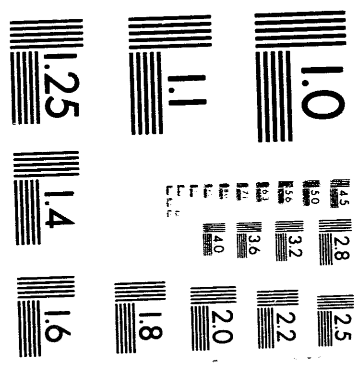

Conf-931156--19

DOE/MC/28138-94/C0304

Development of the Natural Gas Systems Analysis Model (GSAM)

Authors:
M. Godec
M. Haas
W. Pepper
J. Rose

Contractor:
ICF Resources Incorporated
9300 Lee Highway
Fairfax, VA 22031

Contract Number:
DE-AC21-92MC28138

Conference Title:
Fuels Technology Contractors Review Meeting

Conference Location:
Morgantown, West Virginia

Conference Dates:
November 16-18, 1993

Conference Sponsor:
U.S. Department of Energy, Morgantown Energy Technology Center

Development Of The Natural Gas Systems Analysis Model (GSAM)

CONTRACT INFORMATION

Contract Number:	DE-AC21-92MC28138
Contractor:	ICF Resources Incorporated 9300 Lee Highway Fairfax, VA 22031 (703) 934-3000
Contractor Project Manager:	Michael Godec
Principal Investigators:	Mark Haas William Pepper Judah Rose
METC Project Manager:	Anthony M. Zammerilli
Period Of Performance:	June 22, 1992 - June 21, 1995

FY 93 PROGRAM SCHEDULE

	S	O	N	D	J	F	M	A	M	J	J	A	S
Technology Review	—	—	—	—									
Model Review	—	—	—	—	—								
GSAM Design	—	—	—	—	—								
Prototype Development			—	—	—	—	—	—	—	—	—	—	

OBJECTIVES

The objective of this research is to create a comprehensive, non-proprietary, microcomputer model of the North American natural gas system. The model is to explicitly evaluate key components of the natural gas system, including resource base, exploration and development, extraction technology performance and costs, transportation and storage, and end use. It will be used to evaluate alternative METC Natural Gas R&D strategies and to estimate the impact of federal energy and environmental policy initiatives on domestic natural gas potential. The three-year project timetable has been accelerated to provide a working prototype model by December 1993.

BACKGROUND INFORMATION

Recent dramatic changes in natural gas markets have significant implications for the scope and direction of DOE's upstream as well as downstream natural gas R&D. Open access transportation changes the way gas is bought and sold. The end of the gas deliverability surplus requires increased reserve development above recent levels. Increased gas demand for power generation and other new uses changes the overall demand picture in terms of volumes, locations and seasonality.

DOE's Natural Gas Strategic Plan requires that its R&D activities be evaluated for their ability to provide adequate supplies of reasonably priced gas. Potential R&D projects are to be evaluated using a full fuel cycle, benefit-cost approach to estimate likely market impact as well as technical success. To assure R&D projects are evaluated on a comparable basis, METC has undertaken the development of a comprehensive natural gas technology evaluation framework. Existing energy systems models lack the level of detail required to estimate the impact of specific upstream natural gas technologies across the known range of geological settings and likely market conditions.

Gas Systems Analysis Model (GSAM) research during FY 1993 developed and implemented this comprehensive, consistent natural gas system evaluation framework. Rather than a isolated research activity, however, GSAM represents the integration of many prior and ongoing natural gas research efforts. When complete, it will incorporate the most current resource base description, reservoir modeling, technology characterization and other geologic and engineering aspects developed through recent METC and industry gas R&D programs.

PROJECT DESCRIPTION

GSAM is being developed in two phases. Phase I includes the review of existing natural gas extraction technologies, a review of current upstream natural gas computer models and the development of a comprehensive natural gas systems evaluation framework. Phase I concludes with the development, testing and peer review of a working prototype GSAM model and reservoir database, originally scheduled for December 1993. Phase I model development and partial validation of some system components will be completed on schedule. Full system validation and peer review, however, cannot be completed until a reservoir database becomes available (expected by Spring 1994).

Phase II encompasses preliminary use of GSAM to support METC R&D strategy development and estimate impacts of federal policy initiatives on the domestic gas industry. METC will set Phase II priorities and direct selected GSAM modeling enhancements, to be concluded in June 1995. At that time ICF Resources will install GSAM at METC and train METC staff.

Design Philosophy

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.
- *Technology* is characterized in terms of the explicit physical parameters that affect gas contact, flow rates and ultimate recovery, and the costs associated with applying a group of technologies in specified reservoir settings.
- *Production modeling* accounts for unique interactions of geology, technology and reservoir operating practices that influence gas recovery rate and ultimate recovery.
- *Project economics* are analyzed on an industry-standard, discounted cash flow, pro forma basis for both full and incremental project evaluation.
- *Decisionmaking* incorporates the inherent uncertainties and inefficiencies in resource characterization, technology performance and gas markets.

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.

Model Structure

GSAM is segmented into separate Upstream and Downstream Modules linked by an Integrating Module (Figure 1). Modules may be run independently or as an integrated system. For upstream issues, this structure provides the flexibility to examine extraction

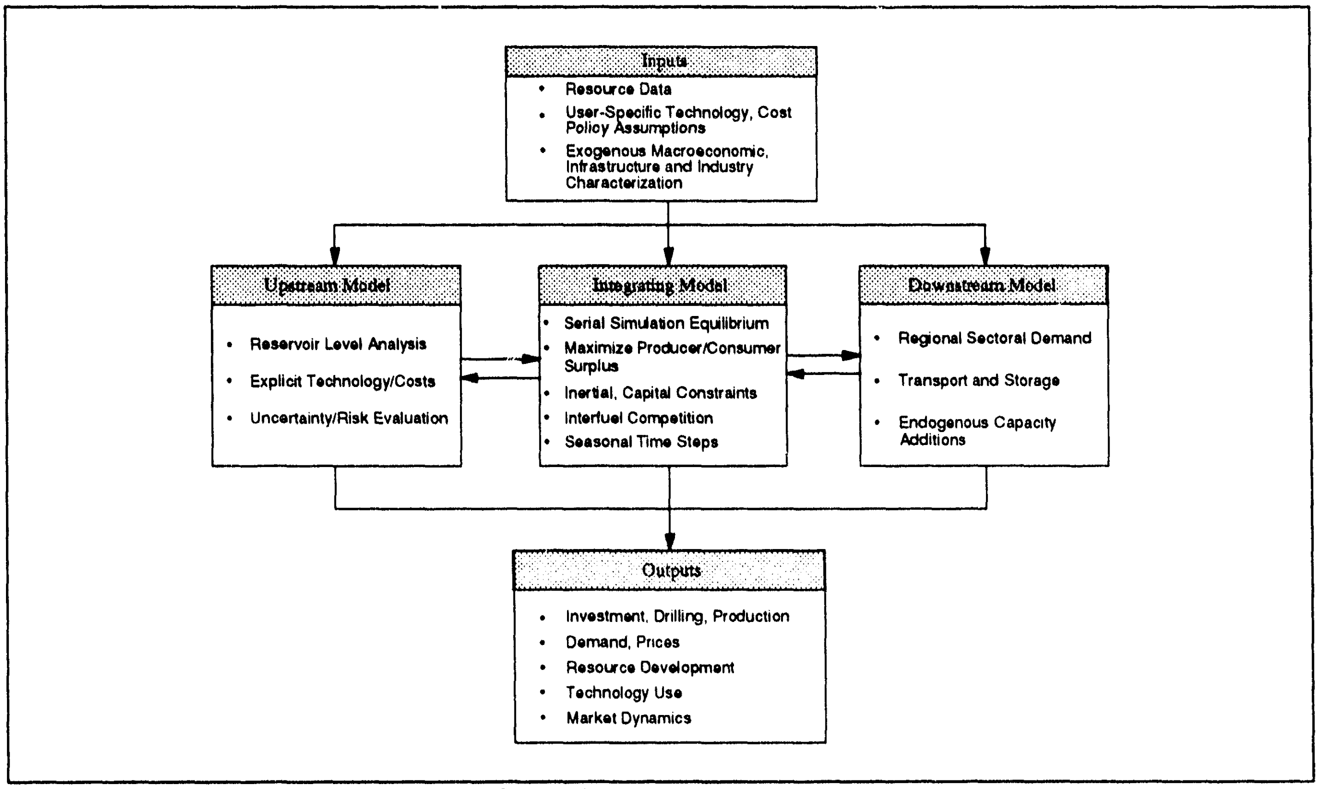

Figure 1 - GSAM Schematic

technology performance or economics of a reservoir, region, resource type or for the entire North American gas market.

Upstream Module

The Upstream Module estimates gas recovery and costs at the level of individual reservoirs. We briefly describe below the key aspects of resource base characterization, reservoir performance modeling, technology characterization, reservoir development, economic evaluation, exploration, treatment of uncertainty, estimation of other gas supplies and the role of technology transfer.

Resource Base Characterization

GSAM will incorporate a reservoir database of about 5,000 fully characterized producing reservoirs. Reservoir data will be primarily derived from the Gas Information System (GASIS), currently under development by METC, and other sources. GSAM users may also provide their own reservoir data. Although the validity and internal consistency of data for each reservoir will have been confirmed in the GASIS development process, GSAM will contain a complete set of default algorithms to assign values for missing or inconsistent reservoir properties.

GSAM evaluates three types of reservoirs: producing, discovered nonproducing, and undiscovered. All reservoirs will be described geologically in a common database format, although the characterization of each will depend on available data. In many cases, reservoir level defaults will be generated by transforming data from higher or lower levels of aggregation, all of which will be documented. (Figure 2).

Producing reservoirs' ultimate recovery or flow rate may be increased by application of improved technology. Accurate characterization of reservoir properties and current depletion status are necessary to accurately estimate this potential using GSAM's reservoir models. GSAM and GASIS developers will work together to history match selected producing

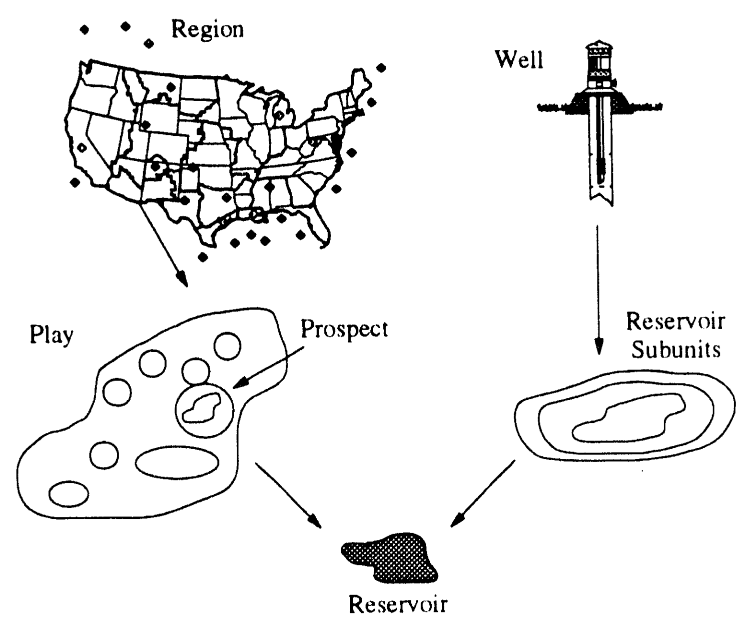

Figure 2 - Transformation of Resource Data to Reservoir Level

reservoirs to verify internal consistency between reservoir properties and production history.

Discovered, nonproducing reservoirs primarily represent reservoirs recently discovered but uneconomic to develop on a sunk-cost basis. Because they are a potentially large source of low-cost, near-term reserve additions, accurate estimates of their number, size and characteristics are critical.

Undiscovered resources are defined in GSAM as typical reservoirs by field size within geological plays. Since known reservoirs to be described in GASIS are likely to adequately represent the range of geological settings that constitute reservoirs yet to be found, they provide acceptable analogs to characterize undiscovered resources. GSAM research in Phase II will enhance the current method to characterize these typical play and size-class specific reservoirs.

Including typical undiscovered reservoirs will add the equivalent of another 5,000 reservoirs to be evaluated. A prospect-play resource appraisal technique will be used to generate undiscovered resource field size distributions from play-specific distributions of known fields, once validated reservoir level data are available.

GSAM makes two additional changes in gas resource base characterization that should improve the ability to evaluate issues such as reserve growth on a more consistent basis. First, all reservoirs will be described on a resource-in-place basis, similar to the procedure for oil. The lack of volumetric reservoir data for gas reservoirs has precluded this characterization in the past. This more realistically accommodates resource accumulation theory and eliminates the need to use implicit technology and economic factors that affect recovery and size classification. With greater consistency, it should be easier to separate the economic, technology, and drilling components of reserve growth.

Second, GSAM will lower the smallest field size class included in its undiscovered resource base. Many producing reservoirs have ultimate recoveries less than the 6 Bcf cutoff used by USGS in its 1989 national assessment. As technology improves, the "minimum" economic size class is likely to decrease. The estimated volume of the undiscovered nonassociated gas resource base used in GSAM will be reconciled with recent USGS estimates and extended to account for economically producible reservoirs as small as 1 Bcf recoverable.

Reservoir Performance Modeling

The need to evaluate technology and operating conditions dictates the level of reservoir modeling detail required. GSAM has developed a suite of dimensionless pressure decline type curves to estimate gas rate and ultimate recovery. The type curve method is grounded in accepted engineering theory and balances the need for explicit technology modeling with the limitations of available reservoir data.

These models were designed to evaluate the unique production mechanisms found in all significant nonassociated gas resources. Separate type curves were developed for various flow regimes (radial and linear), porosity types (single and dual), drive mechanisms (expansion, diffusion/desorption and water) and phases (one or two) (Figure 3).

GSAM uses an enhanced type curve approach that models a flow unit instead of a single closed boundary well. This method estimates well-to-well interference, providing the ability to evaluate the potential of up to two infill episodes. It accommodates changing skin, drainage area and flowing pressure over the well life to estimate the effects of performance degradation (e.g., perforation plugging, proppant embedment) or production practices (e.g., compression, liquids removal). Production is allocated to each well according to production allocation or proration rules specific to each field. At the user's option, the type curves may be run at several levels of detail that allow for faster processing time with a minimum loss of accuracy.

Technology Characterization

The core analytical feature of GSAM is the ability to represent technologies explicitly. Rather than ambiguously representing technology advances as "increased recovery" or "lower cost," GSAM characterizes technologies in terms of the parameters that affect the underlying gas flow equations in the reservoir model or costing algorithms in the economics model.

Module	Reservoir Type	Drive Mechanism	Flow Geometry	Porosity Type	Number of Fluids
I	Conventional Tight	Fluid Expansion	Radial Flow	Single ϕ	Single Fluid* (Gas)
II	Horizontal well Induced fracture	Fluid Expansion	Linear Flow	Single ϕ	Single Fluid (Gas)
III	Conventional Tight	Fluid Expansion	Radial Flow	Dual ϕ	Single Fluid (Gas)
IV	Horizontal well Induced fracture	Fluid Expansion	Linear Flow	Dual ϕ	Single Fluid (Gas)
V	Conventional	Water-Drive	Radial Flow	Single ϕ	Two Fluids (Gas & Water)
VI	Coal/Shale	Diffusion/ Desorption	Radial Flow	Dual ϕ	1 or 2 Fluids Gas or Water/Gas)
VII	Hydrates	Dissociation	Linear Flow	Single ϕ	Two Fluids (Gas & Water) Plus Hydrate
*Geopressured aquifers are analyzed using Module I, except the mobile phase is water.					

Figure 3 - GSAM Type Curve Models

It is inappropriate for a systems model to evaluate individual technologies (e.g., packer types, specific proppants, tubing, drill bits). GSAM is intended to provide insights and general guidance for R&D planning, leaving decisions about specific projects and priorities to METC R&D managers. Therefore, GSAM represents technologies as groups of hardware or processes with a common impact on both reservoir or cost performance, areas subject to a common focus of R&D. GSAM defines five major categories of technology:

- Exploration
- Reservoir Characterization
- Drilling
- Completion
- Production.

Within these categories are 16 subcategories (e.g., Drilling is divided into structures, equipment, fluids and orientation). The GSAM user specifies technology performance parameters for each subcategory for each resource type to be evaluated. Parameters are derived from field studies of existing technology effectiveness or detailed technology process simulations. Figure 4 shows a radial gas flow equation and provides examples of the parameters that might be used to represent changes in technologies or operator practices.

$$q = \frac{0.703\ kh\ (P_c^2 - P_{wf}^2)}{T\ \mu\ z \left[\ln \frac{(r_e)}{(r_w)} - 0.75 + s + D_{q_s} \right]}$$

Technology Performance Parameters	Example Technologies Represented by Parameter
h (net pay)	Formation evaluation, multiple completions, horizontal well
P_{wf} (flowing pressure)	Production practices, compression
r_e (drainage radius)	Well spacing, infill drilling
r_w (wellbore radius)	Slimhole drilling, cavity completions
s (skin)	Formation damage, completion/stimulation, effects, condensate blockage, well placement
D_{q_s} (rate dependent skin)	Wellbore configuration, completion design,production practices

Figure 4 - Representation of Technology Performance

Reservoir Development

Operators decide how to develop a reservoir based on geologic characteristics, available technology and current gas markets. GSAM models each of these factors.

Reservoirs are typically delineated to some traditional average spacing to minimize interference. A plateau production rate from the initial wells is established that optimizes reservoir economics and accommodates field or state rules.

When deliverability can no longer be maintained, the producer evaluates additional development options, including:

- Deplete initial wells
- Recomplete/stimulate initial wells
- Infill (one or more times)
- Combinations of the above.

Valuable information obtained from initial development about the distribution of reservoir properties creates the potential to high-grade additional development. To model this, GSAM separately evaluates additional development for "pay grades" of different reservoir quality. This feature represents the benefits of R&D to improve the accuracy of reservoir diagnostics and geological modeling.

In addition to available technology, costs and markets, additional development decisions are also influenced by the stage of reservoir depletion. GSAM evaluates the technical performance and costs of more than 50 additional development scenarios for each reservoir. Figure 5 shows the potential options available to an operator. Figure 6 shows the potential impact on production of some of these options.

Economic Evaluation

Detailed technology evaluation requires corresponding detail in costing. GSAM costs each characterized technology at the AFE level to determine whether its marginal contribution to reservoir performance justifies its marginal cost. Costs are derived from published sources and supplemented by vendor quotes. A discounted cash flow model is used to fully evaluate projects on an industry standard basis (i.e., pro forma project analysis, including state-specific and federal taxes and any incentives).

Exploration

GSAM models exploration based on expected value of discoveries for drilling in a play or group of plays. Because it is based on extension of past trends, the traditional discovery process method (originally developed by Arps and enhanced by Kaufman and others) is inappropriate to quantify the effects of specific exploration technology advances for a given geological setting.

GSAM is developing an alternative exploration evaluation method that estimates discoveries as a function of the interaction of geological character of the remaining resource base in a play and the resolution and accuracy of the geophysical data acquisition technology being evaluated. Some systems models increase the "artifact" of improved technology (e.g., lower dry hole rates) without accounting for the efficiency limits of the technology. This new method, largely made possible by the availability of detailed play- and size class-specific reservoir characterizations, will make it possible to estimate how long a technology improvement is likely to increase finding or success rates in a given play. Further development and calibration of this method have been deferred until Phase II, when detailed reservoir and exploration data are available.

Treatment of Uncertainty

There are inherent uncertainties in both resource description and extraction technology performance. In some cases, uncertainty reduction may influence operator decisionmaking and increase gas recovery more than technology efficiency improvements.

GSAM has been structured to address all types of uncertainty through one of several statistical techniques. Uncertainties that GSAM can evaluate include those outside of the scope of METC's Natural Gas R&D program (e.g., weather, oil prices). These are important to evaluate because, although not under METC control, they have major implications for the effectiveness of its Natural Gas R&D program success. Other types of uncertainty (e.g., technology process performance, resource characterization, information transfer) can be reduced by directed METC R&D efforts. Evaluation of uncertainty will a major focus of Phase II.

Other Gas Supplies

Other natural gas supplies are estimated at one of several levels of detail:

- Associated-dissolved gas production currently is derived exogenously from DOE's Tertiary Oil Information System (TORIS) and Crude Oil Policy Model (COPM), using technology, macroeconomic and cost assumptions comparable to those used in GSAM. Phase II efforts will provide more integrated estimation of nonassociated and A/D gas.

- LNG is estimated in Phase I as the gradual increase in throughput at existing terminals until current capacity is reached.

- Canadian and frontier resources will be evaluated by the same reservoir method as for the Lower-48, contingent on the availability of detailed reservoir and resource data.

- Synthetic gas sources will be included in Phase II.

Technology Path*		Current-Current		Current-Advanced		Advanced-Advanced	
Development Window**		Open	Close	Open	Close	Open	Close
Pay Grade	Development Option						
1	Recomplete						
1	Infill						
1	Recomplete plus infill						
2	Recomplete						
2	Infill						
2	Recomplete plus infill						
3	Recomplete						
3	Infill						
3	Recomplete plus infill						

*Technology Path incorporates the variation in additional development potential as a function of the relative efficiency of previously applied technologies.
**Development window indicates earliest time (at plateau break) and latest time (economic limit of initial wells) an operator would recomplete or infill.

Figure 5 - Additional Reservoir Development Options

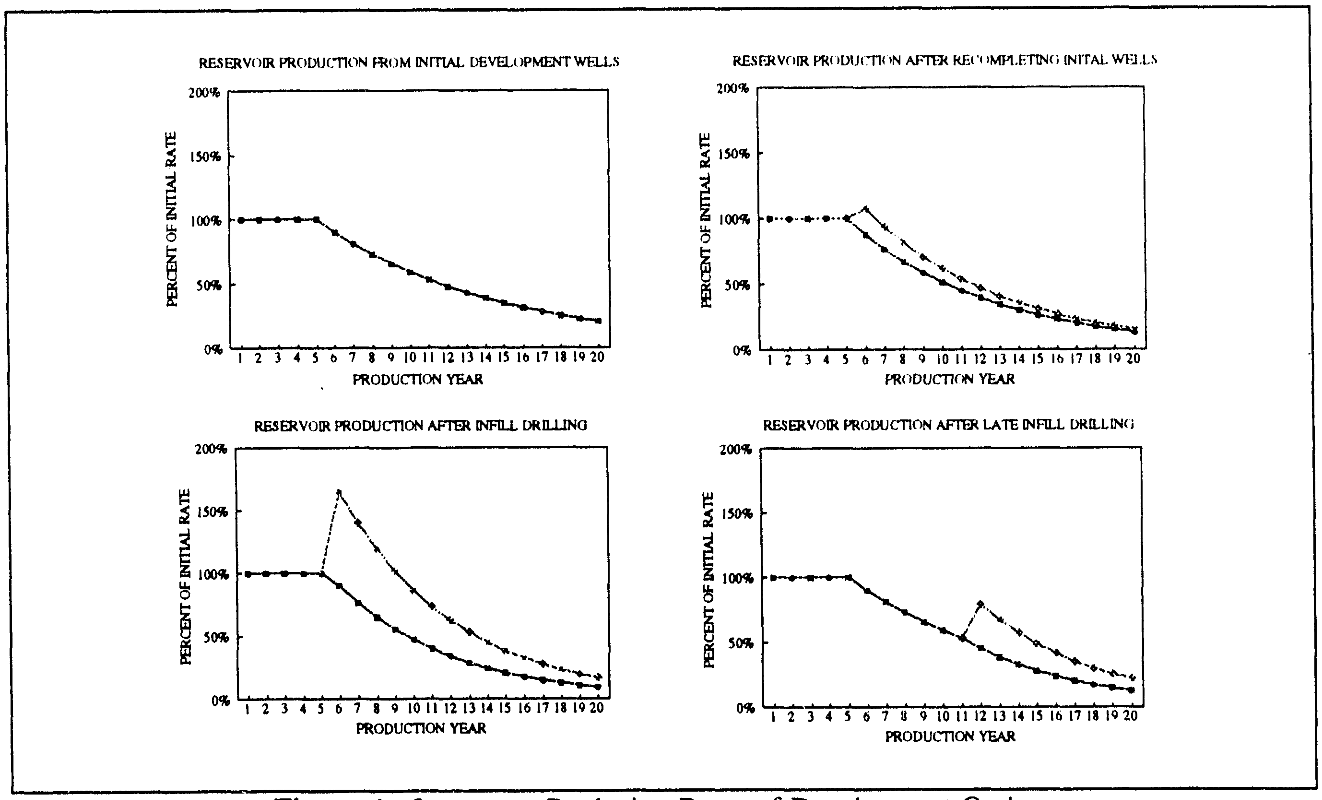

Figure 6 - Impact on Producing Rates of Development Options

Technology Transfer

Advanced technologies must make it into the marketplace to affect gas production or costs. Regardless of its technical merits, a technology R&D project should receive a low priority if market conditions, competing technologies or costs prevent its commercialization.

GSAM characterizes technology commercialization in terms of initial availability, rate of market penetration and market saturation. METC R&D can affect each of these factors, and GSAM can estimate the ability of specific technology transfer strategies to increase technology commercialization (Figure 7).

GSAM tracks the use of each technology by region, resource and over time. This provides the key data to determine whether a technology is likely to be a commercial success, separate from its technical efficiency. It may also identify technologies whose near-term high potential is largely eliminated by changing markets.

Downstream Module

The Downstream Module estimates gas and alternative fuel demand, storage and distribution capacities and costs, and adds transportation capacity as needed. These estimates are made at a more aggregate level (the demand region) than for the Upstream Module.

Downstream natural gas issues are currently a secondary focus of GSAM, but their impact on gas supplies and supply R&D could be significant. For example, the imposition of a carbon tax or emissions trading strategy would dramatically alter the volume and location of needed gas supplies. Widespread commercialization of gas cooling would alter seasonal gas demand, affecting storage needs.

An integrated gas systems model also benefits downstream R&D planning, including that pursued by METC. Fundamental understanding of the volumes and uncertainties of future domestic gas supplies provides the necessary context to evaluate effectiveness of downstream policies and technologies.

We briefly review the major downstream sectors: demand, transmission and storage, and distribution and seasonality.

Demand

Gas demand is modeled by end-use sector (e.g., residential, commercial, electric utility and industrial) for each of 14 demand regions. Transportation (e.g., natural gas vehicles) will be added as a fifth sector in Phase II.

Existing models and databases of gas demand and its drivers are incorporated into the Downstream Module. Models developed by the Electric Power Research Institute, EIA and ICF Resources are used to parameterize demand (e.g., boiler fuel demand). These models have been widely critiqued and were adapted with minimal enhancements for Phase I. Because of the importance of future gas demand for electric power generation, GSAM more explicitly models gas-powered utility generation. This structure allows GSAM to evaluate specific gas demand technologies, such as fuel cells or conversion to liquids.

GSAM also addresses interfuel competition and the impact of changes in "exogenous" factors such as weather, GNP, population growth and electricity demand.

Transmission and Storage

A detailed representation of the nation's gas transportation system is essential to estimate volumes and costs of future gas flows, especially as implementation of Order 636 is completed. GSAM models gas transmission from 26 supply regions and 14 demand regions, resulting in 71 transport links, each of which is characterized by directional capacity, costs and a sophisticated tariff structure (Figure 8).

GSAM endogenously evaluates and builds new pipeline capacity if it is the least-cost alternative to storage, interruption, supplemental peaking or customer-initiated fuel substitution.

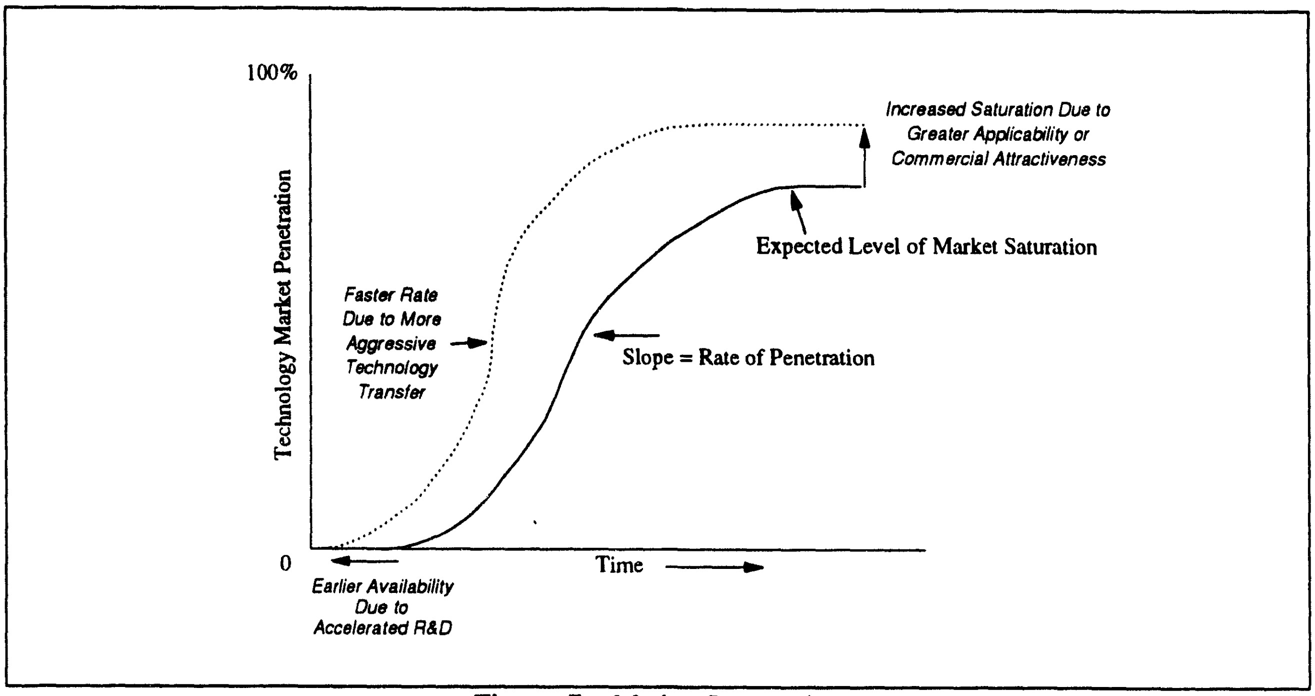

Figure 7 - Market Penetration

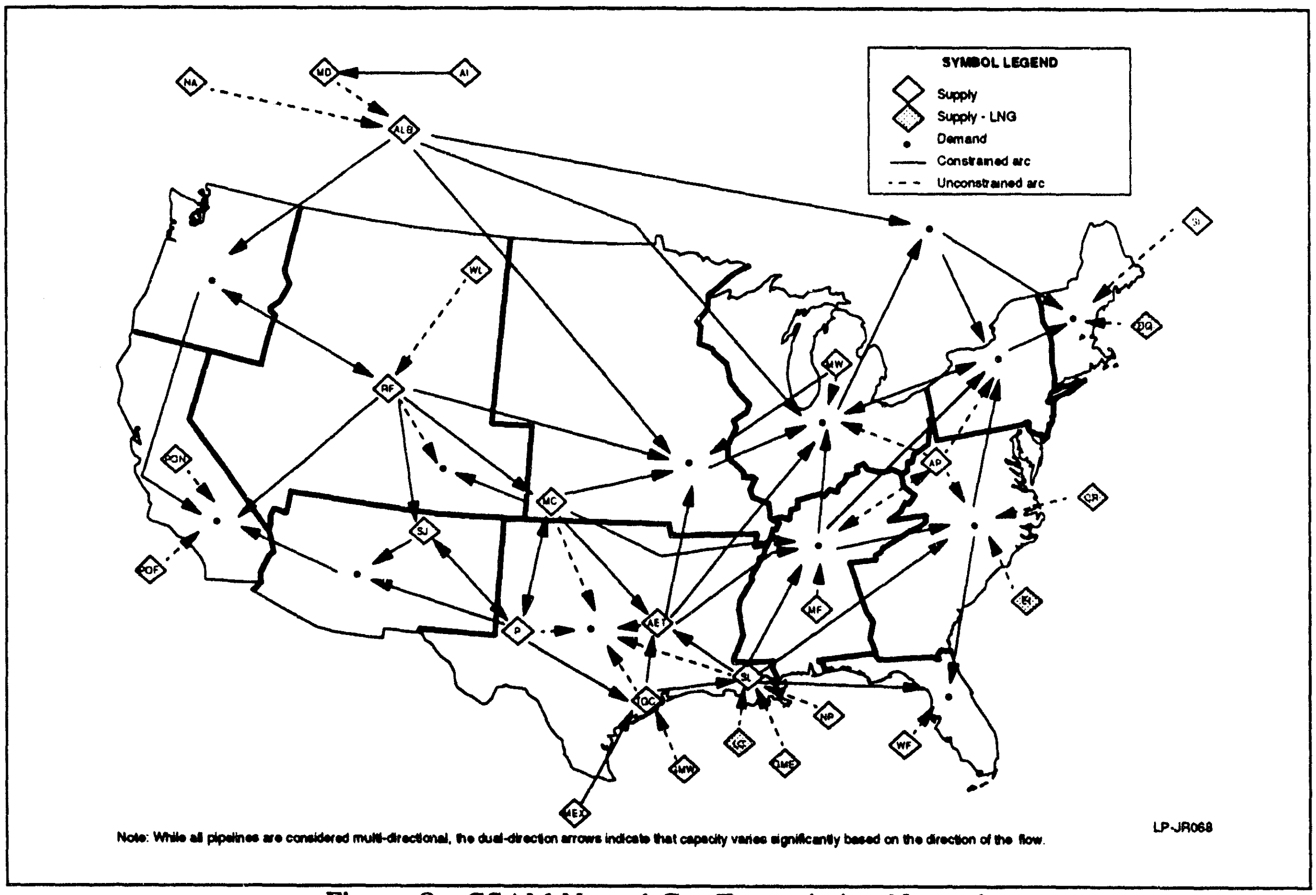

Figure 8 - GSAM Natural Gas Transmission Network

Distribution and Seasonality

Distribution costs represent a significant portion of overall delivered gas costs, thereby affecting purchaser decisionmaking. Since gas demand is highly seasonal, GSAM provides a disaggregated representation of seasonality, storage and distribution.

Load duration curves have been developed from current market studies and proprietary in-house utility planning models. GSAM evaluates the least cost method to supply demand from pipeline, customer storage, propane, LNG or interruption.

Integrating Module

The Integrating Module balances regional demand, transport capacity, and interfuel competition to maximize consumer and producer surplus. For the Upstream Module, it sets the capital and drilling infrastructure constraints that drive exploration and reservoir development decisions.

Integration is implemented through a linear programming optimization that equilibrates regional supply and demand on net gas prices. The model estimates the marginal value of supply to allocate capital and rigs.

Based on the characteristics of the rig fleet and current returns to capital, GSAM retires and adds to drilling infrastructure. Therefore, full and variable drilling costs are explicitly evaluated.

RESULTS

GSAM's disaggregated resource and technology characterization allows it to assess alternative federal natural gas R&D, tax, regulatory and environmental policy initiatives at a previously unavailable 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.

ICF Resources has developed a working prototype of GSAM and is now calibrating the model and data. We reviewed relevant natural gas upstream, downstream and market models 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.

We have developed databases for the gas resource base, engineering costs, exploration, pipeline capacity and volumes, alternative gas sources and gas utilization. Although an accurate reservoir-level database is not yet available, we have generated a synthetic reservoir-level database that broadly reflects the geological characteristics and volumes by region, depth and resource type. This database is being used to provide limited model testing and validation

Reports on our evaluations of Natural Gas Models, Natural Gas Technologies, and GSAM Model Design, will be available at the conclusion of Phase I.

Future Research Activities

Phase II of GSAM will focus on securing reservoir level data and enhancing high priority features. Once the model is validated, GSAM will be used to support DOE and others in technology R&D planning, resource assessment or policy analysis. Potential GSAM enhancements include:

- Enhanced representation of reservoir heterogeneity
- Incorporation of the costs of environmental damage and regulatory compliance
- Enhancement of exploration method to address applicability of specific seismic and survey technologies
- Evaluation of alternative exploration or production tax or royalty incentives
- Refinement of downstream components to address current environmental initiatives or market structure changes.
- Inclusion of downstream gas technologies or issues of concern to METC R&D managers.

DATE FILMED

3/11/94

END