METHODOLOGY DEVELOPMENT FOR THE GAS SYSTEMS ANALYSIS MODEL DRAFT TOPICAL REPORT

TASK 3

Prepared for:

Federal Energy Technology Center
U.S. Department of Energy

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TABLE OF CONTENTS

Page

Abstract iii

1. Methodology Overview and System Capabilities 1

II. Required Inputs 4

III. Upstream Model Methodology 7

Resource Module 11

Reservoir Performance Module 12

Current Resource Status 12

Exploration and Production Module 13

Production Accounting Module 13

IV. Environmental Module (EM) 15

Overview 15

Components and Operation 16

EM Activity Factor File 16
EM Base Waste File 16
EM Waste Management File 17
EM Scenario Assessment File 18
EM Post-Processor 18

V. Downstream Model Methodology 20

VI. Output 23

VII. Summary and Conclusions 24

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

Page

Figure 1 GSAM Structure 1
Figure 2 GSAM Market Logic Flow 3
Figure 3 GSAM Upstream Model Flowchart 7
Figure 4 Analysis of Natural Gas Resources by GSAM Analytical Modules and Databases 14
Figure 5 GSAM's Environmental Module 17
Figure 6 GSAM Demand Model Flowchart 20
Figure 7 GSAM Transportation and Supply/Demand Region Map 22

LIST OF TABLES

Table 1 GSAM Natural Gas Resource Database Format 5
Table 2 GSAM Supply Model Components 9

ABSTRACT

This report provides an overview of the system structure and analytical design of the Gas Systems Analysis Model (GSAM). GSAM has been developed and designed to provide program planning and policy analysis details needed by decision-makers in the Department of Energy, Office of Fossil Energy (DOE/FE). The modular design of GSAM provides the capability to quickly and accurately answer key planning and policy questions concerning the future of the North American natural gas market. As described in this report, GSAM represents all aspects of the gas market from wellbore to burner-tip, assessing future exploration, development, production, transportation, and end-use issues from the point of view of potential investors.

GSAM development has been completed and additional work is underway to enhance and test its unique capabilities. It has been used by various federal offices in key evaluation of future natural gas potential, including metrics analyses of DOE/FE budget processes. Documentation is also being finalized to ensure that GSAM can continue to be enhanced and used in various research and development (R&D) development and planning activities within DOE.

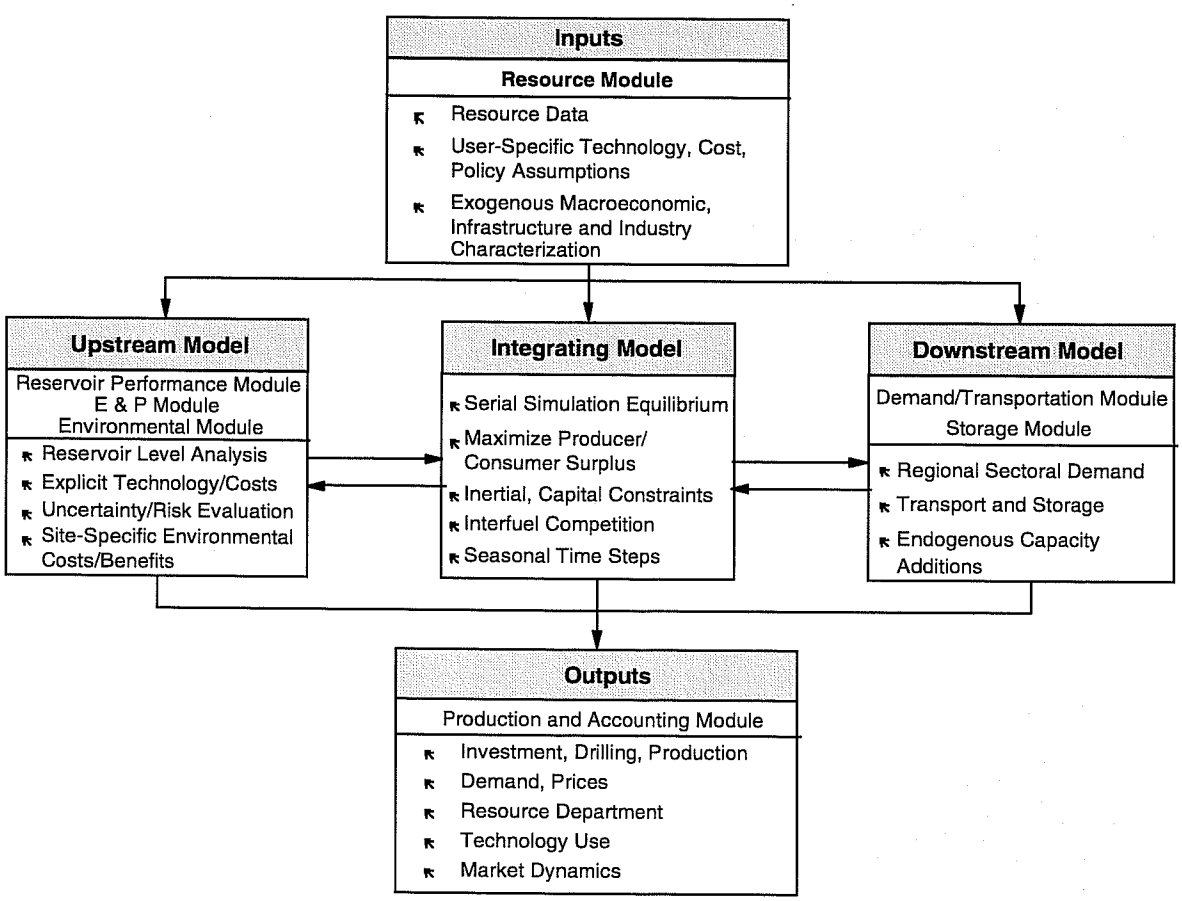
The value of GSAM derives from it ability to evaluate, in a market context, the resource base, operator decisionmaking, and technology impacts at the level of individual reservoir, each with unique physical and economic properties. By incorporating the full market view and appropriately linking to other available models and databases, GSAM will provide unequaled capabilities in assessing domestic natural gas resource potential. This design was specifically created to provide critical insights in planning, focusing, and assessing the success of DOE's resource and natural gas research, development and demonstration activities. This should add planners and managers in maximizing the benefits of specific R&D to the gas industry in the United States.

1. 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 1 provides a schematic overview of GSAM's major analytical components. Each of these six GSAM components is summarized later in this report.

The domestic gas resource is large, diverse, and widely dispersed, both geologically and geographically. Exploration and production (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

Figure 1
GSAM Structure



resource. To fully meet its objective and assist DOE research and development (R&D) managers, GSAM must consistently address both conventional and unconventional gas resources and the many processes used to find, extract, process, transport, store, and utilize natural gas. Despite their disparate nature, conventional, offshore, tight, Devonian shale, coalbed methane, and subquality gas resources share common production obstacles. Resource data used in GSAM describes and models each of these resources in a consistent, yet comprehensive manner. Further, the various exploration, development, production, and processing activities within and across various resources can also be evaluated in a consistent analytical framework. This comprehensive scope and model structure, focused directly on assessing the needs and resulting benefits of gas R&D, is crucial to meeting GSAM's objective.

To maximize both validity and credibility, GSAM's 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 an operator uses in the field to select projects. Additionally, transportation and demand decision are modeled from the viewpoint of the appropriate decisionmaker, each attempting to maximize fully-risked profit in a market context.

GSAM integrates these discrete decisions into a market framework. Investment decisions over time must be justified 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 given region) must justify not only its 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 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 decision. This comprehensive market framework ensures that the estimated impacts of R&D on E&P activities appropriately and credibly reflect market realities. Because FETC products must commercially succeed, this framework finally

II. REQUIRED INPUTS

Since model results are only as useful as the data on which they are based, the GSAM methodology places a high priority on using validated information on domestic natural gas resources. The GSAM methodology relies on accurate and available resource descriptions, at the level of individual reservoirs. As shown in Table 1, each reservoir has been explicitly characterized by rock and fluid properties, depth, pressure, and temperature, as well as resource type, play, location, and current development status. These data, plus carefully selected defaults when required, are used to evaluate the productivity and costs of each reservoir for a set of alternative technologies and policy scenarios. By being able to evaluate known reservoirs, GSAM's comprehensive characterization of the domestic resource provides a credible basis for numerous and varied policy analyses.

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

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

Finally, macroeconomic variables, infrastructure constraints and costs, and gas industry characterizations are required to fully represent the market within which investment decisions are made. These market parameters strongly affect investments in new gas supplies, as well as end-use demand, by imposing realistic limits on regional supplies and inter-regional transportation volumes. These

downstream factors are being derived from historic industry practices and adjusted for fundamental changes in industry structure and recent regulations. Explicit modeling of the full structure of the gas market, consistent with plausible inertial constraints on shifts in capital and infrastructure, expands the credibility of GSAM for both upstream and downstream assessments.

Table 1. GSAM Natural Gas Resource Database Format

Variable ID	Variable Name	Symbol	Units	Description	Format	Notes
RD1000	GSAMID	none	none	unique GSAM ID reservoir code	8 I	include compressed ID codes
RD1010	SOURCE	none	none	source reservoir code	8 I	validation/update reference
RD1020	FLDNAM	none	none	field name	30 A	EIA Master List
RD1030	EIACOD	none	none	EIA field code	10 I	EIA Master List
RD1040	RSVNAM	none	none	reservoir name	30 A	EIA or state
RD1050	STATE	none	none	state	2 A	2 digit API code
RD1060	COUNTY	none	none	county name	3 A	3 digit API code
RD1070	PLYCOD	none	none	play code	4 I	NRG or GASIS play codes
RD1090	BSNCOD	none	none	basin code	3 I	PGC, USGS code
RD1130	GSAMSR	none	none	GSAM supply region	4 I	26 supply regions
RD1140	STATIN	none	code	initial development status	1 I	0 = undiscovered; 1 = disc/undevt; 2 = producing/partially developed; 3 = init devt complete; 4 = fully devt; 9 = abandoned
RD1150	LATLON	none	degr, min, sec	lat/long of reservoir centroid	15 I	DDDMMSS-DDDMMSS
RD1160	DEPCLS	none	none	depositional class	3 I	adapted from DOE oil classes
RD2000	RESCOD	none	code	resource type	2 I	1 = unconsolidated SS; 2 = consolidated SS; 3 = carbonate; 4 = coal; 5 = shale; 6 = hydrate
RD2010	TRAPTY	none	dimensionless	trap type	1 I	dominant trapping mechanism
RD2020	DRIVE	none	code	dominant drive type	1 I	1 = pressure depletion; 2 = water drive; 3 = desorption/depletion
RD2030	DEPTH	D	feet	depth	6.0 F	depth to top of formation
RD2040	GRSPAY	H	feet	gross pay thickness	4 I	gross formation interval
RD2050	NETPAY	h	feet	total net pay in designated formation	6.1 F	total net pay in designated formation
RD2060	PAYDSP	none	dimensionless	pay dispersion	3.1 F	concentration of net pay across gross interval
RD2070	WELDRN	A_d	acres	well drainage area	5.0 F	minimum of drainage area or well spacing
RD2085	PERHOR	k_h	md	horizontal permeability	10.4 F	indicate source of measure (core, log, DST)
RD2090	PERVRT	k_v	md	vertical permeability	4.2 F	k_v:k_h default at 0.3
RD2120	POROST	N	fraction	total porosity	6.4 F	bulk porosity, including fracture porosity
RD2140	WATSAT	S_{wi}	fraction	initial water saturation	6.4 F	indicate source and whether total liquids

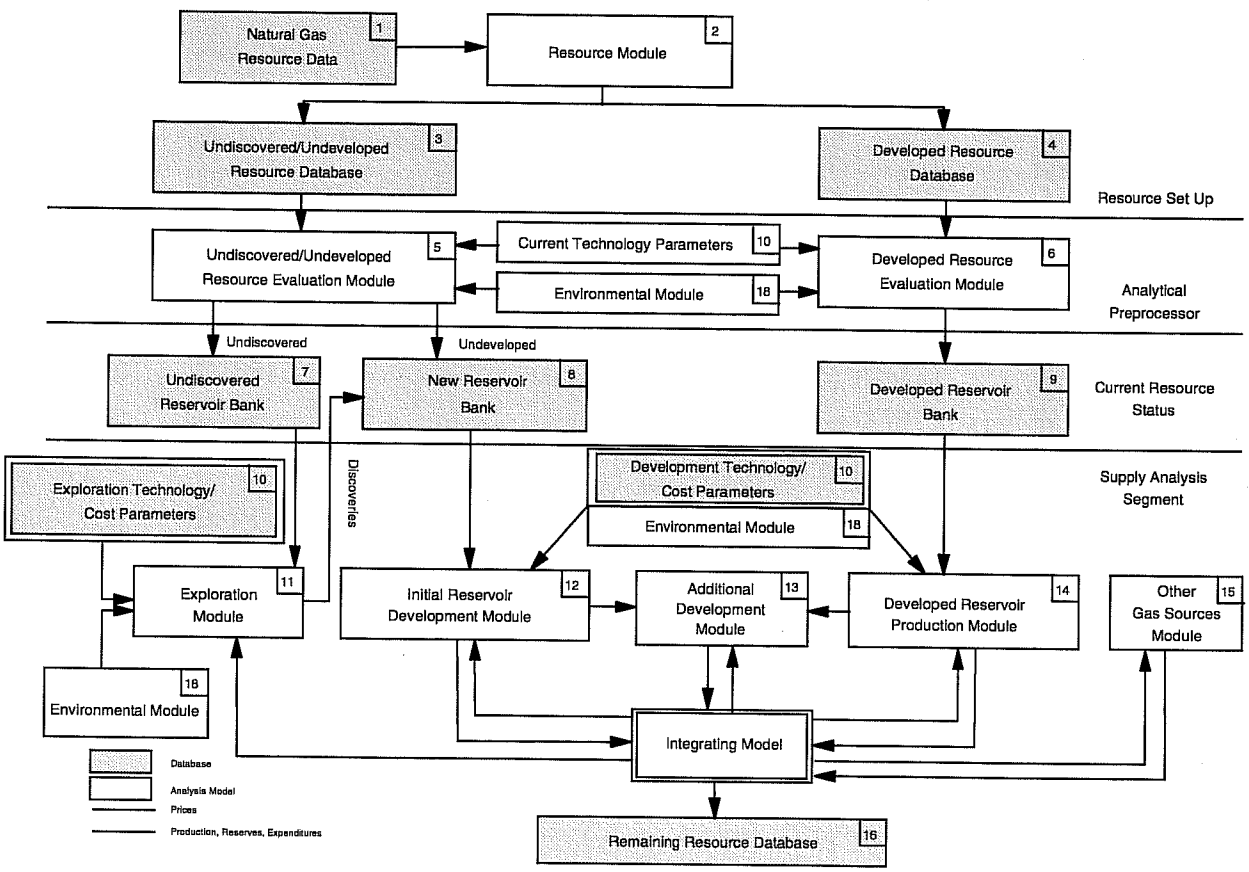
Table 1. GSAM Natural Gas Resource Database Format (continued)

Variable ID	Variable Name	Symbol	Units	Description	Format	Notes
RD2160	PRESIN	P_i	psia	initial reservoir pressure	7.1 F	indicate gradient or measured
RD2170	GASGRV	(	air=1.0	specific gravity of dry gas	6.4 F	indicate source
RD2180	BHTEMP	T	EF	bottomhole temperature	3 I	correct from logs as needed
RD2200	HEATVL	H	btus/scf	heating value	5.0 F	default from gravity, composition data
RD2210	CO2	CO_2	fraction	CO_2 concentration	6.4 F	
RD2220	N2	N_2	fraction	N_2 concentration	6.4 F	
RD2230	H2S	H_2S	fraction	H_2S concentration	6.4 F	
RD2250	WELRAD	r_w	feet	wellbore radius	5.3 F	0.354 in (except slimhole, cavity completion)
RD2290	CHLCON	none	ppm	Cl concentration of produced water	7 I	default at regional average, depositional type
RD2330	FRACSP	L_f	feet	natural fracture spacing	6.2 F	default for lithology
RD2490	PERTYP	none	code	permeability type	1 I	matrix, fracture, or total
RD2500	FRACW	none	inches	natural fracture width	5.3 F	core or history match
RD2510	PORTYP	none	code	porosity type	1 I	matrix, fracture, or total
RD2520	H20RST	none	ohm-meter	water resistivity	5.2 F	
RD2530	TEMRST	none	NF	temperature of resist. measurement	3 I	
RD3000	DISCYR	none	year	date of reservoir discovery	4 I	
RD3010	DISCME	none	code	discovery method	1 I	establish codes
RD3020	SGDVYR	none	year	date of significant development start	4 I	active drilling and production
RD3030	DOMOPR	none	code	dominant operator code 1992	3 I	1 = independents; 2 = integrated;3 = other
RD3040	WLSPAC	none	acres/well	well spacing (current field rule)	8.1 F	per state proration records
RD3050	ACPROV	none	acres	maximum proved area	8.1 F	indicate actual or derived from wells*spacing
RD3060	ACPRVD	none	year	date of proved area estimate	4 I	
RD3070	ACDV92	none	acres	reservoir developed area EOY 1997	6 I	or date used for history match
RD3100	CGPR92	Q	Bcf	cumulative gas prod. EOY 1997	7.3 F	
RD3110	GRSV92	none	Bcf	proved gas reserves (1997)	4 I	document adjustments to public records
RD3180	GWR92	none	MMcf/bbl	1992 gas-water ratio	7.3 F	trend/avg may be more relevant than 1992
RD3190	PRESC	P_c	psia	current bottomhole shutin pressure	4 I	indicate if WHSIP adjusted to BHP
RD3210	PWFCUR	P_{wf}	psia	bottomhole flowing pressure	7.1 F	tie to production data
RD3230	PRORAT	none	(% of AOF)	regul rate constraint/proration limit	2 I	per state regulation
RD3242	GPRDXX	none	Bcf/yr	82-97 gas production	11 @ 6.1 F	
RD3262	OPRDXX	none	Mbbl/yr	82-97 oil production	11 @ 6.1 F	
RD3282	LPRDXX	none	Mbbl/yr	82-97 NGL production	11 @ 6.1 F	
RD3302	TWELXX	none	#	82-97 total wells	11 @ 6 I	
RD3322	PWELXX	none	#	82-97 producing wells	11 @ 6 I	
RD3342	STWL92	none	#	82-97 shutin wells	11 @ 6 I	
RD3380	PRSGTH	P_{sys}	psia	gathering system pressure	4 I	regional average or per reservoir type
RD3390	PZSLOPE	none	psia/Mmcf	P/Z slope	4 I	to be used as calibration of reservoir model

III. UPSTREAM MODEL METHODOLOGY

The consistent evaluation of gas supply under alternative economic, technology, and regulatory conditions is a key objective of GSAM. Figure 3 provides a detailed view of the framework of eight databases and eight analytical modules comprising the logic flow of the Upstream Model. The Environmental module is shown separately, but is an integral part of the upstream modeling and data in GSAM. The integrated, modular design of data and analytical procedures maximizes flexibility in organizing, designing, 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.

Figure 3
GSAM Upstream Model Flowchart



The remainder of this section provides an overview of the upstream model design and logic. Table 2 summarizes each of the analytical modules and databases. The upstream model is grouped into five functions:

- *Resource.* Available resource, play, and reservoir data are transformed into fully characterized distributions of known and undiscovered reservoir units.
- *Reservoir Performance.* All reservoirs are fully evaluated for alternative technology, economic, and policy scenarios.
- *Current Resources Status.* Characterizes the current and potential productivity and economics of each reservoir.
- *Exploration and Production.* In response to market signals generated by the GSAM Integrating Model, allocates exploration, development, and production activity over the forecast period.
- *Production Accounting.* This segment reconstructs the full project revenues, investments, costs, taxes, and profits for all projects developed under the E&P analysis segment.

Table 2 provides descriptions of the individual modules and databases that comprise the entire Upstream Model. The four functional segments are discussed below.

Table 2
GSAM Supply Model Components

1. Natural Gas Resource Data - Contains raw data on reservoir rock and fluid properties, production, reserves, and development. (NRG probable principal initial source, long-term GASIS)

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 Known 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 geological play. This database would describe about 12,000 typical undiscovered reservoirs (900 plays with 13 size classes per play).

4. Developed Resource Database - Same format as the Undiscovered Resource Database, but emphasizes data on current development/production status to define alternative future development options. This database will include an additional, composite reservoir for each play representing all known reservoirs that are not identified in the database. These pseudo-reservoirs will be needed to tie model results to booked reserve estimates and current/historic production levels.

5. Undiscovered/Undeveloped Reservoir Performance 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 well configurations characterized by a distribution of those reservoir properties that affect storage and deliverability or other reservoir engineering components. The property distributions, defined by the appropriate play type and results for the average well by pay grade, will be consolidated into reservoir average production potential and economic values. Production profiles for initial development wells will be stored for use in the analysis modules. Minimum acceptable supply prices (MASP) for exploration, development, continued development, and continued operation will be calculated and required elements stored for use.

6. Development Reservoir Performance 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 fully developed to wide spacing, partially infilled, or beyond infill potential (approaching abandonment). Reservoirs are characterized based on current development status and incremental economics to continue current production and implement all possible additional development options. Fully characterized reservoirs are passed to the Known 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 drops in 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 oil fields). The file also contains economic analysis results including capital, drilling, and sunk cost-basis required wellhead gas prices, indices to typical reservoir production profiles, and other data used to select newly discovered reservoirs for initial development. Reservoirs discovered by new field wildcats are aggregated in the bank by size class and play (roughly a 13 size class by 900 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."

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

Table 2
GSAM Supply Model Components (continued)

and economics for alternative additional development options. Unlike the New Reservoir Bank that has "deposits" from the exploration module, Known Reservoirs are only "deposited" once, at the beginning of the GSAM run. However, they are "withdrawn" rather rapidly since this bank feeds the Known Reservoir Production Module, which implements ongoing development plans, and are passed to the Additional Development Module.

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 based on geological appraisals of typical reservoirs in several generic play "types" (to be defined, but broadly based on lithology, depositional environment, or other gross factors that would significantly influence well-to-well distribution of reservoir properties). The technology assumptions used impact both the preprocessing modules, as well as the Exploration, Initial Development, Known Production, and Additional Development Modules. Technology advances can be modeled as either improved performance, reflected in higher volumes of gas production as predicted from type-curve analysis, improved economics, lower costs or accelerated production, or some combination.

11. Exploration Module - Part of the Exploration and Production 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. 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) (re)stimulation. Development options are based on data supplied by the Known/Undiscovered Resource Evaluation Modules. Since the combination of changing wellhead gas prices, technology availability, and reservoir depletion could change development option economics every year, options are evaluated at the earliest and latest possible years they are likely to be economic. Although interpolation for years between these limits will be based on simplified algorithms tied to reservoir properties and technology scenarios, preliminary examination suggests linear interpolation is adequate. This module implicitly contains an "additional reservoir development bank" that is similar in format and operation to the New/Known Reservoir Banks, but contains only those development options that are available at the 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, eliminating the possibility of a currently economic reservoir "waiting" for advance technology or better prices.

13. Initial Reservoir Development Module - Part of the Exploration and Production 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 [some small economic prospects are developed because that is all an operator has to develop]). This module also handles major GSAM bookkeeping functions of vintaging production, capital expenses, and drilling.

Table 2
GSAM Supply Model Components (continued)

14. Developed Reservoir Production Module - Part of the Exploration and Production "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, Canadian imports, ANGST, and other potentially important or emerging sources of gas used to meet growing demand.

16. Production Accounting Module - Reconstructs full net cashflow evaluations for individual reservoirs and investment decisions , aggregates results at the play , state, region, and national levels, as required.

17. Remaining Resource Database - Repository for unproduced gas resource. Data on resource and marginal costs of next producible block of gas stored for future analysis and research focus. 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.).

18. Environmental Model - This module estimates the incremental unit capital and O&M costs of complying with the user-specified regulatory or technology scenario under consideration. The scenario can reflect either the potential incremental costs associated with more stringent environmental regulations and controls imposed in the future or potential cost savings/efficiency improvements resulting from control technology performance enhancements. It uses locational, operational and environmental data at the reservoir level to characterize E&P waste sources in the natural gas field. Four sub-files calculate waste source population, baseline waste volume, associated scenario compliance costs and associated scenario waste volume reductions. EM then provides the Exploration & Production Module with a set of $/well incremental environmental tangible and intangible capital and O&M costs which are used to calculate the Minimum Acceptable Supply Price. A fifth EM subfile uses GSAM-processed forecast output to estimate waste volume and associated costs over a given time period. To the extent that sufficient risk-based analyses exist, associated scenario benefits can also be modeled for given environmental issues.

Resource Module

All available raw resource data (Box 1) are incorporated into a resource module (Box 2) to be processed, analyzed, and validated into full reservoir descriptions. The module consists of more than simple screens, instead using the distribution of properties within plays to confirm information and estimate missing data. The full characterization of known producing, discovered but undeveloped, and undiscovered reservoirs in the United States also draws on resource assessments available from USGS and MMS (including data from the current national assessment of undiscovered gas resources), and other private and public sources. Additional segments of these modules check for data consistency among reservoirs within plays by size and depth. This evaluation allows data default values to be determined and appropriately incorporated where reservoir data are inconsistent or missing. The completed reservoir

descriptions are stored in one database for undiscovered/undeveloped reservoirs (Box 3) and another database for reservoirs for which initial development and significant production have occurred (Box 4).

Reservoir Performance Module

The number of full, individual, technical, and economic reservoir evaluations required to fully characterize alternative resource, technology, and policy scenarios exceeds 100,000 from most analyses. Therefore, preprocessed evaluations improve the speed and flexibility of GSAM to analyze the natural gas resource and the domestic gas marketplace over a 40 year time period. The Reservoir Performance Module estimates initial production and conducts economic analyses that are used later in the Upstream Model to sequence natural gas resource development. These modules incorporate reduced form reservoir models (type curves) that transform discrete reservoir properties and technology assumptions into reservoir development and production profiles and ultimate gas recovery. These estimates are evaluated using appropriate costs, specific taxes, and economic values to determine discounted net cashflows and project profitability. The economically optimum technology scenarios are flagged and reservoirs that are never likely to be economic are excluded from further analysis. This preprocessor refines the list of reservoirs to the minimum set appropriate for the scenario being analyzed. The preprocessor design feature allows numerous technology scenarios to be evaluated prior to the demand for rapid scenario analysis, vastly reducing the analysis turnaround time.

Current Resource Status

The Current Resource Status function consists of three reservoir banks generated by the Resource Evaluation modules. It provides a current description of the producibility and the relative economic viability and profitability of the undiscovered resource (Box 7), the probable contribution of reservoirs recently discovered and under development (Box 8), and known producing reservoirs (Box 9). The banks only contain economically viable reservoirs within the range of fiscal and technology scenarios being considered. The GSAM resource status will only be regenerated when significant shifts in technology, costs, or available reservoir data would significantly alter the character of the reservoir banks.

Exploration and Production Module

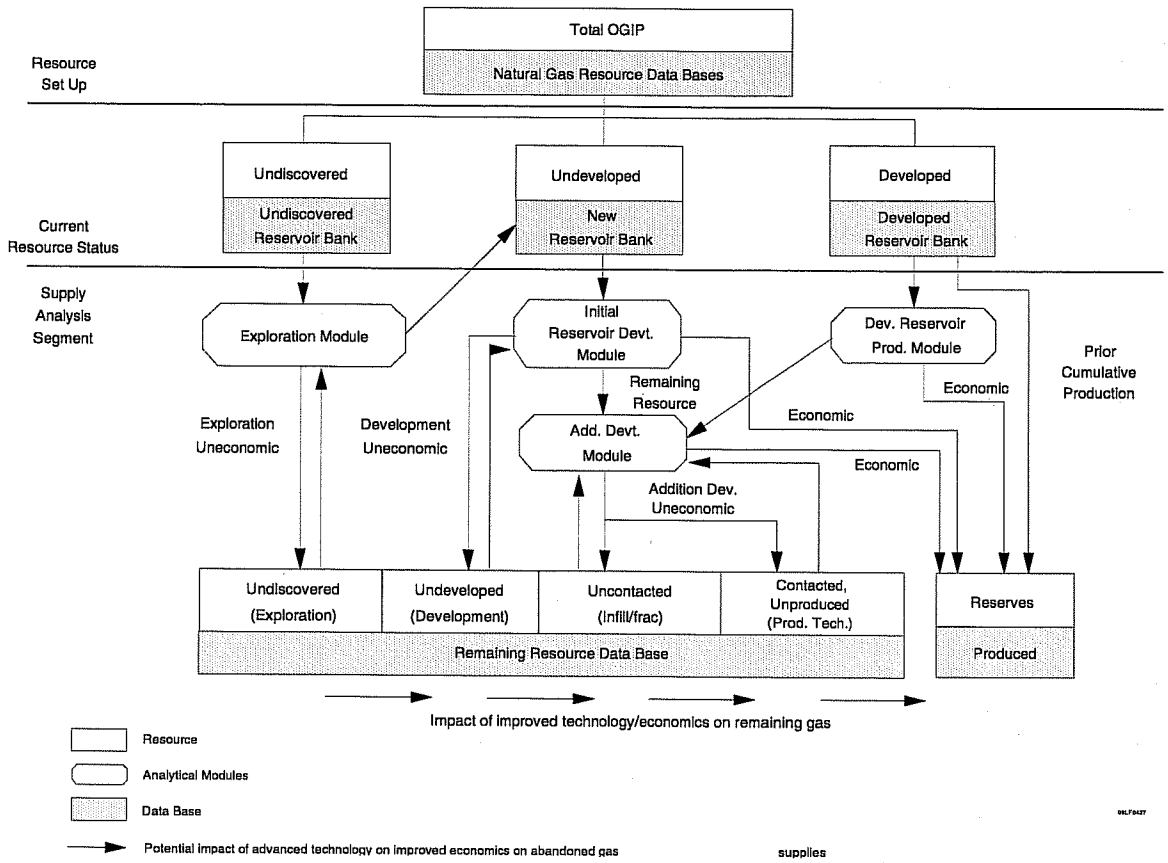
GSAM model decisionmaking for upstream investments is evaluated in five individual modules for exploration (Box 11), initial reservoir development (Box 12), production (Box 14), additional development (Box 13), and additional sources (Box 15; LNG, Canadian imports, and associated gas). These modules evaluate preprocessed, project-specific production and financial summary data against user-specified decision criteria for contemporary market conditions to determine the production from available reservoirs at projected gas price tracks. Again, the modules consider options from the viewpoint of the operator, deciding whether to implement or defer various investment opportunities. For example, the additional development module evaluates investment options for infill drilling or recompletion of initial development wells to maintain reservoir deliverability. The evaluations will be based on reservoir specific evaluations and consider the direct and secondary impacts of changing technology on future production, costs, and reservoir access. The potential for reductions in associated E&P risk are also modeled. A comprehensive discussion of the design structure for modeling technology improvements in GSAM is provided in GSAM Topical Report 1 (Review of Natural Gas Technologies).

Production Accounting Module

GSAM evaluations require a complete documentation of the economic outcomes in various individual reservoirs, geologic plays, states, regions, and for the nation as a whole. This accounting function is accomplished in the Production Accounting Module. This segment summarizes the individual investment decision for each reservoir in the database and reconstructs the full net cashflow based on the specific technology, cost, and market conditions developed in the previous modules. The comprehensive accounting of the revenues, investments, costs, tax deductions an payments, and operating profits allows analysis of the financial impacts of R&D development and policy alternatives within the gas industry. This evaluation tool also provides public sector benefits estimates based on realistic, specific state and national tax structures and their unique impacts on the future profit potential of each reservoir.

The GSAM design also emphasizes the importance of proper accounting of resources by describing, quantifying, and evaluating the remaining domestic gas resource (Box 16) 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 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

Figure 4
Analysis of Natural Gas Resources
by GSAM Analytical Modules and Databases



key physical or economic barriers to production. A key feature of GSAM is its ability to describe resources in terms of gas-in-place. Past reliance on recoverable gas as a unit of analysis has confounded the estimates of the impact of technology on reserve growth and increased recovery efficiency. As recently as the 1992 NPC Natural Gas Study, the inability to characterize gas resources in full volumetric terms compromised the validity of technology and market assessments. GSAM's resource tracking system provides a major advance in the ability to prioritize key R&D activities and overall program strategies.

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

IV. ENVIRONMENTAL MODULE (EM)

Overview

As the demand for natural gas continues its upward trend, the natural gas industry and regulatory community will focus increasingly on the potential environmental impacts of activities associated with the exploration and production of the resource. As a result, the Environmental Module (EM) of GSAM was developed to provide the capability to characterize the impact of changes in environmental regulations and advancements in waste control/mitigation technologies on industry operations as well as on total gas reserves, industry employment, public sector revenues, and, where sufficient data exist, on the environment.

EM can be used to evaluate the impacts of a wide range of possible future environmental regulations. Examples include more stringent requirements for the disposal of produced water and wastes from drilling activity; hazardous air pollutant controls for glycol dehydrators and other potential emission sources; remediation of hydrocarbon- and saltwater-contaminated soil at well sites; and liner installation requirements for reserve pits. In addition, enhancements to particular control technologies for reducing or managing wastes also can be modeled.

Specifically, EM provides the capability to assess how incremental costs of complying with future environmental regulations affect operator decisions to drill new wells, continue to operate existing wells, and, in turn, how these decisions affect natural gas supply and demand relationships. Additionally, EM estimates the baseline volume of waste (prior to the consideration of any new compliance requirements) generated by E&P activities, reductions in waste volumes as a result of the application of waste management controls/practices, the incremental costs for the new compliance requirements and controls, and finally, the cost-effectiveness (e.g., dollars per unit reduction in waste volume) of the controls in meeting the environmental regulation. EM develops these results at the reservoir level, state level, and nationally.

Where traditional national environmental cost impact studies generally use broadly aggregated data (e.g., at the national or regional level) to characterize waste volumes and cost impacts, EM follows GSAM's "bottom-up" reservoir-level framework. EM uses a significant amount of data that characterize the reservoir's geology, geography, and environment as well as the operational characteristics of E&P facilities located to enhance development and production of the reservoir. The data are drawn from a

variety of sources including state and county level environmental databases, pre-processed data on the relationships between reservoir production and gas processing activity, unit emissions factors (e.g., tons of pollutant emitted per operating unit) from existing industry models, and technology cost and performance data for waste management controls and practices. Through this reservoir-level approach, EM captures potentially significant variability in key factors (such as waste volume production, source and operator characteristics, and environmental-specific factors) that ultimately might lead to the uneven distribution of marginal costs and benefits of compliance across sources.

The resulting EM output also provides key information to support environmental R&D activities such as characterizing the range and magnitude of waste generated by natural gas E&P operations; assessing the impacts of changing environmental requirements on gas supply and price; estimating the cost-effectiveness of future environmental regulations; and, identifying and prioritizing R&D activities aimed at reducing the costs for waste management controls.

Components and Operation

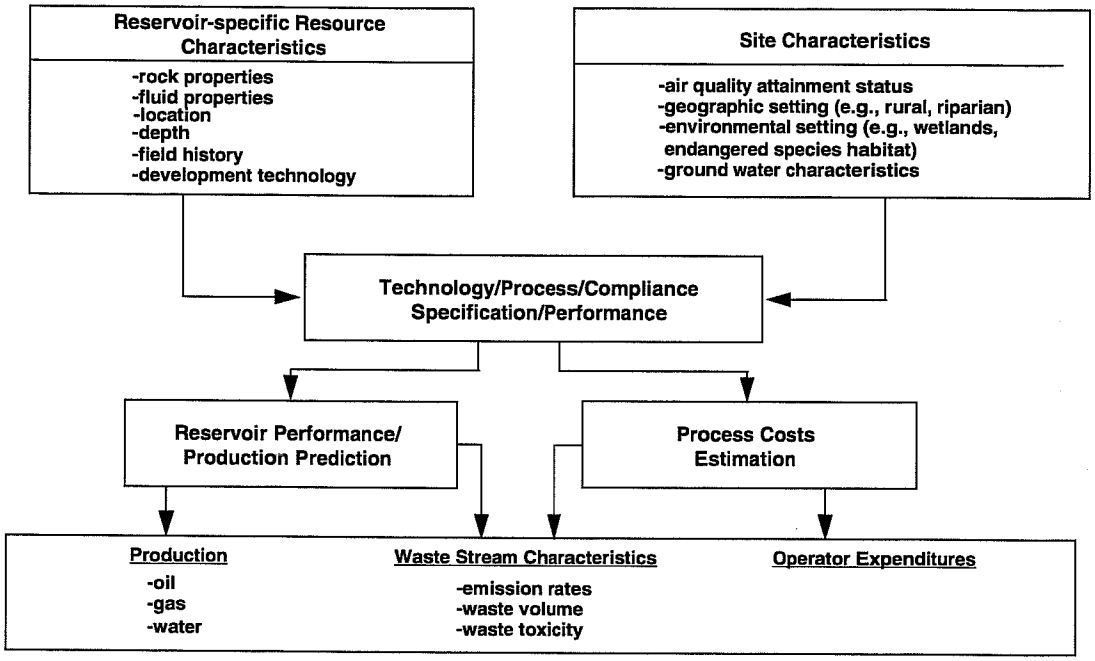
As shown in Figure 5, EM is composed of several files that interact with other GSAM modules (e.g., the Exploration and Production Module, Reservoir Performance Module, and Production Accounting Module) to develop cost impact, waste reduction, and cost-effectiveness estimates of possible future environmental regulatory or technology scenarios. A brief description of each file is provided below.

EM Activity Factor File

The Activity Factor File estimates the number of waste "sources" per reservoir producing waste that may be subject to future environmental regulatory requirements. Examples include existing and new production wells, glycol dehydrators, condensate storage tanks, compressors, and emergency and workover pits. Sources are characterized using reservoir-level data (e.g., throughput, surface pressure) and industry data (e.g., design capacity of storage tanks) in combination with engineering relationships and assumptions to develop the number of sources per reservoir. In certain cases, where data are limited, industry estimates are used in place of "bottom-up" estimates (derived from reservoir data, engineering relationships, and operator practices.)

EM Base Waste File

Figure 5
GSAM's Environmental Module



Once E&P waste sources/activities are characterized, baseline waste volumes are estimated for the sources using data on reservoir characteristics (e.g., reservoir depth, composition of natural gas); environmental characteristics associated with the source's location (e.g., proximity to wetland, aquifer bottom depth); operator-specific characteristics (e.g., use of drilling muds, use of flares on dehydrator condensers); and unit waste (e.g., emissions) factors. Waste volumes are estimated taking into account current waste management practices either as a result of industry standards or state regulatory programs that are more stringent than Federal standards.

EM Waste Management File

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

EM Scenario Assessment File

This file performs a series of capital and operation and maintenance (O&M) unit cost calculations per waste source, per well and per reservoir. These estimates reflect the incremental costs associated with complying with the specified regulatory or technology scenario. If the scenario does not specify the exact method of control, costs are calculated for the least-cost control option. For cases in which the implementation of a particular scenario would lead to controlling the waste stream rather than simply managing it, the reduction in waste can be estimated based on the efficiency of the control in preventing or mitigating waste volumes.

To assess the impact of a new environmental requirement on future reservoir development decisions (e.g., whether or not to drill new wells), the total incremental capital and O&M costs to implement the new requirement at the reservoir level would be expressed on a per well basis by dividing this total incremental cost by the relevant number of wells. This cost would be passed to GSAM's Exploration & Production Module and combined with costs for other factor inputs to estimate the Minimum Acceptable Supply Price (MASP), which is used to evaluate the economic viability of developing the resource over time.

EM Post-Processor

In addition to providing GSAM with incremental environmental compliance cost estimates, EM generates output that characterizes the cost-effectiveness of a particular scenario over GSAM's forecast period of time. To avoid potentially complex and time consuming iterations between EM and other parts of GSAM for each year over which the simulation is run, EM develops the unit incremental environmental cost based on the number of sources within a reservoir for a reference year -- defined as one year before the new environmental regulation would take effect. As a result, this unit cost (expressed in real terms) would remain constant over the time horizon of the simulation. This approach is believed to be reasonable because as reservoir production increases (decreases), the supporting natural gas E&P infrastructure -- which is potentially subject to environmental regulation -- also increases (decreases). For example, as more wells are drilled to increase the production level of a reservoir, it is likely that additional field gas processing capability will be needed, including additional dehydrators, condensate storage tanks, and compressors. Consequently, EM assumes that the ratio of cost to wells is not expected to vary significantly on average. This issue and its implications for the coupling between EM and other GSAM modules will be investigated in greater detail as EM undergoes further development and testing.

Once GSAM generates output results, EM would process this output, such as estimates of throughput and number of wells per reservoir, to develop, for each simulation year:

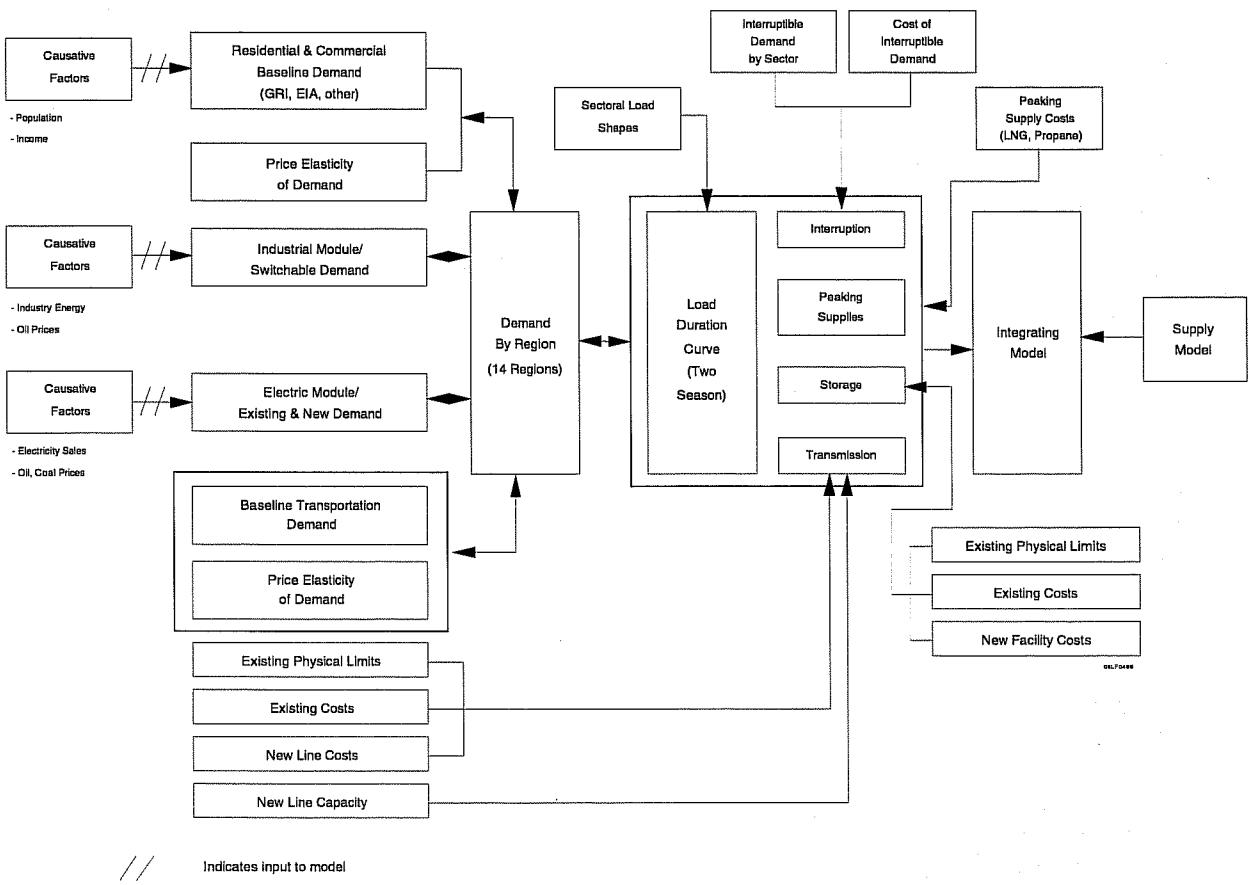
- Total incremental compliance costs;
- Baseline waste volumes and reduction in waste volumes, as applicable;
- The cost-effectiveness of the environmental regulation under consideration in reducing waste volumes.

From the reference year in which the scenario is set to take affect to 2030 (currently, the last forecast year in GSAM), these estimates would be provided for each applicable source/activity at the reservoir level, by state, and nationally. EM eventually combines information on human health and environmental risks and costs to provide a comprehensive assessment of the risk-cost and benefit-cost trade-offs of future environmental requirements under consideration.

V. 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 GSAM methodology and design 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 6 displays the logic and data flow of GSAM's proposed Demand and Integrity Module.

Figure 6
GSAM Demand Model Flowchart



Analysis of demand for natural gas includes regional assessment of consumption by sector and by season. The GSAM modeling system uses existing models of residential, commercial, industrial, and electric utility requirements for gas to determine demand within 15 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, and on gas prices, by modeling the decisions made by end-users in selecting the least-cost fuel. The methodology for assessing overall natural gas demand based on final market prices provides the most realistic assessment figure of demand and wellhead prices. It is consistent with most robust gas market models and provides for linkage with existing databases and models for calibration.

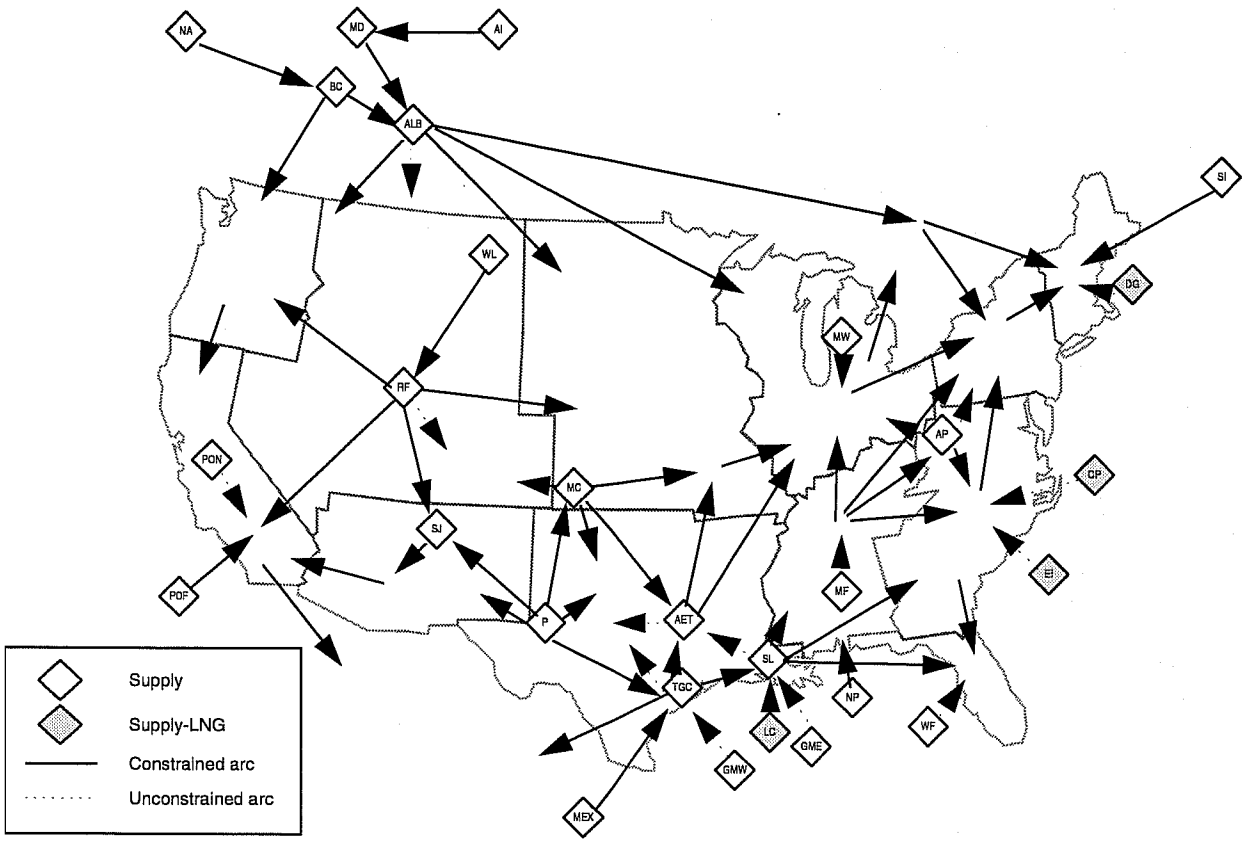
GSAM's downstream modeling methodology provides the breadth and depth of evaluation consistent with the role of GSAM in E&P policy and R&D planning and evaluation. This data can be used to determine the regional equilibration of supply and demand to provide realistic estimates of North American gas market performance.

Gas transportation and storage issues, among the most important issues targeted by DOE's *Domestic Natural Gas and Oil Initiative*, are also directly addressed in GSAM. The ability of existing infrastructure to cost-effectively move gas to market is modeled by GSAM as numerous transport links between supply and demand regions. In addition, the 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 an opportunity to evaluate storage reservoir performance and the need for additional capacity.

The Demand and Integrating Model of GSAM 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. Linear programming techniques solve for gas price and sales volumes against physical capacity and economic constraints among and within 26 supply regions, 15 demand regions, and over 70 transport links (Figure 7).

GSAM's 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.

Figure 7
GSAM Transportation and Supply/Demand Region Map



VI. OUTPUT

The results from the Demand and Integrating Model provide a verifiable and credible basis to forecast future gas supplies and prices, based on given user-specified E&P technology and policy assumptions and a comprehensive resource evaluation. 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 are structured to allow direct export for use by spreadsheets, databases, and graphics software. Spreadsheet data requirements provide a basis for the design, which are generic enough to allow translation for other software. The output format will ensure easy compatibility with other systems models and databases as well.

GSAM output includes significant detail on production, consumption, technology use, resource status, and gas price by region over time. Additional economic variables detailing operator-view economic pro forma, as well as public sector benefit analysis, can also be derived from GSAM reports generated by various modules. Additional information and flexible report formats are available at the analyst's discretion.

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

VII. SUMMARY AND CONCLUSIONS

This report provides a summary of GSAM development activity and documentation of overall system methodology. It supplements and expands on the progress reports previously completed for FETC.

The successful development of GSAM, consistent with the design and overall methodology, significantly improves FETC capabilities to realistically assess the future gas resource potential under a myriad of technology, economic, and regulatory scenarios. The power of GSAM as an R&D policy tool does not limit its direct application in other policy areas; GSAM should become the primary and most credible source for quantitative evaluation of the domestic gas resource. The comprehensive methodology, detailed design, and extensive output generated by GSAM maximizes its potential benefit to various policy-makers and analysts and provides a foundation on which to build additional analytical capabilities, such as for tax and environmental regulatory issues.

With its unique reservoir-level description of the diverse gas resource and detailed engineering-economic assessment modules, GSAM provides the ideal tool for evaluating various policy decisions and trade-offs in the FETC natural gas R&D program. As its capabilities continue to be verified, validated, and expanded through additional testing, peer review, and updating, GSAM can serve as an evolving repository for new data and directly improved evaluations of upstream and downstream aspects of domestic gas markets.