
- 5.2 Integrated system peer review
 - 5.2.1 Overall model
 - 5.2.2 Components in context of integrated model
 - 5.2.3 Reconciliation of component reviews
 - 5.2.4 Recommendations and priorities for further model development
- 5.3 Document validation and peer review process
- 5.4 Correct models/data as needed
- 5.5 Prepare plan for model/data enhancements per peer review
- 5.6 Prepare User's Guide, code description, datasets
- 5.7 Submit testing and validation topical report and briefing

6 DEVELOP ENVIRONMENTAL MODULE

- 6.1 Design database structure
- 6.2 Develop cross reference and aggregation routines
- 6.3 Develop costing algorithm
- 6.4 Conduct initial testing
- 6.5 Develop data priorities
- 6.6 Develop benefits/assessment algorithm
- 6.7 Conduct additional testing
- 6.8 Document testing results and conduct peer review
- 6.9 Determine additional needs, priorities, and enhancements
- 6.10 Revise GSAM reports and user guide as required

7 DEVELOP RESOURCE DATABASE

- 7.1 Evaluate NRG database
- 7.2 Finalize GSAM resource database format
- 7.3 Develop and implement default algorithms for known reservoirs
- 7.4 Generate developed/undeveloped/undiscovered databases
- 7.5 Conduct resource database sensitivity tests
- 7.6 Document resource database and validation

Appendix B - Presentation of GSAM Project Review and Environmental Module Kick-off

Gas Systems Analysis Model (GSAM)
Project Review

Presented to

Morgantown Energy Technology Center
Metairie Site Office
Office of Gas and Petroleum Technology

June 16, 1994

Goals for the Meeting

- **Introduce Team Members for the Next Phases**
- **Brief Recap of Gas Systems Analysis Model**
- **Overview of Rationale and Requirements for the Environmental Module**
- **Propose Initial Design for Integrating Environmental Capabilities**
- **Review Accomplishments Over the Past Year**
- **Develop a Short-Term Action Plan for Implementing Next Phase**

***Overview of the Gas System Analysis Model
(GSAM)***

Presented to

**Morgantown Energy Technology Center
Metairie Site Office
Office of Gas and Petroleum Technology**

**Presented by
Alan Becker**

June 16, 1994

GSAM Objectives

- **Comprehensive, non-proprietary, PC-based model**
- **Assess impact of changes in system components on regional and national gas supply:**
 - **Technology**
 - **Industry activity**
 - **Demand**
 - **Economics**
 - **Policy/regulation**
- **Linkage to existing/future databases and models**
- **Risk analysis capability**

GSAM Structure

Transformation of Various Data to Reservoir Level

GSAM Data Input

■ Volumetric

- Original gas in place
- Initial saturations
- Porosity
- Area
- Thickness
- Initial pressure

■ Geologic

- Permeability
- Heterogeneity
- Depth
- Age
- Play/Basin
- Temperature

■ Gas Properties

- Specific gravity
- Impurities (CO₂, N₂, H₂S)
- Gas volume factors (original and current)

■ Production History

- Cumulative recovery
- Estimated reserves
- Current reservoir pressure

GSAM Upstream Model Flowchart

Analysis of Natural Gas Resources by GSAM Modules and Databases

04LFO47

GSAM Integrating Model

GSAM Logic Flow

GSAM Demand with Seasonality

04LPG099

The GSAM Transmission System Links Supply Regions with Demand Regions

- The model endogenously estimates interregional natural gas transmission.
- New pipelines are built if they are the least-cost alternative to storage, interruption, supplemental peaking operations, or customer-initiated fuel substitution.

Sample GSAM Outputs

- **Resource:** Volumes remaining by location, resource type, reservoir development status and cost to add reserves.
- **Drilling:** Wells and footage by exploration, delineation, infill, successful or dry, and resource type.
- **Reserve Additions and Abandonments:** Current volumes by location, type, method of addition (e.g., discovery, infill, advanced technology, changed gas markets).
- **Production:** Volumes and costs by resource type and location.
- **Technology:** Numbers and locations of each type of technology applied by base and advanced scenarios.
- **Economics:** Capital and operating expenditures, industry revenues, royalties, and Federal, State, and local taxes, by play, region and year.

GSAM Overview in Summary

- **GSAM System is:**
 - **Modularized for easy updating and expansion**
 - **Comprehensive to the R&D planning and analysis needs of METC**
 - **Fast enough to meet tight deadlines with precise evaluations**
 - **Data intensive, allowing user specification of key elements**
 - **Consistent, transparent, and detailed, permitting verification and validation**
 - **Flexible to provide linkage and comparison to other models**

***GSAM Environmental Module
Kick-off Meeting***

Presented to

**Morgantown Energy Technology Center
Metairie Site Office
Office of Gas and Petroleum Technology**

Presented by

**Mike Godec
Glenda Smith**

June 16, 1994

Briefing Objectives

- **Establish Environmental Module goals and capabilities.**
- **Present initial design for Environmental Module.**
- **Discuss schedule for Environmental Module development.**

Briefing Outline

- **Rationale and Requirements for Environmental Module**
- **Environmental Module Design**
- **Development Plans and Schedule**
- **Recap of Features and Uses**

Rationale and Requirements for Environmental Module

Environmental Pressure Can Result in Rising Gas Demand and Constraints on Economic Gas Supplies

Future Compliance Requirements Can Significantly Impact Industry Activity

Two Recent Initiatives Provide Impetus for Environmental Module

- **1992 NPC gas study made several recommendations related to environmental constraints:**
 - **Government should work to create a better balance between costs and benefits of environmental regulations**
 - **Timely and credible technical cost-benefit data should be developed**
 - **New environmental technologies and innovative strategies should be developed.**
- **The Secretary's Domestic Natural Gas and Oil Initiative (DNGOI) calls for:**
 - **Simplifying regulations without compromising environmental protection**
 - **Improving environmental technologies and practices.**
- **Environmental Module supports the implementation of these initiatives.**

Environmental Requirements Must be Addressed Within Market Context

Only GSAM provides this integrated analytical approach

Major Environmental Issues Facing Gas Industry

- **Ever-changing regulatory structure makes it difficult to plan for compliance requirements over project life.**
- **Many regulations fail to consider site-specific differences in operations.**
- **Some requirements offer little flexibility in determining how to meet environmental protection objectives.**
- **Regulations rarely consider the risks posed in determining applicable requirements.**
- **Costs and benefits of environmental requirements may not be balanced**

Limitations of Traditional Analytic Approaches for Addressing Environmental Issues

- **Most gas models project future based on extrapolation of historical trends, which cannot account for impact of rapidly changing environmental requirements.**
- **Current analytical approaches lack ability to consider site-specific characteristics of regulatory requirements and technology performance.**
- **Consequently, capabilities for analyzing benefits, costs, and risks of alternative technologies to meet environmental standards are limited:**
 - **Characterization of risks is inadequate to identify whether alternative requirements result in desired benefits**
 - **Characterization of both costs and benefits of environmental compliance alternatives is not possible.**

GSAM Environmental Module Designed to Overcome These Limitations

- **Impacts of potential future environmental requirements on supply, costs, and technology can be explicitly analyzed.**
- **A detailed database of surface and subsurface conditions, tied to specific gas reservoirs, will incorporate site-specific differences.**
- **Costs and performance of various environmental technologies are specifically included to enable analysis of compliance alternatives.**
- **Risk assessment capabilities based on site-specific data will be explicitly incorporated.**
- **Estimation of costs *and benefits* is a key feature of the Environmental Module.**
- **GSAM provides the structure to analyze the interactions of the gas market when environmental requirements change.**

Environmental Module Builds on GSAM's Strengths

- **Power of GSAM is based on three features:**
 - Detailed characterization of the resource base
 - Explicit technology performance based on resource characteristics
 - Economic decision-making tied to both resources and technologies.

- **Environmental Module parallels this format with:**
 - Detailed characterization of environmental settings, waste management techniques, and regulatory requirements
 - Explicit technology performance based on setting and waste applicability
 - Economic evaluation of future compliance options incorporating the incremental costs of alternative requirements.

Environmental Module Will Assist with R&D Program Planning and Evaluation

- **Gas R&D program:**
 - Understand environmental implications of ongoing gas technology research.
- **Environmental R&D program:**
 - Improve understanding of environmental constraints on gas operations
 - Identify and prioritize areas for environmental research
 - Evaluate benefits of success from particular program areas or specific projects.
- **Requests from Headquarters and Congress:**
 - Analyze impacts of changes in environmental regulations
 - Assess effects of proposed policies
 - Characterize benefits of program activities.

Environmental Module Design

Locational Considerations Key to Environmental Analyses

- **Gas operations occur at over 250,000 well sites in over 30 states.**
- **Surface and subsurface conditions at each of these sites differ.**
- **Site-specific conditions are key to determining:**
 - **Risks posed by industry activities**
 - **Volume of wastes generated**
 - **Appropriate technologies for managing and disposing wastes.**
- **Environmental protection requirements (and costs) may also vary widely from state to state.**

Site Specific Conditions Can Affect Risks Posed

06LP044

Site Specific Conditions Can Affect Compliance Requirements

<i>Availability of Disposal Zone</i>	
Yes -- Can use injection; costs determined by depth of available aquifer and presence/interval to USDWs	No -- Must use offsite transportation of produced water or alternative disposal (acceptable methods depend on state/location)
<i>Location in Ozone Non-Attainment Area</i>	
No -- No additional emissions control technology required, except in California	Yes -- Must install stringent emissions control technologies on all tanks and equipment
<i>Distance from Shore</i>	
More than 3 miles -- Oil-based drilling muds must be barged to shore; water-based mud can be discharged	Less than 3 miles -- No drilling fluids may be discharged; must barge to shore for landfill disposal
<i>Location in Wetlands Area</i>	
No -- No incremental requirements	Yes -- Mitigation may be required; depending on distance, may want to use directional drilling to avoid disturbing wetland and needing mitigation

Locational Cross-Reference File a Key Component of Module Design

- **GSAM conducts all analyses at reservoir level.**
- **Useful data on environmental settings exists at many different levels of aggregation, e.g.,**
 - **State**
 - **County**
 - **Basin**
 - **Field**
 - **Well.**
- **Need method to translate these data to reservoir level for use in GSAM analyses.**
- **Locational file will cross-reference the state, county, basin, play, field, etc. for each reservoir.**

Translating Various Data to Reservoir Level

Locational Cross-Reference File

Reservoir Number	Reservoir Name	State Code	County Code	Basin Code	Region Code	Field Code	Lat./ Long
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Example of Combining Data at Various Levels of Aggregation

- **To calculate incremental cost of requiring offsite disposal of drilling waste:**
 - **Average well depth (by reservoir from GSAM database)**
 - **Average volume of drilling waste generated per foot (regional averages)**
 - **Distribution of drilling mud type [% oil-, % water-based] (regional averages)**
 - **Percentage of waste disposed onsite currently (state averages)**
 - **Availability/distance to offsite disposal facilities (county averages)**
 - **Cost of offsite transportation (national average)**
 - **Cost of offsite disposal (regional averages).**

- **Locational cross-reference file would locate appropriate county, state, and region to apply to each GSAM reservoir so costs could be calculated as precisely as possible based on available data**

Environmental Module Will Include Numerous Data Files

- With few exceptions, data from GSAM reservoir files will not be duplicated in environmental database; instead reservoir and environmental databases will be relationally cross-referenced.
- Data files will contain parameters covering:
 - Surface conditions
 - Subsurface conditions
 - Operational characteristics
 - Waste characteristics
 - Technology performance
 - Regulatory requirements.
- Data on environmental conditions and costs are readily available from wide range of government and private sector sources.

NORM Activity in Excess of Background at Oil and Gas Producing Facilities

Source: A National Survey on NORM in Petroleum Producing and Gas Processing Facilities, API, 1989.

06FL0014

GSAM Environmental Data Files and Example Contents

<p>Surface Conditions</p> <p>Multiple use Federal lands Wetlands Endangered species habitat Wilderness lands OCS moratoria areas Non-attainment areas (ozone, other?) Distance to urban areas Distance to surface water Annual rainfall Evaporation rate Surface water quality Water depth (for offshore reservoirs) Background radiation level</p>	<p>Subsurface Conditions</p> <p>Name of primary/secondary aquifer systems Depth to shallowest USDW - 3,000 TDS - 10,000 TDS Depth of deepest USDW - 3,000 TDS - 10,000 TDS General soil type (sand, clay, etc.) Corrosivity indicator Groundwater quality</p>	<p>Operational Characteristics</p> <p>Disposal well locations Depth of injection zone Number of injection wells Number of abandoned wells Typical depth of surface casing Location of gas processing plants</p>	<p>E&P Waste Characterization</p> <p>Produced water volumes/ratios Associated waste volumes by type Volumes of SO₂, NO_x, VOCs, etc. NORM level Produced water quality</p>
<p>E&P Waste Management</p> <p>Methods of produced water disposal (distribution) Methods of associated waste disposal Methods of drilling waste disposal</p>	<p>Compliance Costs</p> <p>Pit liner cost Cost to install & operate groundwater monitoring Cost of offsite disposal by method Cost to excavate contaminated soil Bioremediation costs Cost of closed drilling system Costs for barging wastes to shore Costs for various aspects of upgrading ASTs Injection well drilling costs MIT costs AOR costs Permit costs Insurance costs</p>	<p>Technology Cost/Performance</p> <p>Membrane filtration: Size, weight Installation cost, operating cost Effectiveness Hydrocyclones: Size, weight Installation cost, operating cost Effectiveness Improved gas flotation: Retrofit cost Incremental operating cost Effectiveness NO_x controls: Type, effectiveness, cost</p>	<p>Regulatory Requirements</p> <p>Current regulatory requirements Potential future regulatory requirements</p> <p>(Format & content of this file dependent on how cost & benefit routines developed)</p>

Areas Where Ozone Nonattainment May Affect Production

Need to Develop Data Priorities

- Large volumes of data could potentially have applicability.
- Structure established so that data can always be added or improved.
- Certain data are logical or essential to include:
 - Environmental data and costs developed for NPC gas study
 - Data to support analysis of any ongoing environmental research.
- Work with DOE to establish criteria for prioritizing further data needs, e.g., data to support analyses of:
 - Anticipated regulations that will affect operations or technologies needed
 - Issues that have potential for major impact on gas operations or facilities
 - Constraints that adversely affect key future gas supply areas.

Environmental Module Provides Its Data to GSAM Technology/Cost Files

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Structure of GSAM Environmental Module

06PL0171

Data Retrieval/Processing Procedure

06LPO645

Example of Compliance Cost Calculation

- **To estimate the incremental cost of offsite disposal of drilling waste:**
 - **Set up routines to calculate:**
 - Waste volume = Well depth X avg. volume of drilling waste per foot**
 - Transportation cost = distance to offsite facility X transportation cost**
 - Disposal cost = transportation cost + offsite disposal cost**
 - Incremental cost = Waste volume X % currently disposed onsite X Disposal cost**
 - **For an individual reservoir, the data corresponding to each variable would be extracted and the actual cost calculated.**

For example:

**(6000 ft/well X 1.24 bbl/ft) X 60% X [(20 miles X \$0.06/bbl/mile) + \$12.50/bbl]
= \$61,157/well**

- **This incremental drilling cost will be incorporated into the GSAM costing module.**
- **This approach for calculating incremental compliance costs has been used in numerous prior analyses.**

Example of Technology/Benefit Assessment Calculation

- Assume that two alternative technologies for reducing NO_x emissions from compressors exist:
 - Technology A will reduce NO_x emissions by 90% and costs \$5,000 to install
 - Technology B will reduce NO_x emissions by 92% and costs \$7,000 to install.
- For a particular location that currently emits 2.8 tons of NO_x per compressor per year, can calculate the benefits as:
 - Use of Technology A will decrease NO_x emissions by 2.52 tons
 - Use of Technology B will decrease NO_x emissions by 2.576 tons.
- Comparing the cost-effectiveness of these technologies:
 - Technology A costs \$1,984 per ton of NO_x removed
 - Technology B costs \$2,717 per ton of NO_x removed.
- If data on human health effects were available could also estimate health benefits of use of each technology.

Development Plans and Schedule

Approach to Environmental Module Development

Module Design Activities

- Design for the database structure needs to be completed:
 - Determine appropriate aggregation conversions for inclusion in locational cross-reference file
 - Structure files to minimize duplication of data
 - Finalize method for combining data at different levels of aggregation for a single parameter.
- Mechanics of linking the routines from the Environmental Module into the technology/cost parameters files of GSAM need to be determined:
 - Start with costing routines
 - Later add benefits/assessment routines.

NPC Study Provides Basis for Initial Tests

Compliance Costs for Regulatory Scenario		
RCRA	Balanced Scenario	More Stringent Scenario
Management and Disposal of Drilling Wastes	<p><i>Cost/well:</i> $= (0.94)(LC)(FUP)(0.38) + (0.06)(LC)(FUP) + (3.00)(DWF)(WD)(0.70)$ where: LC = liner installation cost FUB = fraction of pits that are unlined WD = well depth (feet) DWF = drilling waste volume/foot drilled FOR U.S. AVERAGE GAS WELLS: Cost = \$16,492/well</p>	<p><i>Cost/well:</i> $= (8.10/\text{ft})(\text{average well depth})$ FOR U.S. AVERAGE GAS WELLS (7,217 ft): Cost = \$58,458/well</p>
Disposal of Associated Wastes in Central Disposal Facilities	<p><i>Cost/well/year</i> <u>All regions except Appalachia</u> $= (12.50/\text{Bbl})(\text{Bbl solid waste/well/yr}) + (4.00/\text{Bbl})(\text{Bbl liquid waste/well/yr})$ <u>Appalachia</u> $= (12.50/\text{Bbl})(\text{Bbl solid waste/well/yr}) + (1.00/\text{Bbl})(\text{Bbl liquid waste/well/yr})$ FOR U.S. AVERAGE GAS WELLS: Cost = \$13/well/yr</p>	<p><i>Cost/well/year:</i> $= (12.00)(\text{Bbl associated waste/well/yr}) + (65.00)(\text{Bbl workover waste/well/yr})$ FOR U.S. AVERAGE GAS WELLS: Cost = \$48/well/yr</p>

Initial Tests of Environmental Module

- Start by inputting data for NPC environmental costing scenarios into the database.
- Run GSAM based on these incremental cost data; compare results to those found by NPC.
- Input additional definition to data for NPC scenarios:
 - Greater level of detail
 - Site-specificity where feasible.
- Run GSAM again to compare the impacts of using a more site-specific approach.

Coordination/DOE Input

- **Develop priorities for data inclusion.**
- **Develop scenarios for testing other aspects of the Environmental Module:**
 - **Test technology assessment**
 - **Test benefits estimation.**

Additional Testing, Validation, and Review

- **Run GSAM tests of technology assessment and benefits estimation capabilities.**
- **Examine and validate results from each test.**
- **Document analysis procedures, database status, and testing and validation results.**
- **Provide documentation to review panel.**
- **Identify needs and opportunities for continued development of the Environmental Module.**

Planned Schedule for Completion

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Planned Deliverables for Environmental Module

- **Addendum to Task 3 report on methodology**
- **Addendum to Task 4 model development report**
- **Addendum to Task 5 testing and validation report**

Recap of Features and Uses

Environmental Module Capabilities

- **Incorporate site-specific incremental environmental costs and technology performance in a GSAM analysis to determine the impact of a regulatory or technology change on production, reserves, price, and costs.**
- **Estimate the benefits of a regulatory or technology change (in terms of wastes generated and potentially risks posed) for comparison with costs of compliance and impacts found.**
- **Assess the benefits of various research projects in terms of achieving same level of protection at lower cost or achieving greater protection at same cost.**

Potential Future Enhancements

- **Current focus on upstream issues; as GSAM downstream emphasis grows, need to expand data and environmental analysis related to downstream activities.**
- **Develop links to other models such as Dynamic Energy and GReenhouse Emissions Evaluation System (DEGREES).**
- **Geographic Information Systems (GIS) capabilities.**
- **Better risk assessment and benefits estimation capabilities.**

***Gas Systems Analysis Model (GSAM)
Year Two Project Review***

Presented to

**Morgantown Energy Technology Center
Metairie Site Office
Office of Gas and Petroleum Technology**

Presented by

**Mark Haas
Alan Becker**

June 16, 1994

Year Two GSAM Project Objectives

- **Conclude Technology and Model Reviews (Tasks 1 and 2).**
- **Finalize GSAM Model Design (Task 3).**
- **Develop and Test Prototype GSAM Model (Task 4):**
 - **Resource, Cost and Technology Databases**
 - **Upstream, Downstream and Integrating Models.**
- **Prepare for Review Panel (Task 5).**

GSAM Upstream Model Flowchart

Resource Database Development Activities

- **Model nonassociated gas resource base as individual reservoirs:**
 - **Known producing reservoirs**
 - **Discovered/undeveloped reservoirs**
 - **Undiscovered fields and reservoirs.**

- **Compiled available gas reservoir data:**
 - **Acquired Gas Atlas data and coordinated with GASIS development**
 - **Licensed NRG Significant Fields Database.**

- **Created preliminary resource module to default and validate database**
 - **Created SAS model to evaluate and transform raw data into GSAM databases**
 - **Proposed task to fully validate and characterize nonassociated gas resource base.**

- **Other gas resources derived independently:**
 - **Canadian imports derived using GSAM methodology**
 - **Associated gas resources derived from linkage to oil model (TORIS/COPM)**
 - **LNG, synthetics estimated exogenously.**

Resulting Nonassociated Natural Gas Resource Base

- **Known nonassociated gas resources described as individual reservoirs (170 data elements):**
 - **Location**
 - **Reservoir properties**
 - **Development and production history**
 - **Current status.**

- **NRG Significant Fields Database:**
 - **6,000 predominantly gas reservoirs**
 - **68 major gas plays.**

- **Created a preliminary GSAM resource database:**
 - **Distribution of location and characteristics**
 - **Reconciled to current production and estimated undiscovered volume**
 - **400 known/1,200 undiscovered reservoirs.**

- **Preliminary database being used to test GSAM.**

Technology Characterization

- **Defined five technology categories:**
 - **Exploration**
 - **Reservoir characterization**
 - **Drilling**
 - **Completion**
 - **Production.**

- **Quantified impacts for each technology and resource type category:**
 - **Reservoir performance (equivalent skin, flowing pressure)**
 - **Cost (\$/well, \$/Mcf, \$/year)**
 - **Reservoir access (screen)**
 - **Technology applicability (screen)**
 - **Market penetration (availability, rate, saturation)**
 - **Risk (information, performance, cost uncertainty).**

- **Technology cases to be developed:**
 - **Implemented**
 - **Current**
 - **Advanced (successful R&D).**

Upstream Reservoir Preprocessor

- **Consists of three components:**
 - **Production type curves**
 - **Engineering costing data and algorithms**
 - **Cash flow project evaluation.**
- **Evaluates 81 plausible development options for each reservoir:**
 - **By pay grade (3)**
 - **By development option (3)**
 - **By alternative technology case (3)**
 - **By technology path (3).**
- **Outputs preferred investment option to be selected in integrating model.**
- **Available as a standalone model.**

Production Modeling

- **Type curve models integrated into GSAM:**
 - **Single and dual porosity**
 - **Radial and linear flow geometries**
 - **Depletion and water drives.**
- **Coalbed and Devonian shale models under development.**
- **Model outputs:**
 - **OGIP, reserves and 40-year production**
 - **Alternative development options and technology cases.**
- **Sample output.**

Engineering Costing

- Developed engineering costing data for each GSAM region:
 - Exploration
 - Drilling and completion
 - Facilities
 - Operations.
- Developed costing algorithms to incorporate operational variables:
 - Location and terrain
 - Reservoir size
 - Gas and water production
 - Extraordinary operating conditions or technologies required.
- Costs can be adjusted for market conditions:
 - Changes in gas prices
 - Changes in infrastructure utilization
- Outputs include:
 - AFE level costing summary
 - Breakout of capital, operating and indirect costs
 - Summary of impact of technology case differences.
- Sample output.

Project Evaluation

- **Discounted cash flow model:**
 - **Current state and federal tax laws**
 - **Full depreciation and depletion**
 - **Accommodates variety of proposed tax/regulatory initiatives.**
- **Evaluates and selects the "best" options for each reservoir:**
 - **User-specified decision criteria**
 - **Transforms data to be used by integrating model to select projects.**
- **Full diagnostics are available on a project basis:**
 - **Costs per Mcf of production**
 - **Project pro forma.**
- **Sample output.**

Reservoir Banks

- **Developed method to summarize project characteristics for real-time selection:**
 - **Production profile**
 - **Capital cost and drilling requirements**
 - **Economic performance.**

- **GSAM creates three reservoir banks:**
 - **Producing (operating costs)**
 - **Discovered/undeveloped (sunk exploration costs)**
 - **Undiscovered (full cost).**

- **Sample bank format:**
 - **Gas in place and reserves**
 - **Present values of production, capital expenditures, operating costs**
 - **Scaling factors for changes in gas price and infrastructure capacity.**

Exploration Modeling

- **Developed a modified discovery process model:**
 - **Similar to Arps-Roberts methodology**
 - **Reservoirs discovered in proportion to their area.**

- **GSAM adds an exploration technology component:**
 - **Addresses technology effectiveness as a function of reservoir character**
 - **Discovers reservoirs with user-specified uncertainty (e.g., seismic resolution)**
 - **Readjusts exploration efficiency over time as a function of changing resource base and available technology.**

- **GSAM exploration model estimates:**
 - **New field wildcat discoveries**
 - **Infield exploration discoveries (one component of reserve growth).**

Reservoir Development and Production

- **Known producing reservoirs:**
 - **Curtailment**
 - **Abandonment.**

- **Initial reservoir development.**
 - **Initial drilling and facilities**
 - **Completion of development to standard spacing.**

- **Additional development:**
 - **Recompletion of primary wells**
 - **Infill.**

Integrating Model

- **Method completed to evaluate reservoir banks generated by preprocessor:**
 - **Required wellhead price**
 - **Capital constraints**
 - **Drilling capacity constraints**
 - **Regulatory constraints (resource access screens).**

- **GSAM "produces," "develops," or "discovers," reservoirs per user criteria:**
 - **Known**
 - **Undeveloped**
 - **Undiscovered.**

- **Iterates with downstream model to equilibrate on prices by region.**

- **Sample output by region, year, and development category:**
 - **Reserves and production by resource type**
 - **Drilling, discovery rates, and finding costs**
 - **Technology use**
 - **Expenditures, taxes, and wellhead prices.**

Linkage to Other Models/Databases

- **TORIS/COPM (associated gas).**
- **DOE/EIA upstream models:**
 - Can use summarized GSAM outputs as inputs (e.g., resource base, production, finding costs)
 - Can use GSAM technology sensitivities to calibrate
 - GSAM can use DOE model output as calibration.
- **Downstream models:**
 - Demand data for GSAM from EPRI and EIA models
 - Transport and storage capacity data from FERC, AGA and other sources.
- **Databases:**
 - GASIS will serve as important basis for GSAM resource base.
 - GSAM development will also include linkage with USGS, MMS, PGC and other resource estimators
 - Other databases to be linked as appropriate.
- **Sample output.**

Current Status

- **Upstream preprocessor complete.**
- **Exploration and reservoir development models complete.**
- **Integrating model complete.**
- **Downstream and transport model complete.**
- **Coal/shale production models (in development).**

GSAM Next Steps

- **Develop and integrate Environmental Module.**
- **Continue to test and validate all modules.**
- **Compare and calibrate system and develop linkages.**
- **Conduct review committee meeting.**
- **Enhance and validate reservoir data.**

GSAM Review Committee Goals and Proposed Sub-Group Structure

- **Goal: review the design and capabilities of GSAM for achieving R&D objectives.**
- **Proposed sub-groups:**
 - **Resource and data design**
 - **Exploration modeling review**
 - **Development and production review**
 - **Downstream/demand and linkage review.**
- **Meeting design:**
 - **Two days (9/15/94 - 9/16/94)**
 - **Initial overview (full committee)**
 - **Sub-group sessions and recommendations**
 - **Consolidated review comments**
 - **Environmental module overview**
 - **Next steps.**

***GSAM Peer Review Committee
(Proposed Structure and Member Categories)***

Industry Review Panel (up to 3 per Category)	
Category	Target Companies/Organization
Independent Producers	Mitchell Energy, Santa Fe
Major Producers	Exxon, Mobil, Amoco
Pipeline Companies	Enron, Tennessee, Columbia
Associations of Producers	GRI, IPAA, Locals/Regionals
Associations of Utilities	AGA, Local Groups
Geologic Groups	USGS, State Surveys
DOE Advisors	
Office	Point of Contact
METC	Tony Zammerilli
OGPT	Bill Hochheiser
MSO	Gene Pauling
BOP	R. Mike Ray

GSAM Reservoir Data Enhancement

- **Goal: To develop a comprehensive reservoir-level resource database.**
- **Proposed activities:**
 - **Fully evaluate and compile NRG data into GSAM database**
 - **Develop, document, and justify full resource default methodology**
 - **List critical missing resource data elements**
 - **Develop valid methods to derive key missing data.**

GSAM Time Table

- **7/1/94 - Components ready and tested.**
- **9/1/94 - System integration complete.**
- **9/15/94 - Review committee meeting.**
- **10/15/94 - Final system testing and validation complete.**
- **11/1/94 - Resource data available for final system calibration.**
- **11/15/94 - System transferred to METC computer and initial environmental analyses complete.**
- **6/22/95 - Environmental module complete.**

Sample GSAM Inputs and Outputs

- **Developed and Undiscovered/Undeveloped Resource Database (6 pages)**
- **Production Module Input Data File (1 page)**
- **Production Module Output - 10310600.TCO (5 pages)**
- **Engineering Unit Cost Report (1 page)**
- **Detailed Financial Report (1 page)**
- **Preprocessor Output to Reservoir Bank - MJS.BNK (1 page)**
- **Supply Summary Report (2 pages)**
- **GSAM Integrating Model Output (3 pages)**

Developed and Undiscovered/Undeveloped Resource Database

Var. ID	Variable Name	Symb ol	Units	Description	Variable Type	Source	Notes
1000	GSAMID	none	none	unique GSAM ID reservoir code	Integer	Blank	
1010	RESCOD	none	none	reservoir code	Integer	Blank	
1020	FLDNAM	none	none	field name	Char*30	Rmaster v2 fldname	
1030	EIACOD	none	none	EIA field code	Integer	Rmaster v86 eiaid	EIA master list
1040	RSVNAM	none	none	reservoir formation name	Char*30	Rmaster v68 leasname	
1050	STATE	none	none	state code	Integer	Rmaster v8 stdcod1	2 digit State code, plus 2 digit substate code
1060	COUNTY	none	none	county code	Integer	Rmaster v90 county	3 digit API code
1070	PLYCOD	none	none	play code	Integer	Rmaster v6 cluster	NRG Play Code
1090	BSNCOD	none	none	basin code	Integer	Rmaster v97 provcod	AAPG Province Code
1100	TWNSHP	none	none	township name	Char*8	Blank	
1110	RANGE	none	none	range name	Char*8	Blank	
1120	ONOFFS	none	none	onshore/offshore	Integer	Default = 1	1 = onshore; 2 = offshore Can be expanded to include environmental settings
1130	GSAMSR	none	none	GSAM supply region	Integer		26 supply regions
1140	STATIN	none	code	initial development status	Integer	Blank	0 = undiscovered; 1 = discovered/undeveloped; 2 = initial development underway; 3 = initial development complete; 4 = additional development underway; 5 = additional development complete; 9 = abandoned
1150	LATLON	none	degrees, min, sec	latitude/longitude of reservoir centroid	Integer	Rmaster v92&93 cntplat&cntplon	DDMMSS-DDMMSS

Developed and Undiscovered/Undeveloped Resource Database (Continued)

Var. ID	Variable Name	Symb ol	Units	Description	Variable Type	Source	Notes
1160	DEPCLS	none	none	depositional class	Integer		Oil program equivalent
2000	RESTYPE	none	code	resource type	Integer	Rmaster v9 lithol1	1 = unconsolidated SS; 2 = consolid SS; 3 = carbonate; 4 = coal; 5 = shale; 6 = hydrate; 7 = geopressured aquifer; 9 = unknown
2010	TRAPTY	none	dim	trap type	Integer	Rmaster v102 trapg	1 = structure; 2 = fault; 3 = unconformity; 4 = stratigraphic dominant trapping mechanism
2020	DRIVE	none	code	dominant drive type	Integer	Rmaster v47 drive1	1 = pressure depletion; 2 = water drive; 3 = desorption/depletion
2030	DEPTH	D	feet	depth	real	Rmaster v13 dpthtop	depth from top of surface to top of formation
2035	DEPTSS	D _{ss}	feet	depth subsea	real	Rmaster v13-v70 dpthtop-elev	depth and elevation
2040	GRSPAY	H	feet	gross pay thickness	real	Rmaster v14 thick	gross formation interval
2050	NETPAY	h	feet	total net pay in designated formation	real	Rmaster v14 thick	assumed to be at porosity/saturation cutoffs prevailing when well first tested; effective h may change with technology
2060	PAYDSP	none	dim	pay dispersion function	real	depcls average	concentration of net pay across gross interval
2070	WELDRN	A _d	acres	well drainage area	real	Rmaster v50 spacing1	minimum of drainage area or current well spacing
2085	PERHOR	k _h	md	effective horizontal permeability	real	Rmaster v22 permavg	measured or estimated at in situ conditions
2090	PERVRT	k _v	md	effective vertical permeability	real	Rmaster v22 permavg	regional/play defaults (0.3 typical k _v /k _h)
2100	PERMTX	k _m	md	matrix permeability	real	Rmaster v22 permavg	measured from core

Developed and Undiscovered/Undeveloped Resource Database (Continued)

Var. ID	Variable Name	Symb ol	Units	Description	Variable Type	Source	Notes
2120	PORTOT	ϕ	fraction	total effective initial porosity	real	Rmaster v18 poravg	assumed to be bulk porosity (including natural fracture porosity)
2125	PORMTX	ϕ_m	fraction	matrix porosity	real	Rmaster v25 permtype	
2130	PORCUR	ϕ_c	fraction	current total effective porosity	real	Rmaster v18 poravg	for overpressured reservoirs; for all others $\phi_c = \phi$
2140	WATSAT	S_{wi}	fraction	initial water saturation	real	Rmaster v40 satwatin	assumed to be uniform across reservoir
2150	GASSAT	S_g	fraction	initial gas saturation	real	Rmaster V39 satgasin	
2160	PRESIN	P_i	psia	initial reservoir shut-in pressure	real	Rmaster v45 respres	reservoir pressure at discovery
2170	GASGRV	γ	dim	specific gravity of dry gas	real	Rmaster v57 gasgrav	dry gas gravity assumed to be measured at surface separator; total oil/gas gravity to be estimated separately
2180	BHTEMP	T	°F	bottomhole temperature	Integer	Rmaster v26 temp	corrected in database for cooling effects of drilling muds
2200	HEATVL	H_v	btu/scf	heating value	real	Rmaster v58 gasbtu	default from gravity, composition data
2210	CO2	CO ₂	fraction	carbon dioxide contamination	real	Rmaster v34 carbdiox	possibly higher CO ₂ assumed for coalbed defaults
2220	N2	N ₂	fraction	nitrogen gas contamination	real	Rmaster v36 nitrogen	
2230	H2S	H ₂ S	fraction	hydrogen sulfide contamination	real	Rmaster v35 hsulfide	
2250	WELRAD	r_w	feet	wellbore radius	real	Default = 0.35	equals $X_f/2$ for induced fractures; 0.354 for conventional, 0.25 for slimhole
2260	COMPFR	c_f	psia ⁻¹	formation compressibility	real	Default = 3×10^{-6}	for overpressured zones
2280	SOLGAS	R_{sw}	cf/bbl	gas solubility in brine	real	0.0	standard equations available

Developed and Undiscovered/Undeveloped Resource Database (Continued)

Var. ID	Variable Name	Symb ol	Units	Description	Variable Type	Source	Notes
2290	CHLCON	none	ppm	Cl concentration of produced water	real	Rmaster v59 rsistwat	geopressured reservoirs
2295	CMPWAT	C_w	psia ⁻¹	water compressibility	real	Default = 3×10^{-6}	for overpressured zone
2300	INPORF	ω	dim	interporosity flow factor	real	0.0	for coals and shales
2302	LANGVL	V_L	scf/ft ³	Langmuir volume	real	0.0	for coals and shales
2304	LANGPR	P_L	psia	Langmuir pressure	real	0.0	for coals and shales
2306	PRSDSP	P_D	psia	desorption pressure	real	0.0	for coals and shales
2308	GASCON	GCI	scf/ton	initial gas concentration	real	0.0	for coals and shales
2309	SRPTIM	T	days	pseudo steady state desorption time	real	0.0	for coals and shales
2310	AQURAD	r_{aq}	feet	aquifer radius	real	0.0	10 is cutoff for default for strong/weak drive
2320	AQUPRM	k_{aq}	md	aquifer permeability	real	Rmaster v22 permavg	aquifer assumed to be same permeability as formation unless significant relative permeability effects indicated
2330	FRACSP	FS	feet	natural fracture spacing	real	depcls	default by lithology/play
2335	FRACWI	FW	inches	natural fracture spacing	real	depcls	based on core, history match or default
2340	FRACFL	λ	dim	fracture flow parameter	real	depcls	used for unconventional reservoir model
2350	FRACXF	X_f	feet	induced fracture half length or length of contact of horizontal well	real	technology	
2360	FRACCN	wk_f	md-ft	induced fracture conductivity	real	technology	from producing reservoir history match
2370	FRACSK	s_f	fraction	induced fracture skin factor	real	technology	from producing reservoir history match
2380	FRACPO	ϕ_f	fraction	induced fracture porosity	real	technology	from producing reservoir history match
2480	WATSAF	s_{wif}	fraction	fracture water saturation	real	technology	from producing reservoir history match
3000	DISCYR	none	year	date of reservoir discovery	Integer	Rmaster v193 resdscyr	
3005	DISFLD	none	year	date of field discovery	Integer	Rmaster v99 discyr	date of discovery of first reservoir in field

Developed and Undiscovered/Undeveloped Resource Database (Continued)

Var. ID	Variable Name	Symb ol	Units	Description	Variable Type	Source	Notes
3010	DISMTH	none	code	reservoir discovery method	Integer	Rmaster v100 discmth1	new field wildcat or infield exploration
3020	SGDVYR	none	year	year significant reservoir development drilling starts	Integer	Rmaster v221 startyr1	accounts for delay between discovery and beginning of initial development
3030	DOMOPR	none	code	dominant operator as of 1992	Integer	Rmaster v65 apicod	1 = independent; 2 = integrated; 3 = other
3040	WLSPAC	none	acres/well	well spacing (current field rule)	real	Rmaster v50 spacing1	default or per state proration rules, initial spacing
3045	ACPROD	none	acres	total productive area	real	Rmaster v50*v52 spacing1*spacunit	volumetrically consistent with size class, pay, porosity, etc.
3050	ACPROV	none	acres	maximum proved area	real	Rmaster v105 maxacre	indicate mapped or calculated from well spacing
3060	ACPRVD	none	year	date of maximum proved area estimate	Integer	1991	
3070	ACDV92	none	acres	reservoir developed area EOY 1992	Integer	0.0	
3090	OGIP	none	Bcf	reservoir volumetric original gas in place	real	0.0	tied to heterogeneity factor and size class
3100	CGPR92	none	Bcf	cumulative gas production to 1992	Integer	Rmaster v152 gas91cum	
3110	GRSV92	none	Bcf	proved gas reserves end of 1992	Integer	Rmaster v153 gas91res	check consistency of implied R/P rate
3120	RSVCLS	USG S	class	AAPG reservoir size class	Integer	Rmaster v191 raapgsiz	default of cumulative production and reserves
3180	GWR92	none	MMcf/bbl	1992 gas-water ratio	real	0.0	1992 calculation or average of recent years
3190	PRSCUR	P _c	psia	current bottomhole shutin pressure	real	0.0	default from material balance if no data
3200	WATSAC	S _{wc}	fraction	current water saturation	real	Rmaster v40 satwatin	for water drive and coal/shale reservoirs; for all others S _{wc} = S _{wi}
3205	WATSAB	S _{wa}	fraction	abandonment water saturation	real	0.0	important for water drive volumetrics; function of lithology

Developed and Undiscovered/Undeveloped Resource Database (Continued)

Var. ID	Variable Name	Symb ol	Units	Description	Variable Type	Source	Notes
3210	PRSFLW	P_{wf}	psia	current bottomhole flowing pressure	real	0.0	consistent with cumulative production
3230	PRORAT	none	fraction	proration - rule for wells/reservoir	real	0.0	annual % of AOF
3242 +	GASPRDXX	none	Bcf/yr	1982-92 gas production	real	Rmaster v132 gasXXann	XX = year (e.g., GASPRD91 = 1991)
3262 +	OILPRDXX	none	Mbbl/yr	1982-92 Oil production	real	Rmaster v109 oilXXann	
3282 +	NGLPRDXX	none	Mbbl/yr	1982-92 NGL production	real	Rmaster v155 nglXXann	
3302 +	TOTWELXX	none	#	1982-92 total wells	Integer	Rmaster 199 wlXXactv	
3322 +	PRDWELXX	none	#	1982-92 producing wells	Integer	Rmaster v200 wlXXprod	
3342 +	SHUTWLXX	none	#	1982-92 shutin wells	Integer	Rmaster v199- v200 (wlXXactv- wlXXprod)	
3360	TWLSPAC	none	acres	target well spacing	Integer	0	minimum likely spacing = f (perm) where interference is significant
3380	BPSLOP	n	none	backpressure exponent	real	Default = 0.85	$0.5 < n \leq 1$; default at 0.85
3380	PRSSYS	P_{fs}	psia	operating system back pressure	real	Default = 600	default at 1,000 (600 for low permeability reservoirs)
3390	PZSLOP	none	Mcf/psia	slope of cumulative production vs. p/z	real	0.0	derived from production data
3400	FLDTYPE	none	none	Type of Field	Integer	Rmaster V106 fldtype	1=Oil,2=Gas,3=Both,4=None
3410	PROVCOD	none	none	Province code	Integer	Rmaster v97 provcod	

GSAM INPUT DATA FILE

CASE DESCRIPTION (2 Lines):

GSAM Code: 10310600 Technology: Current Technology

GAS GRAVITY	TEMP. DEG. F	IMPURITIES CONCENTRATIONS			TUBING ID INCHES	SPEED UP CASES 1=Y,0=N
		H2S	CO2	CN2		
.7700	129.	.00	.00	.09	1.995	1

BASIC RESERVOIR INFORMATION

PAY GRADE NO.	INITIAL PRESSURE PSIA	HORIZ. PERM. MD	VERT. PERM. MD	TOTAL POROSITY DECIMAL	INIT WATER SATURATION DECIMAL	NET PAY THICKNESS FEET	WATER SALINITY PPM
1	1110.	100.00		.30	.18	70.7	30000.
2	1110.	50.00		.15	.13	50.0	30000.
3	1110.	25.00		.08	.09	35.4	30000.

FRACTURED RESERVOIR INFORMATION

PAY GRADE NO.	MATRIX PERM. MD	MATRIX POROSITY DECIMAL	NAT'L FRAC SPACING FEET
1	1.00	.1838	.00
2	.50	.1300	.00
3	.25	.0919	.00

FIELD DEVELOPMENT INFORMATION

PAY GRADE NO.	DEPTH FEET	AREA ACRES	INITIAL SPACING ACRES	WELL TYPE (MODULE NO.)			WELLBORE RADIUS, FT		
				INITIAL WELL	FIRST INFILL	SECOND INFILL	INIT WELL	FIRST INFILL	SECOND INFILL
1	4805.	8320.	320.	1	1	1	.35	.35	.35
2	4805.	16640.	320.	1	1	1	.35	.35	.35
3	4805.	8320.	320.	1	1	1	.35	.35	.35

FRACTURED AND HORIZONTAL WELL DATA

PAY GRADE NO.	TYPE (VERT=0, HORIZ=1)			FRAC Xf/HORIZ LENGTH			FRAC COND, MD-FT		
	INIT WELL	FIRST INFILL	SECOND INFILL	INIT WELL	FIRST INFILL	SECOND INFILL	INIT WELL	FIRST INFILL	SECOND INFILL
1	0	0	0	0.	0.	0.	0.	0.	0.
2	0	0	0	0.	0.	0.	0.	0.	0.
3	0	0	0	0.	0.	0.	0.	0.	0.

WATER DRIVE AND UNCONVENTIONAL RESERVOIR DATA

PAY GRADE NO.	AQUIFER (MODULE 5) 0=FINITE 1=INFINITE	TRAPPED GAS SAT'N DECIMAL	MAX. WATER RATE (BPD/WELL)	0=DRY COAL 1=WET COAL 2=DRY SHALE 3=WET SHALE 4=GEO AQUIF		COAL LOCATION 0=EAST US 1=WEST US	COAL/SHALE GAS CONTENT (SCF/TON)
1	0	.30	1000.	-1		-1	0.
2	0	.30	1000.	-1		-1	0.
3	0	.30	1000.	-1		-1	0.

WELL CONTROL INFORMATION

MIN WHP PSIA	MAXIMUM RATE MCFD OR %OF IF 1 OR LESS	PAY GRADE NO.	SKIN FACTORS			SKIN FOR AUTO-REFRACT INITIAL WELL
			INIT WELL	FIRST INFILL	SECOND INFILL	
800.	.25	1	1.0	1.0	1.0	-1.0
		2	1.0	1.0	1.0	-1.0
		3	1.0	1.0	1.0	-1.0

TIME STEP CONTROL (MAXIMUM 199 STEPS)

TIME STEP YEARS	CHANGE TIME YEARS
1.0	40.0

Pay Grade	Gross Gas Recovery (MMcf)	Original Gas-in-Place (MMcf)	Recovery Efficiency (% OGIP)
1	55190.	277841.	19.9%
2	55231.	277841.	19.9%
3	13821.	69460.	19.9%
TOTAL	124241.	625142.	19.9%

The Field Could No Longer Meet the Rate Constraint Beginning in Year 1.

PRIMARY WELLS ONLY, NO INFILLS

[illegible]

35.00	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
36.00	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
37.00	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
38.00	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
39.00	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
40.00	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

PRIMARY WELLS ONLY, NO INFILLS

CUMULATIVE PRODUCTION, MMCF/WELL

# Wells	26.00	.00	.00	52.00	.00	.00	26.00	.00	.00	104.00
	Pay Grade 1			Pay Grade 2			Pay Grade 3			Total
Time	Well 1	Well 2	Well 3	Well 1	Well 2	Well 3	Well 1	Well 2	Well 3	MMcf
1.00	949.	0.	0.	659.	0.	0.	371.	0.	0.	68560.
2.00	1568.	0.	0.	945.	0.	0.	488.	0.	0.	102569.
3.00	1905.	0.	0.	1031.	0.	0.	519.	0.	0.	116622.
4.00	2057.	0.	0.	1054.	0.	0.	528.	0.	0.	122024.
5.00	2107.	0.	0.	1060.	0.	0.	530.	0.	0.	123706.
6.00	2119.	0.	0.	1062.	0.	0.	531.	0.	0.	124124.
7.00	2122.	0.	0.	1062.	0.	0.	531.	0.	0.	124216.
8.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124235.
9.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124240.
10.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
11.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
12.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
13.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
14.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
15.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
16.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
17.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
18.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
19.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
20.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
21.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
22.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
23.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
24.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
25.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
26.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
27.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
28.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
29.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
30.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
31.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
32.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
33.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
34.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
35.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
36.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
37.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
38.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
39.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.
40.00	2123.	0.	0.	1062.	0.	0.	532.	0.	0.	124241.

PRIMARY WELLS ONLY, NO INFILLS

# Wells	26.00	.00	.00	52.00	.00	.00	26.00	.00	.00	104.00
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Time years	Pay Grade 1			Pay Grade 2			Pay Grade 3			Total Ncfd
	Well 1	Well 2	Well 3	Well 1	Well 2	Well 3	Well 1	Well 2	Well 3	
1.00	23346.	0.	0.	10806.	0.	0.	4890.	0.	0.	*****
2.00	20989.	0.	0.	9240.	0.	0.	4062.	0.	0.	*****
3.00	19455.	0.	0.	8565.	0.	0.	3803.	0.	0.	*****
4.00	18621.	0.	0.	8362.	0.	0.	3735.	0.	0.	*****
5.00	18247.	0.	0.	8307.	0.	0.	3715.	0.	0.	*****
6.00	18122.	0.	0.	8293.	0.	0.	3710.	0.	0.	998856.
7.00	18091.	0.	0.	8289.	0.	0.	3708.	0.	0.	997839.
8.00	18085.	0.	0.	8289.	0.	0.	3708.	0.	0.	997616.
9.00	18084.	0.	0.	8288.	0.	0.	3707.	0.	0.	997570.
10.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997557.
11.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
12.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
13.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
14.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
15.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
16.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
17.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
18.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
19.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
20.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
21.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
22.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
23.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
24.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
25.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
26.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
27.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
28.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
29.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
30.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
31.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
32.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
33.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
34.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
35.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
36.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
37.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
38.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
39.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.
40.00	18083.	0.	0.	8288.	0.	0.	3707.	0.	0.	997554.

PRIMARY WELLS ONLY, NO INFILLS

[illegible]

[illegible]

PRIMARY WELLS ONLY, NO INFILLS

WELLHEAD PRESSURE, PSIA

[illegible]

Wednesday June 15, 1994 12:27 PM

[illegible]

Unit Cost
GSAM ID: 10310600 Tech.: Current Technology

Price Assumptions:

Oil (\$/Bbl): .00
 Gas (\$/Bbl): 2.00

Peak Production Rate (Mcf/Day)	1806.
Average Depth (feet)	4805.
Net Pay (feet)	50.
Unit Cost:	
EWC Unit Cost	(M\$/well): .000
DWC Unit Cost	(M\$/well): 172.734
AFE Breakdown	
Contractor Charges	(M\$/well): 53.029
Road & Site Prep	(M\$/well): 7.600
Transportation	(M\$/well): 4.146
Fuel	(M\$/well): 1.036
Mud & Additives	(M\$/well): 10.019
Drillstie Logs & Monitoring	(M\$/well): 1.900
Other Physical Test	(M\$/well): 1.036
Logs & Wireline Evaluations	(M\$/well): 6.391
Wellsite Data Services	(M\$/well): .173
Directional Drilling Services	(M\$/well): 2.764
Perforating	(M\$/well): 2.418
Formation Treatment	(M\$/well): 7.600
Cement & Services	(M\$/well): 8.291
Casing & Tubing	(M\$/well): 23.664
Special Tool Rentals	(M\$/well): 4.664
Drill Bits & Reamers	(M\$/well): 3.973
Wellhead Equipment	(M\$/well): 3.109
Other Equipment & Supplies	(M\$/well): 5.182
Plugging	(M\$/well): 2.246
Supervision & Overhead	(M\$/well): 9.673
Other Expenditures	(M\$/well): 12.264
Stimulation Cost	(M\$/well): 49.220
Compressor Cost	(\$/Mcf): .050
Facilities Cost	(M\$/well): 45.403
Fixed O&M	(M\$/well): 13.207
Variable O&M - Gas	(\$/Mcf): .148
Variable O&M - Water	(\$/Barrel): .250
Compressor O&M	(\$/Barrel): .060
Environmental Unit Cost:	
Environmental Capital Cost	(M\$/well): 4.540
Environmental O&M - Gas	(\$/Mcf): .050
Environmental O&M - Water	(\$/Barrel): .100

Detailed Financial Report
GSAM ID: 10310600 Tech.: Current Technology Case: Primary Wells P.G.: 2

Year	1	2	3	4	5	6	7
Oil Production (MMBO)	.000	.000	.000	.000	.000	.000	.000
Gas Production (BCF)	34.259	14.856	4.485	1.230	.306	.073	.017
Gross Revenues (MMS)	68.52	29.71	8.97	2.46	.61	.15	.03
Gravity/Trans. Cost Adj.	.00	.00	.00	.00	.00	.00	.00
Adjusted Revenues	68.52	29.71	8.97	2.46	.61	.15	.03
Royalties	8.56	3.71	1.12	.31	.08	.02	.00
Net Sales	59.95	26.00	7.85	2.15	.54	.13	.03
Total Operating Cost	14.99	6.55	2.67	1.46	1.11	1.02	1.00
Operating Cost/Mcf	.44	.44	.60	1.18	3.63	14.11	58.91
G&A on Expensed Items	4.29	2.03	.83	.45	.34	.32	.31
G&A on Capitalized Items	1.18	.00	.00	.00	.00	.00	.00
Pressure Maint./Cycling	.00	.00	.00	.00	.00	.00	.00
General O&M	7.81	3.78	1.62	.94	.75	.70	.69
Environmental O&M Costs	1.71	.74	.22	.06	.02	.00	.00
Intangible Investment	5.66	.00	.00	.00	.00	.00	.00
Intang. Exploratory Costs	.00	.00	.00	.00	.00	.00	.00
Intang. Development Costs	5.66	.00	.00	.00	.00	.00	.00
Other Intangible Costs	.00	.00	.00	.00	.00	.00	.00
Environmental Intangible Capital Costs	.00	.00	.00	.00	.00	.00	.00
Portion of Intangibles to Capitalize	1.70	.00	.00	.00	.00	.00	.00
TOTAL INVESTMENTS	11.80	.00	.00	.00	.00	.00	.00
Tangible Investments	6.14	.00	.00	.00	.00	.00	.00
Tang. Exploratory Cost	.00	.00	.00	.00	.00	.00	.00
Tang. Development Cost	3.77	.00	.00	.00	.00	.00	.00
Environmental	.00	.00	.00	.00	.00	.00	.00
Other Tangible Capital	2.36	.00	.00	.00	.00	.00	.00
Depreciable/Capitalized Investments	7.84	.00	.00	.00	.00	.00	.00
Adj. for Federal Tax Credits	.00	.00	.00	.00	.00	.00	.00
Depreciable/Capitalize Base	7.84	.00	.00	.00	.00	.00	.00
Depreciation	1.12	1.92	1.37	.98	.70	.70	.70
Depletable G&G/Lease Costs	.00	.00	.00	.00	.00	.00	.00
Lease Acq. Cost	.00	.00	.00	.00	.00	.00	.00
G&G Costs	.00	.00	.00	.00	.00	.00	.00
Adjustments for Federal Tax Credits	.00	.00	.00	.00	.00	.00	.00
Depletion Base	.00	.00	.00	.00	.00	.00	.00
Expensed G&G/Lease Costs	.00	.00	.00	.00	.00	.00	.00
Lease Purchase Cost	.00	.00	.00	.00	.00	.00	.00
G&G Costs	.00	.00	.00	.00	.00	.00	.00
Net Revenues	59.95	26.00	7.85	2.15	.54	.13	.03
Operator Severance Taxes	3.60	1.56	.47	.13	.03	.01	.00
Operating Costs	14.99	6.55	2.67	1.46	1.11	1.02	1.00
Expensed Int.,G&G, and Lease Acq.	3.96	.00	.00	.00	.00	.00	.00
Depreciation	1.12	1.92	1.37	.98	.70	.70	.70
Depletion Allowance	.00	.00	.00	.00	.00	.00	.00
Taxable Income	36.28	15.96	3.33	-.41	-1.31	-1.60	-1.67
Tax Credit Addback	.00	.00	.00	.00	.00	.00	.00
Intangible Addback	.00	.00	.00	.00	.00	.00	.00
G&G/Lease Addback	.00	.00	.00	.00	.00	.00	.00
Net Income Before Taxes	36.28	15.96	3.33	-.41	-1.31	-1.60	-1.67
State Income Taxes	.00	.00	.00	.00	.00	.00	.00
Federal Income Tax	12.34	5.43	1.13	-.14	-.44	-.55	-.57
Federal Tax Credits	.00	.00	.00	.00	.00	.00	.00
Net Income After Taxes	23.95	10.54	2.20	-.27	-.86	-1.06	-1.10
plus Depreciation	1.12	1.92	1.37	.98	.70	.70	.70
plus Depletion	.00	.00	.00	.00	.00	.00	.00
less Depletable Items	.00	.00	.00	.00	.00	.00	.00
less Depreciable/Capitalized Items	7.84	.00	.00	.00	.00	.00	.00
less Tax Credit on Expensable Items	.00	.00	.00	.00	.00	.00	.00
Annual After Tax Cash Flow	17.23	12.46	3.57	.71	-.16	-.36	-.41
Discounted After Tax Cash Flow	17.23	11.86	3.24	.61	-.13	-.28	-.30
Cumulative Discounted After Tax Cash Flow	17.23	29.09	32.33	32.94	32.80	32.52	32.22

GSAM ID	EIACODE	CASE	Resv.	OGIP	# Wells	MASP	Tot. Cap.	NPV Prod.	NPV Exp.	NPV Inv.	NPV Drill	NPV Non-Drl	NPV Tax	Chg. Exp.	Chg. Inv.	Chg. Tax	Drill Slope	Non-Drl Slope	Feet	H2O Depth	Window Year
10310600	457461	C 1 P *	55.2	277.8	26.	.670	5.9	43.4	28.7	6.5	5.2	1.3	17.7	2.871	1.129	13.415	.354	.402	4805.	0.	1
10310600	457461	C 1 R	55.2	277.8	26.	.705	7.2	43.4	28.7	7.9	5.2	2.7	17.2	2.871	1.411	13.323	.393	.402	4805.	0.	1
10310600	457461	C 1 I	55.2	277.8	52.	.809	11.5	44.5	29.2	12.6	10.4	2.3	16.3	2.921	2.277	13.402	.483	.405	4805.	0.	1
10310600	457461	C 2 P *	55.2	277.8	52.	.865	11.8	44.3	38.1	13.0	10.4	2.6	13.1	3.810	2.258	13.049	.465	.378	4805.	0.	1
10310600	457461	C 2 R	55.2	277.8	52.	.934	14.4	44.3	38.1	15.8	10.4	5.4	12.1	3.810	2.821	12.864	.497	.378	4805.	0.	1
10310600	457461	C 2 I	55.2	277.8	104.	1.157	23.0	44.8	38.3	25.3	20.7	4.5	9.4	3.833	4.553	12.472	.564	.375	4805.	0.	1
10310600	457461	C 3 P *	13.8	69.5	26.	1.266	5.9	11.1	14.0	6.5	5.2	1.3	.8	1.404	1.129	2.953	.553	.356	4805.	0.	1
10310600	457461	C 3 R	13.8	69.5	26.	1.403	7.2	11.1	14.0	7.9	5.2	2.7	.3	1.404	1.411	2.860	.574	.356	4805.	0.	1
10310600	457461	C 3 I	13.8	69.5	52.	1.862	11.5	11.2	14.1	12.6	10.4	2.3	-1.2	1.406	2.277	2.596	.617	.350	4805.	0.	1

Supply Summary Report

Region: United States - L 48

Play: All

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Reserves/Production Summary (BCF):													
BOY Reserves:	181408.	174678.	176037.	184650.	203021.	223669.	241040.	246188.	242171.	234247.	224918.	214988.	204409.
Res. Adds:	8184.	17004.	24919.	35428.	39240.	37055.	25154.	15830.	11262.	8785.	6964.	4759.	3617.
-Production:	14915.	15645.	16306.	17056.	18592.	19684.	20006.	19847.	19186.	18114.	16893.	15338.	13782.
EOY Reserves:	174678.	176037.	184650.	203021.	223669.	241040.	246188.	242171.	234247.	224918.	214988.	204409.	194245.
Expenditure Summary (\$MM)													
Exploration:	87428.	29033.	8740.	4322.	4978.	2902.	16228.	23743.	11330.	4862.	2553.	938.	1624.
Development:	1739.	2780.	3662.	4343.	5185.	4772.	4100.	3034.	1787.	978.	853.	799.	632.
Production:	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Total:	89167.	31813.	12402.	8664.	10163.	7675.	20328.	26777.	13117.	5840.	3405.	1737.	2256.
Cost Breakdown (\$MM)													
Exp-Drilling:	32479.	10380.	3046.	1458.	1667.	954.	5508.	7983.	3375.	1467.	645.	304.	521.
Exp-Other:	54949.	18652.	5694.	2863.	3311.	1948.	10720.	15761.	7955.	3395.	1908.	634.	1103.
Exp-Total:	87428.	29033.	8740.	4322.	4978.	2902.	16228.	23743.	11330.	4862.	2553.	938.	1624.
Devl-Drilling:	1739.	2780.	3662.	4343.	5185.	4772.	4100.	3034.	1787.	978.	853.	799.	632.
Devl-Other:	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Devl-Total:	1739.	2780.	3662.	4343.	5185.	4772.	4100.	3034.	1787.	978.	853.	799.	632.
Cost Breakdown (000\$/Well)													
Exp-Drilling:	.66	.58	.61	.55	.59	.38	.47	.46	.38	.27	.21	.95	.92
Exp-Other:	1.11	1.04	1.15	1.07	1.17	.78	.91	.91	.90	.61	.63	1.97	1.94
Exp-Total:	1.76	1.62	1.76	1.62	1.76	1.16	1.38	1.37	1.28	.88	.85	2.92	2.86
Devl-Drilling:	.46	.27	.26	.27	.31	.37	.51	.48	.36	.23	.23	.24	.31
Devl-Other:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Devl-Total:	.46	.27	.26	.27	.31	.37	.51	.48	.36	.23	.23	.24	.31
Fixed O&M (\$000/	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Var. O&M (\$/mcf)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Tot. O&M (\$/mcf)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Drilling Summary (000 wells):													
Exploration:	49567.	17895.	4963.	2676.	2825.	2506.	11741.	17294.	8850.	5531.	3017.	322.	567.
Devl-Primary:	2182.	9631.	13325.	15286.	15246.	10454.	6202.	4750.	3698.	2640.	2308.	1798.	835.
Devl-Infill:	1565.	554.	833.	1100.	1748.	2582.	1823.	1593.	1289.	1587.	1469.	1514.	1196.
Total:	53314.	28080.	19121.	19062.	19820.	15542.	19765.	23637.	13837.	9758.	6793.	3634.	2599.
Recompletes:	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Exp. Success Rate	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Devl Success Rate	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Reserve Addition Summary (Bcf):													
Primary:	8184.	17004.	24919.	35428.	39240.	37055.	25154.	15830.	11262.	8785.	6964.	4759.	3617.
Secondary:	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Total:	8184.	17004.	24919.	35428.	39240.	37055.	25154.	15830.	11262.	8785.	6964.	4759.	3617.
Reserve Addition Summary (Bcf/Well):													
Primary:	3.75	1.77	1.87	2.32	2.57	3.54	4.06	3.33	3.05	3.33	3.02	2.65	4.33
Secondary:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Total:	2.18	1.67	1.76	2.16	2.31	2.84	3.13	2.50	2.26	2.08	1.84	1.44	1.78
Production Summary - Pre 1993 Fields:													
Prod (Bcf):	13417.	11518.	10223.	8722.	7898.	7243.	6743.	6344.	5966.	5652.	5348.	5111.	4880.

umber Wells:	43997.	43997.	43997.	43997.	43997.	43997.	43.	43997.	43997.	43997.	43997.	43997.	43997.
Avg Rate (mcf/day)	835.52	717.22	636.57	543.11	491.78	451.04	419.90	395.07	371.52	351.95	333.03	318.25	303.87

Production Summary - Post 1993 Fields:

Prod (Bcf):	1497.	4127.	6083.	8334.	10694.	12441.	13263.	13503.	13220.	12463.	11545.	10227.	8902.
Number Wells:	1745.	9450.	20111.	32340.	44537.	52900.	57861.	61662.	64620.	66732.	68578.	70017.	70685.
Avg Rate (mcf/day)	2350.04	1196.47	828.77	706.06	657.88	644.30	627.99	599.94	560.50	511.66	461.23	400.19	345.04

Production Summary - All Fields:

Prod (Bcf):	14915.	15645.	16306.	17056.	18592.	19684.	20006.	19847.	19186.	18114.	16893.	15338.	13782.
Number Wells:	45742.	53447.	64108.	76337.	88534.	96897.	101858.	105659.	108617.	110729.	112575.	114014.	114682.
Avg Rate (mcf/day)	893.31	801.96	696.87	612.14	575.34	556.55	538.11	514.63	483.95	448.20	411.13	368.57	329.24
R/P ratio:	12.71	12.25	12.32	12.90	13.03	13.25	13.31	13.20	13.21	13.42	13.73	14.33	15.09

WH Price (\$/mcf)*****	*****	.00	.00	*****	*****	*****	.00	.00	.00	*****	.00	.00
Revenues (\$MM): *****	*****	0.	0.	*****	*****	*****	0.	0.	0.	*****	0.	0.

Resource Summary (Tcf):

Undiscovered Fields at BOY

Sz Class: 1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 9	2.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 10	4.	1.	1.	1.	1.	1.	1.	1.	0.	0.	0.	0.	0.
Sz Class: 11	10.	7.	7.	7.	7.	7.	7.	5.	2.	1.	1.	1.	1.
Sz Class: 12	23.	21.	20.	20.	20.	19.	19.	17.	17.	15.	11.	11.	11.
Sz Class: 13	53.	47.	46.	45.	45.	45.	45.	44.	42.	39.	39.	34.	34.
Sz Class: 14	11.	6.	4.	2.	2.	2.	2.	2.	2.	1.	0.	0.	0.
Sz Class: 15	14.	6.	4.	2.	2.	2.	2.	2.	1.	1.	1.	0.	0.
Sz Class: 16	65.	62.	57.	49.	37.	27.	25.	22.	15.	10.	9.	7.	5.
Sz Class: 17	60.	58.	46.	38.	34.	17.	15.	15.	15.	8.	4.	4.	4.
Sz Class: 18	511.	472.	266.	23.	15.	6.	0.	0.	0.	0.	0.	0.	0.
Total:	754.	682.	451.	188.	163.	126.	115.	108.	94.	76.	66.	58.	55.

Banked Fields at BOY

Sz Class: 1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 2	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 6	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 7	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 8	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 9	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Sz Class: 10	0.	3.	0.	0.	0.	0.	0.	1.	1.	0.	0.	0.	0.
Sz Class: 11	1.	3.	0.	0.	0.	0.	0.	1.	4.	1.	0.	0.	0.
Sz Class: 12	1.	3.	1.	0.	0.	0.	1.	1.	1.	2.	3.	0.	0.
Sz Class: 13	3.	6.	1.	1.	0.	0.	0.	1.	2.	2.	0.	5.	0.
Sz Class: 14	1.	6.	2.	2.	1.	0.	0.	0.	0.	0.	1.	0.	0.
Sz Class: 15	1.	8.	2.	2.	0.	0.	0.	0.	0.	0.	0.	1.	0.
Sz Class: 16	3.	3.	5.	7.	13.	9.	2.	3.	6.	5.	2.	2.	3.
Sz Class: 17	3.	2.	12.	8.	4.	17.	2.	0.	0.	7.	4.	0.	0.
Sz Class: 18	27.	39.	206.	243.	8.	10.	6.	0.	0.	0.	0.	0.	0.
Total:	40.	73.	231.	263.	25.	36.	12.	7.	14.	18.	10.	8.	3.

GSAM Integrating Model Output

Supply Summary

	1993	1995	2000	2005
Region: Pacific Offshore	46.2	56.2	90.0	141.4
Region: Pacific Onshore	332.1	338.3	421.4	578.2
Region: San Juan	431.6	457.4	504.3	557.9
Region: Rockies Foreland	1237.6	1406.9	1953.7	2619.3
Region: Williston	89.0	80.8	81.3	94.5
Region: Permian	1496.3	1498.9	1491.5	1481.5
Region: Mid-Continent	3314.9	3183.3	2962.1	2716.4
Region: Arkla-East Texas	1379.2	1341.7	1295.8	1202.8
Region: Texas Gulf Coast	2195.7	2343.7	2322.0	2026.5
Region: Gulf of Mexico-West	.0	.0	.0	.0
Region: Gulf of Mexico-East	4956.8	4989.9	5083.4	4511.1
Region: Norphlet	62.6	72.3	124.8	222.6
Region: West Florida	.0	2.1	3.1	4.1
Region: So-Louisiana	1186.4	1190.2	1103.4	925.6
Region: MAFLA Onshore	315.5	357.3	500.6	494.4
Region: Mid-West	165.8	182.4	249.9	370.8
Region: Appalachia	661.6	737.9	1086.1	1637.3
Region: Alberta	4284.0	4921.9	5746.2	5705.0
Total Supply Model	22155.5	23161.2	25019.6	25289.3

Supply Projects:

Project: ANGSTS	.0	.0	.0	.0
Project: MacKensy Delta	.0	.0	.0	.0
Project: Artic Islands	.0	.0	.0	423.0
Project: Sable Island	.0	.0	112.0	112.0
Project: LNG - Current	52.0	52.0	52.0	52.0
Project: LNG - Current	153.4	153.4	153.4	153.4
Project: LNG - \$2.50 Threshold	.0	41.6	41.6	41.6
Project: LNG - \$2.50 Threshold	.0	219.0	219.0	219.0
Project: LNG - \$2.50 Threshold	.0	109.9	109.9	109.9
Project: LNG - \$2.50 Threshold	.0	.0	.0	75.7
Project: LNG - \$3.00 Threshold	.0	.0	.0	109.5
Project: LNG - \$3.00 Threshold	.0	.0	.0	54.7
Total Supply Projects:	205.4	575.9	687.9	1350.8

Peak Supplies:

48.1	.0	.0	.0
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Total Supplies:

22409.0	23737.1	25707.5	26640.1
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Demand by Region and Sector

	1993	1995	2000	2005
Region: New England				
Sector: Residential	163.8	163.7	173.3	174.8
Sector: Commercial	95.7	98.3	108.8	116.3
Sector: Industrial	121.7	132.7	130.0	147.5
Sector: Elec-Gen	141.5	230.9	250.1	256.6
Total Region:	522.7	625.7	662.2	695.2
Region: Middle Atlantic				
Sector: Residential	760.2	734.1	737.2	714.5
Sector: Commercial	453.9	452.0	468.1	475.0
Sector: Industrial	481.7	518.8	540.1	577.3
Sector: Elec-Gen	209.0	406.3	681.7	780.9
Total Region:	1904.8	2111.3	2427.2	2547.7
Region: South Atlantic				
Sector: Residential	351.5	343.5	376.7	403.6
Sector: Commercial	236.1	236.3	274.8	308.8
Sector: Industrial	750.1	795.2	842.2	918.6
Sector: Elec-Gen	30.3	61.5	132.9	195.9
Total Region:	1368.0	1436.5	1626.6	1827.0
Region: Florida				
Sector: Residential	11.7	12.3	13.4	10.3
Sector: Commercial	36.8	41.9	48.7	54.8
Sector: Industrial	98.6	106.2	116.9	131.4
Sector: Elec-Gen	321.3	499.7	609.1	530.0
Total Region:	468.4	660.2	788.1	726.4
Region: East South Central				
Sector: Residential	180.0	180.2	183.0	182.2
Sector: Commercial	127.4	132.7	143.1	152.5
Sector: Industrial	563.6	667.1	727.8	670.7
Sector: Elec-Gen	24.8	49.1	100.6	187.4
Total Region:	895.9	1029.1	1154.5	1192.8
Region: East North Central				
Sector: Residential	1400.3	1378.0	1383.1	1337.8
Sector: Commercial	696.6	706.6	706.3	701.6
Sector: Industrial	1224.2	1271.0	1362.7	1461.0
Sector: Elec-Gen	.0	.0	.0	7.3
Total Region:	3321.1	3355.6	3452.2	3507.7
Region: West South Central				
Sector: Residential	395.9	396.3	402.8	406.1
Sector: Commercial	282.2	294.0	333.4	381.3
Sector: Industrial	3483.5	3549.5	3659.6	3753.4
Sector: Elec-Gen	1130.0	1236.4	1045.5	1032.9
Total Region:	5291.5	5476.2	5441.4	5573.6
Region: West North Central				
Sector: Residential	458.5	458.9	452.9	437.6
Sector: Commercial	314.5	320.9	332.1	341.0
Sector: Industrial	388.7	411.1	429.4	444.4
Sector: Elec-Gen	5.3	13.4	126.7	209.4
Total Region:	1167.0	1204.3	1341.1	1432.3
Region: Mountain 1				
Sector: Residential	52.9	53.3	57.8	58.7
Sector: Commercial	51.0	52.2	59.9	65.3
Sector: Industrial	74.7	78.4	86.9	93.8
Sector: Elec-Gen	73.4	97.4	175.6	226.8
Total Region:	252.0	281.4	380.1	444.6
Region: Mountain 2				
Sector: Residential	217.6	219.7	225.1	222.1
Sector: Commercial	129.3	132.7	142.9	149.4
Sector: Industrial	300.0	321.8	374.0	368.7
Sector: Elec-Gen	120.0	165.2	288.0	361.4
Total Region:	766.9	839.3	1029.9	1101.6
Region: California				
Sector: Residential	514.4	509.3	522.3	502.2
Sector: Commercial	280.6	286.5	318.3	350.5
Sector: Industrial	433.6	451.1	485.0	516.1

Sector: Elec-Gen	60.7	84.4	415.5	464.2
Total Region:	1289.3	1331.3	1741.1	1833.0
Region: Pacific Northwest				
Sector: Residential	72.7	75.2	66.9	77.5
Sector: Commercial	60.8	65.3	68.7	76.7
Sector: Industrial	330.5	347.5	364.7	376.7
Sector: Elec-Gen	59.8	38.7	15.3	38.5
Total Region:	523.9	526.6	515.6	569.4
Region: Canada				
Sector: Residential	574.8	582.5	602.8	614.7
Sector: Commercial	370.8	377.9	396.0	415.2
Sector: Industrial	1126.1	1187.3	1284.4	1305.7
Sector: Elec-Gen	38.6	72.7	71.6	67.7
Total Region:	2110.3	2220.4	2354.8	2403.3
Total for All Regions:				
Sector: Residential	5154.2	5107.0	5197.2	5142.2
Sector: Commercial	3135.8	3197.2	3401.3	3588.3
Sector: Industrial	9377.2	9837.8	10403.7	10765.3
Sector: Elec-Gen	2214.7	2955.8	3912.7	4359.0
Total:	19881.9	21097.8	22914.9	23854.7
Transport Fuel Use:	875.4	917.0	932.7	899.0
Storage Fuel Use:	48.4	51.8	53.5	55.4
Lease & Plant:	1595.2	1667.6	1801.4	1820.8
Net Demand:	22352.5	23682.4	25648.9	26574.5

Supply Price Summary (\$/Mcf)

	1993	1995	2000	2005
Region: Pacific Offshore	2.17	2.25	2.49	2.97
Region: Pacific Onshore	2.17	2.25	2.49	2.97
Region: San Juan	1.97	2.08	2.30	2.77
Region: Rockies Foreland	1.99	2.10	2.26	2.73
Region: Williston	1.89	1.98	2.14	2.59
Region: Permian	1.92	2.07	2.24	2.85
Region: Mid-Continent	1.92	2.07	2.24	2.85
Region: Arkla-East Texas	1.92	2.07	2.24	2.85
Region: Texas Gulf Coast	1.92	2.07	2.24	2.85
Region: Gulf of Mexico-West	.00	.00	.00	.00
Region: Gulf of Mexico-East	2.00	2.16	2.34	2.93
Region: Norphlet	2.00	2.16	2.34	2.93
Region: West Florida	.00	2.37	2.56	3.19
Region: So-Louisiana	2.00	2.16	2.34	2.93
Region: MAFLA Onshore	2.03	2.18	2.36	2.95
Region: Mid-West	2.05	2.22	2.39	3.00
Region: Appalachia	2.14	2.32	2.50	3.11
Region: Alberta	1.98	2.01	2.10	2.72
Average Supply Model	1.97	2.10	2.26	2.85
Supply Projects:				
Project: ANGSTS	.00	.00	.00	.00
Project: MacKensy Delta	.00	.00	.00	.00
Project: Artic Islands	.00	.00	.00	.54
Project: Sable Island	.00	.00	2.29	2.92
Project: LNG - Current	2.48	2.68	2.86	3.50
Project: LNG - Current	2.15	2.31	2.49	3.08
Project: LNG - \$2.50 Threshold	.00	2.68	2.86	3.50
Project: LNG - \$2.50 Threshold	.00	2.52	2.75	3.39
Project: LNG - \$2.50 Threshold	.00	2.52	2.75	3.39
Project: LNG - \$2.50 Threshold	.00	.00	.00	3.08
Project: LNG - \$3.00 Threshold	.00	.00	.00	3.39
Project: LNG - \$3.00 Threshold	.00	.00	.00	3.39
Average Supply Projects:	2.24	2.49	2.63	2.41
Peak Supplies:	3.25	.00	.00	.00