Purpose

GPCM® is RBAC's Natural Gas Market Forecasting System. Originally known as the Gas Pipeline Competition Model, GPCM is a combination software-database system, whose purpose is to enable its users to build models for analysis of natural gas economics, including the sectors of production, transportation, storage, marketing, and sales to distributors and other large customers. GPCM is the latest in a series of systems and models built by Dr. Robert Brooks from the mid-1970s through the present. Making use of the latest PC hardware, software technology and advanced computational algorithms, it enables analysts to do more at their desktop than has ever been possible in the past using mainframe computers with earlier, similar software tools.

Model Structure

Mathematically, GPCM® is a network model. It can be diagramed as a set of "nodes" and "arcs". Nodes represent production regions, pipeline zones and interconnects, storage facilities, delivery points, and customers or customer groups. The connections between these nodes are called "arcs". They represent transactions and flows. Some of these are supplier deliveries to pipelines, transportation across zones and from one zone to another, transfers of gas by one pipeline to another, delivery of gas into storage, storage of gas from one period to another, withdrawal of gas from storage, and pipeline deliveries of gas to customers.

Figure 1
Natural Gas Supply Basins and Major Market Hubs of the US and Canada

[Image of Natural Gas Supply Basins and Major Market Hubs of the US and Canada]

SOURCE: Global Velocity Suite
In general an arc has four input attributes and two output attributes. The inputs are cost (which may depend on transaction volume), a minimum, a maximum, and a loss factor (representing fuel use and miscellaneous losses). The outputs are the amount of the transaction (the flow) and the economic rent associated with the flow. The latter is defined mathematically as the economic value of a unit increase (decrease) in the upper (lower) bound. It generally applies to pipeline transportation and storage capacity and represents the marginal value of increased capacity. Figure 2 outlines a simplified GPCM network model.

Figure 2
Relatively Simple Representation of GPCM Network Model with Nodes and Arcs

The economic value of a solution to this problem is identified in economic theory to be the sum of producer and consumer surplus. These concepts are defined for price sensitive supplies and demands. We assume that each supply source and each customer has a well-defined supply or demand curve. The forms for these curves can be quite general. GPCM only requires the quantity to decrease with increasing price for demand curves and to increase with increasing price for supply curves.

The objective function for this "equilibrium" solution has been shown by Nobel Prize winning economist Paul Samuelson to consist of three terms: the integral of the demand price function...
over demand minus the integral of the supply price function over supply and minus the sum of
the transportation and storage costs. By dividing the applicable range of possible prices into a
number of small steps, we can approximate the integrals in the objective function by linear terms
of the form \( p \cdot \delta q \), where \( \delta q \) is the additional demand (or supply) resulting from the
small price change. Because of the form of the supply and demand functions and the objective
function, each of these terms will be brought into the solution in an economically sensible order to
produce an economically efficient. That is, the cheaper supplies will be used before more
expensive ones and the customers willing to pay more will be served before those willing to pay
less. Thus we are able to use a "linear programming" approach to solve a highly non-linear,
complex model of market clearing behavior in the natural gas industry.

**Transportation and Storage Tariff Structure**

In general, each transportation and storage transaction cost is parameterized by five values: a unit
demand charge, unit firm commodity charge, unit interruptible commodity charge, a "full
discount quantity" (FDQ) and a "zero discount quantity" (ZDQ). The cost model for such
transactions assumes that, for a price, some amount of the capacity could be reserved for certain
customers. The cost of such capacity reservations will be the unit demand charge times the
capacity reserved plus the unit firm commodity charge times the amount actually used. The cost
for interruptible service (interruptible commodity charge) will be lower on average than the total
cost for firm service, but higher than the firm commodity charge. The model says that if demand
for the capacity is higher than the ZDQ, the pipeline will be able to charge the full interruptible
rate for transportation. If not then it will have to discount. The amount of the discount in this
model is maximal when demand falls to FDQ or lower: then the price of transportation is equal to
the firm commodity charge. The discount declines linearly as demand increases from the FDQ up
to the ZDQ. For all demand greater than or equal to ZDQ, the price is the full interruptible
commodity charge, i.e. no discounting is required.

Storage (including LNG) transactions work the same way. There are three storage transactions:
injection, storage, and withdrawal. Injection and withdrawal have the structure just defined.
Storage has a simpler structure: a constant unit cost per period, which may be zero. The user may
model a situation where gas is transported to a storage location on one rate schedule, injected and
withdrawn under another, and delivered to another location under a third. The user may also
model a "bundled" structure involving movement from one location to the storage location and
then downstream to yet a third, all under the same rate structure. The following two figures
outline a generalized LNG supply source model and LNG import terminal model.
Figure 3
**LNG Supply Source Model**

- LNG Import Terminals (LNG Header Pipe Zones)
- Interconnect Links (represent total LNG contract volumes or spot availability)
- LNG Export Zone
- Supply Link
- LNG Liquefaction Plant
- Interconnects (represent LNG contracts and spot markets)

Figure 4
**LNG Import Terminal Model**

- LNG Header Hub (Interconnect)
- Interconnect Link (pipeline delivery only)
- LNG Header Pipe Zone
- Supply Link
- LNG Terminal
- Interconnect Links (pipeline receipt only)
- Direct Customer
- Demand Link
- Storage Link
- Underground Storage Facility

SOURCE: RBAC, Inc.
Marketers are modeled as a single undifferentiated sector in GPCM®. This sector is assumed to mediate all transactions in the model. It is the sector which makes the market by linking gas supply to gas demand through the pipeline and storage system. The bulk of the economic rent due to capacity restrictions is generally distributed to the marketing sector. The assumption is basically that the marketers are able to buy at market conditions, sell at market conditions, and acquire transportation at prices fixed in the short term. Therefore, short term economic rents will not be acquired by the pipeline sector and will go to the marketing sector. Suppliers and customers owning Firm Transportation earn the remainder of these rents. Their rents may be earned by reselling their capacity to others or by using the F/T themselves. Figure 4 gives an indication of the complexity of the U.S. interstate pipeline system including storage facilities.

Figure 5
Natural Gas Infrastructure in North America

User Interface

The user interface is the principal analysis tool contained in the GPCM system. It consists of a set of queries, macros, modules, forms, and reports contained in a Microsoft Access97 file. The user interacts with this interface through Access "Forms". Forms contain data from the database and controls such as button for causing actions to be done. The data displayed in forms is stored in database tables in a separate Access file. These tables are "attached" to the user interface so that they can be viewed and modified by the analyst.
Database

The database file consists of a number of data tables for input and output. The data inputs are primarily of three types: tables representing the basic entities of the model (suppliers, supply regions, customers, demand regions, pipeline zones, storage facilities), tables relating these entities representing the structural linkages in the model (the arcs), and the quantitative data representing supplies, demands, tariffs, capacities, fuel use, etc. The GPCM user typically populates the database via Windows clipboard copy-paste operations from Excel or other spreadsheets. Alternatively, the user can utilize GPCM's built-in data import routines.

EMNET Optimizer

EMNET is a program written by Professor Richard McBride of the University of Southern California Graduate School of Business. It is a specialized linear programming algorithm designed specifically to solve network models such as that used in GPCM. In benchmarking tests on a large variety of such problems, it has proven to be world class in speed and functionality. EMNET has been extended to handle the linearized approximations of non-linear supply, demand, and transportation cost functions required for the solution of the GPCM® model.

Outputs

GPCM contains powerful and flexible tabular and graphical output capabilities. In addition the entire solution can be exported to an Excel spreadsheet for further analysis and reporting.

Following is a list of the pre-packaged screen and hardcopy reports available in GPCM®:

1) Results Summary / Detail
2) Pipeline Usage Summary
3) Supplier Deliveries Detail / Summary
4) Customer Receipts Detail / Summary
5) Supplier Revenue Report
6) Customer Cost Report
7) Transport Results Detail
8) Transport Zone Prices
9) Transport Zone Basis
10) Interconnect Basis
11) Transport Revenue
12) Storage Revenue
13) Transport Zone Utilization
14) Transport Link Utilization
15) Storage Utilization
16) Storage Balance
The following chart summarizes the total flow of information, including volumes and prices, within the GPCM model.

Figure 6
GPCM Flow Chart

SOURCE: Global Energy Decisions and RBAC, Inc.

Report 9 allows the user to find the basis (market price spread) between any two pipeline zones identified in the model in any period of the scenario. The report has a graphical capability which allows the user to produce a time series plot of the basis forecast over the forecast horizon of the case.
The Results Summary Report is an aggregate report of the gas and dollar flows among the various sectors of the gas industry. It shows the forecast aggregate average supply price, average unit return to the marketing sector, average transportation and storage cost per unit delivered, and average cost to customers represented in the model. There is also a graphical routine which allows the user to produce histograms comparing any of the elements of the case summary report for various cases.

Finally, GPCM® has a general purpose graphing capability the analyst can use to plot time series of inputs and/or outputs either one at a time or overlayed against each other. For example, the analyst could plot the time series of market clearing prices in two different regions in the same scenario or in multiple scenarios in order to get a visual perspective on their relative values. All of these on-screen reports can also be sent to the printer for hardcopy output.

In conclusion, combining the GPCM model with Global Energy's North American MARKETS YM data model, fundamentally based world oil, coal and emission models, and Global’s multidisciplinary energy expertise, provides a bottom up fundamental forecast of supply, demand, and market price trends.

Figure 11

**Generalized Equilibrium Solution Example**

![Diagram of Generalized Equilibrium Solution Example]

SOURCE: Global Energy Decisions, Inc.