# NATURAL GAS FLOWS IN THE MIDTERM: METHODS AND RESULTS FROM TERA'S NATURAL GAS NETWORK MODEL

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In June 1978, TERA, Inc. was awarded a contract by the U.S. Department of Energy, Office of Policy and Evaluation, to do a study of the National Energy Transportation System (NETS). This study was part of a larger effort sponsored by a joint task force consisting of the Departments of Energy (DOE) and Transportation (DOT) to identify potential bottlenecks in the U.S. energy transportation system in the period 1985 to 1995. TERA's role in this study was specified to be the development and implementation of a methodology to disaggregate national energy supply and demand scenarios provided by DOE for 1985, 1990, and 1995 into detailed supply and demand forecasts at the Bureau of Economic Analysis (BEA) regional level. In addition, TERA was to be responsible for the development and implementation of a rational methodology for estimating interregional flows of energy materials from each BEA producing region to each BEA consuming region in the country. The energy commodities included in the NETS study were coal, crude oil, refined oil products, and natural gas. This paper describes the results of that study in the area of natural gas.

## Outline of NETS Study

Scenarios for the NETS study were produced by the DOE/MEFS model. This model, more precisely known as the Midterm Energy Forecasting System, is an outgrowth of the Project Independence Evaluation System, PIES. MEFS produces a simultaneous forecast of supplies, demands, and interregional flows for all energy commodities produced and/or consumed in the United States. The MEFS forecast is based on a complicated regional breakdown and is used as an input by the TERA NETS system. The regional breakdown, or level of disaggregation, for the NETS model is the BEA region. These 173 regions were used by BEA through 1978.

For each MEFS forecast, TERA's NETS system disaggregated that forecast into a more highly detailed forecast by BEA. This disaggregation is accomplished by analyzing historical production factors and economic variables which cause local variations in energy production and demand growth rates for subregions within the larger MEFS regions. These economic factors are used to forecast "shares" of production and demand for each of the subregions which, when applied to the DOE/MEFS forecast for the larger DOE regions, enable the model to compute forecasts of production and demand for each BEA.

In addition, since production and demand are not equal for each BEA, energy must be transported between BEA's to achieve a supply/demand balance. The TERA model computes a solution for such "origin-destination flows" using a cost-minimizing linear programming model of the energy transportation system. This solution is totally consistent with the higher level interregional flow data contained in the MEFS solution.

For natural gas, TERA used a BEA level model of the actual and planned natural gas transmission and distribution network in the U.S. based on the GASNET3 natural gas distribution system. This model uses the supply and demand forecast from the disaggregation step to calculate the minimum cost gas transmission pattern which best utilizes existing and planned gas pipeline capacity. In locations where capacity is not sufficient, the model permits and simulates construction of new pipeline capacity. The TERA model also identifies pipeline paths in the network which may be seriously underutilized in the forecast period.

## Development of Data Set to Run Model

### Production Shares

In the NETS natural gas methodology, "production shares" for forecast periods were estimated to be functions of historical production and reserve estimates. A production share is that share of each DOE gas producing region which is produced by each county in that region. BEA production was estimated as the sum of all production in counties within that BEA.

### Demand Shares

In the DOE/MEFS model, natural gas demand was computed for four different end-use sectors for each gas demand region. The four sectors were residential, commercial, industrial, and electric utility. The approach taken by TERA in disaggregating MEFS demand to 173 BEA regions involved estimating demand in these four sectors for essentially every supplier of gas in the country identifying the BEA in which each of these suppliers operated, allocating that demand to that BEA, and finally summing up all such demands for each BEA.

This data enabled an estimate to be made of the shares of regional consumption for each BEA for the base year 1976. Further growth data were needed to estimate shares for 1985, 1990, and 1995. In the TERA natural gas disaggregation model two growth variables were used: population for residential consumption; retail and wholesale trade for commercial consumption. It was assumed that demand would not be growing for the industrial and electric utility sectors and the 1976 shares for each subregion for these two sectors were used.

Network Structure

The NETS natural gas flows model was formulated as a network, a structure consisting of nodes and arcs. Nodes represented either locations or areas in the system and arcs represented the transportation paths between those locations or areas. A network can be graphically represented as a set of circles (nodes) connected by arrows (arcs) pointing from each origin to each destination in the network.

The gas network model used for NETS was based upon currently existing and planned natural gas pipelines in the U.S. Each of these pipelines was modeled as a subnetwork of nodes (representing BEA's) and arcs (representing physical pipelines connecting contiguous BEA's). The NETS model consisted of an aggregation of these pipeline networks. All pipelines delivering gas between the same origin and destination were combined into a single arc in the model. The model included essentially all existing inter and intrastate gas transmission companies which cross BEA boundaries, distributors which crossed such boundaries, and planned pipeline systems.

In order to compute a forecast of flows along the arcs of the NETS model, the following information was needed:

1. supplies and demands for each node
2. capacities of pipelines
3. efficiencies of transporting gas
4. cost of transporting gas.

With this data, and using a special type of linear programming known as a "generalized network" or "network with losses," a set of flows was found which satisfied all demands with the existing supplies, which satisfied the capacity and efficiency constraints, and which minimized the total cost of transportation over the entire network.

Estimating Pipeline Capacity

For most pipeline arcs in this model, Federal Energy Regulatory Commission (FERC) Form 2 reports of the pipeline companies which contained sections on compressor station capacities were used. A regression model of the relationship between pipe sizes and capacities was used to estimate the capacity of arcs where compressor data was not available. Data about pipe diameters "downstream" from compressor stations were obtained from the Federal Power Commission's 1974 map of interstate gas pipelines.

Estimation of Arc Efficiencies

Efficiencies were estimated for each node in the gas transmission network. An engineering definition of efficiency was used (ie. the ratio of gas out to gas in, or the fraction not lost, unaccounted for, or used to run compressors). Node efficiencies were converted to arc efficiencies by using the efficiency of the destination BEA. This method implied that gas flowing from the origin BEA is used or lost in the destination BEA. Thus, pipeline capacity on the arc constrained the amount leaving the origin before losses, not the amount leaving after losses as would have been the case if the efficiency of the arc was assumed to be the efficiency of the origin node.

Pipeline Transmission Costs

Estimates of the cost of shipping gas through the natural gas pipeline system were derived with regression analysis using transmission data for various companies. Transmission data from FERC's Form 2 reports included revenue, distance, and the amount of gas transported by the reporting companies for other pipeline companies.

The cost of shipping gas was shown to be directly proportional to the quantity of gas shipped and inversely proportional to the capacity of the pipeline involved. This is consistent with the fact that gas compressors burn natural gas in the process of moving it through the pipelines and consequently shipping costs would be proportional to distance. Also, large compressor stations are relatively more cost efficient than smaller ones, thus decreasing the costs of larger capacity pipelines.

Aggregating Capacity, Efficiency, and Cost Data

The model was aggregated as follows:

1. Pipeline capacities for companies operating over the same BEA origin to destination arcs were summed to yield overall capacities.
2. Mileages were weighted according to pipeline capacities and then averaged.
3. Costs were weighted according to pipeline capacities and then averaged.
4. Since regional efficiency factors were computed for each BEA region rather than for each company, they were used directly without the need for averaging.

The result of this aggregation process was a data set consisting of the following data and estimates for each arc:

1. Region of origin
2. Destination region
3. Arc capacity in MMCF/year
4. Arc mileage
5. Arc efficiency factor
6. Arc transmission cost in cents/MCF.

## Results and Conclusions

In October 1978 TERA completed the first two NETS scenarios and they served the purpose of testing the preliminary NETS methodology. In April, May, and June 1979 TERA received from DOE the five final scenarios to be used for the NETS study. They were:

1. C-Medium 1985
2. C-Medium 1990
3. C-Medium 1995
4. E-High 1990

5. C-Low 1990

The three C-Medium cases were conservative estimates for supplies and prices for 1985-95 while the E-High case was a pessimistic view and C-Low a cautiously optimistic view for 1990.

Natural Gas Results

For the purpose of identifying potential bottlenecks in the energy transportation system, TERA developed a model of the gas transportation system which would allow for construction of new facilities in addition to those already in place or planned and approved. TERA identified a number of places where new construction was likely to be needed. What follows will concentrate on the three C-Medium cases since the other two were very similar to the 1990 C-Medium case.

In the 1985 C-Medium scenario there were twelve pipelines in the domestic network which appeared to need more capacity. Of these twelve one was very marginal (only 1% additional needed) and two others needed less than 20% extra capacity. The remaining nine lines needed from 43 to 137% extra capacity. In terms of greatest potential problems it appeared that the intrastate movements in West Texas, the movement from Northern Louisiana to Arkansas and the movement from New York to Connecticut were the important ones to consider. Additional "local" difficulties in South Carolina, Georgia, Tennessee, and Alabama were also identified. Minor problems in Arkansas and Southern California were also noted. In general the existing pipeline network and planned additions seemed to account quite well for most of the flows forecast by the NETS model for 1985. The few problems foreseen were mostly due to increasing population and economic growth in the Southeast. The West Texas bottleneck could be due to increased Eastern demand for West Texas gas with few existing links to satisfy it. The increased demand for capacity from Louisiana to Arkansas could reflect a deteriorating Arkansas gas production picture.

In the 1990 case many more lines were predicted to need additional capacity and all bottlenecks for 1985 appeared except the one in the Northeast. This was because the MEFS model assumed that the TAPCO LNG (liquified natural gas) project would be online by 1990 (but not 1985) bringing gas south from Canada and Maine into New England and New York. Thus, there would be less demand for gas in Connecticut in 1990 from Southern sources. New bottlenecks appeared in the north central states of North Dakota, South Dakota, Minnesota, Wisconsin, and Iowa. This principally involved two large companies: Northern Natural and Northern Border. Additional capacity was predicted for Northern Natural to serve Northern Minnesota and Wisconsin customers, possibly due to population and economic growth factors. There also seemed to be additional demand on the Northern Border pipeline to transport gas produced in Montana and North Dakota to the upper Midwest. Northern Border was principally designed to transport gas from Alaska to the Midwest. The NETS model saw it as the best route for increasing quantities of gas produced in Northern Tier to get to Midwestern markets. Assuming Northern Border agreed to increase its capacity to transport this gas, this would also likely result in additional capacity for Montana-Dakota utilities to transport the gas from Montana to the Northern Border pipeline. Additional capacity needs were also predicted for Western Slope Gas to transport more gas from the San Juan Basin producing area to users in Eastern Colorado. Finally a small additional capacity may be needed by Southwest Gas Company due to increased demands in Southern Nevada.

In the 1995 C-Medium scenario major shifts in gas supply resulted in substantial alterations in distribution. From 1990 to 1995 the C-Medium MEFS scenario showed a dramatic drop in interstate deliveries, a large increase in SNG (synthetic natural gas) production, a major decrease in Canadian imports, and correspondingly large increases in LNG imports. These changes resulted in a substantially greater demand for Midcontinent and Rocky Mountain gas in the Midwest, increased demand for Alaskan gas by California, a major decline in gas deliveries from the Gulf Coast to the Northeast, and increased reliance on LNG and "local" SNG supplies. The list was substantially longer than in the 1990 case and included all but four of the lines in the 1990 list. The main locations of new capacity requirements were the Midcontinent corridor (Natural Gas Pipeline of America, Northern Natural, Michigan, Wisconsin) and Texas.

Table 1 (Source: TERA, Inc.) below shows examples of companies having need of greater capacity, and the associated capacity and maximum expected flow of their pipeline systems (both in MMCF/year), as forecasted by the TERA NETS model. C-Medium cases only were selected.

Table 1. Companies needing more capacity (1985).

| Pipeline Company | BEA Region Orig. | BEA Region Dest. | Capacity | Maximum Expected Flow |
|---|---|---|---|---|
| Carolina Pipeline | 26 | 29 | 21,042 | 37,876 |
| " " | 28 | 29 | 7,823 | 14,081 |
| S. Georgia Nat. Gas | 43 | 41 | 21,042 | 48,234 |
| Southern Nat. Gas | 44 | 42 | 68,889 | 124,000 |
| " " " | 44 | 48 | 21,480 | 38,664 |
| E. Tenn. Nat. Gas | 47 | 48 | 13,657 | 26,605 |
| Lo Vaca, Intratex, Delhi | 124 | 126 | 335,280 | 603,504 |

Conclusions of the Study

The two most substantial changes in the model were caused by the reduction of gas imports from Canada. As a result, gas demand in the Midwest must be met from supplies in the Midcontinent area. Substantial capacity increases of as much as 145% from the Texas Panhandle to the Great Lakes will be needed to meet this demand. California may become totally cut off from its traditional Permian supplies since gas from the Permian Basin will be needed in the Midwest. Thus, California will additionally rely on Alaskan gas from both pipeline and LNG tanker.

In summation, from the present to 1995 there appeared to be a clear trend away from traditional sources and delivery systems from the Permian Basin and Gulf Coast toward greater utilization and growth in the Rocky Mountains, Midcontinent, and Northern Tier, as well as increased reliance on Alaskan gas, locally produced SNG, and foreign LNG. However, 1995 is a long time away and many assumptions necessary to run the MEFS model were speculative at best. Significant changes in these assumptions could well result in significant alterations in the more detailed NETS model. Also, due to the dynamic nature of the energy system of the 1970's and 80's, several major policy changes have been made recently. These include the denial of two major LNG projects (TAPCO in New England and El Paso II on the Gulf Coast) and the abandonment of the SOHIO pipeline project. These decisions will have a major impact on natural gas transportation patterns in the midterm.