LA-UR -80-3342

CONF-801210--6

TITLE: ENERGY, HELIUM, AND THE FUTURE--II

AUTHOR(S): Milton C. Krupka
Edward F. Hammel

SUBMITTED TO: Third International Conference on Alternative Energy Sources
Miami Beach, Florida, December 15-17, 1980

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

Form. No. 836 R3
St. No. 2629
12/78

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

ENERGY, HELIUM AND THE FUTURE-II*

Milton C. Krupka and Edward F. Hammel**
Systems Analysis and Assessment Division
Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico, 87545 USA

ABSTRACT

The importance of helium as a critical resource material has been recognized specifically by the scientific community and more generally by the 1960 Congressional mandate to institute a long range conservation program. A major study mandated by the Energy Reorganization Act of 1974 resulted in the publication in 1975 of the document, "The Energy-Related Applications of Helium," ERDA-13. This document contained a comprehensive review and analysis relating to helium resources and present and future supply/demand relationships with particular emphasis upon those helium-dependent energy-related technologies projected to be implemented in the post-2000 year time period, e.g., fusion.

This paper will present an updated overview of the helium situation as it exists today. Since publication of ERDA-13, important changes in the data base underlying that document have occurred. The data has since been reexamined, revised and new information included. The paper will discuss potential supplies of helium from both conventional and unconventional natural gas resources, projected supply/demand relationships to the year 2030 based upon a given power generation scenario, projected helium demand for specific energy-related technologies and the supply options (national and international) available to meet that demand. An updated review will be given of the energy requirements for the extraction of helium from natural gas as they relate to the concentration of helium. A discussion will be given concerning the technical and economic feasibility of several methods available both now and conceptually possible, to extract helium from helium-lean natural gas, the atmosphere and outer space. Finally, a brief review will be given of the 1980 Congressional activities with respect to the introduction and possible passage of new helium conservation legislation.

1. INTRODUCTION

The subject of helium conservation was discussed previously at the First International Conference on Alternative Energy Sources held in 1977. An overview was presented covering the effects of policy then in existence upon the helium needs of the future. More specifically, the activities of the various

---

*Work done under the auspices of the US Department of Energy.

**Consultant to the Los Alamos Scientific Laboratory.

groups within the public and private sectors directly concerned with helium usage and conservation were described [1].

Section 104(e)(3) of the Energy Reorganization Act of 1974, which created the Energy Research and Development Administration, required the Administrator to conduct a study of the energy-related applications of helium and report to the President and Congress his recommendations concerning the management of the federal helium program as it relates to energy. This report, ERDA-13, was submitted to the President and Congress on April 11, 1975.

Since 1975, several bills designed to conserve helium have been introduced in the Congress, several new studies of the problem have been carried out and additional or more accurate information has become available on: (a) helium supplies (reserves and resource base), (b) alternative extraction technologies and (c) energy-related helium demand. These developments have taken place together with the fact that the helium conservation issue has been once again addressed by the 96th Congress (1979-80).

A reexamination of the data base for the 1975 ERDA-13 document, "The Energy-Related Applications of Helium," has now been completed. In particular, the technical data base has been updated and enlarged, and the various socioeconomic, legislative, and international factors associated with helium conservation issues have been reviewed and reevaluated in terms of developments occurring within the past five years [2]. The resulting information is presented and summarized in this paper.

2. RESOURCES

Helium exists in conventional natural gas used as fuel, but its concentration varies from field to field. If natural gases were not now being used for fuel, there would be no controversy over helium conservation. The helium would simply remain stored in the earth. But, because the US natural gas resources are being depleted, the helium contained in fuel natural gas is constantly being lost to the atmosphere.

Helium is extracted from fuel natural gas originating within the Panhandle-Hugoton fields located in Kansas, Oklahoma and Texas. All extraction and distribution systems exist in this region. Concentrations of helium are in excess of 0.4 volume percent. Included in this location is a depleted gas field where approximately 44 billion cubic feet (Bcf) are stored. Both public and private sources are in general agreement that the Panhandle-Hugoton natural gas fields will deplete by about the turn of the century. At such time, since demand for helium will obviously continue, other sources presumably will come into consideration. Dominant among these will be the federal stockpile, certain nonfuel and hence nondepleting natural gas reserves, helium-lean (less than 0.3% by volume) gas streams (if available), and potential imports. Eventually the helium will have to be extracted from the atmosphere itself.

The amount of helium available from natural gas depends upon the amount of residual natural gas, the concentration of the helium in the gas and the availability of the gas for helium extraction processing. Approximately 580 trillion cubic feet (Tcf) of natural gas, through December 1979, have been produced in the US. Estimates by various experts of the nation's remaining and undiscovered recoverable supply of natural gas vary considerably. More importantly, however, these differing estimates impact directly upon helium production because they imply widely varying cutoff times for natural gas production. Recent estimates vary from a low of 418 Tcf [3] to a high of 1019 Tcf [4] with several others in between [2]. Accordingly, estimates of the remaining undiscovered recoverable supply of helium will vary approximately by similar factors. The total US natural gas-derived helium resource base (exclusive of unconventional resources) has been estimated by the US Bureau of Mines (BOM) to be ~718 billion cubic feet (Bcf) as of 1978. This total has been reduced by ~25 Bcf as of January 1980. Sources other than the Bureau however, consider that agency's estimate to be somewhat optimistic.

The BOM helium resource base may be categorized as follows:

a.	Depleting	594	
	Nondepleting	124	718 Bcf
b.	Undiscovered	454	
	Identified	264	718 Bcf
c.	Economic and Identified	182	
	Subeconomic and Undiscovered	536	718 Bcf

The total amount indicated is large when contrasted with current demand and projected needs of future energy-related technologies. Nevertheless, the BOM estimate of 718 Bcf of helium contained in natural gas is not totally available. For example, of the total:

83% is depleting
63% is undiscovered
75% is either subeconomic and undiscovered.

In a strict sense only the measured nondepleting economic reserves can be categorized as a guaranteed reserve supply and this amounts to about 60 Bcf.*

Helium in concentrations > 0.3 vol. % also exists in natural gases with a fuel content generally too low to be marketed. Until now, these helium-rich reserves were "shut-in" and had therefore been considered nondepleting. However, the recent deregulation of natural gas has resulted in fuel gas price increases and it has now become profitable in selected cases to upgrade the fuel content of these gases. Under these circumstances, certain heretofore nondepleting fields either already are being, or may soon be, exploited. Loss of the contained helium to the atmosphere will therefore occur unless federal or private action is taken to recover this helium. Specifically, additional drilling in the Tip Top field (0.5 - 0.9 vol. % helium) has commenced to assess more accurately the reserves of natural gas. Should these reserves prove extensive, large scale production will probably begin in the 1982-1987 year time period.

The discussion above pertains to conventional natural gas sources. In addition natural gas may be obtained from so-called unconventional sources. These include geopressured aquifers, methane-in-coal beds, tight gas sands and Devonian shales. The total reserves from all of these sources are believed to be huge, but simultaneously there remains serious uncertainty as to the real extent of these reserves [2].

*This number includes 6.1 Bcf (measured in the Tip Top field in Wyoming. Also in this field, ~38.5 Bcf are classified as indicated.

Helium content analyses have been conducted on a few samples of natural gas obtained from these sources. In general, the analyses concentrate on the low end of the spectrum (subeconomic). Exceptions in specific locales do exist, however. Coupled with the wide geographic areas over which these sources are dispersed, it is highly doubtful that these will serve as major sources of helium.

Other potential sources of helium (excluding the atmosphere for the moment) were examined. Included were: abiogenic methane, gas hydrates, fusion reactors, coal treatment at high temperatures, minerals and other miscellaneous geologic environments. Of these, only coal may possibly show some promise based on some analyses which suggest high helium contents in the effluent gases released upon pyrolytic treatment [5]. Since the nation is about to embark upon a major synfuels-from-coal development program, the possibility exists that significant amounts of helium could be collected. Much work is required however, in testing the various grades of coal in existence.

3. DEMAND

Estimates of the future demand of any commodity are notoriously uncertain and helium is no exception. Today, it is used in a relatively small number of present-day technologies. Most of these commercial applications, which exploit helium's inert gas properties, could be carried on if absolutely necessary with substitute inert gases such as argon and neon. Given such relatively limited uses and the availability of substitutes, it is somewhat surprising to discover that the growth rate of the US helium industry has been in excess of 12% per year for at least the past fifteen years. Furthermore, actual helium prices (in current dollars) have increased less than 20% over the last 15 years whereas prices of most other commodities, on the average, almost doubled. The reasons for this peculiar market behavior are very complex and are discussed elsewhere [2]. It is clear however, that combined governmental/private sector interrelationships have strongly influenced the market behavior of this commodity.

3.1 Demand Through The Year 2000

The demand for helium as shown by several recent projections is given in Fig. 1. The 1977 and 1978 projections still appear reasonable. In particular, the Midwest Research Institute (MRI) estimate has been utilized as a general reference point in this study [6]. Present annual demand is ~1.1 Bcf.

For the next twenty years, the MRI projection shows a continued modest growth of helium market demand at a rate of about 2.5% per year, tapering off slightly as the year 2000 is approached. The forecast implies that no new technologies requiring substantial amounts of helium will be developed and deployed during this period. MRI has also assumed that the price of helium will not change significantly during this same period.

Total cumulative demand through the year 2000 is expected to be ~25-30 Bcf. Of this quantity, ~12.8 Bcf will be used by federal agencies (DOE, DOD, NASA and others).

The constituent uses of helium as determined by the recent study of the MRI are shown in Table I. Significantly, cryogenic usage exceeds by a wide margin that for any other purpose. Energy-related needs for the period 1980-2000 are modest and can be expected to introduce only minor perturbations to the total demand.

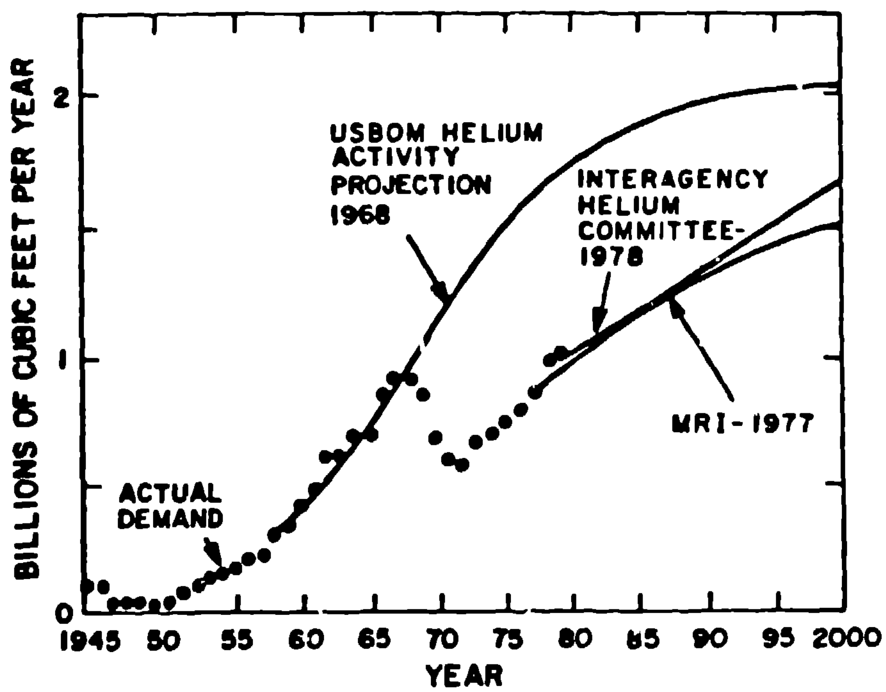

Fig. 1. Market demand for US produced helium through 1979 and alternate projections to the year 2000.

3.2 Demand Scenario For The Post-2000 Year Period

Although substantial amounts of helium will not be needed for energy-related purposes until after the year 2000, the amount required subsequently will depend upon the overall energy demands of the nation and particularly upon the extent to which new helium-dependent technologies are utilized by

TABLE I

CONVENTIONAL HELIUM USAGE

End Use	Percent of Total Volume
1. Cryogenics	34.5
2. Pressurization	16.2
3. Welding	16.1
4. Breathing Mixtures	9.2
5. Leak Detection	4.2
6. Gas Chromatography	4.2
7. Lifting Gas	3.9
8. Heat Transfer	4.0
9. Controlled Atmospheres	2.7
10. Other-purging, medical/clinical, genera. research	5.0

the electrical utility industry.* With respect to the latter, the technologies to be noted already appear to be potentially superior to existing ones technically, environmentally and from the standpoint of improved efficiency. If their reliability can be convincingly demonstrated and if they can also be shown to be sufficiently superior economically to alternative competing technologies, adoption by industry with a reasonable market penetration rate is expected to occur. In this study, it has been assumed that these criteria will be met.

To define helium demand for the early portion of the 21st century, it is necessary to project both US energy consumption and installed electrical generating capacity consistent with overall energy consumption into the same time period.

A number of alternative energy growth scenarios and growth rate estimates have been made by a number of organizations since 1974. During the latter part of 1979 and the spring of 1980, several major reassessments of US energy consumption projections have occurred. These reassessments have been prompted by a growing recognition on the part of forecasters that previous energy use projections have been much too high [7].

In response to these reduced energy growth expectations, two new planning scenarios, the so-called Balanced High Supply (BHS) case and the Best Estimate (BE) case were prepared by the Department of Energy for their FY 82-86 planning exercises [8]. The BHS scenario assumes a favorable domestic energy supply future and projects to a total energy consumption in the year 2000 of 108 Quads, whereas lower supply projections are assumed in the BE case leading to only a 101 Quad consumption by the end of the century. After consideration of: (a) the several recently published and relatively conservative long-term energy supply studies carried out by well-known and respected planning groups not associated with the DOE, (b) the implications of extrapolating DOE's BHS and BE scenarios beyond the year 2000, and (c) the probability of a lower-than-expected 1979-80 energy consumption which will provide a correspondingly lower-than-expected base from which all new energy forecasts must now "take off", an overall energy growth projection identified as He II was adopted by the authors [2]. Through the year 2000, projection He II coincides approximately with that of the mean of the DOE BHS and BE scenarios, through the year 2010 it tracks the CONAES III_3 scenario (3% growth rate for the GNP, energy prices double by the year 2010) [9], and thereafter shows continued energy growth at a rate of about 0.7% per year (reaching 128 Quads in the year 2030). It should be pointed out that the projection He II is not a forecast, but is used solely as a basis for planning and as such represents only a "best guess" of future US energy consumption. Additional details and the rationale for this scenario are given in ref. [2].

Using the DOE BHS and BE scenarios as initial guidance through the year 2000, a projection of installed electrical generating capacity to the year 2030 was made. The procedure adopted was to require that the fraction of total energy utilized in the future by the utility industry for conversion to electricity be a reasonable extrapolation of past behavior and, at the same time, consistent with the views of other informed analysts on how this ratio is most likely to develop beyond the year 2000. Two electrical generating capacity growth curves have been derived.

*Most energy-related applications will be concerned with power generation and distribution for which utilities are expected to continue their present role.

One of these, BC II, is in general accord with recent near term DOE electrical energy supply and demand projections and has been extrapolated to yield about 1480 GWe in the year 2030. The other projection, MS II, assumes a substantial commitment to electrification and yields about 2100 GWe installed capacity by the year 2030. Further discussion on the details of these projections are available in ref. [2].

3.3 Demand From The Year 2000 To 2030

Energy-related uses of helium are projected to be primarily in the area of advanced electric power technology. These uses are not expected to become substantial until well after the year 2000. The energy-related technologies considered include:

(a) Superconducting power transmission lines (SPTL).
(b) Superconducting magnetic energy storage (SMES).
(c) Fusion reactors.
(d) Superconducting motors and generators.
(e) High speed ground transportation.
(f) High temperature gas-cooled reactors (HTGR).
(g) Lighter-than-air transport.
(h) Magnetohydrodynamic power generators (MHD).
(i) Superconducting electronics and instrumentation.
(j) High energy physics.
(k) Stirling engines.
(l) Brayton cycle solar power plants.
(m) VAR control in electric power systems.

Of these, magnetic confinement fusion reactors,* SPTL and SMES will require significant amounts of helium with lesser quantities for the other technologies. These three technologies have been examined in detail on the assumptions that present development trends will be successful and that the electrical utility industry will utilize the technologies [2]. The assumptions presuppose that these new systems will successfully satisfy all of the technological, economic, environmental and other institutional criteria which must be met prior to acceptance and large scale deployment by the industry.

Additional analysis were performed on the other technologies listed above.** The results are shown in Tables II and III and Figs. 2 and 3. The data are presented in terms of the two electrical generating capacity scenarios mentioned in Sec. 3.2. Conventional use remains by far the major consumer of helium.

It must be emphasized that the projected relatively slow introductory phase of these technologies in no way precludes their continued and expanded use in the years beyond 2030. For example, the availability of a virtually-unlimited supply of fuel for the fusion reactor enhances its potential as a primary power source in the years to come assuming technological and economic feasibility can be demonstrated and both environmental and social acceptance follows. Hence, given present engineering designs and successful development

*Detailed data were generated for various Tokamak designs. Needs for other designs of reactors such as the mirror machines were estimated by use of an integral multiplication factor [2].

**These energy-related technologies are included in the "other" category in the tables.

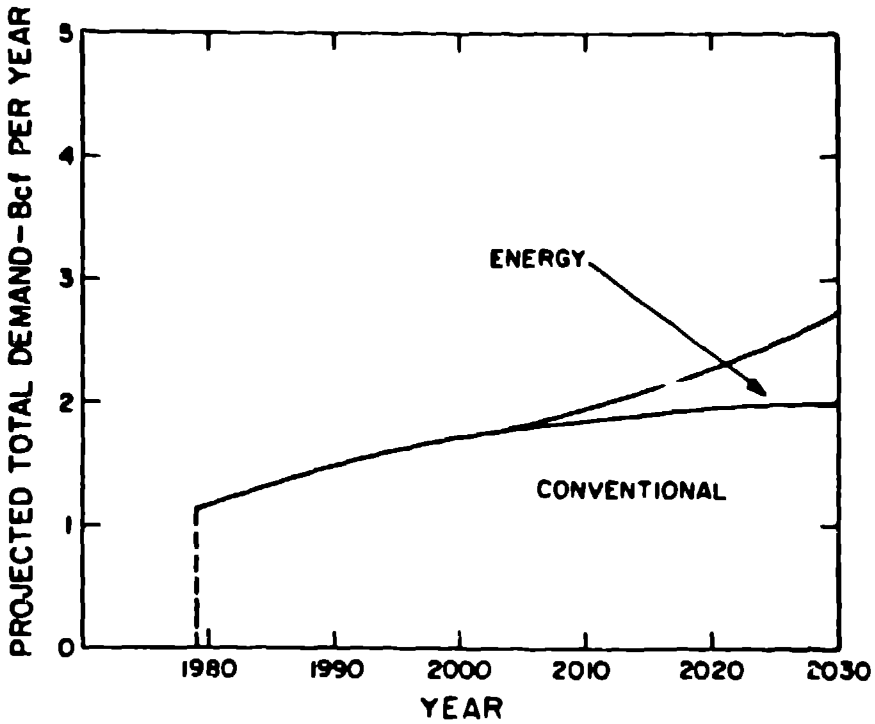

Fig. 2. Projected total annual demand for helium. Data assumes relatively constant helium production costs. The energy demand component includes SPTL, SMES, fusion reactor and "other" energy-related categories.

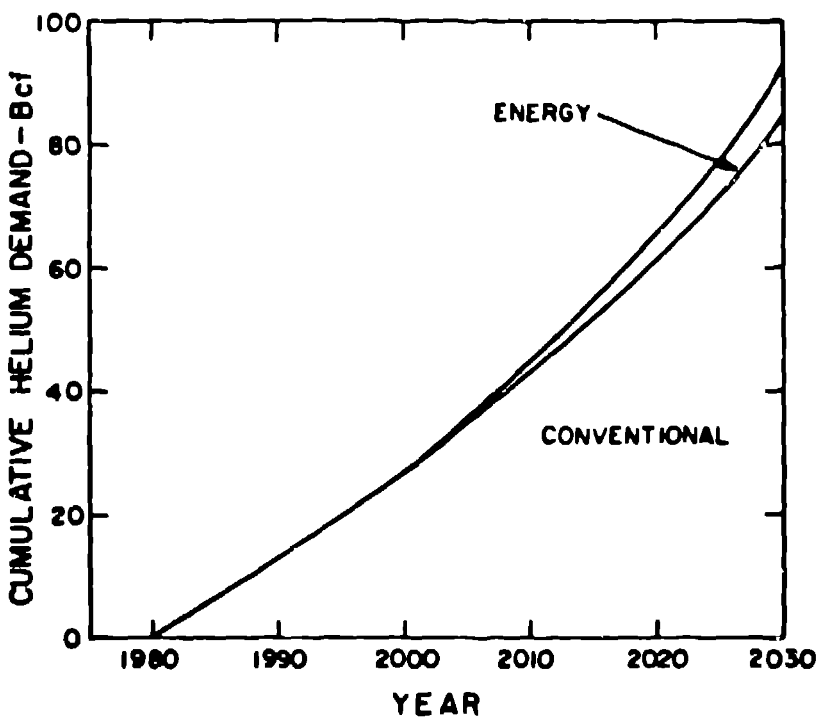

Fig. 3. Cumulative (post-1980) helium demand. Energy demand includes SPTL, SMES, fusion reactor and "other" energy-related categories.

TABLE II

PROJECTED HELIUM ANNUAL DEMAND DATA Bcf PER YEAR[a]

Year	Conventional Uses	SPTL BC II	SPTL MS II	SMES BC II	SMES MS II	Fusion[b] BC II	Fusion[b] MS II	Other BC II	Other MS II	Total BC II	Total MS II
1985	1.28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.28	1.28
1995	1.58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.58	1.58
2005	1.76	0.004	0.010	0.01	0.015	0.01	0.01	0.02	0.03	1.80	1.83
2015	1.84	0.021	0.048	0.03	0.060	0.04	0.05	0.06	0.08	1.99	2.08
2025	1.92	0.052	0.140	0.06	0.150	0.09	0.14	0.10	0.13	2.22	2.48
2030	1.94	0.070	0.204	0.08	0.210	0.12	0.20	0.12	0.16	2.33	2.71

[a]No significance should be attached to third-or even second-decimal places.
[b]For magnetic confinement, Tokamak-type only.

TABLE III

PROJECTED HELIUM DEMAND DATA-CUMULATIVE DEMAND-Bcf[a]

Year	Conventional Uses	SPTL BC II	SPTL MS II	SMES BC II	SMES MS II	Fusion[b] BC II	Fusion[b] MS II	Other BC II	Other MS II	Total BC II	Total MS II
1980	0	0	0	0	0	0	0	0	0	0	0
1990	12.8	0	0	0	0	0	0	0	0	12.8	12.8
2000	28.5	0	0	0	0	0	0	0	0	28.5	28.5
2010	46.0	0.04	0.10	0.1	0.15	0.1	0.1	0.2	0.3	46.4	46.7
2020	64.4	0.25	0.58	0.4	0.75	0.5	0.7	0.8	1.1	66.4	67.5
2030	83.5	0.77	1.98	1.0	2.25	1.4	2.2	1.8	2.4	88.5	92.3

[a]No significance should be attached to second-decimal places.
[b]For magnetic confinement, Tokamake-type only.

and deployment, significant quantities of helium will still be required in the years beyond 2030.

4. SUPPLY

Helium in the US is produced commercially in significant amounts only from helium-rich fuel natural gas, i.e., >0.3 vol. %. Production is obtained from government-owned, privately-owned and so-called conservation plants. The latter are plants originally constructed under a mandate from the 1960 Helium Act. Some of the plants produce crude helium (containing ~20-30% nitrogen), others concentrate on purifying the crude and selling pure helium only. The total US helium production capacity, if all currently operating plants were in full production, is estimated at about 2.4 Bcf/yr for 1980. Actual production is less than this due to natural gas production curtailments, unscheduled plant outages, etc.

Because the gas fields from which helium is now being obtained are being depleted, the amount of helium that can be extracted from these natural gas streams will progressively decrease. Estimates of potential helium production from the conservation plants, the government plant and the private plants as a function of time are shown in Fig. 4. It can be readily seen that towards the end of the decade 1990-2000 the supply of helium from helium-rich fuel natural gas will have decreased to the point that production will cease.

5. THE SUPPLY-DEMAND DILEMMA

Examination of the supply and demand relationships shown in Figs. 2 and 4 reveals the somewhat disquieting news that the present supply of helium from helium-rich natural gas is scheduled to fall below projected demand sometime during the latter part of the present decade. Figure 5 demonstrates this situation more graphically. It is evident therefore, that to supply projected demand additional supply sources must become available.

After 1990, the least costly new sources of helium which can be considered as potential replacements for helium derived from helium-rich natural gas streams are:

1. helium from storage,
2. helium from nondepleting reserves,
3. helium from imports, and
4. helium from helium-lean natural gas streams.

The federally-owned helium in the Cliffside storage reservoir (near Amarillo, TX) is the most immediately accessible source of additional helium available. However, utilization of this source would result in elimination of the nation's helium reserve required for a variety of national security, advanced energy and other needs. Thus, other sources would have to be considered and the helium in storage left alone or used as a last resort.

Certain nondepleting gas fields contain natural gases with methane and other volatile hydrocarbon products in concentrations so low that they have been considered unsuitable for use as fuel gases. It is possible however, to upgrade such natural gases by removal of the diluents (NO_2, CO_2, H_2S, He, etc.). As a result of gas price decontrol, it is now becoming increasingly attractive economically to raise the Btu content of such gases by either physical or chemical processing in order to use upgraded streams directly as fuel or to blend them with other still higher Btu content natural gases. An

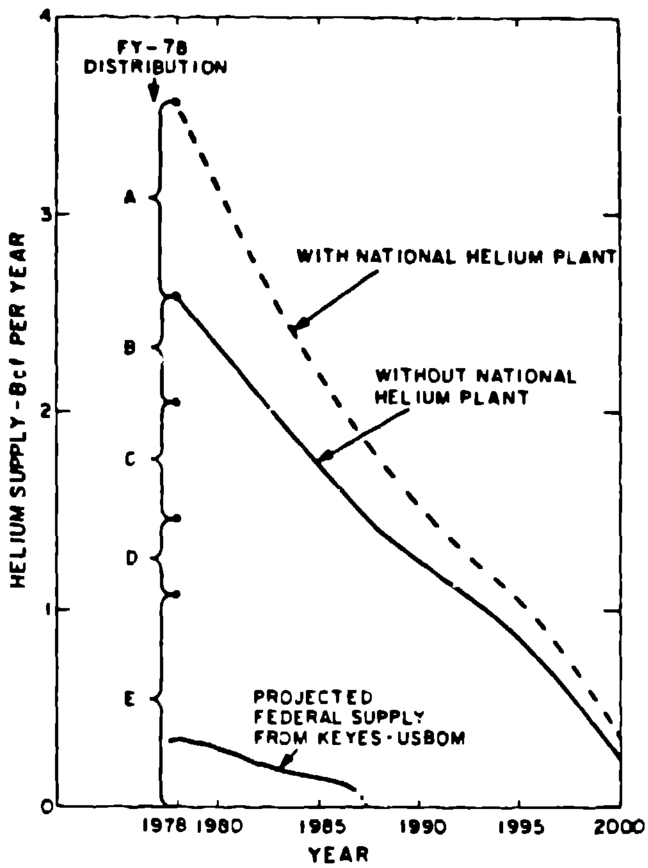

Fig. 4. Potential production from all existing plants from helium-rich natural gas streams to sales, storage and venting.

Legend:

A. Potential production from National Helium Corp. Plant.
B. Natural gas not produced or helium returned to gas stream during unscheduled shutdowns.
C. Vented.
D. Produced and stored.
E. Produced and sold.

example of a nondepleting gas field now undergoing testing to determine the magnitude of its reserves is the Tip Top field mentioned in Sec. 2.

Because of present oversupply, the US is a net exporter of helium. However, certain foreign natural gas fields which are not connected to large consuming areas by pipeline, transport this fuel by liquefying it and loading the product aboard LNG (liquefied natural gas) tankers. During the liquefaction process, the helium contained in such natural gas streams appears as a highly concentrated (5-6% helium) by-product. Since the depletion of such fields is transportation-limited and, by reason of location, this condition is expected to continue well into the 21st century, substantial amounts of helium (~2 Bcf/yr world-wide) will continue to be available from this source at least during the time period co ed by this report and probably beyond. At the present time, no market exists for this helium and no effort is being made to

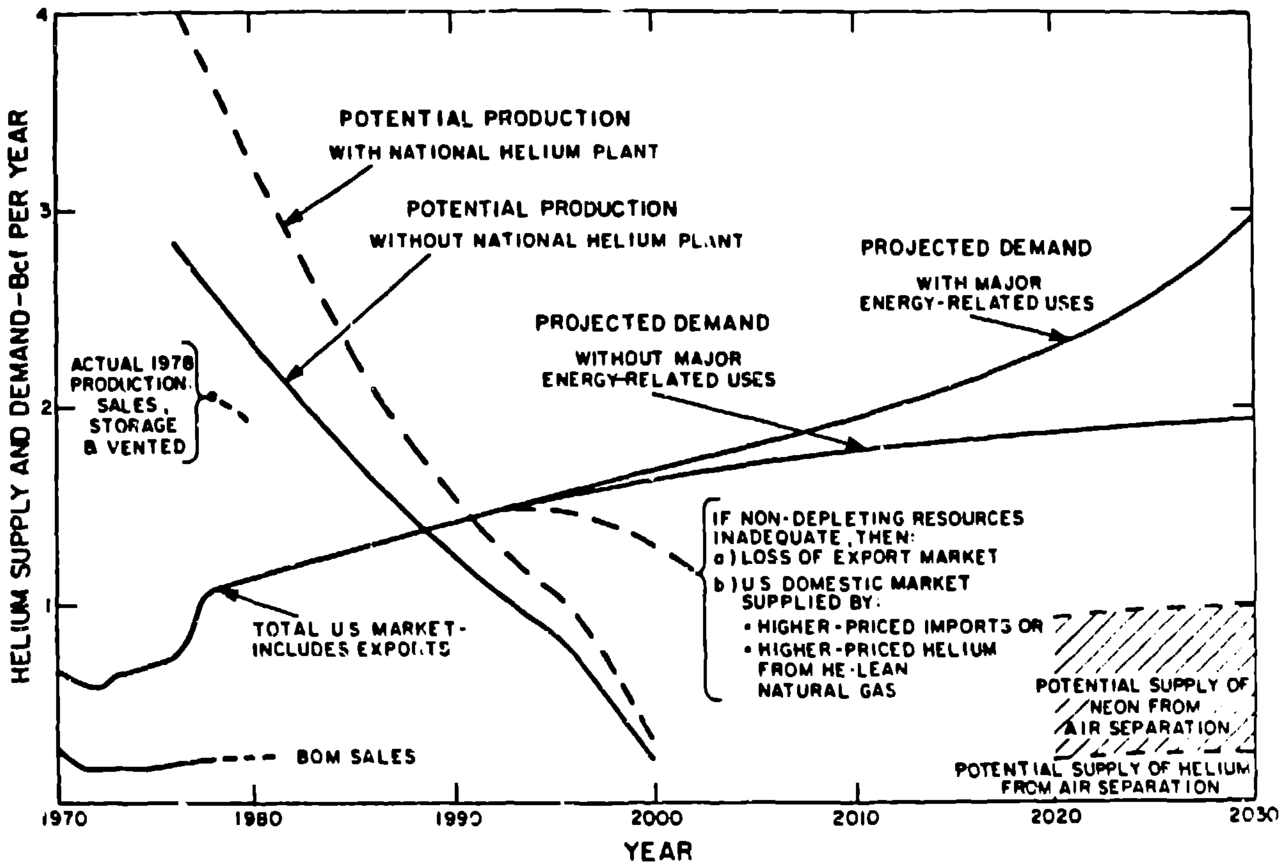

Fig. 5. Intercomparison of projected supply and demand for helium.

recover it. Nevertheless, imports remain as a potential supply option, if required.

The existence of many helium-lean (0.1-0.3 vol. %) gas streams is well-known and in principle can supply additional helium (~30 Bcf-measured). Because these streams are widely dispersed and engineering and economic information is lacking, it cannot be guaranteed, that an adequate number of economically-sited extraction plants could be constructed for the necessary production.

Another potential source includes that quantity obtainable from air separation plants (a He/Ne mixture in the ratio of 1/3 is a by-product). At present the total quantity per year is both too small and too costly. Finally, it may be that sufficient helium exists in the coal and oil shales to be used for synfuel production. Much more information is required however, prior to considering these latter sources.

6. INTERNATIONAL CONSIDERATIONS

As history amply demonstrates, new technological efforts of industrialized nations abroad have closely paralleled those undertaken in the US and vice versa. Thus, it is not unreasonable to assume that the helium requirements of the technologically advanced countries will also continue to increase and may in sum eventually exceed those of the United States. It should be noted however, that the world approach to helium usage and conservation differs markedly from that in the US in that there is no massive stockpiling, small scale recycling efforts are more common, and usage is generally more conserving and less wasteful.

As the largest producer of helium in the world, the US has enjoyed for many years a privileged and lively foreign trade in this commodity. The exports from commercial helium extraction plants have gradually increased to ~18% of the total high purity sales (1.1 Bcf in 1979), ~200 million cubic feet (MMcf) [10].

Production of helium in foreign countries is restricted to: Poland (150 MMcf/year capacity but presently producing about 38 MMcf); Netherlands (~7 MMcf); France (~6 MMcf); USSR (~70 - 100 MMcf, estimated). Canada used to produce ~35 MMcf annually but production has ceased, at least temporarily. The Polish plant has the capacity to supply ultimately the European market.

No comprehensive and systematic studies of foreign helium reserves have ever been made along the lines of the US effort. However, extensive exploration for new sources of natural gas has led to a reasonably systematic sampling and analysis of well products over wide geographical areas. Table IV shows some selected examples of the helium concentrations that have been reported.

Algeria is known to have about 125 Tcf of natural gas reserves scattered among 13 fields. In addition, a score of other unevaluated fields are believed to exist. About 66 % of the known reserves are contained in three giant fields of which the Hassi R'Mel field is estimated to contain some 50 Tcf of natural gas. In addition to being among the largest natural gas fields in the world, the helium content of this field is approximately 0.17 vol.% . Associated helium reserves would therefore amount to ~85 Bcf in this one field alone.

7. ENERGY REQUIREMENTS

It has been assumed in the study that no major technological "breakthroughs" leading to significant decreases in the energy requirements for helium extraction will occur.* Clearly the discovery of new natural phenomena leading to more efficient extraction technologies cannot be ruled out (see Sec. 8), but there appears to be no way of avoiding the fact that the volume of carrier gas that must be treated to extract one unit of helium is inversely proportional to the helium concentration and a major fraction of the energy cost of helium extraction is found to reside in the mechanical work done in handling that carrier gas. Since gas separation technology is now over 100 years old, it can be characterized as a mature technology. Hence, it is not surprising to find that gains in the efficiency of helium extraction technology (with the exception of those attributable to changes in the scale of the operation) have been minimal during the past half century.

The ideal extraction energy required to separate helium from a mixture of gases may be calculated by use of the following equation:

*It should be stressed that the present helium market situation is not conducive to extensive exploratory research in this area.

TABLE IV

HELIUM CONCENTRATIONS IN FOREIGN GAS FIELDS [2]

Country (Field)	Helium Content (volume%)
North Sea Gas Fields:	
British Sector	0.05 - 0.12
Norway Sector	0.02
Netherlands Sector	0.06
Algeria	0.17
Nigeria	0.02
Canada	0.02 - 1.9[a]
Mexico	Trace - <0.05
Australia	Trace - <0.08
Indonesia	<0.02
Iran	0.01 - 0.06
Persian Gulf (General)	<0.007
Poland	0.02 - 0.14
USSR	Various, generally less than 0.15
South Africa	2.9[b]

[a]The amount of helium estimated to exist in Canada natural gas is 30-39 Bcf. Of this total only about 11% is contained in helium-rich (>0.3%) natural gas.

[b]This field is apparently not now being produced.

$$W = - RT (x_1 \ln x_1 + x_2 \ln x_2)^*$$

where: W is the ideal extraction energy,
R is the gas constant,
T is the absolute temperature,
x_1 is the mole fraction of helium, and
x_2 is the mole fraction of air or methane.

The resulting curve shown in Fig. 6 represents the thermodynamic minimum work of isothermal separation of a mixture of helium and air (or methane) at various concentrations of helium. The increasing difference between the actual and the theoretical work that appears as the low helium concentration side of the diagram is approached, arises, as noted previously, from the fact that large mechanical and thermal inefficiencies are associated with the movement of any carrier gas through gas separation equipment. Obviously, as the helium concentration decreases, more such carrier gas must be treated. Based on industry data, a simple model, E = 150/P can be formulated where E is the energy in kilowatt hours per thousand cubic feet (kWh/Mcf) and P is the percent helium. This is also shown in Fig. 6.

*Corrections for the non-ideality of real gases are negligible at the pressures and temperatures involved and the molecular components of air other than helium can be treated as a "single" other component, such as methane.

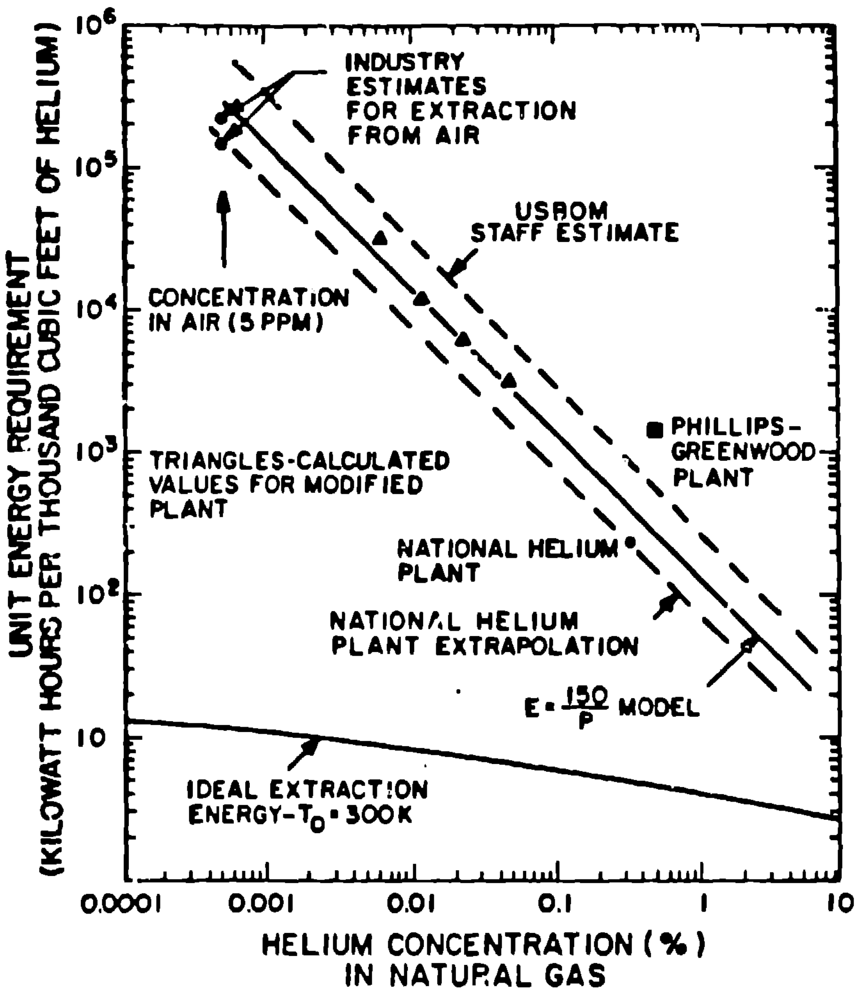

Fig. 6. Actual and calculated helium extraction energy requirements based on the simple model E = 150/P (solid line) and industry data.

To visualize the amount of energy associated with extracting helium from gas mixtures of various concentrations, Fig. 7 plots total energy in units of tons of coal and barrels of oil vs. helium production rate. Note, for example, that it would require approximately 10% of the 1978 annual coal production to produce 1 billion cubic feet of helium per year from 0.001% gas.

8. METHODS OF HELIUM SEPARATION

Separation of helium from natural gas (>0.3 vol. % helium) is effected by low temperature gas liquefaction. In principal this process can be used to effect separation from progressively helium-lean natural gas streams and from all types of very dilute gas streams including the atmosphere. The problem of course is that the total energy required for separation increases markedly as the helium concentration decreases (Fig. 6). For separation from the atmosphere, average concentration of ~5 parts per million (ppm), the required energy of separation has been estimated at ~1.7 x 10^5 kwh/Mcf (Fig. 6).

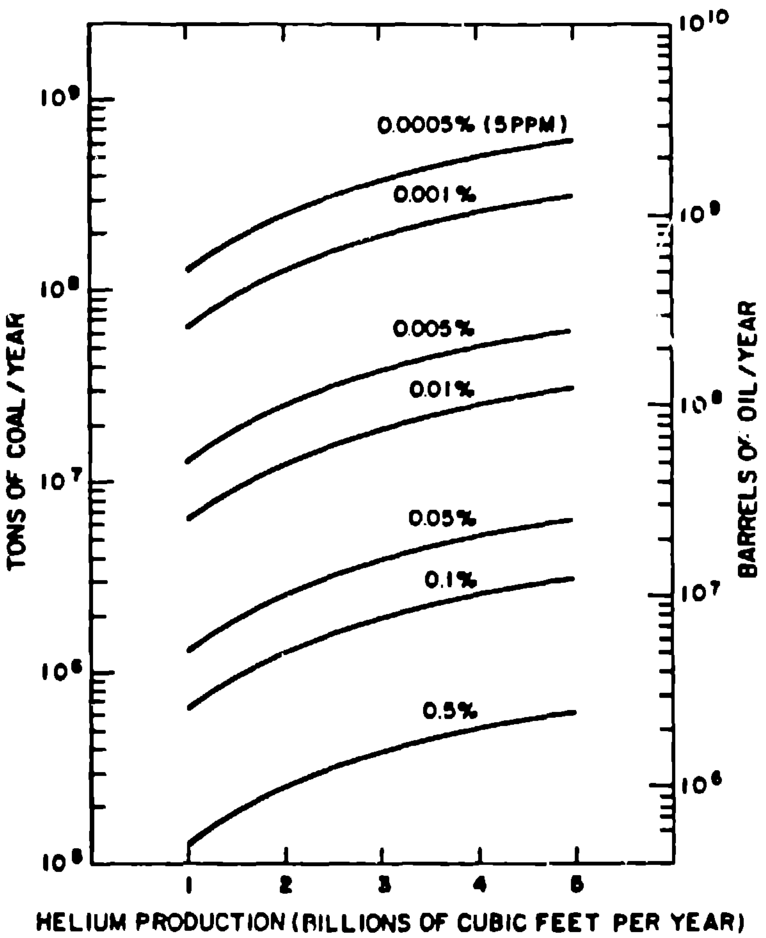

Fig. 7. Total energy required to produce helium from various concentrations of helium in natural gas as a function of annual production rate. (Based on the assumption that the production of 1 MW of electricity requires 10 tons of coal/day or 40 barrels of oil/day).

Interest in the potential separation of helium from the atmosphere arises from the observation that our present sources are depleting and that eventually, the final source must be the atmosphere itself. It has been estimated that the atmosphere contains in excess of 7 x 10^5 Bcf of helium [2]. Although the quantity of helium contained in the atmosphere is enormous compared to any projected demand, the extreme dilution makes it both difficult and expensive to attempt any large scale recovery of atmospheric helium. It has also been estimated that atmospheric extraction costs would be ~$7000/Mcf in 1980 dollars compared to ~$25-30/Mcf (market) from helium-rich natural gas [2]. Hence, because of the large energy and cost requirements for the cryogenic process used in very dilute gas mixtures, it was desirable to investigate other methods for helium separation.

A number of alternate methods were examined for both technical and economic feasibility. These included: diffusion (differential, selective and thermal); photoexcitation (laser, optical and electron bombardment); aerodynamic (gas centrifuge, Becker nozzle and vortex tube); and the "space scoop".

Details of each process have been given elsewhere [ ]. Of these methods (the cryogenic process is of course technically and economically feasible), only the differential and selective diffusion techniques appear to be feasible. Other methods are either marginal, not feasible with state-of-the-art technology or require a more detailed study to establish technical and economic feasibility. A summary of the assessment of helium separation methods is shown in Table V.

TABLE V

SUMMARY OF ASSESSMENT OF HELIUM SEPARATION METHODS

Separation Method	Feasibility Technical	Feasibility Economic[a]	Degree of Development
Cryogenic and Adsorption	yes	yes	state-of-the-art, in practice
Differential Diffusion	yes	yes	state-of-the-art, in practice
Selective Diffusion	yes	doubtful	almost state-of-the-art
Thermal Diffusion	doubtful	no	in use for small quantities of other isotopes
Photoexcitation (Laser)	no	no	conceptual only
Photoexcitation (Optical)	doubtful	no	conceptual only
Electron Bombardment	doubtful	no	conceptual only
Gas Centrifuge	doubtful	no	conceptual only
Becker Nozzle	doubtful	no	conceptual only
Vortex Tube	doubtful	no	conceptual only
Space Scoop	no	no	conceptual only

[a]Economic feasibility for a process is arbitrarily defined as the ability of that process to be operated with an energy consumption range no higher than that of the energy band of Fig. 6.

9. RECENT CONGRESSIONAL ACTIVITIES CONCERNING HELIUM CONSERVATION

Since Congress authorized the original conservation program (1960) and exercises annual spending authority, its involvement has produced much discussion over the years either through individual Congressional advocates and adversaries or formal hearings. Since the termination of the conservation program (1971/1973), several bills have been introduced in the Congress to re-establish some sort of conservation policy and program. Virtually all have died in committee. Although there are several strong advocates in the Congress, there has not been enough interest or strength as a whole to ensure the passage of any given bill to date.

In March of 1979 there was submitted to the 96th Congress (1979-80) H.R. 2620 [11], an act to provide adequate supplies of helium for future energy and conservation purposes. Three hearings were held on H.R. 2620 during 1979 and in consequence a revised version, H.R. 7336, was introduced in the Second Session of the 96th Congress (1980) [12].

As the hearings on H.R. 2620 progressed, it became clear that the general idea of resurrecting the former federal helium conservation program in almost any form was opposed by the economics community, was strongly supported by the scientific and engineering communities and was received with mixed reactions from the industry.

The primary thrust of H.R. 2620 was to require the separation and storage of practically <u>all</u> helium contained in this nation's natural gas as it was withdrawn from reservoirs for use as a fuel or a chemical feed stock. The limiting concentration of helium below which it was unnecessary to remove the helium was set in H.R. 2620 at 0.01%, but in response to the recommendations of many who testified at the hearings on H.R. 2620, this limit has been raised to 0.3 % in H.R. 7336. In addition, several other provisions of H.R. 2620 to which objections were raised during the hearings have also been eliminated or modified in H.R. 7336.

At the present time, one hearing has been held on H.R. 7336. Unfortunately, the consideration of other more urgent energy bills has precluded any attempt to bring the helium bill to a vote in this session of Congress. It must now await the formation of the 97th Congress.

Barring the enactment of specific legislation now undergoing discussion in the Congress, no action is contemplated by the federal government or the natural gas industry to recover helium either from the helium-rich fuel natural gas streams not already being exploited or from any helium-lean fuel natural gas streams. There is not now nor is there predicted to be a high enough market demand for helium prior to the end of the 20th century to warrant the design and construction of privately financed additional extraction plants. In the interim, much of the nation's remaining helium reserves as well as some of its "undiscovered" helium resources will have been dissipated into the atmosphere.

10. SUMMARY

This paper discusses information obtained as a result of a reexamination and revision of the data base underlying the document ERDA-13, "The Energy-Related Applications of Helium." The following is both a summary of the information presented herein as well as conclusions drawn pertaining to the long range effects of the present situation in helium conservation:

- There remain serious uncertainties concerning the extent of domestic natural gas resources. These uncertainties translate themselves into derived estimates of the contained helium, especially into estimates of the helium presumed to be contained in still undiscovered natural gas fields. Despite the significant increase in exploratory drilling activities and the concomitant completion of a very large number of wells, the production of natural gas has tended to decline annually. Furthermore, no other natural gas field equivalent (in both high helium content and size of resource) to that of the Panhandle-Hugoton field has yet been found despite extensive exploration.

- Helium exists in conventional natural gas used as fuel, but its concentration varies from field to field. The total US natural gas-derived helium resource base (exclusive of unconventional resources) has been estimated by the US Bureau of Mines (BOM) to be ~718 billion cubic feet (Bcf) as of 1978. This total has been reduced by ~25 Bcf as of January 1980. Sources other than the Bureau however, consider that agency's estimate to be somewhat optimistic. The estimate of 718 Bcf must be qualified to show that ~83 % is depleting, ~63% is undiscovered, and ~75 % is either subeconomic and undiscovered.

- Unconventional natural gas resources have also been examined as potential sources of helium. In general, it has been found that:

  1. Uncertainties exist with respect to the amount of natural gas in such sources as: geopressured aquifers and shales, Devonian shales, coalbeds and tight gas sands. Although only a few analyses for helium exist, the majority suggest subeconomic levels of helium. High helium contents are occasionally noted in isolated areas but these are not necessarily representative of the bulk resources. The wide geographical distribution of individual sources may well preclude economic exploitation.

  2. Other potential sources were examined including: abiogenic methane, gas hydrates, fusion reactor generation, minerals, coal degradation, and various miscellaneous geolcgic environments. Of these, only coal appears to have any near-term potential assuming that the high helium contents indicated by pyrolysis of a few samples are representative and that massive exploitation of the nation's coal reserves will be undertaken in the years ahead to provide a major new energy source, e.g., synfuel production.

- Current total demand for the US helium is about 1.1 Bcf/yr. It is also worth noting that the helium industry has experienced a large percentage growth in recent years. Major research and industrial uses of helium include: cryogenics, pressurization, welding, breathing mixtures, leak detection and chromatography. Despite the recent large increases in consumption all these uses are expected to increase more slowly in the future, reaching a level of about 1.5 - 1.7 Bcf/yr in the year 2000. Cumulative demand equal to 25-30 Bcf is expected by the year 2000.

- Major energy-related uses of helium are projected to be primarily in the area of advanced electric power technology. These uses are not expected to become substantial until well after the year 2000. How much helium will then be required depends: (a) upon overall energy usage in the US, (b) upon the "mix" of the forms in which the energy will be utilized, and (c) upon the number of new energy technologies now under development by the DOE that ultimately become technically and economically feasible.

- For this study, one energy growth scenario has been developed whose demand estimates are generally consistent with those being used by the DOE for FY 82-86 planning purposes. From this projection two electrical generating capacity growth curves have been derived. One of these, BC II, is in general accord with recent near term DOE electrical energy supply and demand projections and has been extrapolated to yield about 1480 GWe in the year 2030. The other projection, MS II, assumes a substantial commitment to electrification and yields about 2100 GWe installed capacity by the year 2030.

- Several helium-dependent energy-related technologies have been identified which will require significant amounts of helium. The three most important are:

  1. Superconducting power transmission lines (SPTL)
  2. Superconducting magnetic energy storage (SMES) and
  3. Magnetic confinement fusion reactors

  Estimates of helium demand with time have been developed for these technologies and other helium-dependent technologies.

- Conventional uses noted previously could require as much as 1.9 Bcf annually by the year 2030. The combined SPTL, SMES, (Tokamak-type) fusion reactor and other energy-related technology requirements are estimated to be ~0.8 Bcf annually by the year 2030. Cumulative helium requirements amount to about 92 Bcf by the year 2030.

- Total US helium production capacity, if all currently operating plants were in full production, is estimated at ~2.4 Bcf/yr for 1980. Actual production is less. Supply now exceeds demand by a factor of approximately two with the excess being stored or vented. By approximately 1990, the volume flow of the helium-rich natural gas feeding these plants will have decreased to the point that the maximum helium production (supply) available from all of the existing helium extraction plants, private plus government plus conservation, will no longer be sufficient to satisfy demand. A choice will then have to be made with respect to the source of additional helium. The available source options at that time will probably include: (a) federally-owned stored helium, (b) nondepleting helium-rich gas fields, (c) imports, (d) helium-lean gas fields, (e) air separation plants, and (f) coal and/or oil shale plants. The price of the helium from these several options can be expected to vary by about a factor of ten.

- Although the US has been the major world source for helium in the past, foreign gas field sources will assume more importance in the future. A Polish plant, when it reaches its full production capacity, could supply the present European market. A major potential source of helium is available from the Algerian natural gas fields. The latter source will last into the next century. At present, foreign sources, exclusive of Poland, are not being exploited because a sufficiently large market external to the US has not yet developed. Hence, the present large foreign resource is also depleting. During the post-1990 year time period, when projected demand is expected to exceed projected supply, foreign sources of helium will be an important option available to reduce the domestic US supply gap. Looking ahead to when air extraction may be required, imports can provide a further postponement of the time when it will be necessary to resort to this energyintensive process. It should be recognized that growing world-wide demand could also have an effect on the availability of imports for US use.

- Because gas separation technology is relatively mature, significant gains in separation efficiency have at best been minimal in recent years. A major fraction of the energy cost of helium extraction via the cryogenic method is found to reside in the mechanical work done in handling the carrier gas. This additional work is not taken into account in the calculation of the theoretical minimum work of separation. These excess energy requirements, in particular as demonstrated by the increasing difference between actual and theoretical work as the lower helium concentrations in natural gas are approached, arise primarily from the need to handle very large volumes of carrier gas and to compensate for the large thermal inefficiencies existing in the system. In general, the volume of carrier gas that must be treated to extract a unit of helium is inversely proportional to the helium concentration in that gas. In terms of energy, the production of 1 Bcf/yr of helium from the atmosphere would require about 17% of the projected 1980 annual coal production or about 500 million barrels of oil.

- A number of alternative separation methods for extracting helium from the atmosphere, helium-lean natural gases and low-level outer space have been examined for both technical and economic feasibility. Separation methods include: cryogenic; diffusion (differential, selective and thermal); photoexcitation (laser, optical and electron bombardment); aerodynamic (gas centrifuge, Becker nozzle and vortex tube); and the "space scoop". Technical feasibility has already been established for the cryogenic process. Some of the diffusion techniques (differential and selective) are also feasible. Other methods are either marginal, not feasible or require a more detailed study to establish technical feasibility.

- Helium exists in the atmosphere with a steady state concentration of ~5 parts per million. Extraction from the atmosphere is possible but to do so will be much more costly than at present in terms of energy and dollars by a factor of several hundred.

- It has been shown that the helium conservation issue is one of extreme complexity. One particularly important policy problem is whether any action should be taken at present to initiate an effort to extract helium from additional helium-rich sources such as those presently classified as nondepleting. The indeterminacy of the supply/demand situation some 50 years from 1980 only serves to exacerbate this problem. Legislation is presently under consideration in the Congress with the avowed purpose of creating a new national conservation program.

REFERENCES

[1] Krupka, M. C. and Hammel, E. F., Dec. 5-7, 1977. Energy, helium and the future. Miami International Conference on Alternative Energy Sources, Miami Beach, FL.

[2] Hammel, E. F. and Krupka, M. C., August 1980. The energy-related applications of helium - A revision of the ERDA-13 data base. Los Alamos Scientific Laboratory report LA-8455-MS.

[3] Hubbert, M. K., March 8, 1979. Statement at the House Subcommittee on Energy and Power hearings on the Helium Energy Act of 1979, H.R. 2620, Washington, DC.

[4] Potential Gas Committee, Potential Gas Agency, April 1979. Potential supply of natural gas in the US (as of Dec. 1978). Colorado School of Mines, Golden, CO.

[5] Patteisky, K. 1954. The thermal springs of the Ruhr area and their juvenile gases. Gluckauf, 47-48, p. 1508.

[6] Contract between Midwest Research Institute and the US Department of the Interior, Project No. 4157-D, January 31, 1977. Comprehensive investigation and report on helium uses, final report.

[7] Marshall, E., 1980. Energy forecasts: sinking to new lows. Science, 208, p. 1353.

[8] Department of Energy Policy and Fiscal Guidance Energy Projections, 1980. Appendix D.

[9] Freeman, 1979. CONAES, energy in transition 1985-2010, San Francisco.

[10] Annual report to the Congress on matters contained in the Helium Act, 1979. US Department of the Interior, Bureau of Mines, Washington, DC.

[11] Helium Energy Act of 1979, H.R. 2620, 1979. Subcommittee on Energy and Power, Committee on Interstate and Foreign Commerce, US House of Representatives Washington, DC.

[12] Helium Energy Act of 1980, H.R. 7336, 1980. Ibid.