STUDY OF THE FUTURE SUPPLY OF NATURAL GAS FOR ELECTRICAL UTILITIES

Hittman Associates, Inc.

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I. INTRODUCTION

The availability of natural gas as a low sulfur fuel for electrical production was examined in light of historical usage and availability. The goal was to ascertain not only near term but extended demands. Projections were made out through the year 2000. Beyond this time period, there are so many uncertainties that a projection of either demand or supply is not meaningful. Alternate gas sources were also evaluated. Most authorities are in agreement that natural gas cannot continue as the only supply. As a result, such alternates as coal and oil shale gasification, Liquid Natural Gas (LNG), and well stimulation were evaluated in light of our needs.

II. SUMMARY

Natural gas has progressed from a useless gas a few decades ago to a major fuel source today. This growth has been reasonably trouble free up until now. Gas is now, however, approaching a critical period. The value of reserve to production ratio has continued to drop for the past several years reaching 13.3 in 1969. It is felt that a value below 10 is an indicator of a troubled industry (Ref. 1). As one can see, gas is dangerously close to this figure. The reason most experts give for this business posture is the unfavorable pricing structure that has existed for the past several years. As a result, the new drillings have declined for lack of money. Naturally, the reduced drillings resulted in a lower number of "finds". This coupled with an ever increasing consumption rate (20.7 trillion cubic feet in 1969) has resulted in a depressed reserve to production ratio. It does not mean we are running out of gas, but rather an unwillingness by the gas industry to invest in drilling. It is projected that the Federal Power Commission (FPC) will increase pricing over the next few years in order to stimulate the industry. This is felt by most to be too little too late. Accordingly, gas shortages are projected to continue through 1975 until the industry regains the momentum lost over the past several years. These shortages will most effect the electrical utilities. Most states have agreements with the gas utilities which set first priority to residential customers. The net result will be a limited expansion of natural gas consumption for electrical production. Realizing this potential gas shortage, some electric utilities in Texas and Louisiana with plants going on line after 1971 have designed new fossil fuel plants with a dual fuel capability (i.e., gas or oil).

An interesting way to look at the projected growth rate for the utilities is to look at only the incremental supply and demand of natural gas. The projected availability is shown in Table II-1 with corresponding demand shown in Table II-2. A cross comparison points out the projected shortage. To date, we have discussed the near term future of the gas industry. But what about the long term forecast? Most experts feel that the growth rate will continue with the yearly consumption approaching 40,000 trillion Btu's by the year 2000. This is nearly double what it is today. To meet this demand, alternates from pipeline natural gas must be found. Liquefied natural gas (LNG) will be the

TABLE II-1. TOTAL AND INCREMENTAL INCREASE IN NATURAL GAS AVAILABLE FOR USE IN ELECTRIC POWER GENERATION (Trillion BTU/yr.)

(Refs. 11, 12, 13)

CENSUS REGION	1971	1972	1973	1974	1975	1976
New England	1.71	8.76 (1)	8.76 (1)	8.83 (1)	12.04 (2)	12.18 (2)
Middle Atlantic	7.42	14.54 (1)	14.82 (1)	15.00 (1)	39.36 (2)	40.42 (2)
South Atlantic	12.59	13.15	13.75	14.74	46.98 (2)	48.98 (2)
EAST COAST TOTAL	21.72	36.45	37.33	38.57	98.38	101.58
East N. Central	9.46	9.82	10.25	10.75	10.94	12.06
West N. Central	18.93	19.22	20.09	20.32	20.94	20.06
East S. Central	7.45	5.93	8.15	7.78	7.08	8.42
West S. Central	77.92	81.16	84.28	86.20	90.81	89.19
Mountain	8.33	12.19	9.01	9.84	12.18	12.82
INTERIOR TOTAL	122.09	128.32	131.78	134.89	141.95	142.55
Pacific	32.63	73.36	30.90	25.27	158.99 (3)	145.61 (3)
WEST COAST TOTAL	32.63	73.36	30.90	25.27	158.99	145.61
UNITED STATES TOTAL	176.44	238.13	200.01	198.63	399.32	389.74

(1) Assumes importation of 1.1 billion cu. ft. of LNG per month. This proposal currently before the FPC.
(2) Assumes importation of 1.5 billion cu. ft. of LNG per day. This proposal currently before the FPC.
(3) Assumes operation of 1 billion cu. ft. per day pipeline from Alaska.

	1971	1972	1973	1974	1975	1976
UNITED STATES TOTAL CONSUMPTION	3,920.00	4,158.00	4,358.00	4,556.00	4,955.00	5,245.00

TABLE II-2. INCREMENTAL INCREASE IN DEMAND FOR NATURAL GAS DUE TO NEW POWER PLANTS (Trillion Btu/yr) (Refs. 11, 12, 13)

REGION	1971	1972	1973	1974	1975	1976
East Coast	73	34	22	65	--	24
Interior	259	209	172	160	113	226
West Coast	32	31	34	22	30	30
UNITED STATES TOTAL	364	274	228	247	143	280

immediate answer. It will allow significant importation from both the Far East and South America. It has been estimated that as much as 10 percent of our annual consumption in 1980 will be LNG. But this is not the final answer if gas is to survive beyond the year 2030. The reserves are not great enough to maintain the high consumption level. Oil shale or coal gasification must be used to augment the gas supply. Coal alone could increase the potential gas reserve by over a factor of 10. This would yield greater than a hundred-year supply. In general, therefore, one can say that gas will be around for some time to come. The electrical utilities, however, will not increase gas consumption at the same growth rate as the gas industry. In fact, it is projected that although the yearly consumption will rise, the percentage will decrease. The use of alternate gas supplies will force the gas prices upward making it economically unattractive for the large, base loaded utility plants.

III. NATURAL GAS RESOURCES AND PRODUCTION

The United States is the largest consumer of natural gas in the world and will be for the foreseeable future. To maintain this high consumption level requires a reasonable knowledge of near term consumption-demand patterns and an estimate of potential untapped reserves. This type of information comes from many sources including the trade associations, oil companies, and government agencies. Unfortunately, they do not all agree. This must be expected since these parameters are affected by a large number of factors. As a result, the basic inputs must be critically evaluated and the basic assumptions reviewed.

The reserves of natural gas is the one area where most sources seem to agree. They all conclude that there is a large amount of gas remaining underground; the majority of which still remains undiscovered. Before getting into a discussion of the United States reserves, it is worthwhile to briefly review the worldwide picture. Figure III-1 shows the approximate distribution of known world reserves.

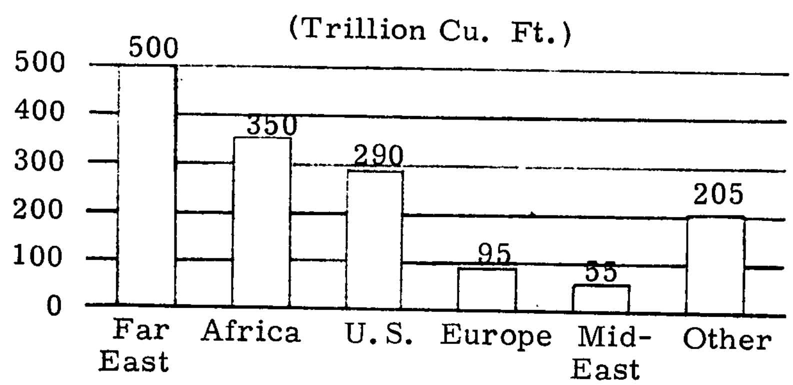

Figure III-1. Worldwide Known Reserves (Ref. 2)

This total known reserve represents approximately a 50 year supply at the current rate. This of course will not be the case, but it does give one an appreciation for the quantities involved. Canada, although not called out separately, has approximately 50 trillion cubic feet of reserves. This ranks them sixth in world reserves. Our southern neighbor Mexico is not as fortunate. Mexico's supply is only rated at a few trillion cubic feet. The term "known" reserve implies that the gas fields have been found and an estimate made of the total underground reservior.

The United States reserves have been estimated in significantly more detail than simply reporting known reserves. Possible and speculative sources have also been estimated. The most notable source for this information is the Potential Gas Committee (PGC) which puts out a biennial report. The latest report, issued December 31, 1970 (Ref. 3) estimates that there are 257 trillion cubic feet in "probable" reserves; 387 trillion cubic feet in areas of established production classified as "possible" and 534 trillion cubic feet in undrilled, speculative regions. A breakout of these categories is shown in Table III-1. These figures are an update from its 1968 estimate. A comparison of the two estimates is shown in Table III-2. As one can see, the estimates agree rather closely. It should be noted that the above reserves of 1178 trillion cubic feet is an addition to the 290 trillion cubic feet of proven reserves.

We have restricted our discussion to date to the entire picture of gas reserves. However, the parameter which is most important to the gas industry is the ratio of proven reserves to yearly production level. The higher the value, the more stable the industry becomes. It is,in a sense, a margin of safety. A review of the United States values for the last eight to nine yars, Table III-3, reveals a dangerous trend. The reserve to production ratio has fallen from 20 in 1962 to 13.3 in 1969. The Committee on Public Works of the U.S. Senate (Ref. 1) indicates that a safe minimum value is 10.0 which is being approached rather quickly. Canada's reserve to production ratio, on the other hand, is much higher. Table III-4 shows the past history with the 1969 level being at 33.4. Although they are in a favorable position with respect to the reserve/ production ratio, their ultimate production rate is limited. A theorical maximum production rate of 5.2 trillion cubic feet can be achieved holding a ratio value of 10. This is approximately 25 percent of the current United States production rate.

We have discussed the gas demand and production. Now let us direct our attention to the chemical form of this fuel. Natural gas is principally a methane base fuel with scattered amounts of ethane, propane, nitrogen, and a number of other gas forms. A percentage breakdown of these gases is shown in Table III-5 for gas wells in both Oklahoma and Texas (Ref. 4). It should be noted that no value for the hydrogen sulfide content has been listed for the "well head" or naturally occurring gas. Unfortunately, the technique used for gathering samples eliminated the hydrogen sulfide from the sample prior to analysis.

TABLE III-1. GENERAL BREAKOUT OF POTENTIAL U.S. GAS*

Supply area	Probable	Possible	Speculative	Total
	(Trillion cu. ft. at 14.73 psia and 60°F as of Dec. 31, 1970)			
	LOWER 48 States			
Onshore (hole depth):				
0-15,000 ft.	141	166	144	451
15,001-30,000 ft.	38	61	63	162
Total	179	227	207	613
Offshore (water depth):				
0-600 ft.	39	89	72	200
601-1,500 ft.	τ	10	28	38
Total	39	99	100	238
Total - Lower 48	218	326	307	851
	ALASKA			
Total - Alaska	39	61	227	327
Grand total (lower 48 and Alaska)	257	387	534	1,178

*Excluding Hawaii and island territories. τ less than 1 trillion cu. ft.
(Ref. 3)

TABLE III-2. ESTIMATED POTENTIAL U.S. GAS SUPPLY

	Probable	Possible	Speculative	Total
	(Trillion cu. ft. at 14.73 psia and 60°F as of Dec. 31, 1970)			
PGC report (12/31/70)	257	387	534	1,178
Last report (12/31/68)	260	335	632	1,227
Change from last report	-3	+52	-98	-49

(Ref. 3)

TABLE III-3. U.S. PROVEN RESERVES AND PRODUCTION OF NATURAL GAS (Trillion CF)
(Ref. 12)

Year	Reserve	Production	Reserve/ Production Ratio
1962	272.3	13.64	20.0
1963	276.2	14.55	19.0
1964	281.3	15.35	18.3
1965	286.5	16.25	17.6
1966	289.3	17.49	16.5
1967	292.9	18.38	15.9
1968	287.3	19.37	14.8
1969	275.1	20.72	13.3

TABLE III-4. CANADIAN PROVEN RESERVES, PRODUCTION AND EXPORTS OF NATURAL GAS (Trillion CF)
(Ref. 19)

Year	Reserve	Production	Net Export	Reserve/ Production Ratio
1964	39.32	-	-	-
1965	40.35	-	-	-
1966	43.45	1.125	0.387	38.6
1967	45.68	1.216	0.443	37.6
1968	47.67	1.395	0.523	34.2
1969	51.95	1.556	0.645	33.4

TABLE III-5. NATURAL GAS CHEMICAL COMPOSITION (Ref. 4)
(in percent)

Oklahoma well-head gas composition from 44 samples.
Texas pipeline gas composition from 11 samples.

	Well-head Average ± S. D.	Pipeline Average ± S. D.
Methane	83.32 ± 8.37	75.5 ± 6.6
Ethane	5.45 ± 3.00	6.6 ± 0.7
Propane	2.71 ± 1.63	3.2 ± 1.1
N-Butane	0.76 ± 0.40	0.92 ± 0.45
Isobutane	0.34 ± 0.22	0.35 ± 0.17
N-Pentane	0.29 ± 0.25	0.31 ± 0.13
Isopentane	0.13 ± 0.10	0.15 ± 0.094
Cyclopentane	0.1 ± 0.06	0.05 ± 0.034
Hexane plus	0.27 ± 0.19	0.22 ± 0.09
Nitrogen	3.96 ± 5.40	11.7 ± 4.9
Oxygen	0.10 ± 0.3	0.06 ± 0.08
Argon	0.00	0.06 ± 0.03
Hydrogen	0.07 ± 0.03	0.02 ± 0.03
Hydrogen Sulfide	0	0
Carbon Dioxide	0.43 ± 0.74	0.31 ± 0.22
Helium	0.093 ± 0.07	0.58 ± 0.34

The sample gas was tapped from the well and bubbled into a water filled vial. The gas displaced the water thereby yielding a known gas sample volume inside the vial. This provides an excellent monitor of sample volume, but also largely eliminated the hydrogen sulfide. Hydrogen sulfide being readily soluble in water was simply dissolved in the water. Although the concentration is unknown, some observations can be made. Sulfur concentration can vary widely from well to well but is generally quite low in production wells. The low concentrations that are present are removed prior to pipeline transportation. This is done to reduce pipeline corrosion caused by the sulfur compounds. The fact that sulfur concentrations can be high is evident by the existence of "sour" wells. These wells have such a high sulfur content that the sulfur is processed commercially. Therefore, a blanket statement that all wells produce gas with negligible sulfur content cannot be made.

IV. GAS ALTERNATIVES

The consumption of natural gas has increased within the United States with each passing year. This increase is projected to continue for the immediate future. The resulting high consumption rate will put an ever increasing burden on the gas reserves. Up to now, the discovery of new gas fields has kept pace with the demand. This cannot continue indefinitely. As a result, new sources must be found.

A. Natural Gas Imports

Imports from neighboring Canada and Mexico have played an ever increasing role in the United States supply. As of 1970, the combined total represented approximately three percent of the overall United States consumption. Mexico has maintained a near constant level while Canada's level has increased significantly. A simple linear extrapolation would lead one to believe that their input would be an ever increasing percentage of our consumption. These increases, however, have merely kept pace with our growing demand. The percentage has stayed nearly constant. As a result, gas import from Canada or Mexico cannot be considered as a significant producer of future demands.

Another source of gas import is the Alaskan fields. They are currently in the early stages of development with production speculated to begin by 1975. The amount of gas piped to the mainland will depend to a large extent on the future pricing structure. The additional pipeline costs are anticipated to be in the range of LNG. As a result, significant import will only occur with high gas prices.

B. Liquefied Natural Gas

Under normal Standard Temperature Pressure (STP) conditions, natural gas is a rather low density fuel. The gaseous form makes it uneconomical for transport by any other means than pipeline. This mode, however, is obviously limited to North America imports. The advent of modern cryogenic technology has made it possible to liquify and transport natural gas economically. Cryogenic Liquid Natural Gas (LNG) tankers are being built for this purpose. Liquid natural gas tanker shipments will become a significant gas source since much of the world's proven gas reserves (37 percent) is located in the developing countries. Liquid natural gas is the only method presently available to export these vast reserves.

The major factors in the development of a large LNG trade are technological ones; further advances are needed to reduce liquefaction and transportaion costs (by about 20 percent). The present nonavailability of cryogenic tankers is the most serious constraint upon the use of LNG.

Several companies have requested FPC permission (Ref. 5) to import LNG and others are expected to follow suit. These companies and the expected (approximate) quantities of imports are presented in Table IV-1. Distrigas is expected to start shipping as soon as FPC approval is obtained. El Paso is expected to start shipping in late 1974. This study assumed Distrigas would be shipping in 1972 and El Paso in 1975. Half of Distrigas' LNG was assumed to go into New England and the other half into Middle Atlantic regions. This is based on LNG docking facilities availability at Everett, Massachusetts, and Staten Island, New York. The LNG from the El Paso agreement was assumed to have an East Coast distribution pattern similar to that for 1975 natural gas.

TABLE IV-1. LIQUID NATURAL GAS IMPORT VOLUME (Ref. 5)

Gas Utility	Quantity of Import	Exporting Country
Distrigas	13.2×10^9 CF/yr	Algeria
Esso LNG	155×10^9 CF/yr	Venezuela
El Paso	548×10^9 CF/yr	Algeria
Philadelphia Gas	----	Venezuela

The importation of LNG would come from three major geographic regions: South America, Africa, and the Middle East. All of these regions are rich in natural gas supplies. Table IV-2 (Ref. 6) presents data on the availability of natural gas from each of these regions.

Although LNG technology and usage is in its infancy, there presently exist several rather large plants. Their approximate capacities are given in Table IV-3. Even though most of these plants are in construction, they will be completed by 1972 or 1973.

TABLE IV-2. AVAILABILITY OF NATURAL GAS FOR LNG PRODUCTION AND EXPORTATION (Ref. 6)

Country	1970 P/C[1]	1970 Possible Export[4] 10^9 CF/yr	1975 P/C[1]	1975 Possible Export 10^9 CF/yr	1980 P/C[1]	1980 Possible Export 10^9 CF/yr
South America						
Bolivia	30.1	24	22.3	376	13.8	294
Brazil	10.8	36	8.5	39	7.3	42
Chile	9.6	244	8.9	280	8.7	323
Columbia	2.6	66	2.0	59	1.8	64
Peru	21.3	61	17.6	66	14.9	73
Venezuela	2.4	498	1.6	296	1.4	294
Africa						
Algeria	12.0	220	12.0	336	12.2	493
Libya	44.0	628	25.5	851	22.0	997
Nigeria	20.3	385	19.4	588	20.1	861
Middle East						
Abu Dhabi	(2)	62	(2)	75	(2)	92
Bahrain	(2)	11	(2)	14	(2)	17
Iran	1.9	117	1.9	350	1.9	500
Iraq	3.5	169	3.2	197	2.9	221
Kuwait	3.5	422	3.2	488	2.9	555
Neutral Zone	(3)	32	(3)	38	(3)	47
Oman	(3)	10	(3)	12	(3)	15
Qatar	(3)	52	(3)	63	(3)	77
Saudi Arabia	3.5	243	3.2	243	2.9	337

[1]Production divided by Consumption (internal)

[2]Minimal internal consumption - misleadingly high P/C ratio

[3]No reliable information

[4]Amount of natural gas (production minus consumption) available for liquefication and export

The future of a relatively large international trade in LNG seems assured by projects currently operating or under construction, but fulfillment of the promise of a truly enormous market is dependent upon many factors such as the substantial reduction in transportation costs. Another very important factor to keep in mind is the extent of offshore gas reserves. If gas from large offshore fields becomes available to either the United States or Japan, LNG importation will decline just as it did in the U.K. with the development of North Sea gas.

TABLE IV-3. LARGE SCALE LNG PLANTS UNDER CONSTRUCTION (Ref. 5, 6)

	Capacity (10^9 CF/yr)
Port Arzew, Algeria	402
Skikda, Algeria	160*
Marsa el Brega, Libya	160*
Brunai, Malaysia	255
Pozo Rica, Mexico	220
Maricaibo, Venezuela	100

C. Gasified Oil Shale and Gas

The oil shale deposits of the western United States represents a potential source of natural gas. Basic work in this field has shown that this method of gas recovery is technically feasible. However, there is a long way to go before we can say that it is also economically competitive. The fact that a large effort in both time and money is necessary to bring this recovery approach on a par with the alternate approaches makes it a doubtful source of gas for at least the next 20 years. Beyond this time, it is difficult to say. Potentially, there are 6000 trillion cubic feet of gas available by this recovery scheme. This supply can hardly be ignored indefinitely.

Coal gasification is another alternative toward overcoming the limited gas supply. The process has been proven feasible on a laboratory basis.

*Ultimate capacity: 320 x 10^9 CF/yr

The second step, which is to build and operate a synthetic gas pilot plant, has been completed and is in operation just outside Chicago (Ref. 7). It utilizes a conversion process known as "Hygas" which produces 250 million cubic feet per day of synthetic gas from 75 tons of coal. This concept of altering coal into gas accomplishes two goals. It will greatly increase the effective gas reserves and will eliminate the SO_2 and particulate pollution problem associated with the direct burning of coal. The 1967 estimated total reserves of 997,000 million tons of coal and lignite (Ref. 1) represents an order of magnitude increase in potential gas reserves. As a result, coal represents the most significant source of natural gas. Its use as a major fuel supply, however, is many years away. The plants today are small by production standards. Also, the technology has not reached the point of being economically feasible. It is felt that, given sufficient Federal funds, it would not be until the early 1980s that large, commercially feasible plants would be brought into production.

D. Gasified Petroleum

Oil gasification is quite similar to coal gasification. It is a process which converts available thermal energy of oil into a gas form. The process has the inherent advantage of yielding a cleaner fuel. Unlike coal, however, oil is in unusually short supply. Its reserve is similar to the natural gas supply. As a result, this gasification process cannot be expected to greatly increase the gas supply unless the use of oil in its natural form is sharply curtailed. It can, however, be used as an emergency gas supply for short periods of time.

E. Increased Productivity of Existing Wells

1. Nuclear Stimulated Gas (Gas Buggy)

The gas reserves within the United States range in size and containing structure. Not all of the gas is in easy-to-get-at pools. A segment of this supply is located in low-permeability geological formations. Wells drilled into this type of ground produce at very low rates. In many cases, this is below an attractive economic level. One approach to release this entrapped gas is to fracture the underground formation by means of a nuclear detonation.

An experiment known as "Project Rulison" has recently been conducted to determine feasibility of this approach. There was little doubt that an explosion would increase yield, but how much and how "clean" the gas would be were two questions only a test could answer. Preliminary results indicate that the yield is up by a factor of 10. The recovery factor may be as high as 50 to 80 percent of the original trapped gas, with induced radioactivity also within predicted limits. If this stimulation does prove feasible, commercial extraction from this field will begin. Two yearly detonations for the next 50 years will yield 0.12 trillion cubic feet yearly (Ref. 1). Under reasonable technical assumptions, then, 20 detonations per year would be required to yield 2.54 trillion cubic feet. This is approximately 10 percent of the projected 1973 demand. Whether or not this is economically feasible remains to be seen.

2. Advances in Conventional Technology

The technology of gas extraction continues to build with each passing year. Today's methods have created production wells from diggings which would have proven economically infeasible several years ago. This trend is expected to continue into the future. As a result, "dead" wells will be reclaimed for production. The gas yield, as a result, however, is not expected to significantly affect gas production levels. It will only affect a small fraction of the total field reserve. Methods which fall into this category are water injection and gas simulation. Both of these processes further the recovery rate from the existing fields.

V. GAS CONSUMPTION AND FLOW PATTERNS

The flow of natural gas within the continental United States is primarily by pipeline. It is mainly produced in the Texas-Oklahoma-Louisiana region and piped to the various consuming regions. The East Coast, as one would expect, is the main consumer. If we were to look at a pipeline map of the United States, we would see two main traffic lanes, one lane going to each coast starting from the gas fields. This flow pattern can be very vividly seen in Figure V-1. It shows the natural gas flow pattern for both 1960 and 1965. This semipictorial approach dramatically shows Texas as the hub for natural gas feeding the rest of the nation. Comparing the changes between 1960 and 1965 shows that the pattern remained reasonably constant with an overall consumption increase of 28 percent. This trend continued through the sixties. By 1969, the total consumption had risen to 20.9 trillion cubic feet. This is a 34 percent increase from 1965. A breakdown by region for 1969 is given in Table V-1. The receipt is the total gross gas volume entering a region. A portion of this amount is simply shipped to another region. This quantity is known as "deliverable." The remaining gas is divided into three categories: consumption, storage, and transmission loss. The latter refers to the gas expended to power the gas-driven pumps along the pipeline and other auxiliary equipment. This amounts to about 1.6 percent of the total gas flow.

Another presentation approach is simply to summarize the national supply and disposition of natural gas. These data are shown in Table V-2. for 1965 through 1969. Several interesting trends are evident. First is the history of lost fuel. Until 1967, fuel losses were on the rise along with consumption. The trend changed in 1967 and has continued. We have gradually increased through the following years. The second area is in the import-export field. Net imports have gradually increased through the years. The level reached 3.3 percent of total supply by 1969. These imports came from two sources, Canada and Mexico. A history of our dealings with these two countries is shown in Figure V-2. Until 1958, the United States was an exporter of gas. The tide reversed in 1958 and since then we have continued to import at an ever-increasing rate. This increase is totally due to increased imports from Canada. Our dealings with Mexico have been maintained at a near constant level of 40 billion cubic feet. This rate is expected to continue for the foreseeable future.

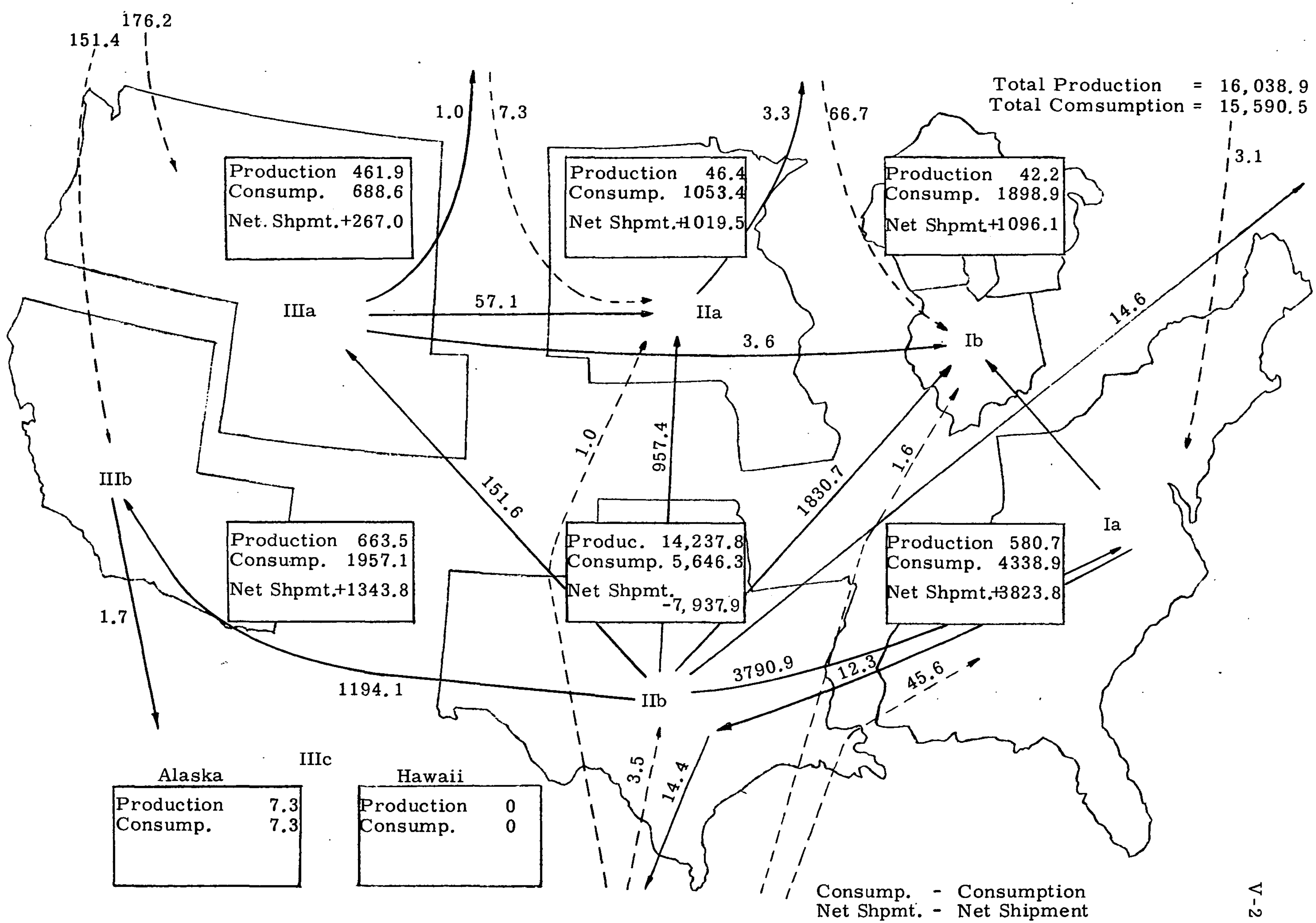

Figure V-1a. Flow Patterns for Natural Gas by Regions - 1965
(Billion Cubic Feet)(Ref. 8)

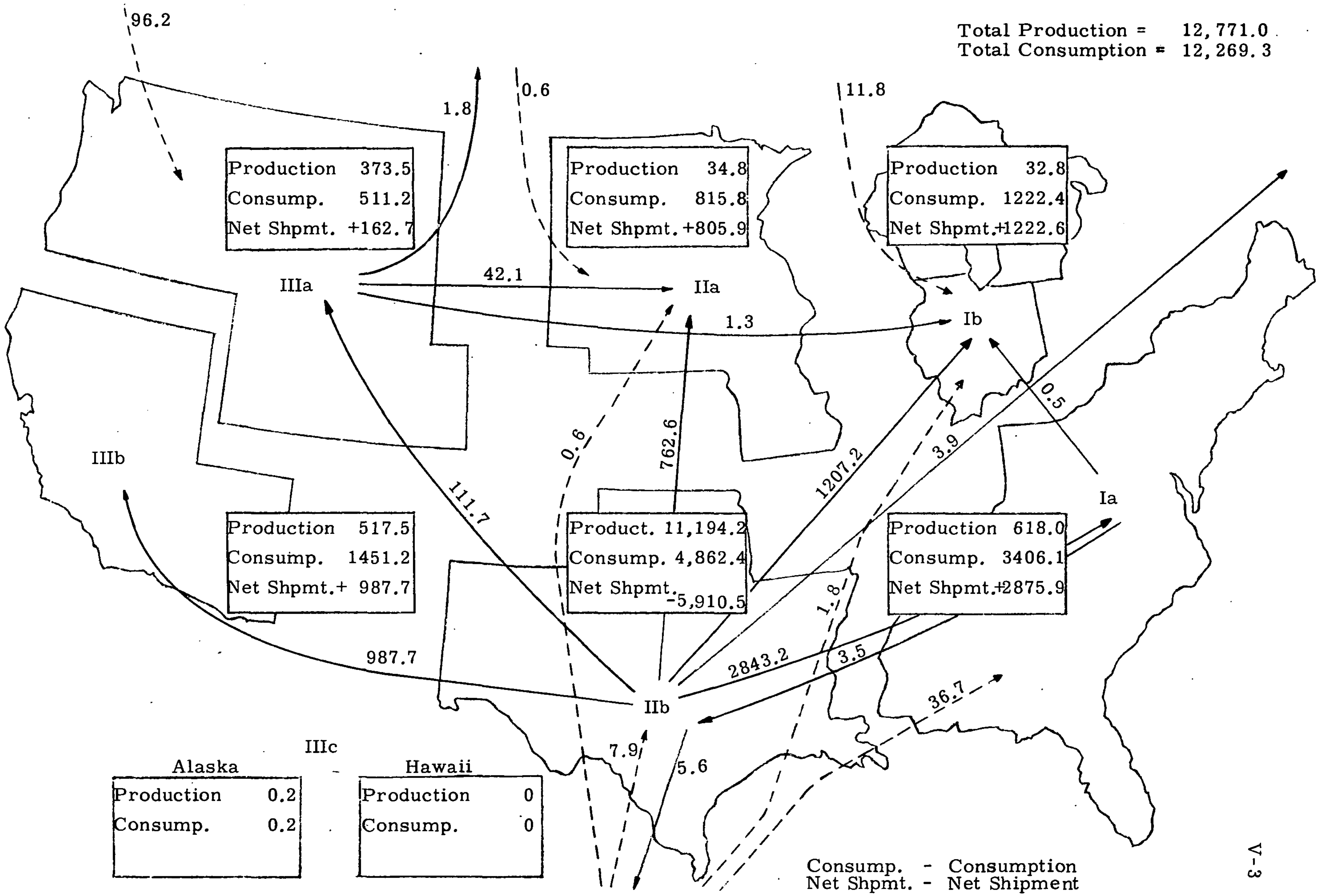

Figure V-1b. Flow Patterns for Natural Gas by Regions - 1960
(Billion Cubic Feet) (Ref. 8)

TABLE V-1. 1969 GAS FLOW AND CONSUMPTION PATTERN (Ref. 9)

			10^6 CF				
Location	Production	Receipts	Deliveries	Net Deliveries	Change in Storage	Transmission Loss	Consumption
New England	--	414,403	183,779	230,624	-253	4,653	226,224
Middle Atlantic	83,995	3,760,893	2,010,701	1,750,192	7,451	72,179	1,754,557
East North Central	89,927	7,975,170	4,221,283	3,753,887	45,078	41,418	3,757,318
West North Central	923,858	6,768,168	5,773,028	995,140	-1,227	12,614	1,907,611
South Atlantic	235,633	6,662,611	5,470,624	1,191,987	-854	24,011	1,404,463
East South Central	212,775	16,804,150	15,861,901	942,839	2,997	32,672	1,119,945
West South Central	16,774,000	5,852,200	15,298,773	-9,446,573	35,413	68,312	7,223,699
Mountain	1,649,502	3,233,009	3,662,267	-429,258	14,195	31,223	1,174,826
Pacific	728,553	2,291,111	604,302	1,686,809	16,700	444,505	2,354,157
Total	20,698,240	53,762,305	53,086,650	675,647	119,500	331,587	20,922,800

TABLE V-2. SALIENT STATISTICS OF NATURAL GAS IN THE U.S. (Ref. 9)

(10^6 CF)

	1965	1966	1967	1968	1969
Supply					
Marketed production	16,039,753	17,206,628	18,171,325	19,322,400	20,698,240
Withdrawn from storage	959,865	1,141,614	1,132,534	1,329,536	1,379,488
Imports	456,394	479,780	564,226	651,885	726,951
Total	17,456,012	18,828,022	19,868,085	21,303,821	22,804,679
Disposition					
Consumption	16,033,189	17,191,711	18,172,894	19,459,939	20,922,800
Exports	26,132	24,639	81,674	93,745	51,304
Stored	1,077,980	1,210,469	1,317,363	1,425,075	1,498,988
Loss	318,711	401,203	296,214	325,062	331,587
Total	17,456,012	18,828,022	19,868,085	21,303,821	22,804,679
Cost					
Cents per 10^3 CF	15.6	15.7	16.0	16.4	16.7

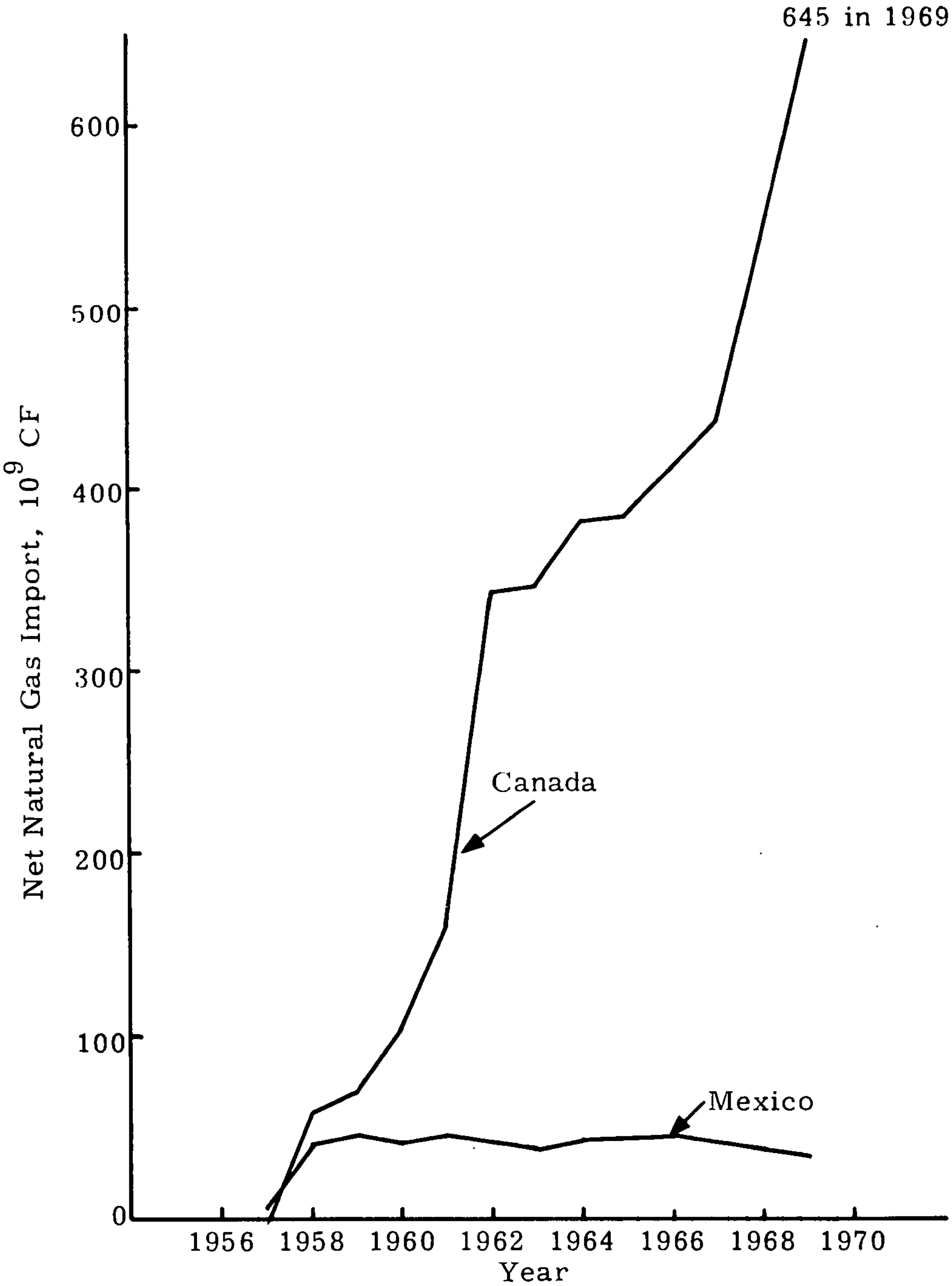

Figure V-2. Net Gas Imports from Canada and Mexico (Ref. 10)

We have discussed the distribution of natural gas within the United States. Now let us concentrate our attention to the consumption levels for electrical power production. Table V-3 presents regional data from 1966 through 1968. In addition, total gas consumption by region is also listed to give one some idea of the gas fraction used for electrical power.

TABLE V-3. TOTAL AND ELECTRICAL POWER CONSUMPTION OF NATURAL GAS (Millions of Therms) (Refs. 11, 12, 13)

		1966	1967	1968
New England	Total	1,800	1,983	2,087
	Power	90.0	92.3	101.2
Middle Atlantic	Total	13,596	14,288	15,057
	Power	963.5	1,109.7	1,218.5
East North Central	Total	29,709	31, 447	33,449
	Power	781.4	857.7	943.1
West North Central	Total	13,970	14,784	15,559
	Power	3,080.1	3,229.4	3,411.6
South Atlantic	Total	9,532	10,325	11,158
	Power	1,241.7	1,377.7	1,475.9
East South Central	Total	8,152	8,343	9,013
	Power	874.5	1,156.3	1,230.4
West South Central	Total	25,174	26,225	28,488
	Power	11,288.6	12,261.1	13,144.1
Mountain	Total	7,463	7,382	8,037
	Power	1,486.3	1,477.3	1,618.1
Pacific	Total	19,536	20,106	21,875
	Power	6,361.7	6,153.4	7,019.2
United States	Total	128,932	134,883	144,723
	Power	26,177.0	27,715	30,163.0

VI. PREDICTION OF GAS SUPPLY AND DEMAND

A review of past gas demand and supply over the history of gas use reveals an ever increasing profile. Recent years have revealed an alarming trend toward a reduced reserve-to-production ratio. Continuation of this trend could seriously impair the industry. As a result, projection of these parameters is all important. Unfortunately, there is a variation of opinion within the field. An example of this variation is clearly shown in Figure VI-1. It is noteworthy that the early predictions (prior to 1967) predict a much lower rate of increased consumption than has been observed to date. Another form of these data is shown in Figure VI-2 in the form of projected production rate. It can be seen that the predictions differ widely. This is due in part to varying impact assumptions to meet the demand. It is our feeling that the actual growth rate will follow some medium profile. The consumption pattern obviously is subjected to the alternate fuel forms. However, the basic cleanliness of gas will maintain an ever increasing demand.

To this point we have discussed overall gas consumption. Electrical utility requirements are of specific interest. It is generally recognized that utilities are the last to get their gas quota. As a result, gas shortages would first be reflected in these requirements. The United States Senate Committee on Public Works has projected this requirement in Figure VI-3. It indicates an ever-decreasing percentage of gas being available for use in electrical production. In addition to this overall prediction, regional data through 1976 are shown in Table II-1.

Our ability to supply these high consumption patterns fall into the category of highly questionable. A look at our national reserves, if this were the case, is shown in Figure VI-4. One can see that our supply will not last long. The answer to this dilemma is to either produce synthetic gas or to import heavily. The latter option will almost surely take the form of LNG importation. The potential of this approach is limited mainly by the tanker fleet necessary to carry these vast amounts of gas.

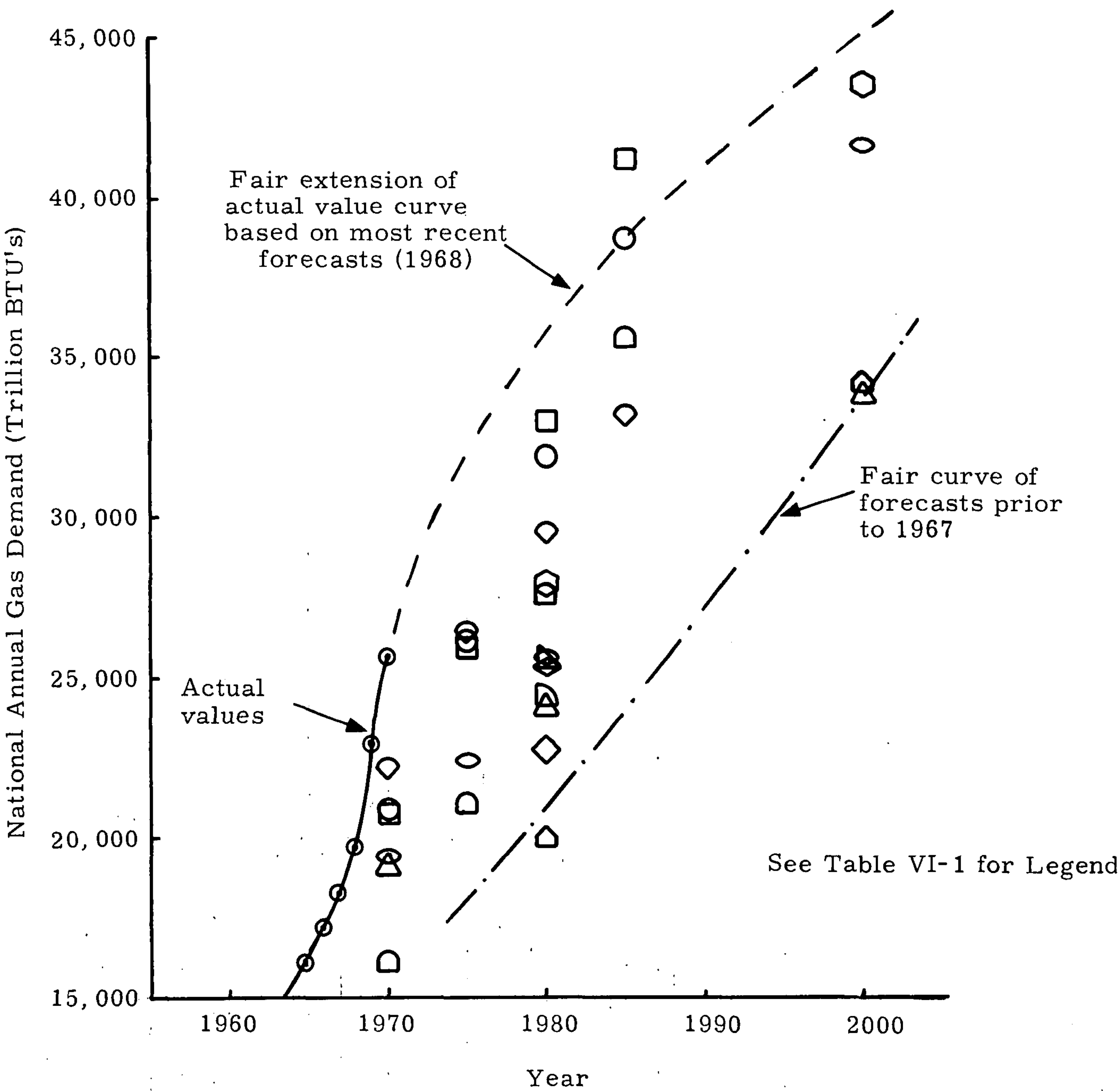

Figure VI-1. Forecasts of U.S. Natural Gas Requirements (Ref. 14)

TABLE VI-1. LEGEND FOR FIGURE VI-1
(Per Ref. 14)

Symbol	Reference
⬡	United States Petroleum Through 1980 United States Department of Interior Office of Oil and Gas, July 1968
◺	Patterns of Energy Consumption in the U. S. William A. Vogely, Division of Economic Analysis Bureau of Mines, U. S. Department of the Interior 1962
◊	Report of the National Fuels and Energy Study Group on Assessment of Available Information on Energy in the United States, Committee on Interior and Insular Affairs, United States Senate, September 1962
⌂	Gas Utility and Pipeline Industry Projections 1968-1972, 1975, 1980 and 1985 Department of Statistics American Gas Association
◇	Future Natural Gas Requirements of the United States Future Requirements Agency, Denver Research Inst. University of Denver, Vol. 2, June 1967 (Under the auspices of the Gas Industry Committee)
○	Competition and Growth in American Energy Markets, 1947 - 1985, Texas Eastern Transmission Corporation, 1968
□	Energy in the United States, 1960-1985 Michael C. Cook Sartorius & Co., September 1967
△	Resources in America's Future Landsberg, Fischman, and Fisher Resources for the Future, Inc. Johns Hopkins Press, 1963
⬭	An Energy Model for the United States Featuring Energy Balances for the Years 1947 to 1965 and Projections and Forecasts to the years 1980 and 2000 Bureau of Mines, IC 8334, July 1968 U. S. Department of the Interior

TABLE VI-1. LEGEND FOR FIGURE VI-1
(Ref. 14) (Continued)

Symbol	Reference
	Outlook for Energy in the United States Energy Division The Chase Manhattan Bank, N. A. October 1968
	Fossil Fuels in the Future Office of Operations Analysis and Forecasting United States Atomic Energy Commission Milton F. Searl, 1960
	Projections of the Consumption of Commodities Producible on the Public Lands of the United States 1980-2000 Prepared for the Public Land Law Review Commission Robert R. Nathan Associates, Inc. Washington, D. C., May 1968

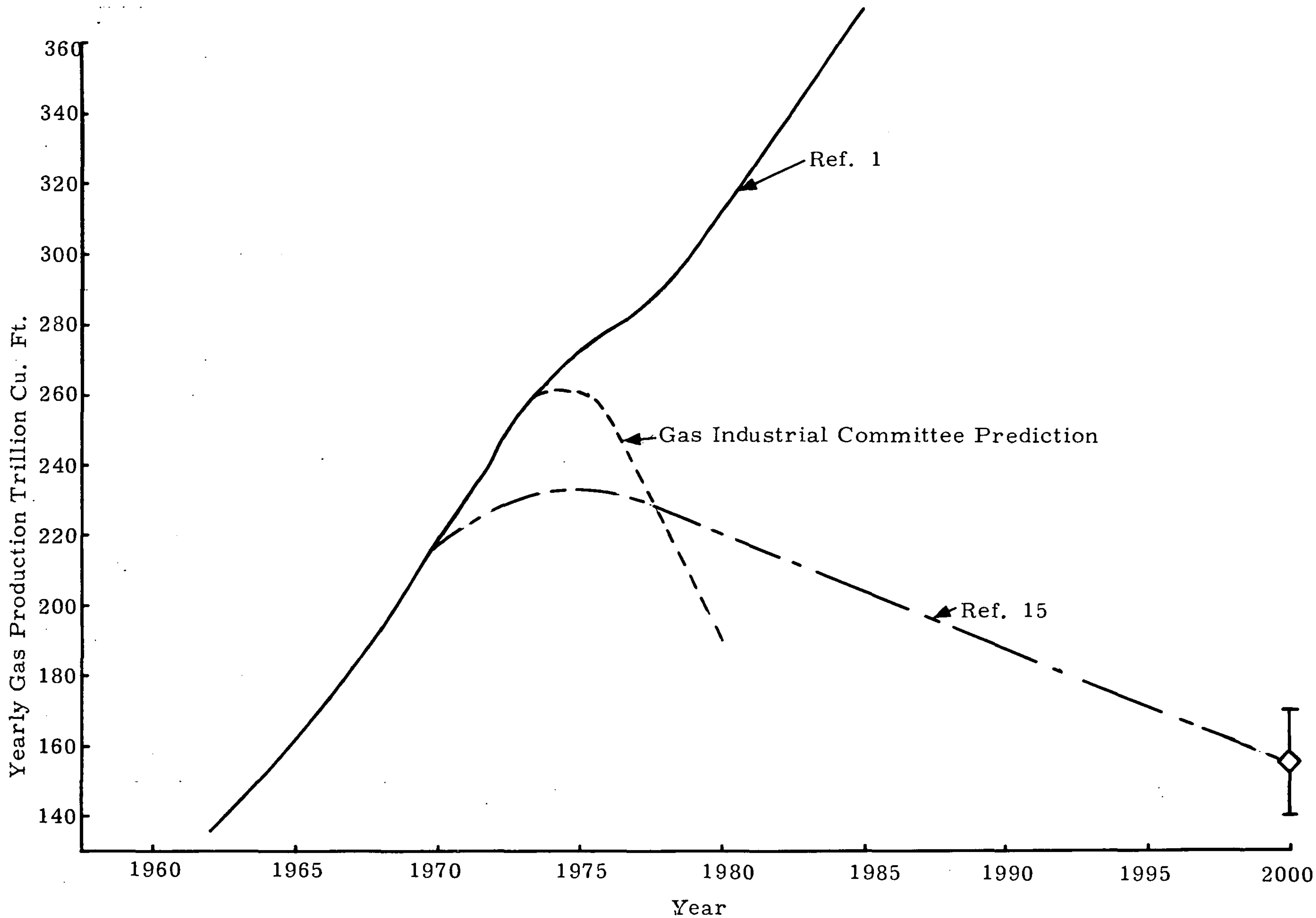

Figure VI-2. Yearly National Gas Production Forecast

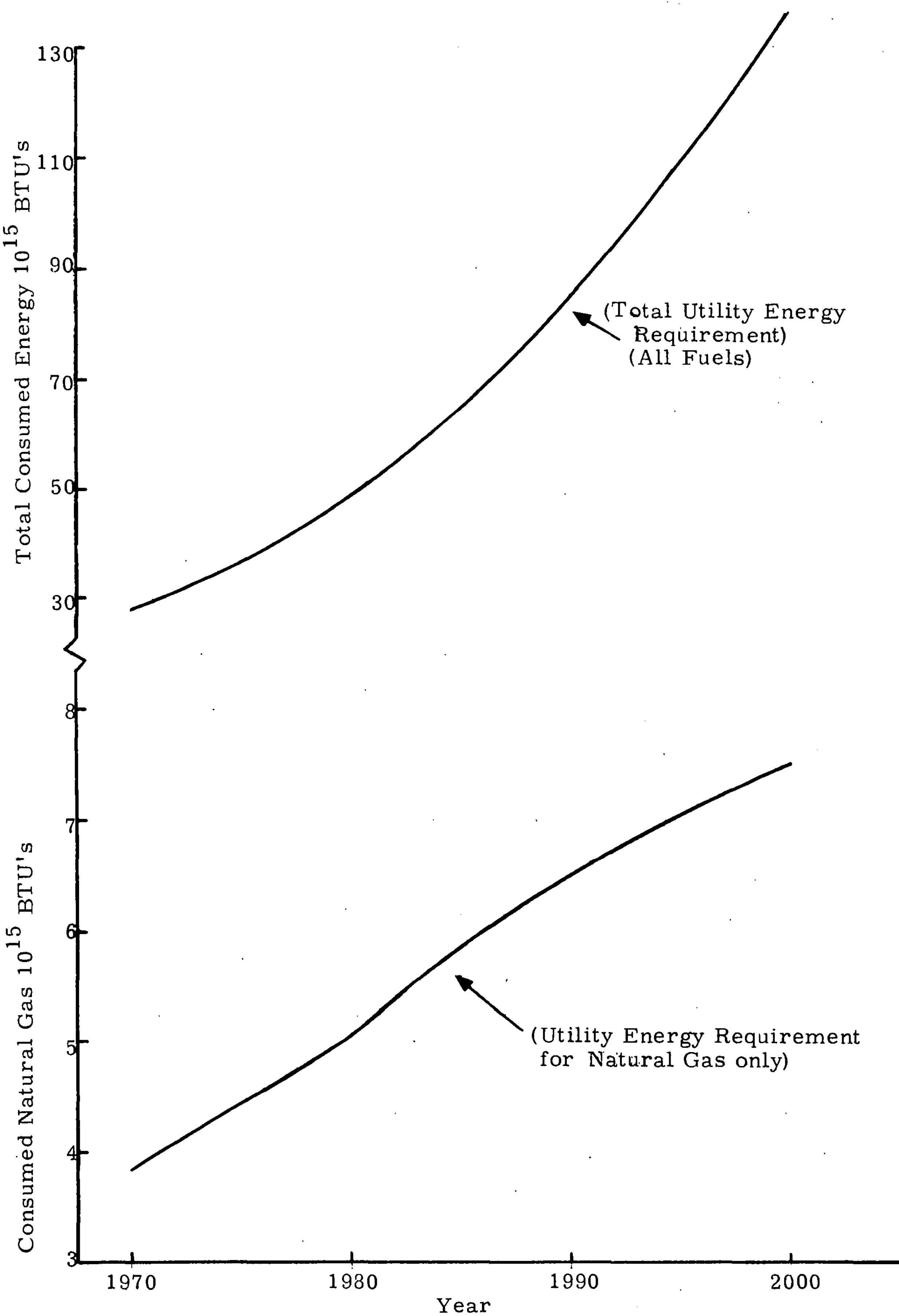

Figure VI-3. Projected Energy Requirements for Electrical Power Generation

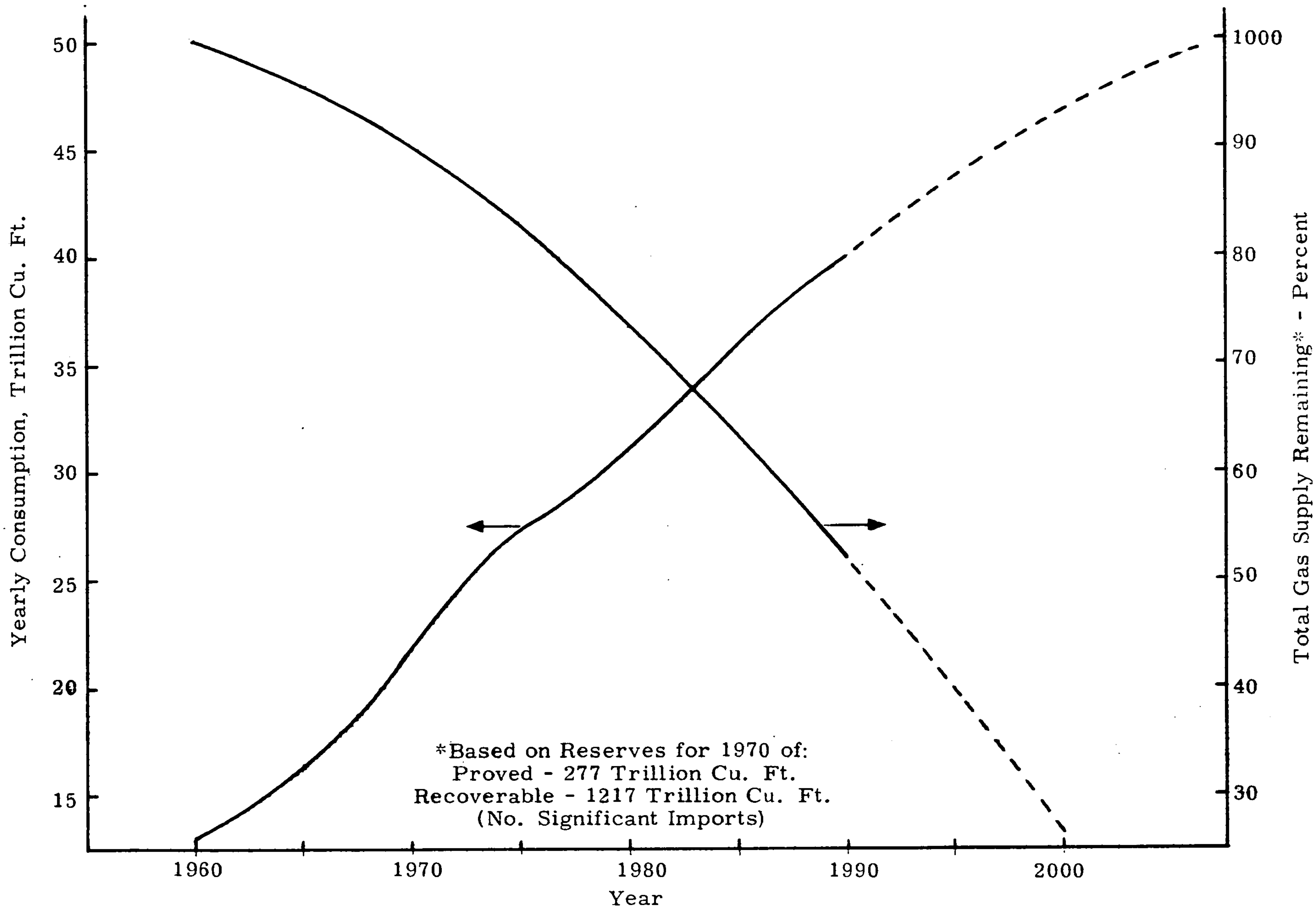

Figure VI-4. Total Gas Reserve Without Significant Imports (Adapted from Ref. 1)

VII. COST IMPLICATIONS

The use, production, and reserve of natural gas is very tightly tied to the existing and projected prices. The gas industry is like any other business. Reasonable return must be potentially available before money is invested. To a large extent, the FPC has controlled the gas price. This control adds stability to the market but also influences the industry's growth rate. A price history from 1962 through 1968 is shown in Table VII-1 for both "wellhead" and "as-burned" bases. As can be seen, the 1962-64 time period had attractive pricing for the industry. As a result, exploration and new discoveries were also up. A similar look at the reserve-to-production ratio would show large values. The poorer economic picture in the succeeding years brought reduced new drillings. As a result, reserve-to-production ratio has dropped to 13.3 in 1969. This does not indicate a scarcity of gas, but rather money. This depressed value has caused the FPC to reexamine wellhead pricing. Within the next few years, an increase in wellhead price is expected. This improvement in price structuring is hoped to, and undoubtedly will, improve the industry's outlook. However, there is a feeling that this pricing will not magically solve the forecasted shortage for the next three to seven years (Ref. 16).

It is also interesting to review the pricing of the "as-burned" price across the nation. Table VII-2 shows this variation during 1968 for the electrical utilities. The primary difference is due to transmission charges. Transmission rates are very complex, but a rule of thumb of 1¢/10^3 CF/100 miles of pipeline expense appears to be valid. This adds roughly one cent per million Btu on the price of gas for 100 miles of transportation. This price factor is why the continental gas fields can deliver gas more cheaply in the midwest where it is produced. The Alaska fields, on the other hand, are reasonably remote and therefore represent a higher-priced source. The estimated transmission charges are expected to be in the 1.5¢/10^3CF/100 mile level.

Liquid natural gas has a different transportation problem. Conventional pipeline transmission is infeasible for water transportation of any distance. Gas fields in the Far East and South America, therefore, must convert the

TABLE VII-1. AVERAGE WELLHEAD PRICE AND ELECTRIC UTILITY "AS-BURNED PRICE cents/10^6 Btu) (Ref. 11, 12)

Year	Wellhead	"As-Burned"
1962	15.5	26.4
1963	15.8	25.6
1964	15.4	25.4
1965	15.6	25.1
1966	15.7	25.1
1967	15.0	24.7
1968	16.4	25.1

TABLE VII-2. "AS-BURNED" PRICE BY CENSUS REGION 1968 (Ref. 11, 12)

Location	Quantity Burned (10^6 CF)	Average Price*	Lowest Average Price for Any State*	Highest Average Price for Any State*
New England	9,266	32.0	31.6	33.6
Middle Atlantic	123,095	35.8	30.2	37.1
South Atlantic	197,798	31.6	27.3	32.9
East Coast	330,159	33.2	27.3	37.1
East North Central	105,556	28.0	26.7	47.7
West North Central	346,908	24.5	23.0	28.5
East South Central	112,274	23.9	20.5	24.9
West South Central	1,304,709	20.1	18.6	25.0
Mountain	157,762	25.9	19.5	36.7
Interior	2,027,209	21.9	18.6	47.7
Pacific	690,622	30.7	30.6	35.2
West Coast	690,622	30.7	30.6	35.2
Total United States	3,047,990	25.1	18.6	47.7

*Cents/million Btu

gas into a cryogenic liquid form to allow tanker transportation. The estimated pricing structure for this process is shown in Table VII-3 for LNG from Venezuela, North Africa, and Nigeria (Ref. 17). These estimates were made by J. Trollux of Sofragaz, the state-owned Algerian gas company. The field price of gas was assumed to be 5.75¢/10^3 CF. Table VII-3 indicates that the only source of LNG which is even nearly competitive with pipeline gas prices comes from Venezuela. As implied by the cost breakdown in Table VII-3 the capital investment involved with LNG plants is quite substantial. The average capital cost for such LNG plants is estimated at approximately $850,000 per million cubic feet per day capacity.

The pricing structure for LNG is significantly different from that of natural gas. Best estimates are that roughly 50 percent of the price would be due to liquefaction, storage, deliquefaction, and dock facilities; 40 percent for shipping; and 10 percent for the field price of the gas. Current agreements between Distrigas and Algeria have the price for their LNG ranging between 68¢/10^3 CF (April to October) and 85¢/10^3 CF (January to February) (Ref. 5). Southern Natural Gas of Georgia has agreed to an initial base price of approximately 65¢/10^6 Btu for LNG supplied by an agreement between El Paso Natural Gas and Algeria (Ref. 5).

With the expected increase in the wellhead price of natural gas, the gap between pipeline gas prices and imported LNG will be narrowed. Moreover, the price gap for LNG will soon be secondary to the decreasing availability of pipeline gas as will that of any additional gas sources such as Canadian gas or coal gasification.

TABLE VII-3. ESTIMATED LNG PRICES (cents/10^3 CF) (Ref. 17)

Country	$300 \cdot 10^6$ CFD Capacity LNG Plant	$600 \cdot 10^6$ CFD Capacity LNG Plant
Venezuela		
Shipping	18.20	14.00
Liquefication, storage, regasification	30.30	24.00
Field gas	5.75	5.75
Total	54.25	43.75
North Africa		
Shipping	25.00	25.00
Liquefication, storage, regasification	33.50	25.00
Field	5.75	5.75
Total	64.25	55.75
Nigerian		
Shipping	34.50	35.00
Liquefication, storage, regasification	35.00	26.00
Field gas	5.75	5.75
Total	75.25	66.75

VIII. CONCLUSIONS AND RECOMMENDATIONS

The use of natural gas has been and will continue to be an important source of fuel within the United States. It represents a very clean fuel and, as a result, a fuel which can become an important control in the fight against pollution. To hold this role, however, will take a concerted effort within the next few years to ensure adequate supplies in the future. Most industry spokesmen are forecasting a gas shortage during the 1972 through 1975 time period. Their feeling is that the die is cast and very little can be done. This is partly true in that the bulk of the solutions will not be available until the latter 1970s. These include such items as LNG import, synthetic gas production, and field stimulation. They will play an ever-increasing role in the gas industry, but not for a while. The degree to which this shortage will exist will vary, depending upon the source. It is generally agreed that gas power generation by electric utilities will decline on a percentage basis due to these shortages and will continue beyond the crisis due to high gas prices. The overall gas consumption, however, will continue to rise. This high consumption level will be met almost entirely by internal production until the latter 1970s. Imports from Canada and Mexico will yield only a small percentage of our demand. Beyond this, LNG imports will play an ever-increasing role. Reference 18 indicates that a dozen new LNG plants will be built in the world in the next decade. Their capacities will be in the one billion cfd range with half their output coming to the United States. An attractive economic picture could yield LNG capturing 10 percent of the United States market by 1981 and increasing during the following years.

Liquid natural gas will meet a large part of the United States demand, but cannot continue well into the 2000s. If gas is to continue its role, coal gasification must pick up the slack. This process can supply sufficient gas for at least another 100 years. This process is currently under pilot plant investigation and could be developed to full scale capabilities in the 1980's.

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