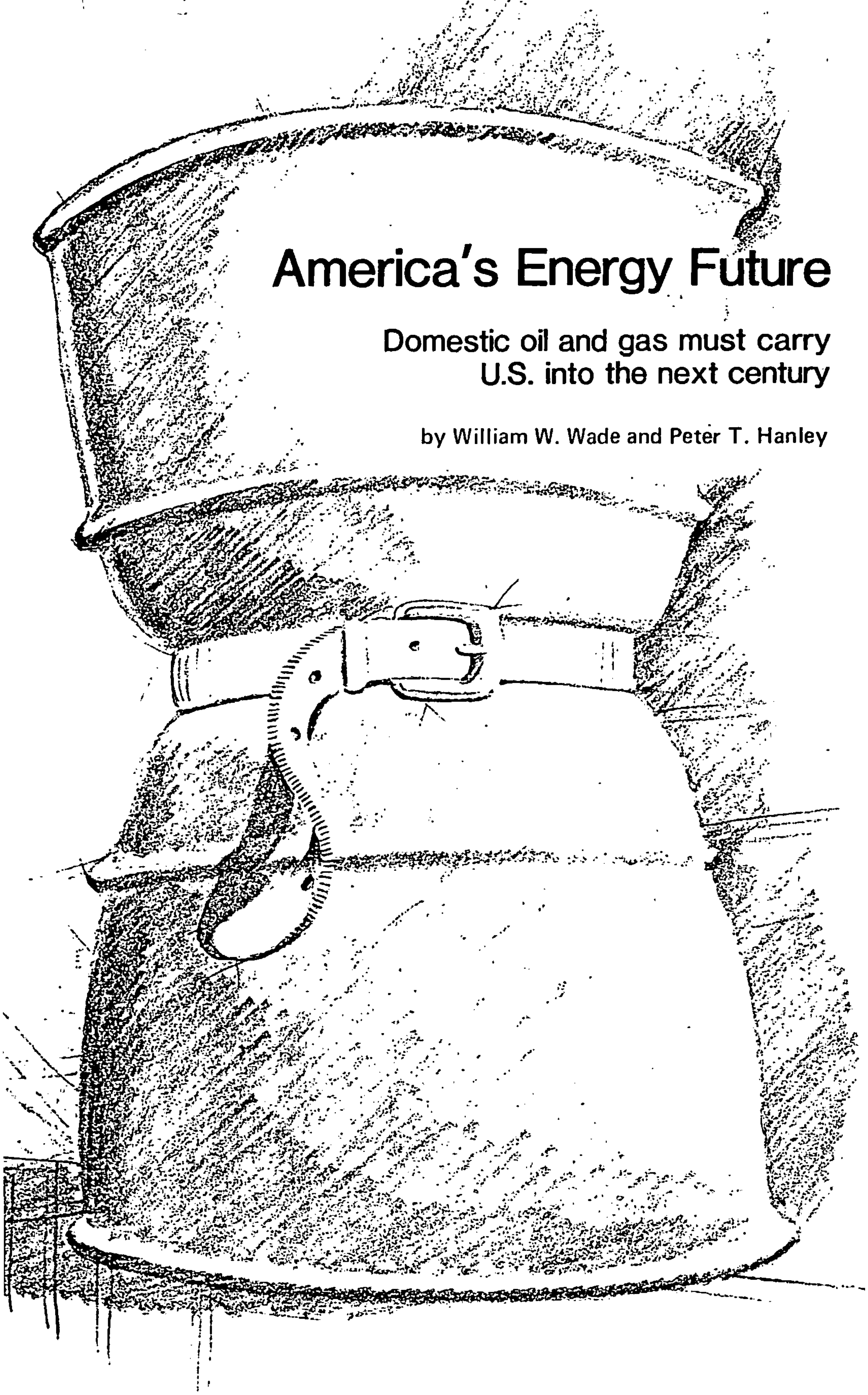
America's Energy Future

Domestic oil and gas must carry U.S. into the next century

by William W. Wade and Peter T. Hanley



only teeth get impacted

The current world oil situation is one which has profoundly impacted nearly every person on the globe. The future trends in world oil supply and demand will, to a large extent, determine how well America will be able to function in the years ahead. At this point, we anticipate that world oil production will be declining before the end of the century, a prospect that the United States must be prepared for.

BACKGROUND: WORLD OIL SUPPLY AND DEMAND

The anticipated demand for energy in the U.S. in the next two decades is a matter of extreme importance. Later in this article, we will discuss the ratio of energy used to gross national product (GNP). By examining this ratio during different periods of the twentieth century, we can develop a basis for forecasting U.S. energy demand in the remainder of the century.

Although alternative energy sources developed with advanced technology will play an important role in the next century, oil and gas will remain the mainstay of America's energy supply throughout the 1980s and into the 1990s.

Alaska's outer continental shelf (OCS) is a critical link to America's oil and gas future. Transforming the inhospitable regions of Alaska's OCS frontier into oil-producing areas will be a monumental task. As a result, Alaska's large oil potential cannot be explored, discovered, and developed in large quantities before the early 1990s.

The years 1983 to 1995 will be the most critical 12-year period in U.S. energy development. Current indications are that by 1983 the Soviets will have shifted from sellers to buyers in the world oil market and will compete directly with western buyers for middle eastern oil. Under the existing OCS lease schedule, incremental supplies of Alaskan oil will not be available to reduce reliance on OPEC imports or mitigate the conflict with the Soviets for Middle East oil until late in this critical 12-year period. No significant supplies of synfuels will be available until late in this 12-year period.

World Oil Production Forecasts

A growing consensus of crude oil production forecasts indicate non-communist world oil production will peak around 1990 and decline thereafter. The average of various forecasts shown in Table 1 reflects the expected trend with a peak near 60 million barrels per day (b/d) by 1990 and slow decline thereafter. A recent Congressional Budget Office study is even more pessimistic. It calls for production in the 56-58 million-b/d range for 1985 and 1990.

Both Exxon and the Central Intelligence Agency (CIA) have emphasized in recent months that throughout the 1970s, new oil discoveries replaced no more than half the oil produced. Prior to 1970, discovery rates were well in excess of production. The CIA has the most gloomy forecast (1): "Global oil production is peaking and will decline throughout the 1980s. . .The expected decline. . . is the result of a rapid exhaustion of conventional crude oil."

Crude oil supply forecasts hinge critically on assumptions about OPEC production. The British Petroleum (BP) forecast of world production not only indicates the possibility that OPEC may limit production to 30 million b/d beyond the mid-1980s; like the CIA's forecast, it is also very pessimistic about the remaining world production capacity. BP assumes that significant new supplies in non-OPEC countries will not be brought into production and believes non-communist world production capacity will peak by 1985 at the latest. Thus, while the average of forecasts in Table 1 shows a peak in 1990, BP and the CIA agree that world oil production could peak sooner and that 1990 and 2000 production levels could be much lower than the average.

OPEC's Continued Importance

The range in the forecasts after 1985 in Table 1 is explained by the various company and agency assumptions about OPEC production. Political considerations emerging within the Middle East oil-producing countries in 1980 suggest that even though proved reserves would allow higher production, OPEC oil during the 1980s probably will not be produced at maximum rates just because consuming countries want the oil. The world in the last two decades of the twentieth century will be oil supply-limited due as a result

TABLE 1.
Non-Communist World Crude Production Forecasts
(Million b/d)

Source	Forecast Description	1980	1985	1990	2000
British Petroleum	OPEC at maximum	–	64	62	52
	OPEC no increase	–	55	52	43
Standard of Indiana	Base case	53.8	59	–	–
	Pessimistic	52.5	55	–	–
Standard of California	1990 Plateau	53	58	60.5	60
Shell	Optimistic	–	–	66.5	70
	Pessimistic	–	–	57	63
Exxon	1979-Year-end	53	–	57	58
CIA	Low	53	48	–	–
	High	–	49	–	–
Congressional Budget Office	–	–	55	56	–
Michael F. Thiel	Upper OPEC	57	65	70	
	95% OPEC limit	55	63	67	–
	Lowest OPEC	47	55	59	–
Average Production		53	57	61	58

Note: For consistency between forecasts natural gas liquids are excluded. Natural gas liquids equal an additional 5 percent.

Sources: *Oil & Gas Journal*, 1980, vol. 78, no. 17, p. 50.

Ibid, 1979, vol. 77, no. 46, pp. 163-169.

Congressional Budget Office, 1980, The world oil market in the 1980s: implications for the United States, May.

Exxon, 1979, *World Energy Outlook*, December.

Pocock, C.C., 1979, *World Oil*, October, pp. 107-111.

Thiel, Michael F., 1979, *World Oil*, October, pp. 123-133.

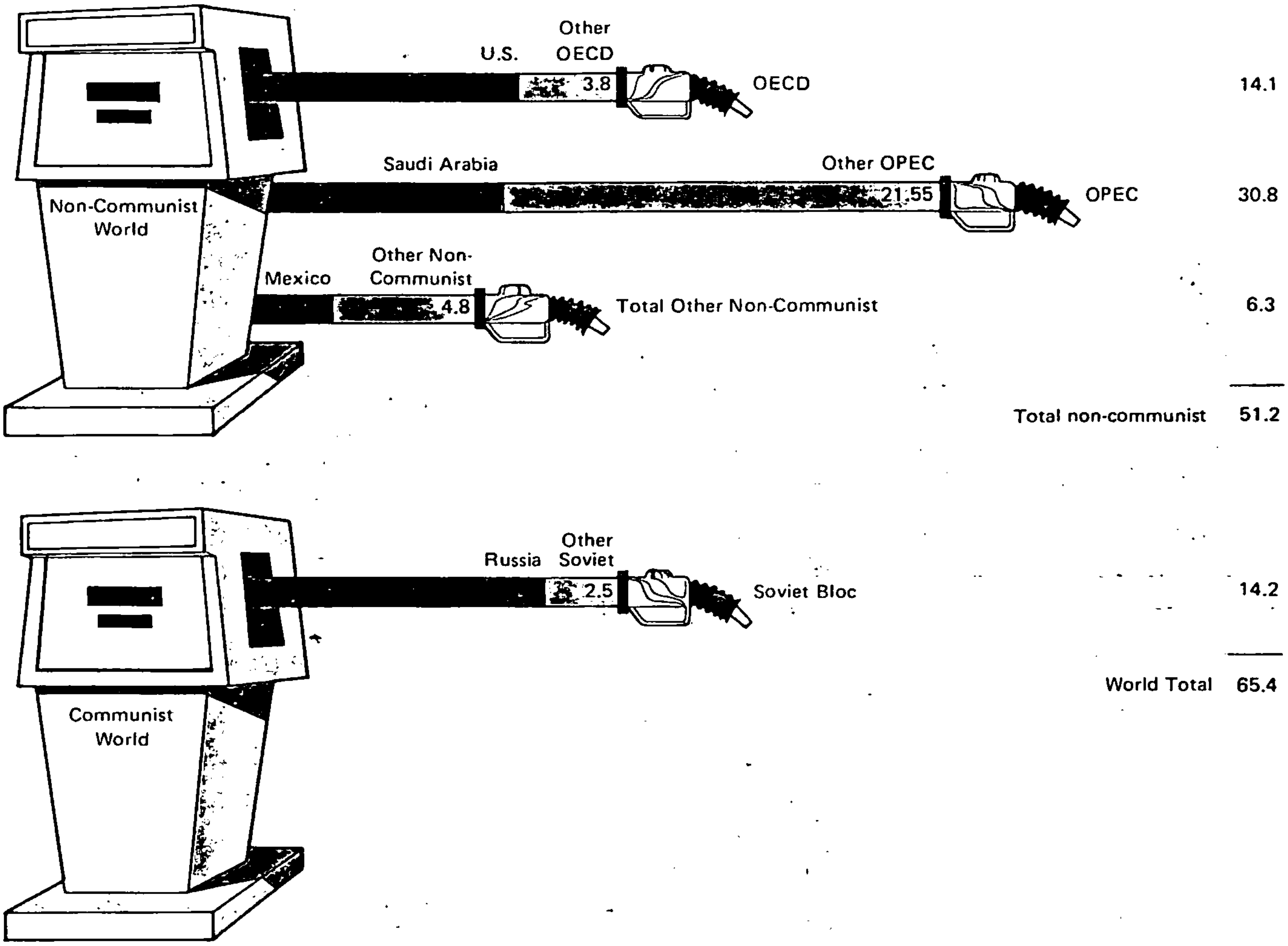


Figure 1. World Oil Production: 1979, Including Natural Gas Liquids (Million b/d). Source: Oil & Gas Journal, *1980, vol. 78, no. 8, p. 59.*

of both political instability and physical resource limitations.

Figure 1 shows that OPEC's share of the non-communist world oil production was over 60 percent in 1979. The world will remain dependent on OPEC's oil throughout the remainder of the twentieth century. The *Oil & Gas Journal* (2) reported, "Most industry analysts expect OPEC production to remain about 30 million b/d at least through 1985." Many OPEC observers believe there will be little economic incentive to exporting countries to expand production much above 30 million b/d after 1985. Incremental production would only increase the OPEC nations' financial assets held in foreign banks and would not benefit their domestic economic growth.

Although Saudi Arabia has maintained its production at 9.5 million b/d for the first half of 1980, the CIA expects the Saudis to announce very soon an 8.5 million b/d or less production limitation (1). Kuwait, which could maintain output at its existing capacity of 2.7 million b/d for at least 50 years, has already limited production to 1.5 million b/d because it cannot use its oil revenue productively. Iran's production is very much dependent on western investment and technology. Whether Iran's production will return to prerevolution levels in this decade cannot be forecast. Furthermore, it is impossible to predict what impact the recent conflict between Iraq and Iran will have on production in either country. So long as the western nations are dependent on OPEC oil, the OPEC countries will be able to increase their revenue flows by raising prices while holding production stable.

So long as the western nations are dependent on OPEC oil, the OPEC countries will be able to increase their prices.

Soviet Supply Problems

A CIA forecast (3) contends that the potential oil shortage in the western world will be compounded by Soviet Bloc production capacity limitations. According to the CIA, USSR output will rise from 11.7 million b/d in 1979 to 12 million b/d in 1980 and then decline—in spite of remaining proved and probable reserves second only to the entire Middle East (490 billion barrels compared to 500 billion for the Middle East).

Soviet production fell short of its five-year plan goal by 500 thousand b/d in

1979. The 1980 goal set in 1975 is between 12.4 and 12.8 million b/d. Hence, if production reaches 12.0 million b/d this year, the shortfall will be 400-800 thousand b/d. The CIA (4) estimates that "production will. . .decline in the early 1980s and drop to a level of about 10 million b/d in 1985."

In spite of its huge resource potential, the USSR has been unable to develop its reserve base. The Soviet production problem is technological. It takes 14 months to drill 3050 m in Russia compared to 34 days in the U.S. A recent article in the *Wall Street Journal* (5) maintains Soviet technology is 30 years behind the west's. As a result, Soviet exploration badly lags. According to Arthur A. Meyerhoff (6), a long-time consulting geologist to Russia, the country's proved reserves amount to only 27 billion barrels compared to 350 billion in the Middle East. Proved reserves in the USSR are 6.0 percent of potential. This figure contrasts with 70 percent for Saudia Arabia.

Both Meyerhoff and the CIA predict that the Soviets will change from a net exporter of 1.1 million b/d in 1979 to a net importer of 700 thousand b/d in 1983. A recent *Oil & Gas Journal* article (7) indicates that 1979 Soviet deliveries to non-communist countries dropped 200 thousand b/d last year from 1977 and 1978 levels. The May 1980 Congressional Budget Office study expects that by 1990 the Soviet block will be importing 2.0 million b/d from the world market. This may be a conservative estimate.

In view of the very tenuous western world oil supply/demand balance existing in 1980 and forecast to continue, a 1.8 million-b/d shift in Soviet supply patterns to the non-communist world could be very disruptive not only to the 1983 world market balance and to the real price of oil, but also to political conditions already uncertain. CIA Director, Adm. Stansfield Turner, was quoted (1) as saying, "The combined western and Soviet oil outlook sets the stage for head-on competition for Mid-East oil."

The Soviets' supply problems overhang Middle East oil supplies and add a specter of danger to an already unstable oil source.

World Supply/Demand Balance

Figure 2 shows a consensus non-communist world oil demand forecast. Informed estimates put western world oil demand probably between 60 and 66 million b/d by 1990—up from 53.0 million b/d in 1979. This represents a range of 1.0-2.0 percent annual growth in consumption to 1990. Thereafter, the western world consumption of oil is dependent on available supplies. Most analysts believe that unconstrained demand still would grow, but more slowly—less than 1.0 percent annually—as shown in Figure 2. Most of this growth is expected to occur in the less developed countries (LDCs) as industrialized nations shift more to coal, nuclear, and alternative fuel sources and achieve greater energy efficiency.

The May 1980 Congressional Budget Office study that has received a certain amount of attention considers 66.4 million b/d the probable 1990 non-communist world oil demand. This forecast predicts a western-world imbalance of nearly 8.5 million b/d by 1990 since the supply forecast is only 58.0 million b/d. Hence, prices must rise to balance supply and demand.

World oil demand growth rate forecasts are vastly lower than they were in late 1979, and industry observers realized how much political instability was associated with future oil supplies. Any demand forecast in the uncertain world of 1980 must be viewed as little more than an idea to think about.

Comparing these demand forecasts with the average production forecast in Table 1 shows a very tenuous balance in 1985 and 1990. After 1990, as global oil production declines, the gap between

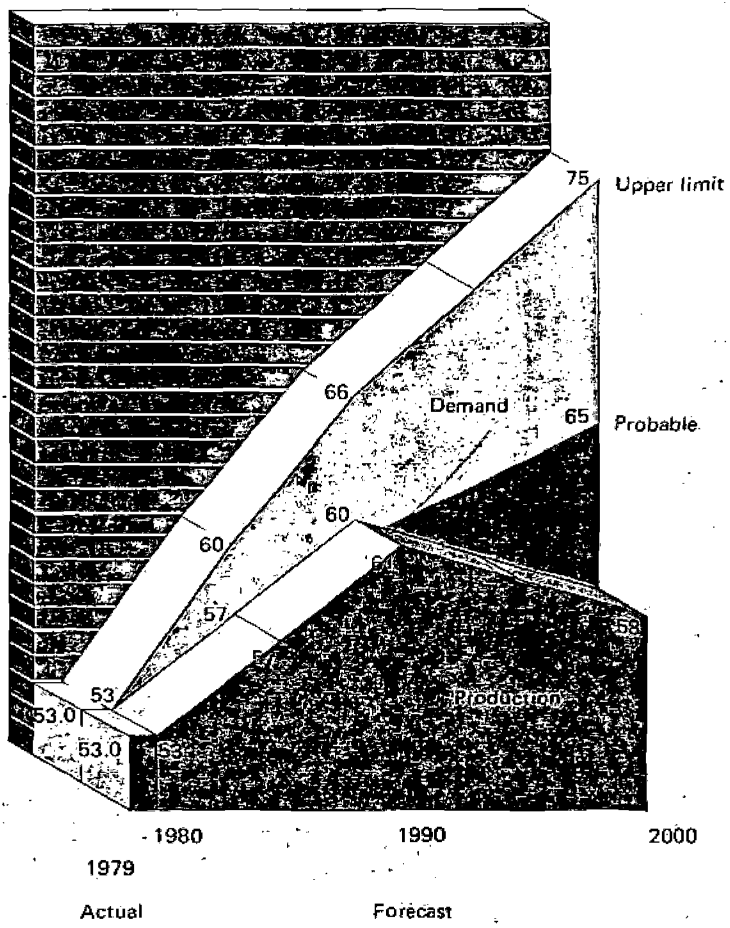


Figure 2. Non-Communist World Oil Demand/Supply Balance (Million b/d)

forecast demand and supply widens. Global demand will have to be met either by increased use of synfuels, alternative energy sources, increased production from the Middle East—or by further conservation and price increases if none of these supply alternatives materialize. This last option threatens our quality of life.

UNITED STATES ENERGY SITUATION

Oil will remain the predominant fuel in the U.S. throughout this century although the fraction of total energy it constitutes will decline. U.S. energy demand during the 1980s and the 1990s will be crude oil supply-limited. These two decades will be a transition period to coal, nuclear, and synfuels. Methods will be sought to produce new energy resources on a large scale and integrate them into the existing distribution network in an economic and environmentally compatible way. However, even by 2000, alternate energy sources will be a very small share of total U.S. energy consumption. With the push for synfuels development, oil's critical role in the remainder of this century must be kept in mind.

Demand: A Radical Change in Consumption Patterns

In early 1979 Shell, Exxon, and Chevron independently forecast 1990 U.S. energy demand to range from 47.6-49.9 million b/d oil equivalent (b/d oe), a narrow range of estimates. They further agreed that crude oil would account for 20-21 million b/d of this total. The 1978 U.S. crude oil demand was 19.2 million b/d of a total of 38 million b/d oe of energy consumed in the U.S.

Underlying Shell's, Exxon's, and Chevron's 1979 forecasts for 1990 were real GNP growth rates between 3 and 3.5 percent. Total U.S. energy use growth was expected to fall within 2.0-2.25 percent between 1978 and 1990.

Figure 3 shows the mid-1980 demand forecast derived from published and unpublished sources. This is based on a 2.6 percent growth rate for real GNP in the last two decades and requires 1.5-1.8 percent growth in total energy use. The 1990 energy forecast has dropped to 43-46 million b/d oe. Oil demand is expected to range between 16-19 million b/d. Sixteen million b/d of oil consumption in 1990 implies a reduction of 17 percent from 1978 use. A recently published Shell forecast calls for 1990 U.S. energy use to amount to only 42 million b/d oe. Of this, Shell expects 17.2 million b/d of oil use—a figure that will remain constant throughout the 1980-1990 decade.

Most of the increase in energy use will come from coal and nuclear fuels, whose combined contribution to total energy use is forecast to increase from 23 percent in 1980 to 42 percent by 2000. Hydro, geothermal, solar, and other alternatives will not become major energy resources during this century. Gas consumption will increase slightly. Consistent with the message carried in *Energy Future* (8), oil, gas, coal, and nuclear—together with increased energy efficiency—are the critical approaches to

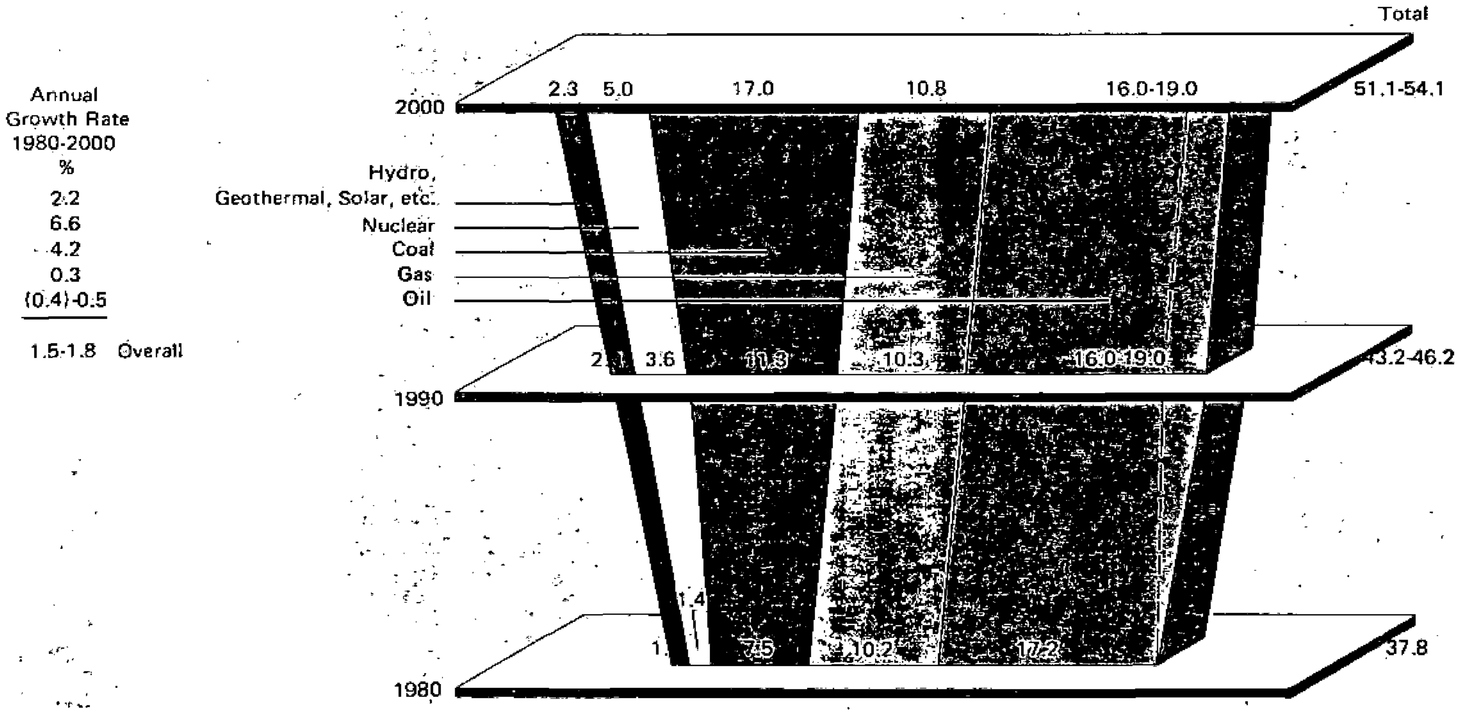


Figure 3. U.S. Energy Forecast: 1980-2000 (Million b/d Oil Equivalent)

solving our energy supply problems for the remainder of this century. Solar power and other renewable resources must await technical advances anticipated in the next century.

This forecast requires a tripling in coal production from 750 million tons last year to 2.0 billion tons by 2000 to achieve the 4.2 percent growth rate shown in Figure 3. During the last 20 years, coal production grew 1.5 percent annually. This coal forecast is mostly a policy goal. If the U.S. does not increase coal output to 2.0 billion tons by 2000, the Electric Power Research Institute (EPRI) forecasts there will be serious shortages of electrical generating capacity (9).

Potential for Conservation in the United States

Forecasting future U.S. energy use implies forecasting both the rate of growth of the U.S. economy and the way we use energy to produce the mix of goods and services within the economy. Figure 4 shows that the relationship of energy use to U.S. economic activity has not been constant during this century.

Four distinct phases can be discerned from Figure 4 relating energy use to U.S. aggregate economic activity (GNP) over the historical period 1900-1980:

1. Energy use per dollar of GNP increased until 1917, reaching a peak of nearly 100 thousand Btu per dollar of real GNP. (This trend began in the preceding century.)
2. Energy use per dollar of GNP decreased between 1917 and 1944 to a trough near 60 thousand Btu.
3. Between 1944 and 1970 energy use remained relatively constant, fluctuating around 60,000 Btu.
4. Since 1970 energy use per dollar of GNP has decisively turned downward—with no fluctuation.

When we consider the difference between economic efficiency and energy efficiency, the determinants of the three distinct energy/GNP trends shown in Figure 4 between 1900 and 1970 can be contrasted with the downward trend during the 1970s.

Economic efficiency is concerned with how the various inputs to production—including energy—are combined in the production process. This depends both on the relative costs of the inputs and their relative contribution to the total cost of the production process. Before 1973 energy costs contributed less than 3 percent of the total cost of production. This was the age of abundant cheap energy. Capital and labor accounted for the largest share of the cost of production.

In contrast to other developed economies of the world—for example, Japan and Europe—labor in the U.S. has historically been more costly and more scarce than the country's more abundant supplies of natural resources and capital wealth. Hence, economic efficiency was attained by using labor sparingly, energy intensively, and capital wisely.

Energy efficiency, on the other hand, refers to the amount of energy converted to work compared to the amount that

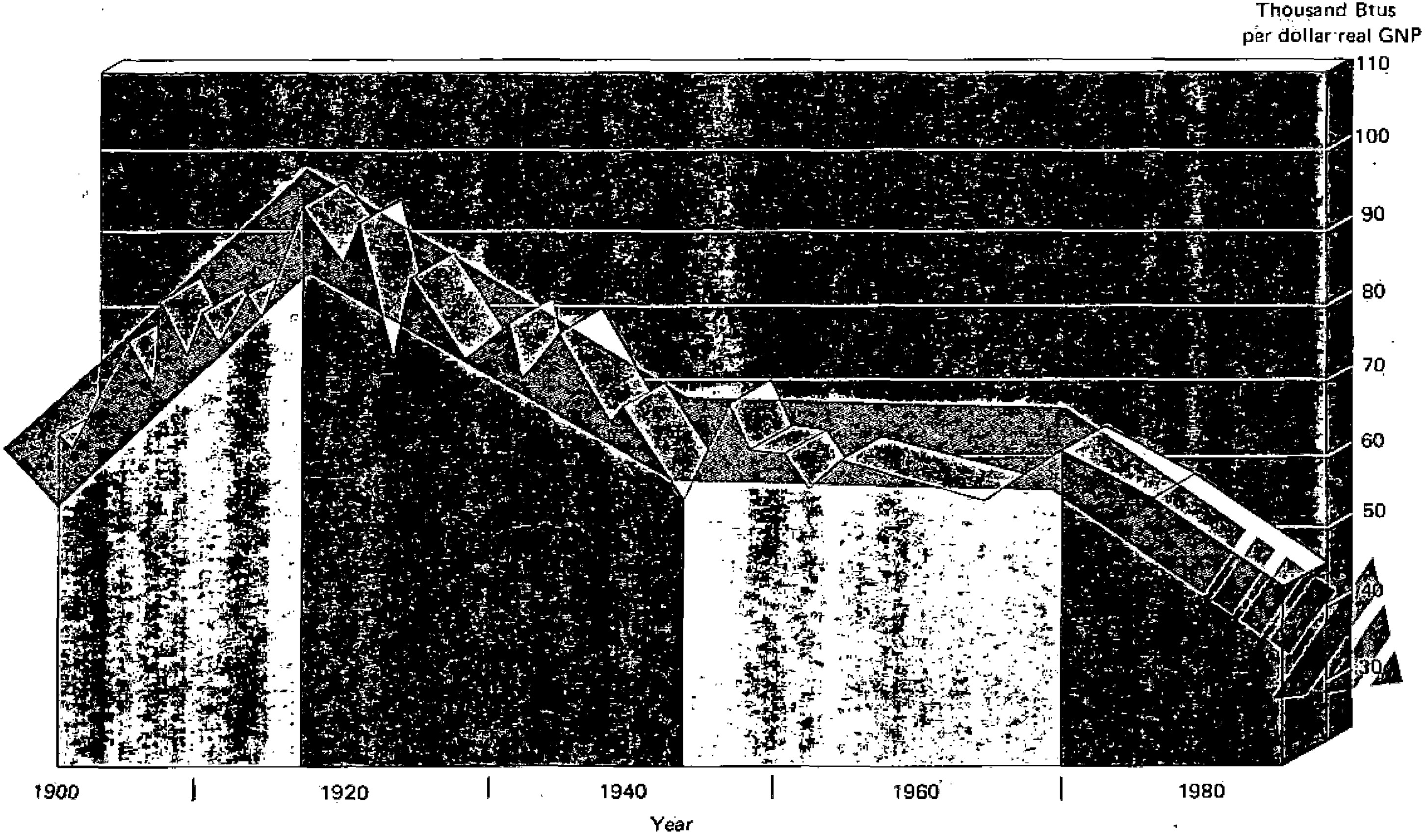


Figure 4. Energy Use Per Dollar of GNP

goes to waste. The increasing and then decreasing trend in the energy/GNP ratio between 1900 and 1944 can largely be explained in a thermodynamic context.

Prior to World War I, the U.S. was rapidly industrializing as the nation transformed from an agrarian economy. Industrialization during this period was accomplished by rapid mechanization. This early industrial mechanization was very thermally inefficient. Rapid industrialization with energy-inefficient mechanization accounted for the increasing energy/GNP ratio during this period.

After World War I the expansion of other less energy-intense sectors of the economy, together with significant improvements in the thermal efficiency of energy use, accounted for most of the decreasing trend in the energy/GNP ratio through the end of World War II. During this period the U.S. shifted from a coal-based economy to a gas- and oil-based economy. Technological advancements associated with the availability and use of gas and oil contributed to improved energy efficiency in a major way. The diffusion of electricity during this period was another major source of improved energy efficiency.

Energy's share of the cost of production has risen to more than 10 percent since the 1973 Arab Embargo, and it is now the fastest rising input cost. Not surprisingly, the energy/GNP ratio has sharply changed.

The flat 25-year period between World War II and 1970 is more difficult to explain. It has prompted some observers unaware of the longer trends to believe that there is a direct relationship between energy use and economic growth. Clearly, Figure 4 shows this is not true in the longer historical context. After World War II labor costs were rapidly rising. This created an impetus to substitute energy-intense machinery and equipment for labor. Labor productivity rose rapidly during this period as machines were innovated to free labor from the production process. Rapid economic growth in the post-World War II era was matched by rapid energy use to economize labor.

Energy's share of the cost of production has risen to more than 10 percent since the 1973 Arab Embargo, and it is now the fastest rising input cost. Not surprisingly, the energy/GNP ratio has sharply changed and turned decisively down. This time the downward trend in the ratio is clearly directed toward achieving economic efficiency by reducing energy use as opposed to the broad move toward achieving better thermodynamic energy efficiency in the 1917-1944 period. Energy use per dollar of GNP has been reduced 14 percent during the rapid price inflation period of the 1970s. Consumers and producers have discovered that both groups are responsive to energy price increases.

Will this trend continue? The relative costs of both consumer goods and inputs determine the energy intensity of the inputs chosen by producers and the bundle of goods purchased by consumers. Market prices of energy and tax incentives afforded by government conservation policies have each caused a clear change in the way we use energy, given the technology choices currently available to us.

Future energy consumption patterns will depend on future technology. Energy price increases relative to the costs of other inputs and consumer goods (as well as government programs) have focused a lot of effort on research and development to produce innovative ways of using less energy. If these trends continue, it is reasonable to expect that the ratio of energy use to GNP will continue to decline.

How much? Between 1917 and 1944 the energy/GNP ratio declined 1.5 percent annually. Between 1970 and 1980 the downward trend in the ratio has also been 1.5 percent. The changes that occurred in each of these two time periods were caused by different economic forces. In the former period, the primary economic force was to expand output. Industry learned to combine all of the inputs of production in better ways and with better technology to get more GNP per unit of all inputs—including energy. Hence, the energy/GNP ratio declined mainly because of policies designed to increase output (GNP).

In the current period the primary economic force is directed simply to reduce total energy use and, specifically, reliance on oil and gas. Currently, existing policies are directed toward substituting new energy-efficient capital investment to conserve the use of energy.

Figure 5 shows how the ratio of energy use to GNP could change if the trend continues to improve at 1.0, 1.5, and 2.0 percent annually to 2000. By 2000 the ratio could fall between 36 thousand and 44 thousand Btu per dollar of GNP— down from 54 thousand Btu in 1980 and 62 thousand Btu in 1970.

Figure 5 shows how improvements to energy efficiency could affect the projected energy demand if energy efficiency continues to improve and GNP grows at a constant 2.6 percent. By 2000, U.S. energy use could fall between 42.2 and 51.6 million b/d oe. This forecast is much lower than the 51.1-54.1 million b/d oe forecast shown in Figure 3. The 1990 range shown in Figure 5, 40-44 million b/d oe, agrees with the range in Figure 3, 43-46 million b/d oe. The conventional forecast in Figure 3 suggests that improvements to energy efficiency may slow down or reach a plateau after 1990. No matter what, however, the U.S. will still use more energy in 2000 than at present—but it will be getting a lot more out of the energy than it does now.

Domestic Oil Supplies

While U.S. oil consumption growth rates will drop significantly, the oil industry still faces a herculian task to develop sufficient domestic reserves to meet demands during the next two decades. The U.S. is currently producing flat-out at the rate of approximately 3.6 billion barrels/year. As of January 1, 1980, proved reserves amounted to 27.1 billion barrels—an inventory sufficient to last only 7.5 years, through mid-year 1986 at current production rates. Thus, to hold domestic production at current levels for another 7.5 years beyond mid-year 1986, the oil industry will have to find and develop reserves between now and 1986 that are at least equal to the current total proved reserves.

The upsurge in drilling activity in response to higher prices suggests the oil industry is attacking this monumental exploration task. Most forecasts of domestic oil production for the coming decade predict domestic production near present levels. The 1979 production of crude and natural gas liquids (NGL) was 10.2 million b/d. Table 2 shows the forecast sources of oil supplies that will be

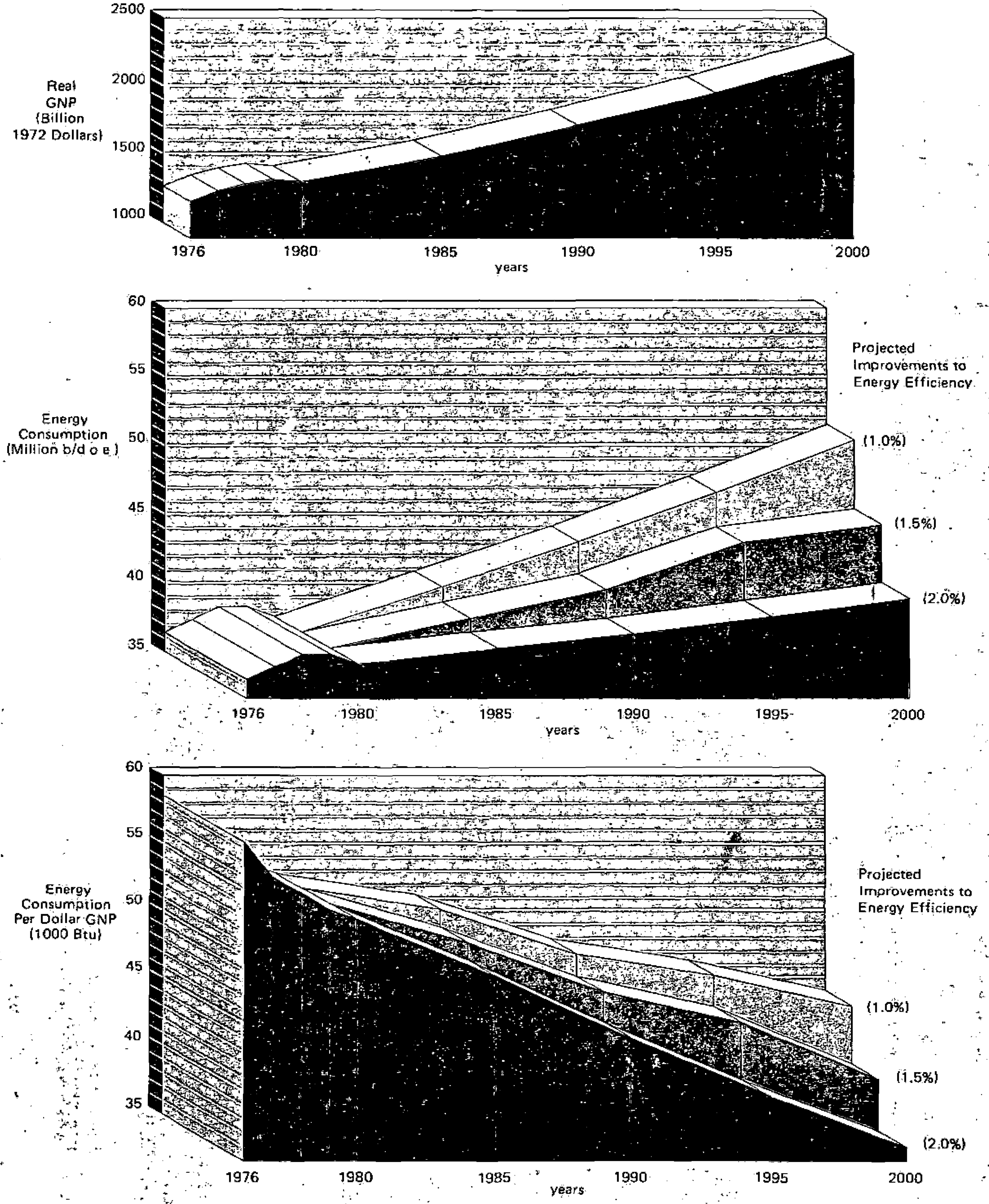


Figure 5. Energy-GNP Relationship

Notes: GNP is projected to the year 2000 at a constant 2.6 percent growth rate.
Energy use is projected in relation to 2.6 percent growth in real GNP.

available to meet forecast demand. Lower 48 production is shown to be declining throughout the next two decades. The general belief is that this is an irreversible trend. Prudhoe Bay will also begin to decline soon after the mid-1980s. Consequently, America's domestic oil future is tied to two great hopes: 1) new reserves of oil will be discovered and produced in a timely manner in the OCS of the United States (most of these are expected to be found in Alaska); and 2) synthetic oil production will take off in the 1990s.

Table 2 shows that by 1990 foreign imports are unlikely to be lower than current imports. (Due to the recession, imports have averaged a little over 7 million b/d during the first half of 1980. This is down from 8.4 million b/d for 1979.) Even if synfuels add the equivalent of 1 million b/d of oil and production from newly discovered Alaskan reserves is near the U.S. Department of Energy maximum estimate of 900 thousand b/d, 7-9 million barrels of imported oil will be required in 1990 to maintain oil supplies at their existing recessionary 17.2 million-b/d level.

TABLE 2.
United States Oil Supply Forecast
(Million b/d oil equivalent)

Sources of Oil	1979	1980	1990	2000
Lower 48	8.8	8.3	6.0- 7.1	5.6- 6.1
Proven Alaskan Reserves	1.4	1.6	1.3	0.4
New Alaskan Discoveries	–	–	0.5- 0.9	0.6- 2.1
Synthetic Fuels	–	–	1.0	4.6
Imported Fuels	8.4	7.3	7.5- 8.7	4.8- 5.8
Total	18.6	17.2	16.0-19.0	16.0-19.0

Note: Natural gas liquids have been included in these figures.

Sources: Exxon, 1979, *U.S. Energy Outlook, 1980-2000*, December.

Department of Energy, 1979, Petroleum supply alternatives for the northern tier and inland states through the year 2000, October 31.

By 2000, if synfuels contribute significant fuel supplies as anticipated, foreign imports are expected to decline. This forecast, showing a decline in foreign oil imports instead of a definite rise, represents a significant change. Most industry forecasts have maintained consistently that foreign imports are more likely to be higher than lower by 1990 despite increased energy efficiency and slowed energy growth forecasts. The recent Shell study maintains that foreign imports will be 8.6 million b/d in 1990. It must be remembered, moreover, that the oil forecasts in Table 2 support only a 2.6-percent growth in real GNP. This is only about two-thirds of the U.S. historic average since World War II.

Alaska's Link to Future U.S. Oil Supplies

The security of the U.S. oil supply has become a major impetus behind U.S. energy policy. While the current recession has created a small surplus in the world oil market, exporters still possess great leverage and importers remain vulnerable. U.S. officials remain worried about the impact of import supply disruptions on the U.S. economy and quality of life. The U.S. and much of the rest of the world will remain critically dependent on oil from the politically unstable Middle East until sometime in the next century, when alternative technologies and sources of energy are developed. Minor import supply disruptions will continue to have major economic disruptions. When these will occur cannot be forecast. To the extent that U.S. energy policies can stimulate domestic production or reduce demand for oil, the U.S. will become less vulnerable to unpredictable disruptions.

John Swearingen, Chairman of Standard Oil of Indiana, summed it up at a meeting of the Commonwealth Club of San Francisco, California on February 1, 1980: "The U.S. must do everything possible to reduce its reliance on unstable sources of supply."

Alaska's OCS appears to be America's best hope for new oil supplies. One-half to two-thirds of America's estimated resources are expected to be found under Alaska's OCS. In spite of Project Independence in 1974, and six years of subsequent political sound and fury, fewer than 1 million of Alaska's 200 million OCS acres have been leased and explored.

Transforming the inhospitable regions of Alaska's OCS frontier into oil producing areas will be no small task. Consequently, Alaska's vast OCS potential will not be explored, discovered, developed, and supplied to the lower 48 in significant quantities before the early 1990s under Department of Interior's existing five-year lease schedule.

The Department of Energy forecast, together with existing Alaskan production shown in Table 2, imply a recovery of approximately 12-13 billion barrels of oil from Alaska in the next 20 years. Current proved reserves in Alaska total about 9 billion recoverable barrels. Latest OCS resource estimates range between 7 and 32 billion barrels (10). Hence, a forecast of 12-13 billion barrels over the next 20 years may be a conservative estimate of the production potential of Alaska.

Figure 6 shows approximately when new discoveries in the Alaskan OCS can become oil supplies to the United States. The time scale is associated with the April 1980 U.S. OCS lease schedule and the long time period required to explore, discover, delineate, develop, and produce oil in the hostile areas of Alaska's OCS.[*] The soonest any production could start is 1987, from the Beaufort Sea, assuming that current litigation[†] concerning the

---

[*] Dames & Moore has been under contract to the Alaskan OCS office of the Bureau of Land Management (BLM) for nearly three years to provide petroleum development scenarios for all Alaskan lease sale areas studied to date under the BLM Socioeconomic Studies Program (SESP).

[†] The U.S. District Court in Alaksa recently dismissed a suit by environmentalists concerned about fish and whales in Beaufort Sea. The suit was filed against the state of Alaska, the U.S., and several oil companies. Unless this decision is overturned by a higher court, exploration of Beaufort Sea will proceed in the winter of 1980/1981.

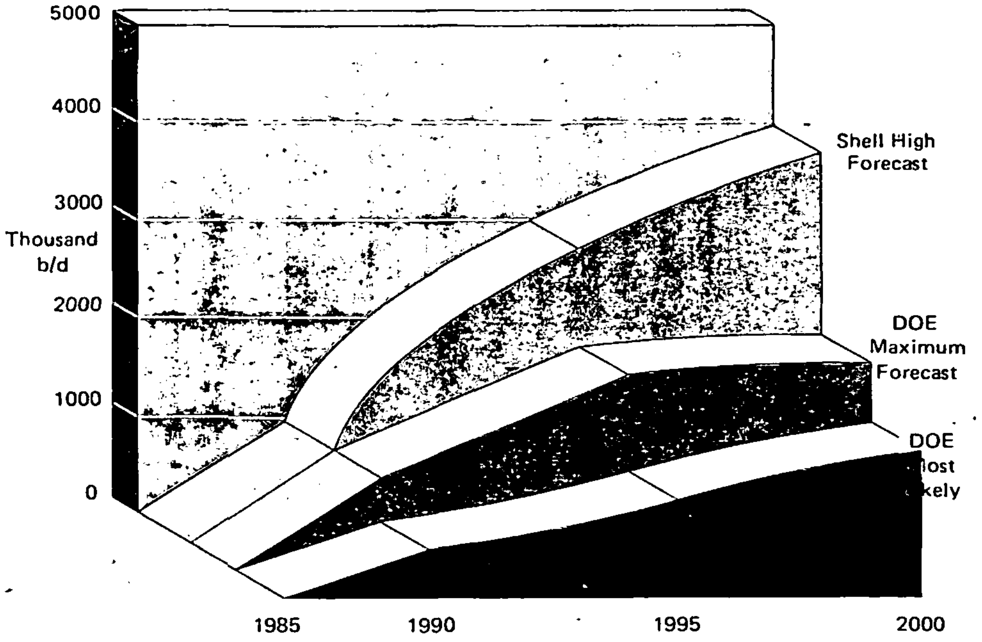


Figure 6. The Timing of Potential New Oil Supplies from the Alaskan OCS

sale is settled and exploration commences in the winter of 1980/81.

The estimated production levels shown in Figure 6 are based on Department of Energy (DOE) and Shell estimates. However, the accuracy of the methodology used in these estimates has not been established. Hence, the range of estimates for production of new Alaskan discoveries are shown only for discussion. Additional research is required to determine a better estimate of the range of potential Alaskan supplies.

CONCLUSION

To the extent that OCS lease tract development is delayed by litigation, new oil and gas supplies will slip further away from our immediate needs. New supplies from the Beaufort Sea, originally hoped for by 1987, may be delayed.

The typical American energy consumer needs to understand that:

- We need Alaskan oil in the near future–within the critical 12-year period 1983-1985 to facilitate the transition to emerging energy alternatives and mitigate our reliance on OPEC oil.
- Exploration and development of the OCS under Alaskan frontier conditions will take seven to nine years from the date of each lease sale.
- Supplies developed under the existing lease sale schedule won't amount to very much new oil and gas for the U.S. in the 1980s.
- Litigation and delays could preclude very much new Alaskan oil and gas supplies until late in the 1990s.

America's best hope to meet energy requirements for the rest of this century is to establish a critical path toward OCS development compatible with Alaska's environmental and socioeconomic integrity, and then to move decisively along that path.

REFERENCES CITED

1. *Oil & Gas Journal*, 1980, vol. 78, no. 17, p. 50.
2. Ibid, 1979, vol. 77, no. 46, pp. 163-169.
3. Ibid, 1979, vol. 77, no. 32, p. 108.
4. Ibid, 1979, vol. 77, no. 52, p. 87.
5. *Wall Street Journal*, 1980, March 25.
6. Meyerhoff, Arthur A., 1980, Presentation to the Commonwealth Club of California. San Francisco, April 29.
7. *Oil & Gas Journal*, 1980, vol. 78, no. 30, p. 128.
8. Stobaugh, R., and Yergin, D., 1979, *Energy Future*.
9. Esselman, Walter H., 1980, Sixth Annual Conference on Coal Production and Transportation, April.
10. *Oil & Gas Journal*, 1980, vol. 78, no. 11, p. 85.

BIBLIOGRAPHY

Beck, Robert J., 1980, High prices, recession slash oil demand. *Oil & Gas Journal*, vol. 78, no. 30, p. 96.

Bonner & Moore Associates, 1980, *1985 California Oil Scenario Study*. Ad Hoc Industry and Government Study, March.

California Energy Commission, 1979, Energy choices for California. . . Looking ahead, March.

______, 1979, Energy futures for California, two scenarios, 1978-2000, November.

______, 1979, Fuel price & supply projections, 1980-2000, November.

______, 1979, California's energy challenge: the next 20 years, November.

______, 1979, California energy demand, 1978-2000: a preliminary assessment, August.

Congressional Budget Office, 1980, The world oil market in the 1980s: implications for the United States, May.

Department of Energy, 1979, Petroleum supply alternatives for the northern tier and inland states through the year 2000, October 31.

Esselman, Walter H., 1980, EPRI's projection of electrical energy demand and supply. PLM, Sixth Annual Conference on Coal Production and Transportation, April.

Exxon, 1979, *Energy Outlook, 1980-2000*. Exxon, December.

Ford Foundation, 1979, *Energy: The Next Twenty Years, An Overview*, Report by a Study Group. Balinger Publishing Co., Cambridge.

Oil & Gas Journal, 1979, California ponders ways to match crude refining. *Oil & Gas Journal*, vol. 77, no. 16, pp. 27-30.

______, 1979, CIA: global oil supply outlook poor. *Oil & Gas Journal*, vol. 77, no. 36, pp. 50-51.

______, 1980, CIA sees global oil production peaking. *Oil & Gas Journal*, vol. 78, no. 17, p. 50.

______, 1980, Offshore oil, gas estimates rise only for Alaska. *Oil & Gas Journal*, vol. 78, no. 11, p. 85.

______, 1979, Oil in the eighties: tight supply soaring capital outlays. *Oil & Gas Journal*, vol. 77, no. 46, pp. 163-169.

______, 1980, Shell: U.S. oil use to hit 17.2 million b/d plateau in the '80s. *Oil & Gas Journal*, vol. 78, no. 23, p. 96.

______, 1980, Soviet oil export volume dropped during 1979. *Oil & Gas Journal*, vol. 78, no. 30, p. 128.

______, 1979, U.S. petroleum industry will face monumental task in next decade. *Oil & Gas Journal*, vol. 77, no. 46, pp. 170-184.

Pocock, C.C., 1979, Prospects for oil and gas: a look ahead to year 2000. *World Oil*, October, pp. 107-111.

Stobaugh, Robert, 1979, After the peak: the threat of imported oil, *in* Stobaugh, Robert and Yergin, Daniel, eds., *Energy Future*, Report of the Energy Project at the Harvard Business School. Random House, New York.

Thiel, M.F., 1979, World oil & OPEC: the razor's edge. *World Oil*, October, pp. 123-133.

Wall Street Journal, 1980, Technology of finding and producing oil is weak point for Soviets. March 25.

APPENDIX of

ENERGY RELATED INFORMATION AND TERMS

compiled by

Owen Osborne
Assistant Professor of Electrical Engineering

with supplementary notes by

W. D. Loveland, Associate Professor of Chemistry
A. H. Robinson, Professor of Nuclear Engineering

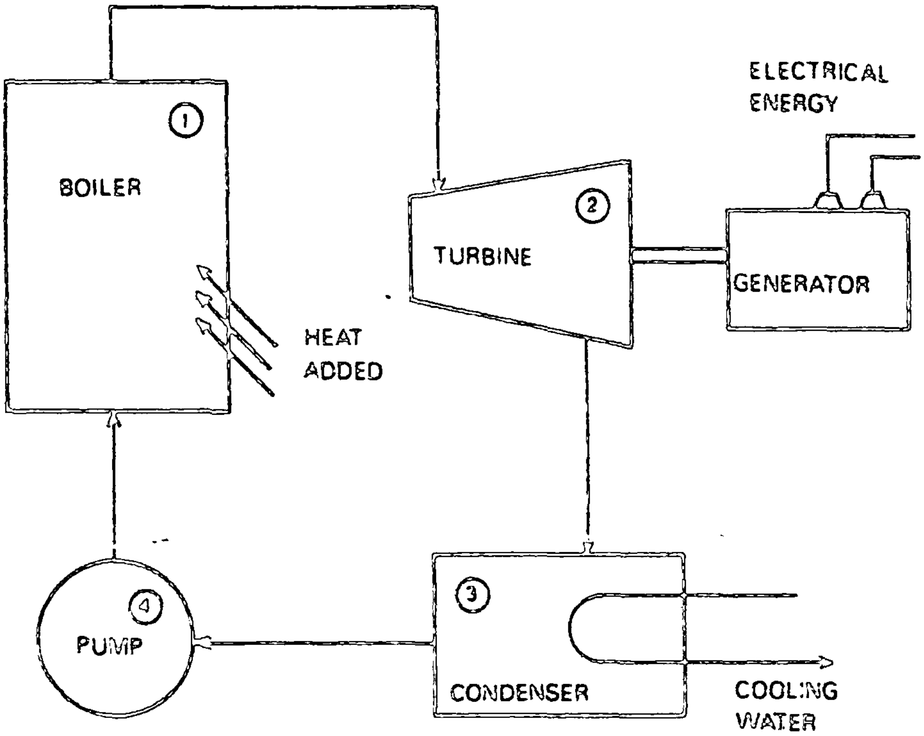
in Magnitude and Deployment
Schedule of Energy Resources

Office of Energy Research and Development
Oregon State University

1976

The Rankine Cycle

The basic principle that all steam power plants rely on to make electricity from heat energy is the Rankine cycle. Although real plants may use variations, such as superheat, reheat, and regeneration, the basic cycle consists of the four processes shown in the figure below.



In the boiler the liquid (in the case of steam plants, water) is turned into vapor (steam) at constant pressure. The high-pressure, high-temperature vapor is then run through a turbine which turns the generator. The vapor leaves the turbine at a low temperature and pressure and enters the condenser. In the condenser the vapor is converted at constant pressure back to liquid again by removing some heat from it. This is necessary so that the liquid, which has a much smaller volume than the vapor, can be pumped back into the boiler again. Thus, the cycle continues by repeatedly heating the liquid to vapor, turning the turbine, condensing the vapor and reheating it again in the boiler.

The efficiency of such a cycle is defined by the relation:

$$\eta = \text{thermal efficiency} = \frac{\text{useful energy obtained } (= \text{electrical output})}{\text{energy added (heat in)}}$$

The maximum possible theoretical efficiency for any system that converts heat energy to electrical energy is given by the formula:

$$\eta_{max} = \frac{(\text{maximum vapor temperature}) - (\text{cooling water temperature})}{(\text{maximum vapor temperature} + 460)}$$

where the temperatures are given in °F. (It should be noted that this formula applies to <u>any</u> system regardless of whether steam or any other liquid or gas is used.)

As an example of the use of the formula, consider a geothermal plant that receives heat at 220°F and uses cooling water at 100°F (from a cooling tower). Using the formula the maximum theoreticallly possible efficiency is 18 percent. In practice the thermal efficiencies of real plants are often as low as half of the theoretical value. A typical modern fossil steam plant receives steam at 1400°F and cooling water at 90°F. The theoretical efficiency would be 70 percent. The actual efficiency of the real fossil steam system is about 40 percent.

From the formula for the maximum possible efficiency it is clear that as the difference between the maximum temperature of the steam (or any other liquid) and the temperature of the cooling water approaches zero, the thermal efficiency goes to zero. For example, in the case of ocean thermal plants the temperature difference is only about 40°F. Thus, the thermal efficiency will be very low. It is important to note that as the thermal efficiency decreases the capital costs per unit of electrical output rise rapidly.

-- A. H. Robinson --

Energy and Power

In speaking of energy resources, two different ways of speaking about these resources are used. One group of people will speak of <u>energy</u> in units of Btu, kWh, tons of coal, etc., while others (primarily concerned with electricity) will speak of <u>power</u>. Power is a measure of how fast energy can be supplied. The most common use of power is in describing electrical generating capacities (in MW, GW, KW, etc.). To find the energy equivalent of an electrical generating capacity, one follows (by-convention) the following prescription:

$$\left\{\begin{array}{c}\text{electrical generating}\\ \text{capacity}\\ \text{[in KW, MW or GW]}\end{array}\right\} \times \left\{\begin{array}{c}\text{number of hours}\\ \text{per year = 8760}\end{array}\right\} \times$$

$$\left\{\begin{array}{c}\text{fraction of time}\\ \text{plant operates}\\ (\sim 0.6)\end{array}\right\} \times \left[\begin{array}{l}\text{how much more energy would}\\ \text{have to be used in a thermal}\\ \text{power plant to generate this}\\ \text{much electricity}\\ \qquad (\sim 3)\end{array}\right]$$

$$= \text{Energy (KWh, MWh, GWh)}$$

-- W. D. Loveland --

Acronyms of Agencies and Associations

AEC	Atomic Energy Commission; see ERDA, NRC.
AGA	American Gas Association; trade association; publishes estimates of natural gas resources.
API	American Petroleum Institute; trade association; publishes estimates of petroleum resources.
EPA	Environmental Protection Agency; federal regulatory agency having prime responsibility for environmental impact of power plants.
EPRI	Electric Power Research Institute; funded by electric utilities to conduct research of interest to the industry.
ERDA	Energy Research and Development Administration; federal agency administering research in all forms of energy production--solar, geothermal, coal, petroleum, and nuclear; successor agency to the research functions of AEC and several other federal offices, such as OCR.
FEA	Federal Energy Administration; federal agency responsible for allocation of energy resources, especially petroleum; promotes energy conservation; supports conservation research.
FPC	Federal Power Commission; economic regulatory commission; notably responsible for setting wellhead price of natural gas.
IGT	Institute of Gas Technology; funded by natural gas utilities to conduct research of interest to the industry.
NASA	National Aeronautics and Space Administration; federal agency; involved in research in wind power and photovoltaic power generation
NBS	National Bureau of Standards; federal bureau; includes among its duties various research interests.
NRC	Nuclear Regulatory Commission; federal agency; successor to the regulatory functions of AEC.
NSF	National Science Foundation; federal agency making grants for research in all branches of science, including subjects relating to energy; see also RANN.
RANN	Research Applied to National Needs; a program of research grants administered by NSF.

A Note about Abbreviations

Numerical abbreviations are likely to be composed of two elements: first, an abbreviation of a numerical prefix expressing some multiple or fraction of units; and second, an abbreviation of a unit which measures some basic property. Examples of both elements are:

Prefix	Meaning
pico (p)	divide by 1 trillion (10^{-12})
nano (n)	divide by 1 billion (10^{-9})
micro(μ)	divide by 1 million (10^{-6})
milli(m)	divide by 1 thousand (10^{-3})
kilo (k)	multiply by 1 thousand (10^{3})
mega (M)	multiply by 1 million (10^{6})
giga (G)	multiply by 1 billion (10^{9})

Knowing the two ingredients, it is easy to understand or to employ numerical abbreviations. Examples:

Abbreviation	Full Term	Meaning
mg	milligram	one thousandth of a gram
μc	microcurie	one millionth of a curie
kt	kiloton	one thousand tons

Common Energy-related Units

bbls (BBLs)	barrels
bbl/d (BBL/D)	barrels per day
Btu	British thermal unit
c	curie
cm^3	cubic centimeters
ft^3	cubic feet
°C	degrees Centigrade
°F	degrees Fahrenheit
g	gram
gal	gallons
gal/min	gallons per minute
GW	gigawatt
g	gram
kg	kilogram
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hours
m	meter
MW	megawatt
MWd	megawatt day
MWe	megawatt electrical
MWt	megawatt thermal
MMB (MMb)	million barrels
MMcf	million cubic feet

ppm	parts per million
lb	pound
lb/hr	pounds per hour
psi	pounds per square inch
psia	pounds per square inch absolute
rad	rad
rem	rem
r	roentgen
scf	standard cubic feet
scfd	standard cubic feet per day
sec	second
Mcf	thousand cubic feet
Mcfd	thousand cubic feet per day
t	ton
TCF	trillion cubic feet
W	watt

Energy Related Terms

alternating current (AC): an electric current that reverses its direction of flow periodically (see frequency) as contrasted to direct current (DC).

ambient temperature: temperature of the surrounding cooling medium, such as gas or liquid, which comes into contact with the heated parts of the apparatus.

anthracite: a hard, black, lustrous coal that burns efficiently and is therefore valued for its heating quality.

Atomic Energy Commission (AEC): a five member commission established after World War II to supervise and promote use of nuclear energy. The commission was abolished in 1975 with its functions transferred to the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC).

barrel: a liquid volume measure equal to 42 U. S. gallons, commonly used in expressing quantities of petroleum and petroleum products; (bbl).

baseload: the minimum load of a utility (electric or gas) over a given period of time. Units in baseload service are operated at full capacity all the time.

binary cycle: an energy recovery system which results in heat exchange between two separate fluid circulation systems. The purpose of a binary cycle is to obtain higher efficiency from the energy source.

bioconversion: a general term describing the conversion of one form of energy into another by plants or microorganisms. Synthesis of organic compounds from carbon dioxide by plants is bioconversion of solar energy into stored chemical energy. Similarly, digestion of solid wastes or sewage sludge by microorganisms to form methane is bioconversion of one form of stored chemical energy into another, more useful form.

bituminous coal: soft coal; coal that is high in carbonaceous and volatile matter. When volatile matter is removed from bituminous coal by heating in the absence of air, the coal becomes coke.

[illegible]

chain reaction and the excess neutrons can be used to breed more fuel; (2) Some nonfissionable nuclei can be converted into fissionable nuclei by capture of a neutron of proper energy. Nonfissionable uranium-238, for example, can thus be bread into fissionable plutonium-239 upon irradiation with high-speed neutrons.

British Thermal Unit (Btu): the quantity of heat necessary to raise the temperature of one pound of water one degree Fahrenheit. One Btu equals 252 calories, gram (mean), 778 foot-pounds, 1055 joules and 0.293 watt-hours. (also BTU)

bus: an electrical conductor which serves as a common connection for two or more electrical circuits. A bus may be in the form of rigid bars, either circular or rectangular in cross-section, or in form of stranded-conductor overhead cables held under tension.

busbar: an electrical conductor in the form of rigid bars, located in switchyard or power plants, serving as a common connection for two or more electrical circuits.

calorie: originally, the amount of heat energy required to raise the temperature of 1 gram of water 1 degree Centigrade. Because this quantity varies with the temperature of the water, the calorie has been redefined in terms of other energy units. One calorie is equal to 4.2 joules.

central station power: production of power--usually electrical in large quantities at a generation plant as opposed to production at the point of consumption.

coal: a solid, combustible organic material formed by the decomposition of vegetable material without free access to air. Chemically, coal is composed chiefly of condensed aromatic ring structures of high molecular weight. It thus has a higher ratio of carbon to hydrogen content than does petroleum.

coal gasification: the conversion of coal to a gas suitable for use as a fuel.

coal slurry pipelines: a pipeline which transports coal in pulverized form suspended in water.

conduction: the process by which energy is transferred directly from molecule to molecule. It is the way in which electricity travels through a wire or heat moves from a warm body to a cool one when the two bodies are placed in contact.

continental shelf: the submerged shelf of land [illegible] from the exposed edge of a continent. [illegible] as those areas where the water is less than 200 meters (600 feet) deep.

controlled thermonuclear reactor (CTR): controlled fusion, that is, fusion produced under research conditions, or for production of useful power.

convection: the transfer of heat by the circulation of a liquid or gas.

core: the central part of a nuclear reactor which contains the nuclear fuel.

critical mass: the minimum amount of a fissionable material, such as uranium-235 or plutonium-239, that is required to sustain fission in a nuclear reactor.

crude oil: petroleum liquids as they come from the ground. Also called simply "crude".

curie: the unit of radioactivity. One curie is the amount of a radioactive isotope necessary to produce 3.7×10^{10} disintegrations per second. One gram of radium has 1 curie of radioactivity.

decay, radioactive: the process whereby atoms of radioactive substances experience transformation into atoms of other elements with attendant emission of penetrating radiations (gamma ray) and some nuclear particles. Each radioactive substance has a unique decay rate which may range from a fraction of a second to hundreds of years or more.

demand: the rate at which electric energy is delivered to or by a system or to a piece of equipment expressed in kilowatts, kilovolt-amperes, or other suitable unit at a given instant or averaged over any designated period of time. See load.

depletion allowance: a tax allowance extended to the owner of exhaustible resources based on an estimate of the permanent reduction in value caused by the removal of the resource.

deuterium: a nonradioactive isotope of hydrogen whose nucleus contains one neutron and one proton and is therefore about twice as heavy as normal hydrogen. Often referred to as heavy hydrogen.

diesel oil: the oil fraction left after petroleum and kerosene have been distilled from crude oil.

direct current (DC): an electric current, such as that produced by a battery, in which the electrical potential does not change its sign, so that the voltage is essentially [illegible] with time. In a direct current, therefore, energy is carried by a continuous, undirectional flow of electrons through a conductor.

doubling time: in the long-term (multi-cycle) operation of a breeder reactor system, the time required to achieve a net doubling of the inventory of fissionable material present in the system, expressed in years. Doubling time depends on the breeding gain and the specific power at which the reactor operates.

electrical energy: the energy associated with electric charges and their movements. Measured in watt hours or kilowatt hours. One watt-hour equals 860 calories.

electron: an elementary particle with a rest mass of 9.1×10^{-28} grams, bearing either a positive or negative electric charge. Negative electrons orbit the atomic nucleus; their transfer or rearrangement between atoms underlies all chemical reactions. Either negative or positive electrons (sometimes called positrons) may be emitted from atomic nuclei during nuclear reactions; they are then called beta particles and they are the constituents of beta rays.

energy: the capacity to produce heat or do work. A quantity which is conserved, although it may be exchanged among bodies and transformed from one form to another, converted between heat and work, or interconverted with mass.

energy conversion: the transformation of energy from one form to another.

enrichment: the process of increasing the concentration of fissionable uranium-235 in uranium from the naturally occurring level of about 0.7 percent to the concentration required to sustain fission in a nuclear reactor, generally about three percent. The principal method of enrichment is gaseous diffusion, but gaseous centrifugation is also receiving much attention, particularly abroad.

environmental impact statements: the analytical statements that balance costs and benefits of a federal decision. Required by the National Environmental Policy Act (NEPA), section 102(2)(c).

exponential growth: type of growth illustrated by the compound interest law. A useful characteristic of an exponential growth rate is that the "doubling time", or the length of time required for the growing thing to double in size, is constant.

fast breeder reactor: a nuclear reactor that [illegible] neutrons at the fast speed of their initial emission from the fission process, and that produces more fissionable material than it consumes.

fast neutron: high energy neutron. Fast neutrons are utilized in the fast breeder reactor both to produce nuclear fissions and to transform fertile material (e.g., ^{238}U) into fissionable nuclear fuel.

fast reactor: a nuclear reactor in which the fission chain reaction is sustained primarily by fast neutrons. Fast reactors contain no moderator and inherently require enriched fuel. They are of interest because of favorable neutron economy which makes them suitable for breeding.

feedstock: fossil fuels used for their chemical properties, rather than their value as fuel, e.g., oil used to produce plastics and synthetic fabrics.

fertile material: a material, not itself fissionable by thermal neutrons, which can be converted into a fissionable material by irradiation in a nuclear reactor. The two basic fertile materials are uranium-238 and thorium-232.

fission: the splitting of a heavy nucleus into two approximately equal parts (which are radioactive nuclei of lighter elements), accompanied by the release of a relatively large amount of energy and generally one or more neutrons. Fission can occur spontaneously, but usually is caused by nuclear absorption of neutrons or other particles.

fissile material: any material fissionable by slow neutrons. The three basic ones are uranium-235, plutonium-239, and uranium-233.

fluidized bed: a reaction chamber in which finely divided solid reactants are suspended and maintained in a state of turbulent motion by a stream of gas or liquid from below. As a result, the reactants flow and mix freely, the entire surface area of the particles is exposed to the fluid for reaction, and a high rate of heat transfer is obtained.

fly ash: the fine, solid particles of noncombustible material residue carried from a bed of solid fuel by the gaseous products of combustion.

fossil fuel: any natural occurring fuel of an organic nature, such as coal, oil shale, natural gas, or crude oil. Fossil fuels are organically formed from living matter.

fuel: a substance used to produce heat energy, [illegible] or nuclear energy by nuclear [illegible] fuel cell: a device for converting the energy released in a chemical reaction directly into electrical energy.

fuel cycle: the series of steps involved in supplying fuel for nuclear power reactors. It includes mining, refining of uranium, fabrication of fuel elements, their use in a nuclear reactor, chemical processing to recover remaining fissionable material, reenrichment of the fuel, refabrication into new fuel elements and waste storage. Fuel cycle is sometimes used to refer to a similar series of steps for fossil fuels.

fusion: the combining of atomic nuclei of very light elements by collision at high speed to form new and heavier elements, resulting in the release of energy.

gallon: a unit of measure. A U.S. gallon contains 231 cubic inches, 0.133 cubic feet, or 3.785 liters. It is 0.83 times the imperial gallon. One U.S. gallon of water weighs 8.3 lb.

gas cooled fast breeder reactor (GCBR): a fast breeder reactor which is cooled by a gas, usually helium, under pressure.

gas, manufactured: a gas obtained by destructive distillation of coal, or by the thermal decomposition of oil, or by the reaction of steam passing through a bed of heated coal or coke. Examples are coal gases, coke oven gases, producer gas, blast furnace gas, blue (water) gas, carbureted water gas. Btu content varies widely.

gas, natural: a naturally occurring mixture of hydrocarbon gases found in porous geologic formations beneath the earth's surface, often in association with petroleum. The principal constituent is methane.

gas turbine: an engine which converts chemical energy of liquid fuel into mechanical energy by combustion. Gases resulting are expanded through a turbine.

gaseous diffusion: the principal process for enrichment of uranium; that is, for increasing the concentration of fissionable uranium-235 in a mixture of uranium isotopes to the level required to sustain fission in a nuclear reactor.

gasification: In the most commonly used sense, gasification refers to the conversion of coal to a high-Btu synthetic natural gas under conditions of high temperature [illegible] in a more general sense, conversion of coal into a usable gas.

gasoline: a petroleum fraction [illegible] branched chain, cyclic, or aromatic hydrocarbons.

generator: a machine which converts [illegible] electrical energy.

geopressured reservoir: a reservoir whose wellhead pressure is substantially greater than normal as a result of the pressure of the earth above it.

geothermal energy: the heat energy available in the rocks, hot water, and steam in the earth's subsurface.

geothermal steam: steam drawn from deep within the earth. There are about 90 known places in the continental United States where geothermal steam might be harnessed for power. These are in California, Idaho, Nevada, and Oregon.

Gross National Product (GNP): the Nation's total national output of goods and services at current market prices.

half-life, radioactive: time required for a radioactive substance to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

heat: a form of kinetic energy, whose effects are produced by the vibration, rotation, and general motions of molecules.

heat exchanger: any device that transfers heat from one fluid (liquid or gas) to another or to the environment.

heavy water: deuterium oxide; that is, water in which all hydrogen atoms have been replaced by deuterium.

heat pump: a refrigeration machine that is used for heating rather than cooling. Expanding refrigeration fluid removes heat from a large heat source, the fluid is then compressed, and the heat resulting from compression is discharged to a heat exchanger next to the surroundings to be heated.

heat sink: the medium or location to which waste heat is discharged.

high-temperature gas-cooled reactor (HTGR): a reactor fueled with blocks of graphite containing fissile and fertile material and cooled with helium. HTGR's are operated at a high temperature which permits conversion of heat to electricity with high efficiency.

hydraulic fracturing: a general term, for which there are other trade or service names, for the fracturing of rock in an oil or gas reservoir by pumping a fluid under high pressure into the well. The purpose is to produce artificial [illegible] in the rock in order to increase permeability.

hydrocarbon: a [illegible] compound containing only carbon [illegible] fossil fuels are predominantly hydrocarbons, with varying amounts of organic compounds of sulfur, nitrogen, and oxygen, and some inorganic materials.

hydroelectric plant: an electric power plant in which energy of falling water is converted into electricity by turning a turbine generator.

joule: a unit of energy or work which is equivalent to one watt per second or 0.737 foot-pounds.

kerosene: the petroleum fraction containing hydrocarbons that are slightly heavier than those found in gasoline and naphtah.

kilowatt (kW): 1,000 watts. A unit of power equal to 1,000 watts or to energy consumption at a rate of 1,000 joules per second. It is usually used for electrical power. An electric motor rated at one horsepower uses electrical energy at a rate of about 3/4 kilowatt.

kilowatt-hour (kWh): a unit of work of energy equal to that expended by one kilowatt in one hour. It is equivalent to 3.6 M joules.

kinetic energy: the energy of motion; the ability of an object to do work because of its motion.

light-water reactor (LWR): a nuclear reactor in which ordinary water or light water is the primary coolant/moderator with slightly enriched uranium fuel. There are two commercial light-water reactor types--the boiling water reactor (BWR) and the pressurized water reactor (PWR).

lignite: a low grade coal of a variety intermediate between peat and bituminous coal.

liquefaction (of coal): the conversion of coal into liquid hydrocarbons and related compounds by hydrogenation.

liquefied natural gas (LNG): natural gas that has been liquefied by cooling to about -140°C. In this form, it occupies a relatively small volume and can be transported economically by ocean tanker.

liquefied petroleum gas (LPG): a mixture of gaseous hydrocarbons, principally propane and butane, which can be liquefied under moderate pressure at normal temperatures.

liquid metal fast breeder reactor (LMFBR): a nuclear breeder reactor cooled by [illegible] [illegible] in which [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible].

lithium: element No. 3 (symbol, Li; atomic weight 6.94). As found in nature, lithium consists of a mixture of two stable isotopes--lithium-6 (7.5 percent) and lithium-7 (92.4 percent). Lithium-6 is of interest as a possible fuel or source thereof for the generation of power from a controlled thermonuclear reaction.

load: the amount of power needed to be delivered at a given point on an electric system.

load growth: the growth in energy and power demands by a utility's customers.

Lurgi Process: the chief commercially available process for coal gasification. Having originated in Germany, this process has limited application in the United States because of problems of scaling up the size of operations and characteristics of U.S. coal. The Office of Coal Research and American Gas Association are jointly funding further development.

margin: the difference between the net system generating capability and system maximum load requirements including net schedule transfers with other systems.

market penetration rate: the fraction of new and replacement market which is held by a particular process or product.

megawatt (MW): 1,000 kilowatts, 1 million watts.

metallurgical coal: coal with strong or moderately strong coking properties that contains no more than 8.0 percent ash and 1.25 percent sulfur, as mined or after conventional cleaning.

methane (CH_4): the lightest in the paraffinic series of hydrocarbons. It is colorless, odorless and flammable. It forms the major portion of marsh gas and natural gas.

middle distillate: one of the distillates obtained between kerosene and lubricating oil fractions in the refining processes. These include light fuel-oils and diesel fuel.

mine-mouth plant: a steam-electric plant or coal gasification plant built close to a coal mine. It is usually associated with delivery of output via transmission lines or pipelines over long distances as contrasted with plants located nearer load centers and at some distance from sources of fuel supply.

[illegible]: a material, for example graphite or water, [illegible] a large portion of the energy [illegible] permits the reactor to operate at low fuel enrichments.

National Environmental Policy Act (NEPA): an act passed in 1970 requiring that the environmental impact of most large projects and programs be considered. Among its important provisions is one requiring a detailed statement of environmental impact of and alternatives to a project to be submitted to the government before the project can begin.

natural gas: naturally occurring mixtures of hydrocarbon gases and vapors, the more important of which are methane, ethane, propane, butane, pentane, and hexane. The energy content of natural gas is usually taken as 1032 Btu/cu.ft.

natural uranium: uranium as found in nature, containing 0.7 percent uranium-235, 99.3 percent of uranium-238 and a trace of uranium-234. It is also called normal uranium.

net reserves: the recoverable quantity of an energy resonance that can be produced and delivered.

neutron: an elementary particle with approximately the mass of a proton but without any electric charge. It is one of the constituents of the atomic nucleus. It is frequently released during nuclear reactions and, on entering a nucleus, can cause nuclear reactions including nuclear fission.

nitrogen oxides (NOx): chemical compounds of nitrogen (N) and oxygen (O). A product of combustion of fossil fuels whose production increases with the temperature of the process. It can become an air pollutant if concentrations are excessive.

nuclear energy: energy released as particulate or electromagnetic radiation and heat during reactions of atomic nuclei.

nuclear fission: the splitting of large atomic nuclei into two or more new nuclear species, with the release of large amounts of energy.

nuclear fuel cycle: the various steps which involve the production, processing, use and reprocessing of nuclear fuels.

nuclear fusion: the process by which small atomic nuclei fuse together with the release of large amounts of energy.

nuclear power plant: any device, machine, or assembly that converts fission nuclear energy into some form [illegible] such as electrical power.

nuclear reactor: a device in which a fission [illegible] be initiated, maintained, and controlled [illegible] component is a core with fissionable fuel. It usually has a moderator, reflector, shielding, coolant and control mechanisms. It is the basic machine of nuclear power.

ocean thermal energy conversion (OTEC): electricity generation by making use of the temperature difference (some 40°F) between the top and bottom layers of the ocean to convert a fluid to vapor which in turn powers a turbine generator.

oil shale: a sedimentary rock containing solid organic matter from which oil can be obtained when the rock is heated to a high temperature.

Organization of Petroleum Exporting Countries (OPEC): founded in 1960 to unify and coordinate petroleum policies of the members. The members and the date of membership are: Abu Dhabi (1967); Algeria (1969); Indonesia (1962); Iran (1960); Iran (1960); Kuwait (1960); Libya (1962); Nigeria (1971); Qatar (1961); Saudi Arabia (1960); and Venezuela (1960). OPEC headquarters in Vienna, Austria.

outage: the period in which a generating unit, transmission line, or other facility, is out of service.

particulate matter: solid particles, such as the ash, which are released from combustion process in exhaust gases at fossil-fuel plants.

peaking capacity: that part of a system's equipment which is operated only during the hours of highest power demand.

peaking load: the greatest amount of all of the power loads on a system, or part thereof, which has occurred at one specified period of time.

petroleum: an oily flammable bituminous liquid that may vary from almost colorless to black, occurs in many places in the upper strata of the earth, is a complex mixture of hydrocarbons with small amounts of other substances, and is prepared for use as gasoline, naphtha, or other products by various refining processes.

petroleum refinery: a plant that converts crude petroleum into the many petroleum fractions (asphalt, fuel oil, gasoline, etc.). Usually this conversion is accomplished by fractional distillation.

photon: a quantum of electromagnetic energy having properties of both a wave and a particle, but without mass or electric charge.

[illegible] conversion: transformation of [illegible]

directly into electricity by means of a solid state device such as the single crystal silicon solar cell.

plasma: an electrically neutral, partially ionized gas in which the motion of the constituent particles is dominated by electromagnetic interactions. The study of plasma motions is called magnetohydrodynamics (MHD).

plutonium (Pu): a heavy, fissionable, radioactive, metallic element with atomic number 94. Plutonium-239 occurs in nature in trace amounts only. However, it can be produced as a by-product of the fission reaction in a uranium fueled nuclear reactor and can be recovered for future use.

pollution: the accumulation of wastes or by-products of human activity. Pollution occurs when wastes are discharged in excess of the rate at which they can be degraded, assimilated, or dispersed by natural processes. Sometimes noxious environmental effects not caused by human activity are also called pollution.

potential energy: energy which is not associated with motion—thus that which is stored in chemical bonds and water at high elevations are forms of potential energy.

power: the rate at which work is done or energy is transferred. Power is measured in units of work per unit time; typical units are the horsepower and the watt.

pressurized-water reactor: a power reactor in which heat is transferred from the core to a heat exchanger by water kept under high pressure to prevent it from boiling. Steam is generated in a secondary circulation system.

primary fuel: fuel consumed in original production of energy as contrasted to a conversion of energy from one form to another.

proton: a positively charged elementary particle having a mass of about 1.7 x 10^{-24} grams, roughly 1840 times as great as the mass of an electron. Protons are constituents of atomic nuclei and are emitted in some nuclear reactions.

proved reserves: the estimated quantity of crude oil, natural gas, natural gas liquids or sulfur which analysis of geologic and engineering data demonstrates with reasonable [illegible] to be recoverable from known oil or gas fields [illegible] economic and operating conditions.

pumped storage: an arrangement in which [illegible] storage reservoir at a higher [illegible] electricity is being generated [illegible] for electricity, this [illegible] of electricity as in a hydroelectric power plant.

radiation: the process by which energy in the form of electromagnetic radiation is emitted from matter. Also, the electromagnetic or particulate rays that are emitted from atoms or molecules as they undergo internal change.

radioactivity: the spontaneous decomposition of an atom accompanied by the release of energy.

reactor: any device in which a chemical or nuclear reaction is sustained in a self-supporting chain.

refinery: an industrial complex for processing crude oil by distillation and chemical reactions so as to produce a separate petroleum product. Typical crude fractions, from top to bottom or simple to complex, are : ether, methane, and ethane (the gasolines); propane and butane; kerosene, fuel oil and lubricants; jelly paraffin, asphalt and tar.

reserves: the amount of a fuel or other mineral resource known to exist and expected to be recoverable by existing techniques and under existing economic conditions.

reserve generating capacity: extra capacity maintained to generate power in the event of unusually high demand or a loss or scheduled outage of regular generating capacity.

residual fuel oil: a high-viscosity fuel oil that must be heated before it can be pumped and handled conveniently. Residual fuel oil is the petroleum fraction that is collected after all lower-boiling fractions have been distilled away. It is used primarily in industry, in large commercial buildings, and for the generation of electricity.

secondary recovery: oil and gas obtained by the augmentation of reservoir energy; often by the injection of air, gas or water into a production formation.

slow neutron: a low energy neutron, sometimes called a thermal neutron. The energy of a slow neutron is about 0.025 electron volts, in contrast to the energy of a fast neutron, which may exceed 1,000 electron volts. Slow neutrons are very efficient in causing fission of uranium-235. Nuclear power plants now in operation are designed to use slow neutrons to sustain the fission reaction.

smog: term used broadly to mean polluted air. There are [illegible] types of smog which are produced [illegible] pollutants under [illegible] [illegible] [illegible] from photochemical [illegible] hydrocarbons [illegible] of polluted air. Term is derived from smoke and fog.

<u>solar cell</u>: a device which converts solar radiation to a current of electricity.

<u>solar constant</u>: the average intensity of solar radiation striking the atmosphere. The solar constant is measured on a plane perpendicular to the path of the radiation. Its value is 1.36 kilowatts per square meter.

<u>solar furnace</u>: an optical device with large mirrors that focuses the rays from the sun upon a small focal point to produce very high temperatures.

<u>solar spectrum</u>: the total distribution of electromagnetic radiation emitted from the sun, minus those wave lengths that are absorbed by the solar atmosphere.

<u>stack gas desulfurization (scrubber)</u>: treating of stack gases to remove sulfur compounds.

<u>steam power plant</u>: a plant in which the prime movers (turbines) connected to the generators are driven by steam.

<u>strip mining</u>: the mining of coal by removing covering material (the overburden) and "stripping" away the entire underlying coal seam. Other forms of coal mining are underground, and auger mining in which coal is drilled out of seams exposed along the side of a mountain.

<u>synthetic natural gas (SNG)</u>: a manufactured gaseous fuel generally produced from naphtha or coal. It contains 95 to 98 percent methane, and has an energy content of 980 to 1035 Btu per standard cubic foot, about the same as that of natural gas.

<u>tar sands</u>: sedimentary rocks which contain viscous, heavy petroleum that cannot be recovered by conventional methods of petroleum production.

<u>tertiary recovery</u>: use of heat and other methods other than fluid injection to augment oil recovery (presumably occurring after secondary recovery).

<u>thermal pollution</u>: an increase in the temperature of water [illegible] from waste heat released by a thermal electric plant to the cooling water when the effects on other [illegible] are [illegible].

<u>thermal power plant</u>: any electric power plant which [illegible] generating heat and converting the heat [illegible]

thermal reactor: a nuclear reactor in which the fission process is propagated mainly by thermal neutrons, i.e., by neutrons that have been slowed down until they are in thermal equilibrium with the atoms of the moderator.

thermionic device: a device which converts heat into electricity by "boiling" electrons from a hot metal surface and condensing them on a cooler surface.

thermodynamics, laws of: the first law of thermodynamics states that energy can neither be created nor destroyed. The second law of thermodynamics states that when a free exchange of heat takes place between two bodies, the heat is always transferred from the warmer to the cooler body.

thorium (Th): a naturally radioactive element with atomic number 90 and, as found in nature, an atomic weight of approximately 232. The fertile thorium-232 isotope is abundant and can be transmuted to fissionable uranium-233 by neutron irradiation and in turn used as nuclear reactor fuel.

ton: a unit of weight equal to 2,000 pounds in the United States, Canada and the Union of South Africa, and to 2,240 pounds in Great Britain. The American ton is often called the short ton, while the British ton is called the long ton (tonne). The metric ton, or 1,000 kilograms, equals 2,204.62 pounds. Depending upon specific gravity, a long ton or metric ton will equal from 6.5 to 8.5 barrels of oil.

tritium (T): a man-made radioactive isotope of hydrogen with two neutrons and one proton in the nucleus.

turbine: a motor, the shaft of which is rotated by a stream of water, steam, air, or fluid from a nozzle and forced against blades of a wheel.

uranium (U): a radioactive element with the atomic number 92 and, as found in natural ores, an average atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7 percent of natural uranium) which is fissionable (capable of being split and thereby releasing energy) and uranium-238 (99.3 percent of natural uranium) which is fertile (having the property of being convertible to a fissionable material). Natural uranium also includes a minute amount of uranium-234.

waste heat: [illegible] which is at temperature very close [illegible] ambient [illegible] not valuable for production of power and must be discharged to the environment.

[illegible]: equipment [illegible]

operations, which are radioactive and for which there is no further use. Wastes are generally classified as high-level (having radioactivity concentrations of hundreds to thousands of curies per gallon or cubic foot), low level (in the range of 1 microcurie per gallon or cubic foot), or intermediate.

watt: a unit of power. It is the rate of energy use or conversion when one joule of energy is used or converted per second. (A joule is about 0.25 calories.)

watt-hour: the total amount of energy used in one hour by a device that uses one watt of power for continuous operation. Electrical energy is commonly sold by the kilowatt hour (1,000 watt-hours).

well head: oil or gas brought to the surface, ready for transportation to refinery or ship or pipeline. Well head costs usually refer to the cost to bring the oil or gas to the surface and do not include costs of transportation, refining, distribution or profit.

work: the transfer of energy from one body to another; or the energy itself, in the process of transfer. Work and energy are measured in the same units.

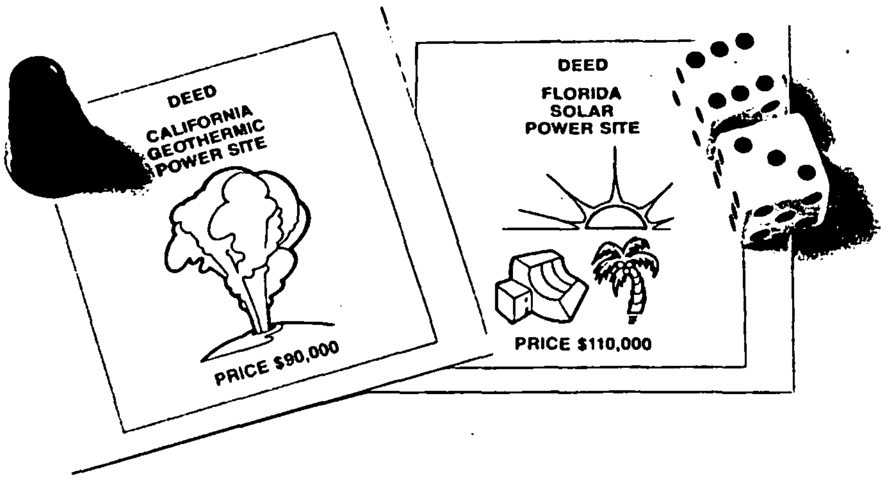
ENERGY UNIT CONVERSION CHART*

CUBIC FEET NATURAL GAS** (CF)	BARRELS OIL (bbl)	SHORT TONS BITUMINOUS COAL (T)	BRITISH THERMAL UNITS (Btu)	MEGAJOULES (MJ)	KILOWATT HOURS ELECTRICITY (kWhr)
0.001	--	--	1	.001054 (1054 J)	0.000293
0.948	0.00017	0.00004	948	1	0.278
1	0.00018	0.00004	1,000	1.054	0.293
3.41	0.00061	0.00014	3,413	3.6	1
948.6	0.17	0.038	948,600	1,000 (1 GJ)	278
1,000 (1 MCF)	0.18	0.04	1 MILLION	1,054	293
3,413	0.61	0.14	3.41 MILLION	3,600	1,000 (1 MWhr)
5,600	1	0.22	5.6 MILLION	5,900	1,640
25,000	4.46	1	25 MILLION	26,400	7,325
948,600	170	38	948.6 MILLION	1,000,000	278,000
1 MILLION (1 MMCF)	180	40	1 BILLION	1,054,000	293,000
3.41 MILLION	610	140	3.41 BILLION	3,600,000	1 MILLION (1 GWhr)
1 BILLION (1 BCF)	180,000	40,000	1 TRILLION	1.054 BILLION	293 MILLION
1 TRILLION (1 TCF)	180 MILLION	40 MILLION	1 QUADRILLION (QUAD)	1.054 TRILLION	293 BILLION

*Based on the following standard fuel heating values:
1 Cubic Foot Natural Gas = 1,000 Btu = 1.054 MJ
1 Barrel Crude Oil = 5.6 Million Btu = 5,900 MJ
1 Pound Bituminous Coal = 12,500 Btu = 13.2 MJ

**Synthetic Natural Gas (SNG) and Liquefied Natural Gas (LNG) will have approximately the same heating value. To convert from one unit to another, locate the horizontal row in which the unit you are converting from has a value of 1. Then read across to select the conversion factor by which you must multiply to arrive at the new unit. For example, to convert from "cubic feet of natural gas" to "short tons of coal," read down the "cubic feet" column until you arrive at the value of 1 (row 3); then read across to the "coal" column to find the factor 0.00004. Thus, 50 ft³ natural gas = (50)(0.00004) tons coal = 0.002 tons coal.

[illegible] the Institute of Gas Technology.



Alternative Fuels

by Peter Gottlieb, Ph.D.

Peter Gottlieb, Dames & Moore's Director of Computer Services, has managed a wide variety of engineering and environmental studies for nuclear and alternative energy projects. He directed a cost/benefit analysis of alternative modes of energy production for the California Energy Resources Conservation and Development Commission and has presented expert testimony concerning alternative energy resources before the U.S. House of Representatives Subcommittee on Energy and the Environment.

Declining domestic supplies of oil and natural gas are forcing us to look for alternatives. The first choice for substitution is the old standby, coal. But coal is not the complete answer. To begin with, it is expensive to burn because of stringent air pollution control requirements. Also, it will become more expensive to mine and transport as high-quality local deposits are used up (although it will remain cheaper than oil or natural gas). Above all, recurrent oil supply crises should have taught us the folly of reliance on any single fuel type for a major portion of our energy budget, especially an imported fuel.

Nuclear power was once viewed as the low-cost, environmentally harmonious fuel of the future. However, questions of safety, security, and increased construction costs have considerably diminished near-term prospects for greatly expanding this energy source. We are thus left with a bewildering array of alternative fuels, most of which are highly touted by their respective proponents, and very few of which have ever been tested in a practical energy production situation. For each of these fuels the competing claims of large resource availability, low cost, and very low environmental impact must be carefully evaluated.

The purpose of this paper is to compare the total reserves and costs of some of the more popular alternative fuels to the extent that the present uncertain state of knowledge and lack of practical commercial experience will permit. We will present these alternative fuels in groups having similar origins and similar costs and/or energy potential and will conclude with a comparison of all the alternative fuels and some projections of future trends.

"UNCOMMERCIAL" HYDROCARBONS

The uncommercial hydrocarbons include syngas (synthetic natural gas from coal), synoil (synthetic oil from coal), alcohol from coal, and oil from shale. These synthetic fuels constitute a very large resource, which reflects the fact that each is derived either from coal, which is very abundant, or shale, which is nearly as abundant. (Note that three of these alternatives are derived from coal and are thus to some degree mutually exclusive—coal burned to manufacture one derivative cannot be burned again to manufacture another.)

The main obstacle to the development of these synthetic fuels has been the large initial capital investment required. Because of the current energy situation, however, the federal government may subsidize their production and make up the price differential between the synthetic fuels and the natural hydrocarbons.

The main advantage of these fuels is their relatively large supply. Expressed in quads—short for quadrillion (10^{15}) British thermal units* (Btu)—the resources of this category could total 6,000, the equivalent of 75 years of our

---

*A Btu is the amount of heat energy required to raise the temperature of one pound of water (about a pint) one degree Fahrenheit.

total energy consumption (from all sources) of 80 quads per year.

Our estimates for costs and total resources for these four fuel types are compared in Figure 1. The process characteristics and problems associated with each are described below.

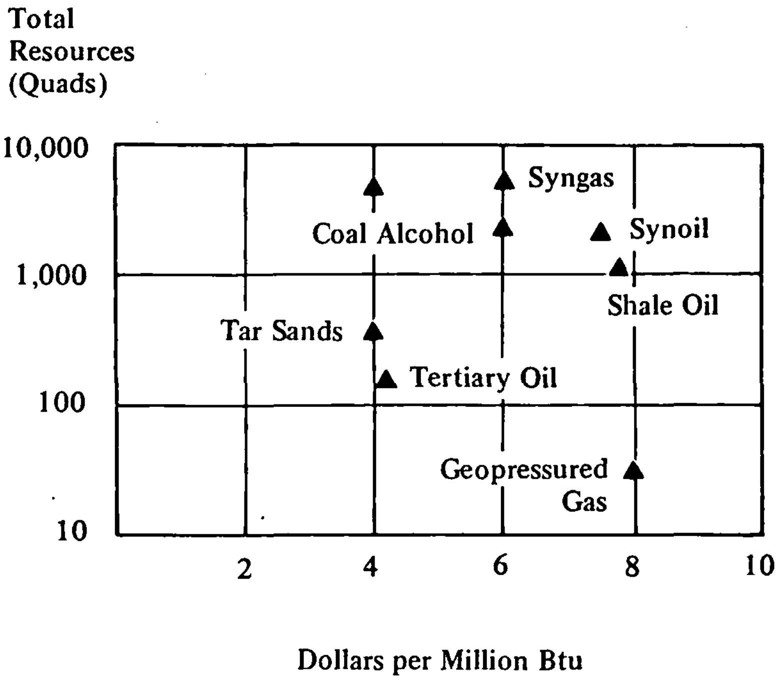


Figure 1. Uncommercial hydrocarbons: total resources versus cost per million Btu

SYNGAS

Of these four synthetic fuels, syngas has had the most commercial development. The earliest form of syngas, which was produced by simply passing steam over hot coal, was used for street lighting about a century ago (before the widespread availability of natural gas). The product was a low-energy gas (150 Btu per cubic foot) consisting mostly of hydrogen and carbon monoxide. Current gasification processes still begin with this reaction as an initial step, but the energy content of synthetic gas must be increased to approximately 1,000 Btu per cubic foot if it is to be transported economically over long distances. This can be accomplished by reacting the carbon monoxide and hydrogen catalytically to produce methane and carbon dioxide. Before this step, known as methanation, can take place, the concentration of hydrogen must be increased to provide the proper ratio for the reaction.

Commercial experience is almost entirely with the Lurgi process, which was used in Germany to produce natural gas (and gasoline) during the later stages of World War II, when their traditional oil supplies were cut off. The Republic of South Africa has developed this technology even further in an effort to lessen its dependence on politically unreliable foreign oil.

A number of other gasification technologies are also being developed in the United States, primarily to optimize the conversion of one or more of the broad range of domestic coal types. Unfortunately, the high capital investment, which appears to be required for all these processes, makes the resulting fuel too expensive—at least $4.00 per million Btu compared with $2.50 for natural gas (in 1978 dollars)—to risk development on a large commercial scale in the United States. There have however been a number of pilot plants (financed primarily by the Department of Energy), and construction on a few small commercial plants is beginning.

COAL LIQUEFACTION

The methane produced in coal gasification can be easily converted to methyl alcohol (methanol). Coal can also be converted to gasoline or oil (synoil), either directly or by reactions of the methane produced in the gasification process. Unfortunately, the synoil process is less energy-efficient than the gasification process (or methanol production) because of the extra steps needed to produce the heavier, longer-chain molecules. The total resource is only half what we would expect to get from gasification (as can be seen from the comparison in Figure 1). Nevertheless, liquid hydrocarbon fuels are essential to the functioning of our current transportation system, and there is considerable political support for the production of gasoline from coal.

Despite the lower efficiency of liquid synthetic fuel production, the Republic of South Africa has embarked on an ambitious program to provide some measure of energy independence by producing oil from coal. The South Africans have developed a process (called SASOL) similar to the Lurgi gasification process, but which produces gasoline directly. South Africa's first SASOL unit is already on-line, SASOL 2 is nearing completion, and by 1983 the country hopes to be nearly 50 percent self-sufficient in oil.

OTHER HYDROCARBON ALTERNATIVES

Oil from shale and tar sands is not presently commercial in the United States, but these sources are expected to see considerable activity in the 1980s. Estimated recoverable resources in the United States and their costs are shown in Figure 1 for comparison with the other uncommercial hydrocarbons.

Enhanced recovery of oil from existing wells is already in commercial practice and should not be considered an alternative fuel source. Some of the newer techniques (e.g., application of heat by burning some of the oil in place or use of detergent) are still in the development stage; they are grouped together as "tertiary oil" in Figure 1.

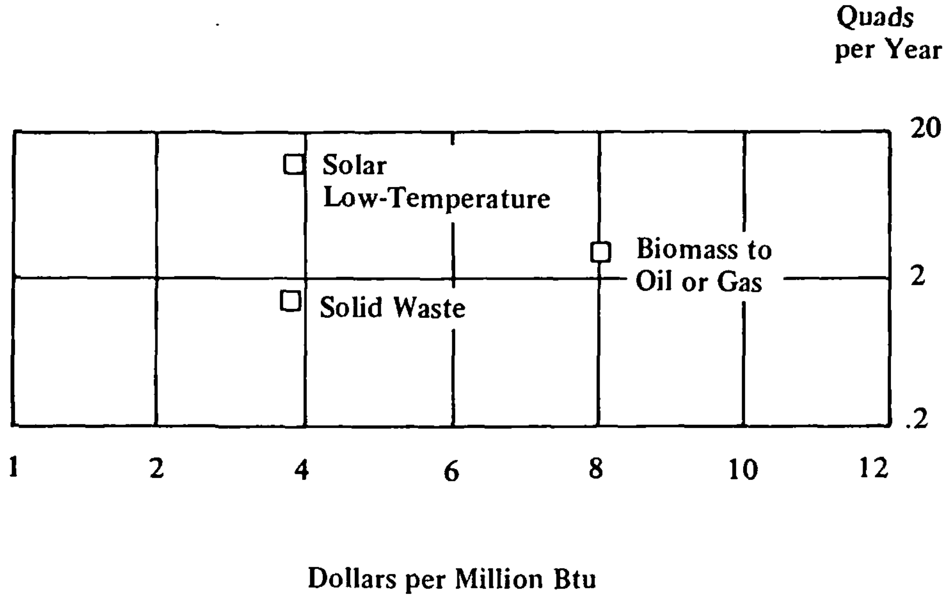


Figure 2. *Marginally economic renewable resources: quads per year versus cost per million Btu*

The remaining uncommercial hydrocarbon of significant potential for large supplies is geopressured brine. This is a geographically limited source, with the most promising brine reservoirs located near the Gulf Coast of Texas and Louisiana. The high reservoir pressure makes any well difficult to control, and the high concentration of brine necessitates an expensive disposal process. Improved well control technology and the use of the brine as a source of geothermal energy may make such projects commercially feasible. Unfortunately, the first test drilling in Texas resulted in a blowout, so the project is being redrilled. Another test well has begun in Louisiana. There is considerable controversy concerning the total resource that might be recoverable from this source, so the estimates shown in Figure 1 may be somewhat optimistic.

The 1980s will also see the exploitation of other unconventional sources of natural gas: Devonian shale, tight gas sands, and coal seams. The latter are already extracted extensively before mining of "gassy" coal deposits, in order to reduce the danger of explosion. However, none of these resources is large enough to show up on the scale of Figure 1.

RENEWABLE FUEL SOURCES: MARGINALLY ECONOMIC

The marginally economic, renewable fuel sources can be grouped in three main categories: solid wastes can be burned to provide energy or pyrolyzed to provide oil; biomass can be converted to alcohol or gas via fermentation or anaerobic digestion; and solar energy can be used for such low-temperature applications as water heating and industrial drying processes. The maximum annual energy potentially available and the estimated cost for each of these categories are shown in Figure 2. Under the most favorable circumstances we could get a total of 20 quads per year, or about one-fourth of our total energy consumption rate.

SOLID WASTE

The lowest-cost of these three categories is the combustion of solid waste, primarily because the fuel is free. For several years the city of Nashville, Tennessee, has been heating a major portion of the downtown area with steam produced by burning municipal solid waste. This material does not have a heating value rich enough to support efficient electric power generation, but it does burn hot enough when mixed with some other fuel.

The Union Electric Company, of St. Louis, Missouri, conducted a demonstration program using a fuel consisting of 90 percent coal and 10 percent solid municipal waste. For this particular project, the solid waste was shredded fine enough to be fed into the boilers through the same type of nozzles used for the pulverized coal. This experiment was terminated a few years ago, however, partly because of community protest over the location of trash storage facilities.

BIOMASS

The fermentation of alcohol from various agricultural products appears to have been practiced since the beginning of civilization. In response to the hardships induced by the 1979 oil shortage, some enterprising distillers have switched from the production of ethyl alcohol (ethanol) for drinking to motor fuel. The distillers can save money because the product need not be of such high purity, but the alcohol is still more expensive than the gasoline it is intended to replace, even with strong tax incentives.

This scheme is very popular as a means of disposing of surplus corn and maintaining or increasing agricultural prices, but as a long-range program it may not make much sense. If the energy used for producing the fertilizer and powering the agricultural vehicles is accounted for, the total energy input to the alcohol production process is more than the energy content of the product, even if some credit is given for the protein-rich spent grain byproduct (which is used for animal feed). In other words, we might be better off by simply curtailing surplus corn production. The process can be brought into a more favorable balance by burning the nongrain parts of the corn as the heat source for the distillation process and/or by improving the efficiency of the distillation process. A breakdown of the energy consumption for current practice is given in Table 1.

There are also greater efficiencies pos-

Table 1. Energy balance for the production of ethyl alcohol from corn using traditional fermentation and/or distillation processes (units are 10^3 Btu per gallon of ethanol produced)

INPUT		OUTPUT	
Agricultural			
Fertilizer	20	Ethanol (energy value as motor fuel plus refinery energy inputs)	144
Machinery (manufacture and repair)	15	Feed by-product	16
Miscellaneous (e.g., chemicals, seeds, and transportation)	15	Agriculture waste (stalks and cobs)	64
	50		
Process			
Cooking and fermentation	26		
Distilling	42		
Purifying	15		
Evaporation	45		
Drying	20		
	148		
Total Input	198	Total Output	224

sible with higher sugar content crops. Sugar cane is the basis of the Brazilian program, by which it is hoped to replace nearly 50 percent of gasoline consumption with ethanol. Sugar cane is more appropriate than corn because it has a lower protein content (and thus consumes less fertilizer), because the stalk portion of the plant (called bagasse) is quite suitable for fueling the distillation in coal liquefaction, and because, in Brazil, sugar cane can be tended and harvested with much less mechanical energy than corn in the United States.

Another energy source in this category is wood, which can either be burned directly or converted to alcohol. Ever since the oil embargo of 1973 a great many homes have been converted to burn wood for winter space heating, especially in New England, where firewood supplies are plentiful due to natural reforestation of abandoned agricultural lands. Wood can be fermented to alcohol, but feeding bacteria on cellulose is much more complex than fermenting sugar to alcohol. Since wood is fairly uniform chemically, it can also be converted to alcohol via nonbiologic chemical processes, but these reactions are fairly complex and must usually be performed at high pressures (which complicates the problem of feeding raw material to the reactor).

In Figure 2 we estimate that biomass has the potential for producing twice as much energy annually as solid waste, as estimated from the amount of forest and other crops that could be harvested for this purpose. Some staunch advocates of biomass have spoken of devoting half our agricultural acreage to energy crops, but the resulting competition for prime agricultural land and skilled farm management would greatly increase the price of foodstuffs. Biomass can be obtained without impacting prime agricultural land if low-density crops are grown on marginal land, or if we collect agricultural and forest residues which currently are largely wasted (although they do provide some soil conditioner). However, the energy required for gathering such dispersed sources would probably be as great as the energy to be obtained from the process.

SOLAR LOW-TEMPERATURE

In the southern part of the United States, solar energy was sometimes used for domestic water heating before natural gas was readily available and, more recently, in special situations where natural gas delivery systems were either too expensive or not available. Over 1000 solar hot water heaters were in use in Southern California at the turn of the century, and, until about ten years ago, when natural gas finally became widely available, there were nearly 40,000 simple rooftop units in central Florida. Today a significant number of these simple units are still used in Israel, Australia, and Japan.

Today's ever-increasing cost of fossil fuels is bringing back solar water heating as a feasible alternative. Because the main item of expense is the large storage tank required to carry the customer through the night and the inevitable cloudy days, systems that already have large storage capacities will become economically viable first. The outstanding example is the swimming pool, which is simply one huge storage tank. (Similarly, apartment houses already maintain large hot water storage capacities by virtue of the extensive piping system necessary for distribution throughout the building.) Heating a swimming pool by solar energy will produce an economic payback within ten years—even at today's artificially low natural gas prices of about $3.00 per thousand cubic feet. With decontrol, that price will at least double within the next four years, making other domestic uses of solar water heating competitive.

A number of large, well established companies have been developing highly efficient, moderately priced solar collectors for water heating. Grumman Aircraft has been marketing (and improving) solar hot water units for the past several years, and Sears Roebuck has just begun test marketing a unit for domestic use. With tax credits of up to 55 percent of the total system cost, we can expect the use of solar energy for low-temperature applications to increase rapidly.

In addition to residential hot water heating, a number of low-temperature industrial processes would also be appropriate candidates. Examples are drying processes and low-temperature evaporation (as in certain distillation processes). Because of the large number of potential applications, solar low-temperature would appear to have the largest potential annual production rate of any marginally economic source, as indicated in Figure 2.

RENEWABLE FUEL SOURCES: GEOGRAPHICALLY LIMITED

The geographically limited renewable energy sources include wind, geothermal, tidal, and hydroelectric. All of these have applications today, and hydroelectric is quite widespread. They are only to be found, however, in limited geographical areas where the environmental conditions are particularly favorable. The geographic restriction also implies a limit to the total production rate. The source with the largest potential is wind, and it will probably have a maximum of less than 2 quads per year for the foreseeable future, as shown in Figure 3.

WIND

Wind has historically been used primarily to propel sailing vessels and power windmills for pumping water and is certainly the oldest source of mechanical energy. Today most wind development efforts are aimed at the production of electrical energy, with several small projects being funded by DOE. The first wind energy project to feed electricity into the grid will probably be the 3-megawatt (peak) wind turbine being constructed for Southern California Edison. Although the winds at the site (in Banning Pass, near Palm Springs) have the highest persistence of any in Southern California, the duty cycle of the wind turbine is expected to average only 25 percent. The cost of the electricity thus generated will be significantly higher than that generated by conventional methods, but mass production may bring the price down. The crucial factor may be the lifetime of the windmill blades, which could fail from stress or from erosion by sand or other windborne particulates.

Wind energy may again be used to propel shipping on a widespread basis, possibly sooner than the large-scale application for electricity. Some marine engineering experts have suggested that half of all oceangoing shipping could be conveniently accommodated by 800- to 10,000-ton sailing vessels equipped with auxiliary power for maneuvering in harbors and escaping stagnant wind conditions. Hundreds of thousands of small sailboats are already being used for pleasure cruises, and they are certainly economically competitive with their powered counterparts. Recent improvements in the aerodynamics of sail design, navigation, and weather forecasting should enable large sailing vessels to perform much better than they did when they were a major mode of transportation nearly 100 years ago.

GEOTHERMAL

Geothermal power is also included in this category, although it is only renewable where especially favorable geologic conditions allow the ground water to recharge the producing aquifers. Renewable or not, this resource is limited to specific geographic areas. A geothermal steam field in Sonoma County, California, produces 600 megawatts of electricity, satisfying a major part of the electrical needs of San Francisco, and will soon support an increase in power output of over 1,000 megawatts. The only other commercial geothermal facility in North America is at Cerro Prieto, Mexico; it produces 75 megawatts and will soon be expanded to 150 megawatts.

The superheated water deposits beneath California's Imperial Valley are potentially much larger energy sources. They are already supporting several research and development projects, but their commercial feasibility remains questionable. These brines are highly corrosive, which may necessitate frequent, expensive turbine replacement, and the spent brine must be disposed of with minimum environmental impact. Also,

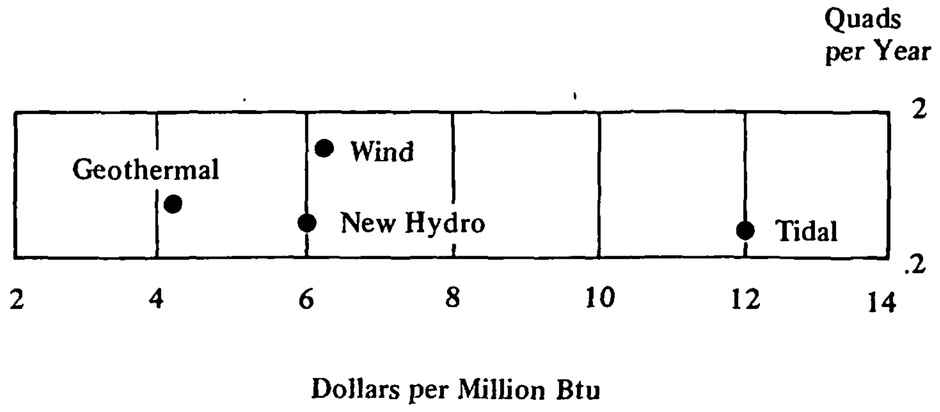


Figure 3. Geographically limited renewable resources: quads per year versus cost per million Btu

this relatively low-temperature electrical generating process will require large volumes of water for cooling.

There are two other speculative geothermal resources. The hot brines in the geopressured natural gas of south coastal Texas and Louisiana were mentioned earlier in connection with unconventional sources of natural gas. Tens of millions of dollars are also invested each year in hot dry rock geothermal. The proposal is to extract the heat from the anomalously hot rock by pumping cold water down one drill hole and extracting heated water from a nearby "gathering well." However, the extensive cracking of the hot rock (required to maintain contact for efficient heat transfer) will probably take a good deal of money and time just to show the feasibility.

Medium-temperature geothermal reservoirs, which can be exploited for space heating, are located in Idaho, Oregon, and Texas, and demonstration projects are now under way.

HYDROPOWER

Hydropower is certainly the largest renewable energy source in the United States, providing over 10 percent of our electricity, but this is down from nearly 30 percent in 1950. Hydropower has expanded very slowly, while total electricity production has increased over five-fold, because most of the good hydropower sites have long since been taken. In the future, development efforts will be concentrated on the less efficient low-head (and even run-of-the-river) sites, where water turbines will harness the power of the current. The exploitation of even these marginal resources will be restricted geographically to sites or rivers with a sufficiently steady flow.

TIDAL POWER

Tidal power is even more limited geographically than conventional hydropower—the tidal reservoir, or bay, must be of just the right configuration to produce a resonance in the shallow water waves generated by changes in the gravitational fields of the sun and the moon as the earth rotates. In addition, this properly configured, resonant bay must be situated on a coastline that, to some degree, focuses the tidal surge generated in the open ocean. This open ocean tidal surge and the changing (alternating) gravitational forces combine to pump energy into large tidal oscillations, and it is the magnitude of these oscillations that permits energy to be extracted from this low-head hydro source.

In North America the ideal geomorphic conditions are found only in the Bay of Fundy (Maine and Newfoundland) and Cook Inlet (Alaska). Exploiting even these limited resources would be quite expensive; the cost per unit of peak generating capacity is only slightly higher than for conventional coal or nuclear, but the duty cycle of these plants is less than 50 percent. That there would be a significant loss as the system shifts from high to low tide on the semidiurnal cycle is immediately apparent. There is, however, a more subtle but even greater loss on the monthly cycle, as the sun and moon move from pulling together on the same side of the earth to cancelling each other out when they are on opposite sides.

Only one moderately sized tidal power plant exists—at La Rance, France, at the mouth of the Rhone River. This plant, which produces 240 megawatts of peak power, was originally planned to be the precursor of half a dozen similar plants, but the operating experience gained has not been especially encouraging.

RENEWABLE SOURCES: VERY EXPENSIVE

There are two sources in this category, both solar. As shown in Figure 4, both sources have a large potential, but they are also an order of magnitude more expensive than present conventional electric generating processes.

SOLAR HIGH-TEMPERATURE (THERMAL-ELECTRIC)

Low-temperature solar applications such as hot water heating and industrial drying processes are almost economically competitive, even at today's artificially low energy prices, but the high-temperature solar process for producing electricity is currently much more expensive than present technology. Large sums of money are being spent in hopes of developing a cheap technology of very lightweight reflectors. Thousands of these would focus sunlight on a central boiler elevated several hundred meters above the mirror array (hence the name "power tower"). Under contract to DOE, Southern California Edison will construct a $100 million prototype facility in the Mojave Desert. The design should generate enough steam to produce a peak power output of 10 megawatts of electricity—less than one percent of its current system capacity. The capital investment, over $10,000 per kilowatt, is more than ten times that required for more conventional coal or nuclear generation. Even if the initial capital costs can be reduced tenfold by technological innovation and mass production, the cost of maintenance and repair (removing dust from the reflectors and replacing units damaged by windstorms) may be much higher than the operating costs of a coal or nuclear plant (including fuel).

PHOTOVOLTAIC CELLS

Photovoltaic semiconductor cells for the direct conversion of solar energy into electricity have been used to power spacecraft functions for many years. For very expensive spacecraft the high cost of the photovoltaic cells is not much added burden, but here on earth it imposes a severe constraint.

Proponents of solar power are fond of saying that the raw material (silicon) for photovoltaic cells is more abundant than any fuel. Sand (silicon dioxide) will certainly always be cheap, but the amount of energy required to extract the silicon from its tight bond with oxygen and refine it to the necessary purity is greater than the resulting solar cells are expected to be able to produce with today's technology. It has been estimated that a photovoltaic cell would have to operate for seven years to pay back its energy debt, and most solar cells exposed to atmospheric environments have not lasted that long.

Research workers expect to reduce photovoltaic costs and production energy requirements by a factor of 20 to 30 within the next ten years. Achieving this would require a breakthrough in each of three areas—producing the highly purified silicon, growing the (single) crystals and cutting them into individual cells, and fabricating the arrays (including protective cover glass and mechanical support systems). The requirement that single crystals be grown could be eliminated if another breakthrough greatly improved the performance, or lowered the cost, of polycrystalline silicon. Research directed at these objectives is continuing.

It is frequently argued that increased R&D spending will lower the cost of these solar electric systems enough to make them economically feasible. The FY 1980 DOE budget already allocates $680 million to this purpose, a major portion of which is devoted to demonstration projects based on obviously uneconomic technologies. For example, $21.5 million is budgeted for a group of nine photovoltaic projects at an average cost of $23 per peak watt; at this rate a solar photovoltaic system for a minimal, 1,500-square-foot house would cost nearly $100,000. Such projects, however, may be useful for political purposes, if only to demonstrate that the technology is much too expensive at present.

SOURCES OF QUESTIONABLE FEASIBILITY

Several sources appear to offer very large, or even unlimited energy sources, but the technology requires such large-scale facilities that engineering feasibility has not yet been demonstrated, let alone economic feasibility. Sources in this category are (in order of current promise and funding) thermonuclear fusion, ocean thermal electric conversion (OTEC), photovoltaic arrays in stationary orbit (which can be exposed to sunlight nearly 24 hours a day), water turbines powered by the Gulf Stream, and wave power.

THERMONUCLEAR FUSION

Controlling thermonuclear fusion has been a research goal for nearly 30 years. The concept has considerable intuitive appeal; after all, the hydrogen bomb is much more powerful than uranium or plutonium bombs, and the basic fuel ingredient, deuterium, can be extracted from seawater in virtually unlimited quantities. The idea of a smaller reactor with unlimited fuel supply is certainly attractive, but despite the hundreds of millions now being spent on this program, a self-sustaining thermonuclear reaction is still not expected to be achieved for at least five years, at which time the real engineering problems of extracting useful energy can be tackled. First of all, the only nuclear reaction likely to be achieved for quite some time is the lowest-temperature one, and it requires lithium fuel as well as deuterium. Lithium is probably no easier to find than uranium, so the overall fuel supply picture for thermonuclear fusion should be no better than that for fission breeder reactors (for which we expect reasonable fuel supplies to be available for 700 years). Second, maintaining the walls of the thermonuclear fusion reactor chamber is expected to pose a major problem because these walls will be exposed to intense bombardment by neutrons. In fact, the ultimate practicality of fusion energy production may be determined by whether the lifetime of the inner walls of the reactor chamber is reckoned in months or weeks.

OTEC

In ocean thermal electric conversion (OTEC), the temperature differential between the cold ocean depths and the warmer surface is exploited. The massive structures required to pump huge amounts of ocean water are expensive and pose serious logistical problems, but the critical question is whether the heat transfer surfaces can be cleaned easily enough that slime buildup does not reduce efficiency to the point at which the system will no longer operate. DOE is currently spending about $30 million a year on this program, much of it on a demonstration facility in Hawaii.

SATELLITE POWER SYSTEM

The satellite power system is a completely "blue sky" concept. It consists of a large photovoltaic array (up to 5 miles square) deployed in synchronous orbit to capture sunlight nearly 24 hours a day, free of the efficiency-reducing effects of attentuation from the earth's atmosphere and damage from the weather. The power would be transmitted back to earth on a high-powered, narrow microwave beam produced by a large antenna. This system will, however, require an inordinate amount of resources to be placed in orbit. Also to be considered are the potential impact of large volumes of rocket exhaust on the ionosphere and the safety problems associated with the microwave receiving stations here on earth.

OTHER CONCEPTS

Several other concepts, such as Gulf Stream hydro, wave power, and windmills in the ocean (where the prevailing winds are steadier than over the continents) have been advanced, but they have not yet been considered seriously. In fact, defining the potential engineering problems has not even begun.

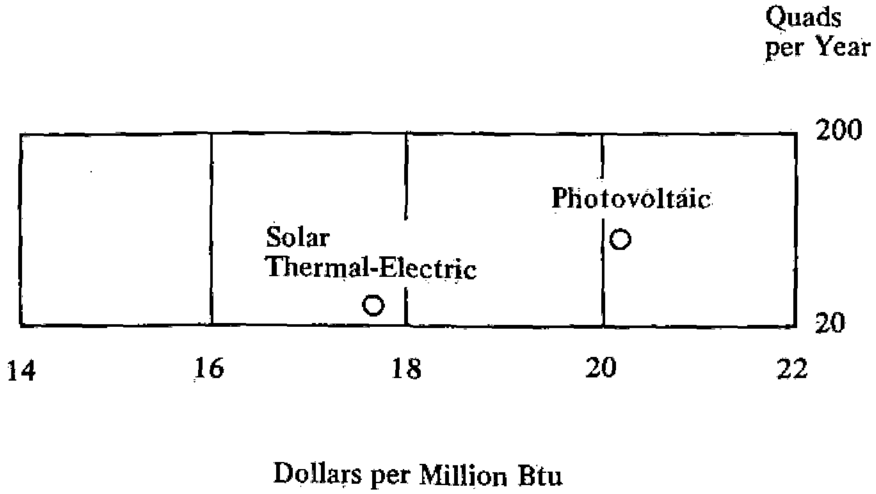


Figure 4. Very expensive renewable resources: quads per year versus cost per million Btu

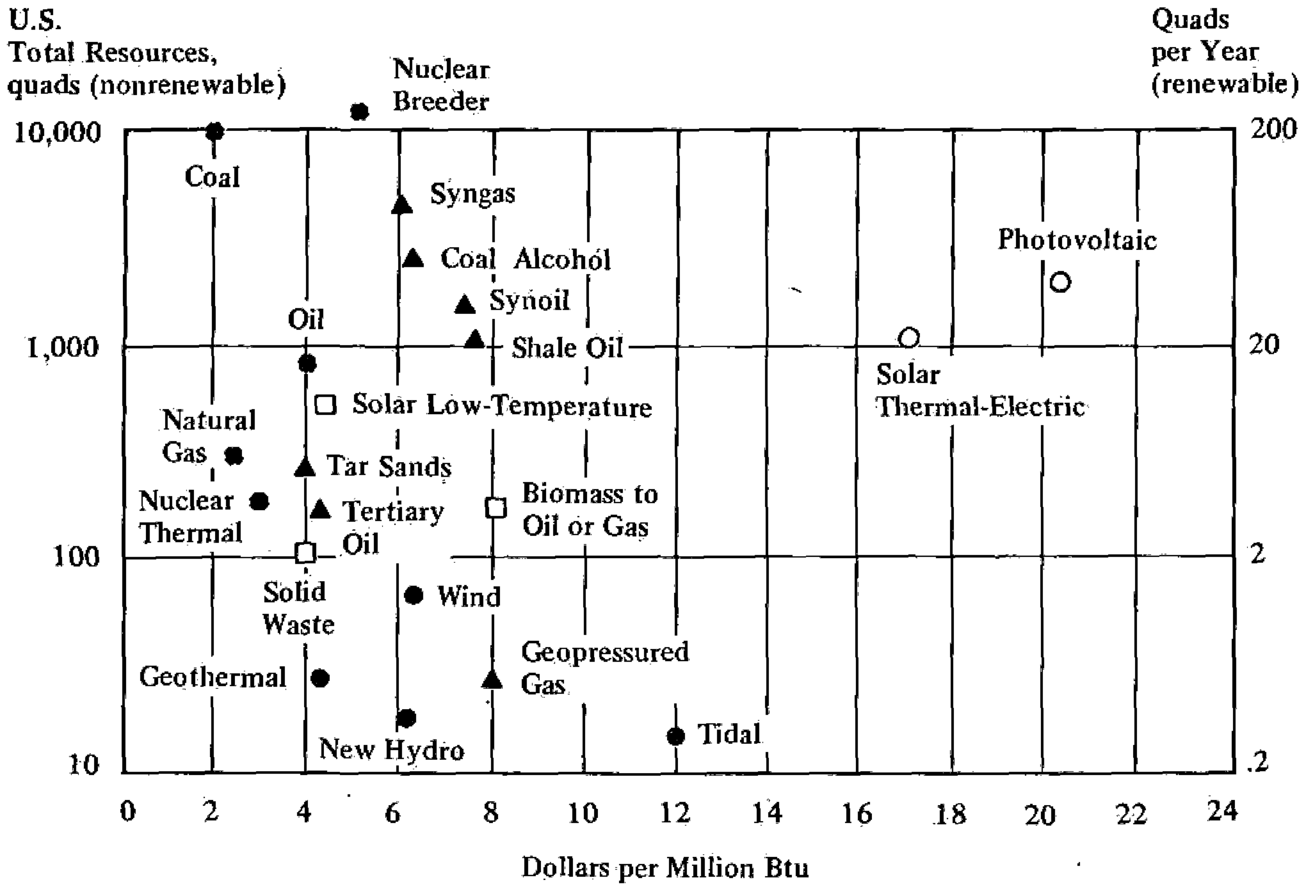


Figure 5. Composite comparison of alternative energy sources: costs and total reserves

CONCLUSION

The great number of energy alternatives in all these categories are compared in Figure 5. The left-hand scale, which shows total resource, applies to the nonrenewable sources, and the right-hand scale, which shows the annual rate of resource availability, applies to renewable resources. A correspondence has been established between renewable and nonrenewable sources through a 50-year lifetime; in other words, the energy extracted from a renewable source for 50 years should be equal to the total energy from an equivalent nonrenewable source.

Figure 5 shows that the technical alternatives that will begin to become available during the 1980s will become increasingly expensive. As we run out of the cheaper fuels, the more expensive alternatives will come into wider use. But will the cost seriously inhibit the overall economic growth of our economy?

A balanced strategy for the 1980s will require the continued development of coal and nuclear power, with conservation measures applied wherever possible without seriously restricting economic growth. We will see increasing development of alternative sources during the 1980s, but only where they can be reasonably cost effective and not too much more expensive than the conventional sources. As oil and natural gas become increasingly expensive, the alternative sources will begin to become a significant factor in our energy economy.

BIBLIOGRAPHY

Aster, R.W. (1978) "Economic Analysis of a Candidate 50 cents/wpk Flat Plate Photovoltaic Manufacturing Technology," DOE/JPL-1012-78-17, Jet Propulsion Laboratory, Pasadena, Calif.

Bergeson, Lloyd (1979) "Sail Power for the World's Cargo Ships," *Technology Review*, March/April, pp. 22-36 (Vol. 81, No. 5).

Considine, D.M., ed. (1977) *Energy Technology Handbook*, McGraw Hill Book Co., New York.

Gray, P.J., and O.K. Gashus (1972) *Tidal Power*, Plenum Press, New York-London.

U.S. Department of Energy Fiscal Year 1980 Congressional Budget Request.

Wade, Nicholas (1979) "Oil Pinch Stirs Dreams of Moonshine Travel," *Science*, June 1, pp. 928-9 (Vol. 204, No. 4,396).

Comparative Energy Balances for Ethanol Production

Source: **Fuel From Farms**
SERI/SP-451-519
February 1980

SEIDB
Solar
Energy
Information
Data Bank

Managed by
Solar Energy Research Institute
A Division of Midwest Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

Operated by
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

COMPARATIVE ENERGY BALANCES FOR ETHANOL PRODUCTION

Energy balances are a confusing and controversial subject. The sources of the confusion are varied but most stem from differences in opinion regarding what must be included for consideration and the proper approach to use. One of the principal sources of confusion is the type of energy balance being investigated in a given case. Some energy balance studies compare the total energy contents of the products and coproducts with the fossil energy consumed in their production. Other studies compare the amount of crude petroleum energy required to produce a given amount of petroleum substitute. Whatever types of energy are compared, an energy balance study has the objective to compare the energy input to a system with the energy output of the system. If the energy input is greater than the energy output, the energy balance is said to be negative; conversly, if the energy output of the system is greater than the energy input to the system, the energy balance is said to be positive. The causes of disparity among the various studies include differences in assumptions and reference technologies, and ambiguities in defining the boundaries of the given system under consideration.

Consider the ethanol production system shown in Figure D-1. Energy inputs to the system include the liquid fuel and manufacturing energy required to produce the feedstocks and the electrical and heat energy required to convert the feedstocks into ethanol. Note that the solar energy input is not included. Energy output of the system is in the form of ethanol which can be used in vehicles and other applications and other coproducts. To illustrate how differences in opinion among various studies can arise, consider the ethanol energy balance studies of Scheller and Mohr [1] and Reilly [2]. For 1 bushel of corn, the two studies calculate similar values for the total nonrenewable energy inputs as follows:

ENERGY BALANCES
(Basis: 1 Bushel Corn)

Energy Inputs	Scheller & Mohr	Reilly
Agricultural Energy	119,000 Btu	135,000 Btu
Direct on-farm		
Fertilizer and chemicals		
Transport		
Ethanol Process Energy	370,000 Btu	368,000 Btu
Cooking and fermentation	64,000	
Distilling and centrifuging	105,000	
Dehydration	37,000	
Evaporation of stillage	113,000	
Drying of stillage	51,000	
TOTAL ENERGY INPUT	489,000 Btu	503,000 Btu

From similar values of energy input, Scheller and Mohr proceed to calculate a positive energy balance, while Reilly calculates a negative energy balance. Reilly considers the outputs to be 2.6 gallons of ethanol, with a total (lower) heating value of about 191,000 Btu, and the stillage coproduct which can be given an energy credit of about 49,000 Btu [3]. Subtracting the energy input of 503,000 Btu from the total of energy output of 240,000 Btu, Reilly obtains a negative energy balance of 260,000 Btu. However, Scheller and Mohr include, as an additional coproduct, the heat content of 75% of the corn stover to be used as energy input into the ethanol production process. This amounts to an additional energy output of about 322,000 Btu. Thus, Scheller and Mohr would calculate a total energy output of 562,000 Btu and achieve a positive energy balance of about 73,000 Btu for each bushel of corn processed into ethanol.

REFERENCES

1. Scheller, W., Bohr B. "Net Energy Balance for Ethanol Production." Presented at the 171st National Meeting of the American Chemical Society, New York, April 7, 1976.

2. Reilly, P.J. "Economics and Energy Requirements for Ethanol Production." Department of Chemical and Nuclear Engineering, Iowa State University; January 1978.

3. Chambers, R.S., Herendeen, R.A., Joyce, J.J., and Penner, P.S. "Gasohol: Does It or Doesn't It Produce Positive Net Energy?" *Science*, Volume 206 (no. 4420): November 16, 1979, pp. 789-795.

Resource People and Organizations

- Associations and Organizations
- Biologists
- Chemists
- Colleges
- Component Manufacturers
- Consultants
- Co-Ops in Operation
- Economists
- Educators
- Engineers
- Engine Modification Engineers
- Enzyme Producers
- Molecular Sieve Manufacturers
- On-Farm Operating Plants
- Plant Operation Consultants
- Sources of Public Financing

NOTICE

The following list of resource people and organizations is provided for your information. Neither DOE nor SERI recommend or vouch for these sources. We would appreciate receiving additions or revisions to this information.

Source: **Fuel From Farms**
SERI/SP-451-519
February 1980

SEIDB
Solar Energy Information Data Bank

Managed by
Solar Energy Research Institute
A Division of Midwest Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

Operated by
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

ASSOCIATIONS AND ORGANIZATIONS

American Agriculture Movement
308 Second Street, SE
Washington, D.C. 20515
202/544-5750

The Bio-Energy Council
1625 Eye Street, NW
Suite 825A
Washington, D.C. 20006
Contact: Carol Canelio
202/833-5656

Brewers Grain Institute
1750 K Street, NW
Washington, D.C. 20006

Corn Development Commission
Route 2
Holdrege, NE 68949

Distillers Feed Research Council
1435 Enquirer Building
Cincinnati, OH 45202
Contact: Dr. William Ingrigg
513/621-5985

Gasohol USA
10008 East 60th Terrace
Kansas City, MO 64133
816/737-0064

The Grange
Route 1, Box 154
Waterloo, NE 68069
402/359-5605

International Biomass Institute
1522 K Street, NW
Suite 600
Washington, D.C. 20005
Contact: Dr. Darold Albright
202/783-1133

Mid-America Solar Energy Complex
8140-26th Ave., South
Bloomington, MN 55420
612/854-0400

National Farmers Organization
Surprise, NE 68667

National Farmers Union
Denver, CO 80251

National Gasohol Commission, Inc.
521 South 14th Street, Suite 5
Lincoln, NE 68508
402/475-8044 or 8055

National Center for Appropriate Technology
P.O. Box 3838
Butte, MT 59701
406/494-4577

Small Farm Energy Project
P.O. Box 736
Hartington, NE 68739
Contact: Renise Remmel
402/254-6893

Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401
Contact: Paul Notari
Clay Smith
Steve Rubin
303/231-1207

The Wheat Growers
Route #1, Box 27
Hemingford, NE 69438
Contact: Vic Haas
308/487-3794

The Wife Organization
Osceola, NE 68651

BIOLOGISTS

Antonios A. Antonopoulos
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439
312/972-3368

Paul Middaugh
University of South Dakota
Brookings, SD 57007
605/688-4116

Robert Middaugh
1704 Third Street
Brookings, SD 57006
605/692-5760

Micro-TEC Lab, Inc.
Route 2, Box 19L
Logan, IA 51546
Contact: John W. Rago
712/644-2193

Leo Spano
The Army/Navy Lab
Natick, MA 01760
617/653-1000, Ext. 2914

CHEMISTS

Lance Crombie
Route 1
Webster, MN 55088
507/652-2804

John P. Dickie
401 Sible Street
St. Paul, MN 55101
612/291-2813

Harry P. Gregor
Columbia University
353 Seeley West Mudd Building
New York, NY 10027
212/280-4716

John Lang
Box 423
Dubuque, IA 52001
319/582-1867

Antonio R. Moreira
Colorado State University
Fort Collins, CO 80523
303/491-5252

Richard Spencer
Southwest State University
Marshall, MN 56258
507/537-7217

COLLEGES

Talladega College
627 West Battle Street
Talladega, AL 35160
Contact: Richard A. Morrison
(205) 362-8800

Mid-South Energy Project
Mississippi County Comm. College
Box 1109
Blytheville, AR 72315
Contact: Harry Smith
(501) 762-1020

Modesto Jr. College
Modesto, CA 95350
Contact: Ron Alver
(209) 526-2000

College of Siskiyous
800 College Avenue
Weed, CA 96094
Contact: Gary Peterson
(916) 938-4463

Lamar Comm. College
2401 South Main
Lamar, CO 81052
Contact: Bill Henderson
(303) 336-2248

Delaware Tech. & Comm. College
1832 N. Dupont Parkway
Dover, DE 19901
Contact: Rich Morchese
(302) 678-5416

Brevard Comm. College
1519 Clearlake Road.
Cocoa, FL 32922
Contact: Maxwell King
(305) 632-1111

College of Southern Idaho
315 Falls Avenue West
Twin Falls, ID 83301
Contact: James Taylor
(208) 733-9554

Kankakee Comm. College
Box 888
Kankakee, IL 60901
Contact: M.E. Marlin
(815) 933-0345

Lake Land Comm. College
South Route 45
Matoon, IL 61938
Contact: Robert D. Webb
(217) 235-3131

Lincoln Land Comm. College
Springfield, IL 62708
Contact: Robert Poorman
(217) 786-2200

Vincennes University
Vincennes, IN 47591
Contact: Daryle Riegle
(812) 882-3350

Des Moines ATVI
2006 South Ankeny Blvd.
Ankeny, IA 50021
Contact: Richard Byer
(515) 964-6228

Eastern Iowa Comm. College
2804 Eastern Avenue
Davenport, IA 52803
Contact: Robert Illingsworth
(319) 242-6841

Iowa Central Comm. College
330 Avenue M
Fort Dodge, IA 50501
Contact: Edwin Barbour
(515) 576-3103

Paducah Comm. College
Box 1380
Paducah, KY 42001
Contact: Donald Clemons
(502) 442-6131

Nicholls State University
Thibodaux, LA 70301
Contact: William Flowers
(504) 446-8111

Cecil Comm. College
1000 North East Road
North East, MD 21901
Contact: Robert Gell
(301) 287-6060

Springfield Tech. & Comm. College
One Armory Square
Springfield, MA 01105
Contact: Robert Geidz
(413) 781-6470

Clark University
450 Main
Worchester, MA 01610
Contact: Harry C. Allen
(617) 793-7711

Mott Comm. College
1401 East Court Street
Flint, MI 48503
Contact: Charles Roche
(313) 762-0237

Southwest State University
Marshall, MN 56258
Contact: Richard Spencer
(800) 533-5333

NW Mississippi Junior College
Highway 51
North Senatobia, MS 38668
Contact: William Oakley
(601) 562-5262

State Fairground Comm. College
Sedalia, MO 65301
Contact: Marvin Fielding
(816) 826-7100, Ext. 60

South East Comm. College
Milford, NE 68405
Contact: Dean Roll
(402) 761-2131

Onondaga County Comm. College
Syracuse, NY 13215
Contact: Andreas Paloumpis
(315) 469-7741

Navajo Comm. College
Box 580
Shiprock, NM 87420
Contact: Raymond Housh
(505) 368-5291

North Dakota State School of Science
Wahpeton, ND 58075
Contact: Claire T. Blikre
(701) 671-2221

Pitt Comm. College
Box Drawer 7007
Greenville, NC 27834
Contact: William Fulford
(919) 756-3130

Panhandle State University
Box 430
Goodwell, OK 73939
Contact: Gene Reeves
(405) 742-2121

Eastern Oregon State College
8th & K Streets
LaGrande, OR 97850
Contact: Terry Edvalson
(503) 963-2171

Lehigh County Comm. College
2370 Main Street
Schnecksville, PA 18078
Contact: Robert Walker
(215) 799-1141

South Dakota State Univ.
Brookings, SD 57007
Contact: Paul Middaugh
(605) 688-4111

Oglala Sioux Comm. College
Box 439
Pine Ridge, SD 57700
Contact: Roberta Barbalace
(606) 867-5110

Navarro Jr. College
Box 1170
Corsicana, TX 75110
Contact: Darrell Raines
(214) 874-6501

Texas Tech. University
Lubbock, TX 79409
Contact: Steven R. Beck
(806) 742-2121

University of Vermont
Burlington, VT 05405
Contact: Robert B. Lawson
(802) 656-2990

College of the Virgin Islands
Contact: Michael Canoy
St. Thomas, VI 00801

Washington State University
Box 708
Chehalis, WA 98532
Contact: Larry Gueck
(206) 748-9121, Ext. 212

Eastern Wyoming College
3200 West C
Torrington, WY 82240
Contact: Charles Rogers
(307) 532-7111

COMPONENT MANUFACTURERS

ACR Process Corporation
602 East Green Street
Champaign, IL 68120

ALCOGAS
220 Equitable Building
730 17th Street
Denver, CO 80203
Contact: Evan L. Goulding
303/572-8300

W. A. Bell
P.O. Box 105
Florence, SC 29503

Easy Engineering
3351 Larimer Street
Denver, CO
303/893-8936

D. N. Gray
Biotechnology and Toxicology
Toledo, OH 43666
419/247-9206

Great Northern Equipment Company
3550 Great Northern Avenue
Route 4
Springfield, IL 62707
Contacts: Dale Devermon
Ray Kramer
217/787-9870

Jerry Joseph
Middle State Mfg. Co.
16th Avenue, Box 788
Columbus, NE 68601
402/564-1411

Rochelle Development Inc.
Box 356
Rochelle, IL 61068
Contact: John Askvig
815/562-7372

Silver Engineering Works Inc.
3309 Blake Street
Denver, CO
Contact: Richard D. Smith
303/623-0211

Sludge Express Company
Sheldon, IA
Contact: David Vander
712/324-3305

3T Engineering Inc.
Box 80
Arenzville, IL 62611
Contact: Wm. C. Talkemeyer
217/997-5921

United Industries
P.O. Box 11
Buena Vista, GA 31803
Contact: John Daniel
912/649-7444

Vendome Copper and Brass
153 North Shelby Street
Box 1118
Louisville, KT 40202
502/587-1930

E. Dale Waters
Double "L" Mfg. Inc.
P.O. Box 533
American Falls, ID 83211
208/226-5592

Wenger Alko-Vap System
1220 Rochester Boulevard
Rochester, IN 46975
Contact: Oscar Zehier
219/223-3335

Weslipp
Franklin, NE
Contact: Brian Hayers
303/425-3101

CONSULTANTS

Bartlesville Energy Technology Center
Bartlesville, OK
Contact: Jerry Allsup
918/336-4268

Battelle Columbus Laboratories
505 King Avenue
Columbus, OH 43201
Contact: Billy Allen
614/424-6424

Center for Biology of Natural Systems
Washington University
St. Louis, MO
Contact: David Freedman
314/889-5317

EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415
Contact: Don LaRue
208/526-0509

Energy Inc.
P.O. Box 736
Idaho Falls, ID 83401
Contact: Steve Winston
208/524-1000

Environmental Group
RD #3
Quakertown, PA 18951
Contacts: Jack Hershey
Bob Meskunas
215/536-8243

Galusha, Higgins and Galusha
P.O. Box 751
Glascow, MT 59230
Contact: Jim Smrcka
406/228-9391

William S. Hedrick
844 Clarkson
Denver, CO 80218
303/832-1407

Pincas Jawetz
Independent Consultant on
Energy Policy
425 East 72nd Street
New York, NY 10021
212/535-2734

TRW Energy Systems Group
8301 Greensboro Drive
McLean, VA 22102
Contacts: V. Daniel Hunt
Mani Balasubramaniam
Harlan L. Watson
Warren Standley
703/734-6554

CO-OPS IN OPERATION

Ted Landers
New Life Farm
Drury, MO 65638
417/261-2553

ECONOMISTS

Tom P. Abeles
3704 11th Avenue South
Minneapolis, MN 55407
612/825-9451

Bill Elsey
5230 Navaho Drive
Alexandria, VA 22313
703/256-7694

Edward Falck and Company
1625 Eye Street
Washington, D.C. 20006
Contact: Michael H. Pete
202/331-1989

David Freedman
Center for the Biology of
Natural Systems
Washington University
Box 1126
St. Louis, MO 63130
314/889-5317

Southern Illinois, Inc.
P.O. Box 327
Energy, IL 62933
Contact: John McCarty
618/993-6322

Office of Energy Management
and Conservation
1533 North 12th
Bismarck, ND 58501
Contact: Clay Dunlap,
Federal Aid
Coordinator
701/224-2250

EDUCATORS

Keith Allen
State Fair Community College
Sedalia, MO 65301

Carrol deBrockart
P.O. Box 12068
Salem, OR 97309
503/378-8609

Tom Bullock
University of Nebraska
Lincoln, NE 68588
402/472-3578

William Flowers
Nichols State University
Thibadoux, LA 70301
800/535-2840

Anne Kunze
RFD 1, Box 210
Woonsocket, SD 57385
605/796-4602

Lowell Langerman
Route 2
Fayette, IA 52142
319/425-3244

Mike Levi
North Carolina State University
Raleigh, NC 27607
919/737-3386

Malcolm Lillywhite
P.O. Box 2043
Evergreen, CO 80439
303/674-1597

Marvin Lind
257 Jewett Boulevard
Des Moines, IA 50309
515/243-0881

Cliff McBride
1900 Clarendon Road
Sedalia, MO 65301
816/826-7100, Ext. 44

Ted McFadden
9539 Fort Foote Road
Oxon Hill, MD 20022
301/839-5019

Paul Middaugh
South Dakota State University
Billings, SD 57007
605/688-4116

Y. T. Pei
475 Steamboat Road
Greenwich, CT 06830
203/622-9020

Gordon Rowe
Des Moines Area Community
College
2006 South Ankeny Blvd.
Des Moines, IA 50021
515/964-6266

Aline Shermie
Nichols State University
Thibadoux, LA 70301
800-535-2840

Herbert Staulcup
Washington University
Campus Box 1196
St. Louis, MO 63130
314/889-6600

Dr. James H. Tangeman
Colby Community College
Colby, KS 67701
913/462-3984

Charles Thornhill
Pratt Community College
Pratt, KS 67127
316/672-5641

Dean Wuesterberg
RFD 1
Donahue, IA 52746
319/843-3032

ENGINEERS

William P. Bailey
2508 Northwest 87th
Seattle, WA 98117

Ernie Barcell
Seven Energy Corp.
3760 Vance
Wheat Ridge, CO 80030
303/425-4239

Ulrich Bonne
Honeywell Inc.
Corp. Tech. Center
10701 Lyndale Avenue South
Bloomington, MN 55420
612/887-4477

Robert S. Chambers
808 South Lincoln Avenue #14
Urbana, IL 61801
217/384-8003

Miles Connors
Stone and Webster
One Penn Plaza
New York, NY 10001
212/760-2000

Dave Decker
Tilden Fertilizer
Tilden, NE 68781
402/368-5317

Wayne C. Faulconer
Distillation and Mass Transfer
Consultant-Engineering
6307 East Ninth Street
Wichita, KS 67208
316/686-6537

Bryan Hayes
Franklin, NE 68939

Bill and Lesa Hedrick
844 Clarkson Street
Denver, CO 80218
303/832-1407

H. M. Neely
P.O. Box 587
Colby, KS 67701
913/462-2641

Kenneth J. Schmitt
Alternative Energy Ltd.
650 Pine Street
Colby, KS 67701
913/462-7531

Dr. William A. Scheller
University of Nebraska
Lincoln, NE 68588
402/472-2750

Henry Schowalter
1508 West John
Grand Island, NE 68801
308/384-9165

R. E. Talkemeyer
Agri-Fuels Gasohol
3-T Engineers
Arenzville, IL 62611
217/997-2188

Steven J. Winston
Route 3, Box 239
Idaho Falls, ID 83401
208/522-6413

ENGINE MODIFICATION ENGINEERS

Mart Kirik
222 McIntyre Street West
North Bay, Ontario P1B 2Y8
Canada

Dick Pefley
University of Santa Clara
Santa Clara, CA 95053
408/984-4325

Kenneth J. Schmitt
Alternative Energy Ltd.
650 Pine Street
Colby, KS 67701
913/462-7531

Southwest Research Institute
San Antonio, TX

Chuck Stone
California Legislature
Sacramento, CA 95814
916/445-7518

Thomas J. Timbario
1900 Sulphur Spring Road
Baltimore, MD 21227
301/247-5666

Ying-Nien Yu
Ying Manufacturing
Corporation
1957 West 144 Street
Gardena, CA 90249
213/770-1756

ENZYME PRODUCERS

Biocon, Inc.
261 Midland Ave.
Lexington, Kentucky 40507
606/254-0517

Norbert Haverkamp
Compost Making Enzymes
Rural Route 1, Box 114
Horton, KS 66439
913/486-3302

Miles Laboratories, Inc.
Enzyme Products Division
P.O. Box 932
Elkhart, IN 56515
219/564-8111

Novo Laboratory, Inc.
59 Danbury Road
Wilton, CT 06897
203/762-2401

Scientific Products Co.
North Kansas City, MO 64116
816/221-2533

MOLECULAR SIEVE MANUFACTURERS

W. R. Grace
P.O. Box 2117
Davison Chemical Division
Baltimore, Maryland 21203
Contact: Paul E. Cevis
301-659-9000

ON-FARM OPERATING PLANTS

Don Cook
Route 1, Box 17A
Craig, CO 81625
303/824-6746

Lance Crombie
Route 1
Webster, MN 55088
507/652-2804

Lowell Fey
5169 Ute Highway
Longmont, CO 80501
303/823-5052

Forrest Flippo
RFD 4
Abilene, KS 67410
913/263-4367

Larry Hardimon
Route 1

White Heath, IL 61884
217/687-2622

Brian Hultine
Rural Route 2
Saronville, NE 68979
402/773-4746

Dick Johnson
Felox Corporation
7703 Normandale Road
Minneapolis, MN 55435
612/835-1103

James Miles
Box 83, Route 1
New Albin, IA 52160
507/724-2387

Marvin Oerke
RFD 3, Box 194
Butler, MO 64730
816/669-5159

Jim Pufahl
Box 99, Route 2
Milbank, SD 57252
605/432-4169

Lloyd Reeser
Route 1
Weldon, IL 61882
217/736-2539

LeRoy Schartz
RFD 3
Great Bend, KS 67530
316/793-7144

Dr. L. Eugene Schroder
North Route
Campo, CO 81029
303/523-6787

Eldon L. Shelter
S&S Galvanizing Co.
P.O. Box 37
Clay Center, NE 68933

Roger Sweet
Agrifuels, Inc.
Crookston, MN 56716

Albert Turner
Southwest Alabama Farmers Co-op
Selma, Alabama
205/683-8800

Alan and Archie Zeithamer
Route 2, Box 63
Alexandria, MN 56308
612/762-1798 (Alan)
612/763-7392 (Archie)

PLANT OPERATION CONSULTANTS

Harland Anderson
Five Woodcrest Drive
Burnsville, MN 55337
612/825-9451

Daniel Archer
1351 Waconia Avenue, SW
Box 1445
Cedar Rapids, IA 52406
319/398-0644

Midwest Solvents Co., Inc.
1300 Main Street
Atchison, KS 66002
913/367-1480

Miles Connors
One Penn Plaza
New York, NY 10001
212/736-1500

Development Planning and Research Associates
2000 Research Drive
P.O. Box 727
Manhattan, KS 66502
Contacts: Milton David
Robert J. Buzenberg
913/539-3565

Donald Miller
2900 Vernon Place
Cincinnati, OH 45219
513/281-2800

Jim Kumana
1050 Delta Avenue
Cincinnati, OH 45208
513/871-7500

E. Kirchner
10 South Riverside Plaza
Chicago, IL 60606
312/454-3685

William J. Jones
1818 Market Street
Philadelphia, PA 19103
215/299-8193

Robert Chambers
808 South Lincoln #14
Urbana, IL 61801
217/384-8003

Dale Devermon
3550 Great Northern Avenue
Route 4
Springfield, IL 62707
217/787-9870

William S. Hedrick
844 Clarkson
Denver, CO 80218
303/832-1407

Dr. Ing. Hans Mueller
Chemapec, Inc.
230 Crosways Park Drive
Woodbury, NY 11797
516/364-2100

Jackson Yu
50 Beale Street
San Francisco, CA 94119
415/768-2971

GB Fermentation Industries, Inc.
One North Broadway
Des Plaines, IL 60016
312/827-9700

Joseph L. Gordon
Box 7808
Boise, ID 83729
208/386-5670

Don Smith
Rural Route 1, 650 Pine
Colby, KS 67701
913/462-7531

Glen Brandt
Brandt Chemical Co.
P.O. Box 277
Pleasant Plains, IL 62677
217/626-1123

Enerco, Inc.
139A Old Oxford Valley Road
Langhorne, PA 19047
Contact: Miles J. Thomson
215/493-6565

Biomass Suchem
Clewiston, FL 33440
Contact: Dr. Ron DeSpephano
813/983-8121

Continued on Page E-10

Plant Operations Consultants - *Continued*

Guaranty Fuels
1120 East Main Street
Independence, KS 67301
913/331-0027

Midwest Solvents Co.
1300 Main Street
Atchison, KS 66002
Contact: Howard Hinten
913/367-1480

Steven J. Winston
Route 3, Box 239
Idaho Falls, ID 83401
208/522-6413

Bibliography

- General

- Conversion
- Coproducts
- Design
- Distillation
- Economics
- Energy Balance
- Environmental Considerations
- Feedstocks
- Fermentation
- Hardware-Equipment
- International
- Regulatory
- Transportation Use

Source: **Fuel From Farms**
SERI/SP-451-519
February 1980

Solar Energy Information Data Bank
Managed by
Solar Energy Research Institute
A Division of Midwest Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

Operated by
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

GENERAL

Introductory

Brown, M. H., *Brown's Alcohol Motor Fuel Cookbook*, Desert Publications, Cornville, AZ. 86325, 1979, 14 pp. ($9.95).

Commoner, B., *The Politics of Energy*, Alfred A. Knopf, NY, 1979, 102 p.

Crombie, L., *Making Alcohol Fuel—Recipe and Procedure*, 1979, 40 p. Available from Micro-Tech Laboratories, Inc., Route 2, Box #19, Logan, IA 51546. ($4.50).

Gibat and Gibat, *The Lore of Still Building*, 1978, 128 p. Available from Micro Tech Laboratories, Inc., Route 2, Box #19, Logan, IA 51546. ($4.00)

Jawetz, Pincas, "Calculations Linking Farm Policy to Energy Policy," Testimony at Hearings on The Gasohol Motor Fuel Act of 1978, U.S. Senate, Subcommittee on Energy Research and Development, Committee on Energy and Natural Resources, Washington, D.C., August 7-8, 1978, U.S. Government Printing Office, Washington, D.C. 20402, 1978 Publication No. 95-165, pp. 113-142.

National Alcohol Fuels Producers Association, Lincoln, NE, *A Learning Guide for Alcohol Fuel Production*, 1979, 600 p. Available from NAFPA, 2444 B Street, Lincoln, NE 68502, $75.00 with membership.

Nellis, M., *Making it on the Farm. Alcohol Fuel is the Road to Independence*, 1979, 88 p. Available from American Agriculture News, P.O. Box 100, Iredell, TX 76649. ($2.95).

Pimental, D.; et al., "Energy and Land Constraint in Food Production," *Science*, Vol. 190 (No. 4126), November 21, 1975, pp. 754-61.

Reports

Alcohol Fuels Workshop, A Symposium presented for the Farmers Home Administration, Washington, D.C., September 20, 1979.

Third International Symposium on Alcohol Fuels Technology, Asilomar, CA, May 28-31, 1979.

Baratz, B.; Ouellette, R.; Park, W.; Stokes, B.; Mitre Corporation, "Survey of Alcohol Fuel Technology, Volume I," Technical Report No. M74-61-Vol. 1; November, 1975; 43 p. Available from NTIS, PB-256007/6ST, $7.25 paper copy, $3.00 microfiche.

Department of Energy, "Report of the Alcohol Fuels Policy Review," Report No. DOE/PE-0012, June 1979, 119 p. Available from Superintendent of Documents, Stock No. 061-000-00313-4, Washington, D.C.

Freeman, J. H.; et al., American Petroleum Institute, *Alcohols—A Technical Assessment of Their Application as Fuels*, API Publication No. 4261, July 1976.

Office of Technology Assessment, *Gasohol—A Technical Memorandum*, September 1979, 69 p. Available from Superintendent of Documents, U.S. Government Printing Office, Stock No. 052-003-00706-1.

Magazines

Alternative Sources of Energy, Alternative Sources of Energy, Inc., Route 2, Milaca, MN 56353, $6.00/yr. (bimonthly).

BioTimes, The International Biomass Institute, 1522 K Street NW, Suite 600, Washington, D.C. 20005, $10.00 including membership. (monthly).

Farm Show Magazine, 8500 - 210 Street, Lakeville, MN 55044. ($9.00/yr).

Gasohol USA, National Gasohol Commission, P.O. Box 9547, Kansas City, MO 64133, $12.00/yr. (monthly).

Mother Earth News, Mother Earth News, P.O. Box 70, Hendersonville, NC 28739, $15.00/yr. (bimonthly).

Small Farm Energy Project Newsletter, Center for Rural Affairs, P.O. Box 736, Hartington, NE 68739, free. (bimonthly).

Solar Life, SEINAM (Solar Energy Institute), 1110 Sixth Street NW, Washington, D.C. 20001, $5.00/yr. (monthly).

Congressional Hearings

National Fuel Alcohol and Farm Commodity Production Act of 1979, Hearings before the Subcommittees on Conservation and Credit Department Investigations, Oversight and Research, and Livestock and Grains, Committee on Agriculture, U.S. House of Representatives, 96th Congress, May 15-16, 1979. Available from U.S. Government Printing Office, Stock No. 052-070-05071-3.

Oversight—Alcohol Fuel Options and Federal Policies, Hearings before the Subcommittee on Energy Development and Applications of the Committee on Science and Technology, U.S. House of Representatives, 96th Congress, May 4, 1979, June 12, 1979, No. 26—the Committee on Science and Technology.

The Gasohol Motor Fuel Act of 1978, Hearings before the Subcommittee on Energy Research and Development of the Committee on Energy and Natural Resources, U.S. Senate, 95th Congress, August 7–8, 1978, Publication No. 95-165.

Alcohol Fuels, Hearings before the Subcommittee on Advanced Energy Technologies and Energy Conservation Research, U.S. House of Representatives - 95th Congress, July 11–12, 1978. Available from U.S. Government Printing Office (No. 350-520).

Alcohol Fuels, Special Hearing before the Committee on Appropriations, U.S. Senate, 95th Congress, January 31, 1978. Available from U.S. Government Printing Stock Office, No. 052-070-04679-1.

CONVERSION

Bruschke, H., "Direct Processing of Sugarcane into Ethanol," Paper presented at the International Symposium on Alcohol Fuel Technology: Methanol and Ethanol, Wolfsburg, Federal Republic of Germany, November 21–23, 1977. Availability: NTIS, CONF-771175, Complete proceedings, $15.25 printed copy, $3.00 microfiche.

Morrison, Robert T.; Boyd, Robert N., *Organic Chemistry,* 3rd Edition, 1973, Allyn and Bacon, Inc., Rockleigh, NJ.

COPRODUCTS

Distillers Feeds, Distillers Feed Research Council, Cincinnati, OH 45202.

Paturau, J. M., *By-Products of the Cane Sugar Industry,* Elsevier Publishing Company, Amsterdam, 1969, 274 p.

Reilly, P. J., Iowa State University, Ames, IA. "Conversion of Agricultural By-Products to Sugars," Progress report, 1978.

Winston, S. J., Energy Incorporated, "Stillage Treatment Technologies," October 1979, 20 p.

Winston, S. J., Energy Incorporated, "Current State-of-the-Art Stillage Use and Disposal," October 1979, 30 p.

Wisner, R. N.; Gidel, J. O., Iowa Agriculture Experiment Station, "Economic Aspects of Using Grain Alcohol as a Motor Fuel, with Emphasis on By-Product Feed Markets," Report No. 9; June 1977.

DESIGN

Altsheller, W. B.; et al., "Design of a Two-Bushel Per Day Continuous Alcohol Unit," Chemical Engineering Progress, Vol. 43 (No. 9), September 1947, pp. 467–472.

Brackett, A. T.; et al., "Indiana Grain Fermentation Alcohol Plant," 1976, 80 p. Available from Indiana Department of Commerce, State House, Room 336, Indianapolis, IN 46204. (free).

Chambers, R. S., ACR Process Corporation, Urbana, IL, "The Small Fuel-Alcohol Distillery: General Description and Economic Feasibility Workbook," 1979, 21 pages. Available from ACR Process Corporation, 808 S. Lincoln Ave., Urbana, IL 61801. (free).

Katzen, Raphael Associates, "Grain Motor Fuel Alcohol Technical and Economic Assessment Study," Report No. HCP/J6639-01, June 1979, 341 p. Available from NTIS, $12.00 paper copy, $3.00 microfiche.

DISTILLATION

King, C. J., *Separation Processes,* McGraw-Hill, N.Y., 1971.

Tassios, D. P., ed., *Extractive and Azeotropic Distillation,* Advances in Chemistry, Number 115, American Chemical Society, Washington, D.C., 1972.

McCabe, W.; Smith, J. C., *Unit Operations in Chemical Engineering,* Third Edition, McGraw-Hill, NY, 1976.

ECONOMICS

David, M. L.; Hammaker, G. S.; Development Planning and Research Associates, "Gasohol Economic Feasibility Study," Final report, July 1978.

Economics, Statistics, and Cooperative Service, "Gasohol from Grain—The Economic Issues," Final Report AGERSF-21, January 19, 1978, 23 p. Available from NTIS, PB-280120/7ST, $4.00 printed copy, $3.00 microfiche.

Jenkins, D. M., Battelle Columbus Laboratories, "Technical Economic Analysis of the Manufacture of Ethanol from Corn Stover," November 1977.

Jawetz, P., "A New Way to Calculate the Savings from Fuels Substituted for Petroleum," Energy Research Reports, Vol. 5 (No. 18), October 15, 1979.

Koppel, J., Northeast Midwest Institute, Washington, D.C., *Guide to Federal Resources for Economic Development,* September 1979, 137 p.

ENERGY BALANCE

Alich, J. A.; Scholey, F. A.; et al., SRI International. "An Evaluation of the Use of Agricultural Residues as an Energy Feedstock: A Ten Site Survey," Report No. TID-27904/2, January 1978, 402 p. Available from NTIS, $13.25 paper copy, $3.00 microfiche.

Commoner, B., Center for the Biology of Natural Systems, Washington University, St. Louis, MO, "The Potential for Energy Production by U.S. Agriculture," Testimony before the U.S. Senate Committee on Agriculture, Nutrition, and Forestry, Subcommittee on Agricultural Research and General Legislation, July 23, 1979.

Jawetz, P., "Alcohol Additives to Gasoline—An Economic Way for Extending Supplies of Fuel and for Increasing Octane Ratings," American Chemical Society National Meeting, September 9-14, 1979; Division of Petroleum Chemists, Vol. 24 (No. 3), pp. 798-800, Washington, D.C., reprint.

Ladisch, M.R.; Dyck, K., "Dehydration of Ethanol: New Approach Gives Positive Energy Balance," *Science,* Vol. 205 (No. 31), August 3,1979, pp. 898-900.

Lewis, C. W., "Fuels from Biomass-Energy Outlays vs. Energy Returns: A Critical Appraisal," *Energy,* Vol. 2 (No. 3). September 1977, pp. 241-8.

ENVIRONMENTAL CONSIDERATIONS

Brown, D.; McKay, R.; Weir, W., "Some Problems Associated with the Treatment of Effluents from Malt Whiskey Distilleries," Progress in Water Technology, Vol. 8 (No. 2/3), 1976, pp. 291-300.

Jackson, E. A., "Distillery Effluent Treatment in the Brazilian Nationale Alcohol Programme," The Chemical Engineer, April 1977, p. 239-242.

Kant, F. H.; et. al., U.S. Environmental Protection Agency, "Feasibility Studies of Alternative Fuels for Automotive Transportation," Report No. EPA-460/374-009, 1974. Available from NTIS, PB235 581/GGI, $4.50 paper copy, $3.00 microfiche.

Lowry, S. O.; Devoto, R. S., Georgia Institute of Technology, "Exhaust Emissions from a Single-Cylinder Engine Fueled with Gasoline, Methanol, and Ethanol," Combustion Science and Technology, Vol. 12 (No. 4, 5, and 6), 1976, pp. 177-182.

FEEDSTOCKS

Chubey, B. B.; Dorrell, D. G., "Jerusalem Artichoke, a Potential Fructose Crop for the Prairies," Journal of the Canadian Institute of Food Science Technology, Vol. 7 (No. 2), 1974, pp. 98-100.

Lipinsky, E. S.; et al., Battelle Columbus Laboratories, "System Study of Fuels from Sugarcane, Sweet Sorghum and Sugar Beets," Vol. 1, *Comprehensive Evaluation,* Report No. BMI-1957, Vol. 1, March 15, 1977; Vol. 2, *Agricultural Considerations,* Report No. BMI-1957; Vol. II, December 31, 1976; Vol. 4, *Corn Agriculture,* Report No. BMI-1957 A; Vol. IV, March 1977.

Nathan, R. A., Battelle Columbus Laboratories, "Fuels from Sugar Crops," Report No. TID-22781, July 1978. Available from NTIS, $8.00 paper copy, $3.00 microfiche.

National Academy of Sciences. *Atlas of Nutritional Data on United States and Canadian Feeds.* 1971. Available from NAS, 2101 Constitution Ave., Washington, D.C. 20418.

Portola Institute. *Energy Primer.* 1978.

Potato Alcohol. A Solution to the Energy Crises and Higher Prices for Spuds, Potato Grower of Idaho, April 1978, 50 p.

Stauffer, M.D. *Jerusalem Artichoke - Production.* Available from Agriculture Canada, Research Station, P.O. Box 3001, Morden Manitoba, ROG IJO, Canada. 1979.

FERMENTATION

Engelbart, W., "Basic Data on Continuous Alcoholic Fermentation of Sugar Solutions and of Mashes from Starch Containing Raw Materials," Paper presented at the International Symposium on Alcohol Fuel Technology: Methanol and Ethanol, Wolfsburg, Federal Republic of Germany, November 21-23, 1977. Available from NTIS, CONF-771175, complete proceedings $15.25 printed copy, $3.00 microfiche.

Lipinsky, E. S.; Scantland, D. A.; McClure, T. A., Battelle Columbus Laboratories, "Systems Study of the Potential Integration of U.S. Corn Prodution and Cattle Feeding with Manufacture of Fuels via Fermentation," Report No. BMI-2033, Vol. I, June 4, 1979. Available from NTIS.

Miller, D. L., Department of Agriculture, Peoria, IL. "Ethanol Fermentation and Potential," Paper presented at the Cellulose Conference in Biotechnological Bioengineering, No. 5, pp . 345, Berkeley, CA, June 25, 1974, USA.

HARDWARE · EQUIPMENT

Lukchis, G. M., "Adsorption Systems: Part 1. Design by Mass-Transfer-Zone Concept," Chemical Engineering, June 11, 1973, pp. 111-116.

Lukchis, G. M., "Adsorption Systems: Part III. Adsorbent Regeneration," Chemical Engineering, August 6, 1973, pp. 83-90.

INTERNATIONAL

Jawetz, P., "The Common Sense Approach in Developing Fuel Alcohols." Workshop on Fermentation Alcohol for Use as Fuel and Chemical Feedstock in Developing Countries, Vienna, Austria, March 26-30, 1979, Paper no. ID/WG.293/12, United Nations Industrial Development Organization. (Papers dated: February 5, 1979—abstract, March 26, 1979—paper).

Ribeiro, Filho F. A., "The Ethanol-Based Chemical Industry in Brazil," Workshop on Fermentation Alcohol for Use as Fuel and Chemical Feedstock in Developing Countries, Vienna, Austria, March 1979, Paper No. ID/WG.293/4 UNIDO, United Nations Industrial Development Organization.

Sharma, K. D., "Present Status of Alcohol and Alcohol Based Chemical Industry in India," Workshop on Fermentation Alcohol for Use as Fuel and Chemical Feedstock in Developing Countries, Vienna, Austria, March 26-30, 1979, paper no. ID/WG.293/14 UNIDO, United Nations International Development Organization.

REGULATORY

Abeles, T. P.; King, Janna R., Minnesota Legislature Science and Technology Project, "Parameters for Legislature Consideration of Bioconversion Technologies," February 1978, 45 p. Available from NTIS, PB 284742/45T, $4.50 paper copy, $3.00 microfiche.

Bureau of Alcohol, Tobacco, and Firearms, *Ethyl Alcohol for Fuel Use,* Informational Brochure, ATF PX 5000.1, July 1978, 7 p.

Bureau of Alcohol, Tobacco, and Firearms, *Alcohol Fuel and ATF,* Informational Brochure, ATF P5000.2, August 1979, 4 p.

TRANSPORTATION USE

Adt, R. R., Jr., et al., University of Miami, "Effects of Blending Ethanol with Gasoline on Automotive Engines' Steady State Performance and Regulated Emissions Characteristics," Topical Report, January 1978.

Allsup, J. R.; Eccleston, D. B., "Ethanol/Gasoline Blends as Automotive Fuel," Report No. BETC/RI-79/2, May 1979, 13 p. Available from NTIS, $4.00 paper copy, $3.00 microfiche.

Bernhardt, W., "Future Fuels and Mixture Preparation Methods for Spark Ignition Automobile Engines," Progress in Energy and Combustion Science, Vol. 3 (No. 3), 1977, pp. 139-150.

Bushnell, D. J.; Simonsen, J. M., "Alcohol Assisted Hydrocarbon Fuels: A Comparison of Exhaust Emissions and Fuel Consumption Using Steady-State and Dynamic Engine Test Facilities," Energy Communications, Vol. 2 (No. 2), 1976, pp. 107-132.

Panchapakesan, N. R.; Gopalakrishnan, K. V., "Factors that Improve the Performance of an Ethanol-Diesel Oil Dual-Fuel Engine," Paper presented at the International Symposium on Alcohol Fuel Technology: Methanol and Ethanol, Wolfsburg, Federal Republic of Germany, November 21-23, 1977. Available from NTIS, CONF-771175, complete proceedings $15.25 printed copy, $3.00 microfiche.

Scott, W. M., Ricardo Consulting Engineers, "Alternative Fuels for Automotive Diesel Engines," Paper presented at the Symposium on Future Automotive Fuels-Prospects, Performance, and Perspective, Warren, MI, October 6, 1975, in *Future Automotive Fuels: Prospects, Performance, and Perspective,* Colucci, J. M.; Gallopoolos, N. E. (eds.); pp. 263-292. Available from NTIS, CONF-751018.

Bureau of Alcohol, Tobacco and Firearms Regional Offices

Source: **Fuel From Farms**
SERI/SP-451-519
February 1980

SEIDB Solar Energy Information Data Bank

Managed by
Solar Energy Research Institute
A Division of Midwest Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

Operated by
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

BATF REGIONAL OFFICES

Central Region
Indiana, Kentucky
Michigan, Ohio,
West Virginia

Regional Regulatory Administrator
Bureau of Alcohol, Tobacco, and Firearms
550 Main Street
Cincinnati, OH 45202
Phone (513) 684-3334

Mid-Atlantic Region
Delaware, District of
Columbia, Maryland,
New Jersey, Pennsylvania,
Virginia

Regional Regulatory Administrator
Bureau of Alcohol, Tobacco, and Firearms
2 Penn Center Plaza, Room 360
Philadelphia, PA 19102
Phone (215) 597-2248

Midwest Region
Illinois, Iowa, Kansas,
Minnesota, Missouri,
Nebraska, North Dakota,
South Dakota, Wisconsin

Regional Regulatory Administrator
Bureau of Alcohol, Tobacco, and Firearms
230 S. Dearborn Street, 15th Floor
Chicago, IL 60604
Phone (312) 353-3883

North-Atlantic Region
Connecticut, Maine,
Massachusetts, New Hampshire,
New York, Rhode Island,
Vermont, Puerto Rico,
Virgin Islands

Regional Regulatory Administrator
Bureau of Alcohol, Tobacco, and Firearms
6 World Trade Center, 6th Floor
(Mail: P.O. Box 15,
Church Street Station)
New York, NY 10008
Phone (212) 264-1095

Southeast Region
Alabama, Florida, Georgia,
Mississippi, North Carolina,
South Carolina, Tennessee

Regional Regulatory Administrator
Bureau of Alcohol, Tobacco, and Firearms
3835 Northeast Expressway
(Mail: P.O. Box 2994)
Atlanta, GA 30301
Phone (404) 455-2670

Southwest Region
Arkansas, Colorado,
Louisiana, New Mexico,
Oklahoma, Texas, Wyoming

Regional Regulatory Administrator
Bureau of Alcohol, Tobacco, and Firearms
Main Tower, Room 345
1200 Main Street
Dallas, TX 75202
Phone (214) 767-2285

Western Region
Alaska, Arizona,
California, Hawaii,
Idaho, Montana,
Nevada, Oregon,
Utah, Washington

Regional Regulatory Administrator
Bureau of Alcohol, Tobacco, and Firearms
525 Market Street, 34th Floor
San Francisco, CA 94105
Phone (415) 556-0226

Solar Energy Information Data Bank
SEIDB

Reading List

Prepared by the Solar Energy Information Center, Solar Energy Research Institute
A Division of Midwest Research Institute

Alcohol Fuels

It is the intent of this list to provide a basic introduction to the use of alcohol for fuel.

BOOKS

AUTO FUELS OF THE 1980's. Jack Frazier; Solar Age Press, Indian Hills, WV. 1978. The potential of methanol as an alternative fuel is discussed with remarks on how this and other alternative fuels are "sabotaged" by rich industrialists and government. Research and statistics on methanol are reviewed.

GASOHOL. Ken Bossong and Maureen Paskin; Citizens Energy Project, Report Series. no.24, Spring, 1978, 7 pp. Overview of alcohol fuels and several gasohol programs. Statistics and forecasts are given and the question is raised as to when alcohol fuel will get moving.

METHANOL AND OTHER WAYS AROUND THE GAS PUMP. John W. Lincoln; Garden Way Press. Charolette, VT, 1976, 134 pp. Discusses the methanol alternative to gasoline, both in blended form or straight. Other exotic types of fuels and engines are reviewed and future fuels are surveyed.

METHANOL TECHNOLOGY AND APPLICATION IN MOTOR FUELS. J.K. Paul; Noyes Data Corp., Mill Rd at Grand Ave., Park Ridge, NJ 07656, Chemical Technology Review, v. 114, 1978, 85 pp. Several studies on methanol gasoline blend performances are presented. Graphs and diagrams are included.

GOVERNMENT REPORTS AND PUBLICATIONS

ALCOHOL FUELS: HEARINGS BEFORE THE COMMITTEE ON APPROPRIATIONS. U.S. Senate, Ninety-Fifth Congress, Second Session, Special Hearings. 1978. Available from: Government Printing Office, Washington, DC 20402. Papers, letters, and reports are given by various people in the governmental, industrial and private sectors discussing the many aspects of alcohol fuels.

* * * *

This list makes no attempt to be comprehensive and does not imply special endorsement. Publications cited here, as well as additional books, government publications, and journal articles are available from your local library or bookstore. They should not be ordered from the Solar Energy Research Institute.

5/79

ALCOHOL FUELS: HEARINGS BEFORE THE SUBCOMMITTEE ON ADVANCED ENERGY TECHNOLOGIES AND ENERGY CONSERVATION RESEARCH, DEVELOPMENT AND DEMONSTRATION OF THE COMMITTEE ON SCIENCE AND TECHNOLOGY. U.S. House of Representatives. Ninety-Fifth Congress. Second Session, July 11, 12 and 13, 1978. Available from: Government Printing Office. Washington Potential of alcohol fuels is given from private industry with discussion by government officials. Detailed reports with bibliographies are included.

BIOMASS-BASED ALCOHOL FUELS: THE NEAR TERM POTENTIAL FOR USE WITH GASOLINE. W. Park, E. Price, D. Salo. MITRE Corp. Prepared for the Department of Energy. Aug. 1978. Available from: National Technical Information Service. Springfield, VA 22161. Report No. HCP/T4101-3. Requirements and prospects for a nationwide alcohol-gasoline fuel system based on biomass-based alcohol. Production technology and economic aspects are reviewed.

ENGINE IMPROVEMENT POSSIBILITIES AND ENVIRONMENTAL CONSEQUENCES OF ALCOHOL USAGE. University of Santa Clara; Prepared for the U.S. Department of Energy Contractor's Meeting. October 1978. Various graphs, charts, and tables are given on several tests of methanol fuels on engine performance and emission.

EVALUATION OF METHYL ALCOHOL AS A VEHICLE FUEL EXTENDER. R.T. Johnson and R. K. Riley. Final Report, August 1975. 152 pp. Prepared for the U.S. Department of Transportation. Available from:: National Technical Information Service. Springfield, VA, 22161. Report No. DOT-TST-76-50. Behavior of methanol-gasoline blends in automobiles were explored. Specifically octane ratings, effects of methanol blends on emissions, and fuel economy. Results given.

METHANOL: HEARINGS BEFORE THE SUBCOMMITTEE ON ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION OF THE COMMITTEE ON SCIENCE AND TECHNOLOGY...U. S. House of Representatives, Ninety-Fourth Congress, First Session, June 17, 19, 1975. Available from: Government Printing Office, Washington, DC 20402. Statements from government officials and private industry are given discussing the possibilities of methanol as a future fuel source.

METHANOL: ITS SYNTHESIS, USE AS A FUEL, ECONOMICS, AND HAZARDS. Thesis. David L. Hagen. Dec. 1976. Published by U.S. Energy Research and Development Administration. Springfield, VA 22161. Proposed and existing production methods of methanol are discussed. Possible sources of feedstocks are reviewed. Historical background for methanol research is given. Comprehensive bibliography is included.

METHANOL AS AN AUTOMOBILE FUEL. A. Landman. U.S. Department of Transportation. Report No. DOT-TSC-OST-77-31, 1977. Results of various tests on methanol blends are presented. Information gaps are covered. Production methods for methanol are discussed and several source materials are reviewed.

STATUS OF ALCOHOL FUELS UTILIZATION--TECHNOLOGY FOR HIGHWAY TRANSPORTATION. Mueller Associates, Inc. Prepared for the U.S. Department of Energy, June 1978. Available from: National Technical Information Service, Springfield, VA 22161. Report Number HCP/M2923-01. Covers topics of exhaust emissions, performance and fuel economy, and environmental considerations. Results of fuels testing, are given. Previous technology status is summarized in appendix.

PROCEEDINGS

METHANOL AS A FUEL....Seminar Swedish Methanol Development Co. Stockholm, Sweden, March 21-22 and 24, 1976. vol. 1, 36 pp. Seminar Report. Workshop reports for three groups, formulation, applications and production, are summarized. Names and addresses for attendees are listed.

METHANOL AS A FUEL....Seminar Swedish Methanol Development Co. Stockholm, Sweden, March 21-22 and 24, 1976. Vol. 2, 118 pp. Seminar Papers. Thirteen papers are presented, discussing various aspects of methanol/alcohol fuel mixtures.

INTERNATIONAL SYMPOSIUM ON ALCOHOL FUEL TECHNOLOGY--METHANOL AND ETHANOL...Wolsburg, Federal Republic of Germany, Nov. 21-23, 1977. English Translation published by U.S. Department of Energy, July 1978. Report No. CONF-771175. Available from: National Technical Information Service, Springfield, VA 22161. Economical and political aspects, the application of alcohols in automobiles, the production of methanol and ethanol from different sources, the optimization of alcohol fuels, and environmental issues are discussed. Forty-five papers were presented.

ARTICLES

ALCOHOL BURNS BETTER THAN PETROL. Mazingiro. No. 2: pp, 93-94; 1977. Brazil plans to use 10% ethanol mixture as automobile fuel. Ethanol to be produced from biomass-derived sources.

BRAZIL GROWS ITS MOTOR FUELS. F. Garner. Environment. vol. 20 (No. 1): pp, 5, 40; January/February, 1978. As a national energy policy, Brazilian fuels must be supplemented or replaced with alcohol produced from fermentation of biomass. This alcohol fuel program has potential to make Brazil energy independent.

ETHANOL MOTOR FUELS AND "GASAHOL". T. A. Sladek. Mineral Industries B. vol. 21 (No. 3): pp, 1-6: May, 1978. Fermentation of biomass to produce ethanol for motor fuels. Biomass sources are surveyed.

GASAHOL: ALCOHOL FUELS: LIKELY TO PRODUCE MORE PROBLEMS THAN BENEFITS. Chevron World. vol 56.(No. 2): pp, 10-13; Spring, 1978.

GASAHOL: ENERGY MOUNTAIN OR MOLEHILL? Earl V. Anderson, Chemical and Engineering News. vol. 56 (No. 31): pp, 8-16, July 31, 1978. Views of both proponents and opponents are given. Pro's say ethanol blend can reduce oil imports, con's say that it takes more energy to produce methanol and it will increase imports.

GASOLINE DOES TOO, MIX WITH ALCOHOL. Wm. A. Scheller. Chemtech. vol. 7 (No. 10): pp, 616-623; October, 1977. Production of ethanol and performance of "gasohol" is described.

GASOLINE-ALCOHOL MIXTURE IGNITES DISPUTE. A. J. Parisi. New York Times, pp, D3; May 3, 1978. Plan for a "gasahol give away day". Also discusses marketing and production of ethanol.

GROW ALCOHOL AS A REPLACEMENT FOR GASOLINE. J. P. McClosky. Energy Sources. vol. 2 (No. 1): pp, 53-60; 1975. A plan is presented where biomass crops are planted specifically to produce alcohols through fermentation for gasoline blending.

NEW PROCESS MAKES GASOLINE FROM ALCOHOL. V. Elaine Imay. Popular Science. vol. 212; pp, 90-91; June, 1978. Conversion of alcohol, which can be produced from coal, biomass, or wastes, directly into high-octane gas.

PAVING THE WAY FOR ALCOHOL FUELS. Hal Bunton. Environmental Action. vol. 10 (No. 10): pp, 4-8; September 23, 1978. U S alcohol fuel program lags behind Sweden, Brazil, and West Germany. Environmentalists could give a big push to make alcohol fuels a major contributor.

PAY NOW? OR PAY LATER? Forbes. vol. 123: pp, 36-37; February, 1979. Overview of gasohol is given with discussion of what government and industry can do to get gasohol moving.

RESEARCH NEWS/ALCOHOL: A BRAZILIAN ANSWER TO THE ENERGY CRISIS. A. L. Hammond. Science. vol. 195 (No. 4278): pp, 564-566; February 11, 1977. Brazilian alcohol fuels program is discussed.

* * * *

For additional technical papers and reports, consult SOLAR ENERGY: A BIBLIOGRAPHY: CITATIONS, TID 3351-R1P1, March 1976, 585 pp, $13.75; INDEXES, TID 3351-R1P2, March 1976, 398 pp, $10.75.

For references since 1976, consult SOLAR ENERGY UPDATE, available on a subscription basis as NTISUB/C/145. The annual subscription rate for one volume (calendar) year (12 issues plus cumulative index) is $27.50. A single issue is $3.25.

These are published by Technical Information Center, Department of Energy, and are available from the National Technical Information Service (NTIS), Springfield, VA 22161.

Summary of Ethanol Legislation

- **National Legislation**
- **State Legislation**

Source: **Fuel From Farms**
SERI/SP-451-519
February 1980

Solar Energy Information Data Bank

Managed by
Solar Energy Research Institute
A Division of Midwest Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

Operated by
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

NATIONAL LEGISLATION

Farm Act of 1977

Provided $60 million in loan guarantees to build four pilot alcohol fuel plants in the United States.

National Energy Act of 1978

Provided motor fuel excise tax exemptions on gasoline/alcohol blends worth 4 cents per gallon of blend or 40 cents per gallon or $16.80 per barrel of alcohol in 10 percent blends. Alcohol fuels are also eligible for Department of Energy entitlements, currently worth approximately $2.10 per barrel of ethanol or five cents per gallon.

Alcohol Fuels Production Incentive Act of 1979 (S. 906)

Proposes a 10 percent investment tax credit (in addition to the current 10 percent credit) for alcohol fuels production equipment; provides a new 5 percent investment tax credit for buildings used in alcohol fuel production; authorizes the Department of Treasury to make up to $250 million in loan guarantees to cover up to 50 percent of the cost (up to $10 million per loan) of building or refinancing alcohol fuel plants or equipment; amends the Emergency Petroleum Allocation Act to provide priority to producers and marketers of gasohol or gasoline for use in gasohol when petroleum supplies are short.

Public Works and Economic Development Act of 1979 (S. 914)

Awaiting House-Senate Conference Committee consideration. The legislation proposes:

Senate-Passed Provisions

Authorizes EDA grants for facilities for production of alcohol for use as motor fuel when such grants will create or preserve jobs in small towns.

Funds for such grants are limited to 5 percent of funds under Titles I & II of EDA Act. Under authorization levels in S.914, funding would total $39.1 million annually.

House-Passed Provisions

Authorizes $100 million in FY80 & FY81 in EDA grants and loans for construction and operation of facilities producing alcohol or methane from renewable resources.

Energy Security Act (S. 932)

Awaiting action by the House-Senate Conference Committee. The legislation proposes:

House-Passed Provisions

Sets national goal for total synthetic fuel (including gasohol) production of 500,000 barrels per day in 1985, 2 million barrels per day in 1990.

Authorizes $3 billion for the President to buy synfuels and allows him to establish a federal synfuel corporation.

Senate-Passed Provisions

- **I—Title I: Synthetic Fuels Corporation Act of 1979**
  - Goal: production of synfuels equal to 1.5 million barrels of oil by 1995.
  - Establishes Synthetic Fuels Corporation with authorization of $20 billion, with up to $1 billion eligible to aid projects that use biomass and are basically large scale.
  - Authorizes corporations to provide price guarantees, purchase agreements, loan guarantees, loans, joint ventures, and direct construction to secure synfuel production.
- **II—Title II: Agricultural, Forestry, and Rural Energy Act of 1979**
  - Goal: achieve net energy independence for agricultural and forest production, processing and marketing; and 50 percent reduction in petroleum and natural gas use by rural residents and communities by the year 2000.
  - Establishes Agricultural, Forestry and Rural Energy Board in USDA which will report to Congress by 9-30-80 on agricultural, forestry, and rural energy needs and resources; and will provide a rural energy production, use, and conservation program by December 31, 1981.
  - Authorizes $50 million annually for applied research on agriculture, forestry, and rural energy production, use, and conservation.
  - USDA to complete study by 12-31-82 on alternative crop-livestock systems to produce foodstuffs and fiber,as well as biomass for use in energy production.
  - Mandates four to eight USDA Wood Energy Centers, and four to eight USDA Agricultural Biomass Energy Centers, which will do research, demonstration projects, field tests, and provide technical information. Authorizes $3 million annually for Wood Centers, and same amount for Biomass Centers.
  - State extension services to hold agricultural biomass energy workshops with goal of 100 workshops each year.
  - Authorizes $250 million annually in USDA loans for on-farm or commercial biomass energy projects. One-third must go to projects

which produce no more than 2 million gallons of alcohol per year.

  - Authorizes $500 million annually in USDA loan guarantees for commercial or on-farm biomass energy projects, with one-third going to projects that use wood, and one-fourth going to small-scale projects that produce no more than 2 million gallons of alcohol per year.
  - Authorizes $100 million annually in USDA grants for biomass energy demonstration projects.
  - Amends existing USDA programs to provide $390 million in authorization for loans, loan guarantees, insured loans, and makes eligible loans for energy systems using nonfossil fuels.
  - Authorizes $85 million over 4 years for rural electric projects using alternative energy sources (biomass, wood, solar, etc.) and conservation technologies.
  - Allows USDA to permit acreage set aside to be used to produce commodities for use in making alcohol for fuel.
- **III—Title III: Gasohol Motor Fuels Act of 1979**
  - Goal: establishes national goals of 60,000 barrels per day of alcohol fuels in 1982, and a volume of alcohol fuels from renewable resources equal to 10 percent of estimated domestic gasoline consumption in 1990.
  - Establishes Office of Alcohol Fuels in DOE and authorizes $1.2 billion in loan guarantees, price guarantees, and purchase agreements for alcohol fuel production facilities that use renewable resources, with at least one-third of that total going to facilities that produce no more than 2 million gallons of alcohol per year.
  - Authorizes the CCC to sell its sugar holdings at less than normal prices to producers of ethanol for use in motor fuel.
  - Mandates use of gasohol in all federal motor vehicles where it is available at reasonable prices and quantities (exceptions are possible for national security reasons).
  - Mandates USDA-DOT study on possible requirement that all new cars use gasohol or alcohol, and on barriers to the widespread marketing of gasohol.
  - Amends Natural Gas Policy Act of 1978 to facilitate natural gas allocations to certain types of activities related to the production of alcohol for fuel.
  - Authorizes Presidential allocation of gasoline to utilize alcohol not able to be blended into gasohol due to a lack of gasoline.
- **IV—Title IV: Domestic Energy Policy Act of 1979**
  - Establishes procedure for setting and updating national energy targets for imports and domestic production, which includes energy produced from renewable resources.
  - Requires an energy impact report on every bill, rulemaking, or executive order in the federal government.

STATE LEGISLATION

The following is a brief summary of legislation that has been passed by state legislatures within the United States.

Many of the state legislatures were in session at the time the information was accumulated for this book. We recommend that any further information needed regarding state legislative bills be obtained directly from the clerks or secretaries of the respective legislature. The reader should recognize that errors in the interpretation of the legislation contained in this report are possible. Gasohol Tax Credit legislation is highlighted within each state's legislation summary.

Arkansas

S.B. 454—passed 1979.

Gasohol Tax Exemption. Exempts gasohol from motor fuel tax (9.5 cents).

California

S.B. 318—passed 1979.

The Department of General Services would prepare a plan utilizing a fuel containing at least 5% alcohol for use in at least 25% of the vehicles maintained by the Department.

A.B. 1401—passed 1979.

Authorizes the Department of Motor Vehicles to establish a 10-year methanol fuel experimentation program.

S.B. 771—passed 1979.

The State Energy Resources Conservation and Development Commission shall implement a program to demonstrate residue conversion technologies at appropriate locations throughout the state to encourage private-, public-, and investor-owned utility participation in this program. Fifteen million dollars have been appropriated from the general fund to carry out the purpose of this bill.

Colorado

S.B. 80—passed 1978.

A nine-member committee was created to promote the production of gasohol, alcohol, and related industrial hydrocarbons from Colorado agricultural and forest products. Eighty thousand dollars were appropriated for administration of the bill.

H.B. 1135—passed 1978.

Gasohol Tax Exemption - 5 cents. Motor fuel which contains at least 10% alcohol, derived in Colorado, will receive a 5-cent excise tax reduction if sold in counties with a population exceeding 200,000. As the availability of gasohol increases, all state and local vehicles will be required to use gasohol.

H.B. 1463—passed 1979.

Gasohol Tax Exemption - 5 cents. The tax exemption applies to a blend of gasoline and 95%-pure alcohol derived from agriculture commodities and forest products. Reduces the real and personal property tax assessment for alcohol production facilities producing alcohol for use in motor vehicles. Provides a voluntary check-off of off-highway gasoline refund tax money to be placed into a special fund for the use of gasohol promotion.

H.B. 1607—passed 1979.

Gasohol Tax Exemption - 5 cents. Expands the definition of gasohol to include motor fuels containing alcohol derived from hydrocarbon or carbon-containing by-products or waste products. Grants a reduction in the property tax to facilities used for the production of such alcohol. The tax exemption applies to a blend of gasoline and alcohol that is produced from Colorado products derived from hydrocarbon or carbon-containing by-products or waste products with a purity of at least 95%.

Connecticut

Public Act 627—passed 1979.

Gasohol Tax Exemption - 1 cent. Lowers state sales tax on gasohol from 11 cents to 10 cents per gallon, and exempts the motor fuel used in van pool vehicles (which is already exempt from the motor fuel tax) from the state sales tax.

Hawaii

S.B. 1581, S.D. 1, H.D. 1—passed.

(Act 131, Session Laws of Hawaii 1978)

Act 131, which is an omnibus appropriating bill for alternate energy research and development, appropriates $500,000 for the conversion of an old Seagram distillery to a plant capable of producing 700,000 gallons of ethanol per year for gasohol purposes. The Act also appropriates $330,000 to establish a corn-to-ethanol research and development program.

Indiana

S. 218—passed 1979.

Gasohol Tax Exemption - 4% Sales Tax. The tax exemption applies to a 10% blend of agriculturally derived ethyl alcohol in fuel.

Iowa

H.F. 491—passed 1978.

Gasohol Tax Exemption - 10 cents. Effective July 1, 1979, exempts fuel excise tax on motor fuel containing at least 10% alcohol, distilled from agriculture products, from July 1, 1978, ending June 30, 1983. (In Iowa there is a sales tax on excise tax-exempted gasohol which in effect decreases the total tax credit to approximately 7 cents.)

Kansas

H.B. 2345—passed 1979.

Funds totaling $60,000 shall be transferred from the Corn Commission, Grain Sorghum Commission, Soybean Commission, and Wheat Commission to the Kansas Energy Office to be used for the purpose of study and analysis of grains for use as energy resource alternatives.

H.B. 2324—passed 1979.

Gasohol Tax Exemption - 5 cents. The tax exemption applies to a 10% blend of 190-proof ethyl alcohol produced from grain grown in Kansas used in all motor vehicle fuels and shall be effective July 1, 1979. The tax exemption shall be reduced 1 cent per year until no tax exemption remains after July 1, 1984. All motor vehicles owned and operated by the State of Kansas and subdivisions shall be operated with a 10% blend of ethyl alcohol when reasonably obtainable.

Louisiana

H.B. 571—passed 1979.

Gasohol Tax Exemption - 8 cents. Exempts the retail sale of gasohol from state sales tax use, and motor fuel tax.

S.C.R. 99—adopted 1979.

Requests the Department of Natural Resources to conduct a feasibility study for obtaining methane gas from sugarcane as an alternate energy source.

H.B. 1033—passed 1979.

To qualify for the purchase of oil, a small refiner must have in operation a facility for the distillation of methanol or ethanol produced from Louisiana agricultural commodities.

Maryland

S.B. 807—passed 1979.

Gasohol Tax Exemption - 1 cent. The tax exemption shall apply to a 10% blend of ethyl or methyl alcohol.

S.B. 823—passed 1979.

To permit the Maryland Industrial Development Financing Authority to encourage and insure loans for the development and production of a certain motor fuel known as gasohol.

H.B. 1628—passed 1979.

Requires the Secretary of Agriculture to study the effectiveness of an ethanol and gasoline mixture. Requires the Secretary of Agriculture to inititate a 1-year program of tests using gasohol in eight state-owned vehicles.

Missouri

H.B. 72—passed 1979.

Authorizes the Department of Natural Resources to analyze the potential for increased utilization of coal, nuclear, solar, resource recovery and reuse, energy-efficient technologies, and other energy alternatives, and to make recommendations for the expanded use of alternate energy sources and technologies.

Montana

Resolution 28—adopted 1979.

Provides for a State Oversight Gasohol Committee to be appointed under the Department of Natural Resources for the Gasohol Program.

S.B. 523—passed 1979.

Provides a lower property tax on equipment, buildings, and inventory of gasohol production by as much as 3%.

H.B. 402—passed 1979.

Gasohol Tax Exemption. The tax exemption for gasohol is reduced by 2 cents for each of three succeeding 2-year periods, and the remaining 1 cent tax exemption expires in 1989.

In 1978, $25,000 was allocated from the alternate energy program to study gasohol in Montana.

Nebraska

L.B. 776—passed 1971.

Established the Agricultural Products Utilization Committee to promote research and development of gasohol, and to analyze the marketing and testing of gasohol. The Grain Alcohol Fuel Tax Fund was created with an initial appropriation of $40,000 and a provision whereby one/eighth of the motor fuels tax, which is refundable to nonhighway uses, is used to promote the activities of the committee. L.B. 776 also provided for a 3-cent tax credit for the sale of gasohol.

L.B. 1207—passed 1972.

Made changes in L.B. 776. Stated that in order to qualify as a special fuel the blend had to be at least 10% agricultural ethyl alcohol or at least 190 proof. L.B. 1207 also directed the Committee to sponsor research and development of industrial uses of by-products resulting from the amended L.B. 776, to increase the exemption from 3 cents to 5 cents on gasohol, and increased the Legislative tax review limitation from 10 million to 20 million gallons of gasohol sold which permits the legislature to review the tax credits.

L.B. 424—passed 1978.

Provided for matching funds (up to $500,000) to any city, county, or village wishing to build a gasohol plant.

L.B. 52—approved 1979.

Gasohol Tax Exemption - 5 cents. Amended L.B. 776 to increase the exemption from 3 cents to 5 cents on gasohol and increased the legislative tax review limitation from 10 million to 20 million gallons of gasohol sold which permits the legislature to review the tax credit.

L.B. 74—passed 1979.

Requires that the Department of Roads implement a program using gasohol in its vehicles to the extent that gasohol supplies are available. Gasohol must contain Nebraska-produced alcohol.

L.B. 571—passed 1979.

The Governor is authorized to enter into agreements with municipalities or counties to build and maintain grain alcohol plants. The State of Nebraska will have the option to purchase the plant. An Alcohol Plant Fund is created, to be established from funds transferred from the Highway Trust Fund or as appropriated from the legislature; the state gas tax is increased one cent to provide additional revenue for the Highway Fund to support the Alcohol Plant Fund.

New Hampshire

H.B. 201—passed 1979.

Gasohol Tax Exemption - 5 cents. The gasohol tax exemption applies to a 10% blend of alcohol manufactured in New Hampshire, derived from agriculture commodities and forest products, with a purity of 99%.

New Jersey

A.R. 3034—passed 1979.

Directs the Energy and Natural Resources Committee of the General Assembly to study large-scale use of gasohol and other alcohol-based fuels.

New Mexico

S.J.M. 9—adopted 1978.

Resolution requesting the Division of Energy and Minerals Department to study the feasibility of using gasohol in New Mexico.

New York

S.B. 9860-A—passed 1978.

Directs the Commissioner of General Services to conduct a study of the feasibility of using gasohol for state-operated vehicles through a comprehensive road test.

S.B. 2393—passed 1979.

The Commissioner of General Services is directed to conduct an experimental program to test the feasibility of using a mixture of gasoline and alcohol as fuel for state-operated motor vehicles.

North Dakota

S.B. 2338—passed 1979.

Gasohol Tax Exemption - 4 cents. The tax exemption applies to a blend of 10% agriculture ethyl alcohol (99% pure) and 90% unleaded gasoline.

H.B. 1384—passed 1979.

Establishes an Agriculture Products Utilization Commission funded by a 1/8-cent gasoline refund tax reduction, $200,000 appropriated from July 1, 1979 to June 30, 1980.

Oklahoma

S.B. 248—passed 1979.

Gasohol Tax Exemption - 6.5 cents. The gasohol tax exemption applies to a 10% blend of ethanol, alcohol, and gasoline.

Oregon

H.B. 2779—passed 1979.

Requires use of gasohol in certain state-owned vehicles to the maximum extent commercially feasible effective January, 1980.

S.B. 927—passed 1979.

Creates solar, wind, geothermal, water, agricultural and forest residue, and gasohol energy task forces and an Alternate Energy Development Commission to prepare comprehensive alternate resources plans to be submitted to the governor and legislature.

H.B. 2780—passed 1979.

Exempts commercial ethanol or methanol gasohol plants from property tax and corporate income tax effective June 30, 1981, of which 90% is used for a 10% blend of gasohol and not produced from petroleum, natural gas, or coal.

Rhode Island

H.R. 7891—adopted 1978.

Requesting that the State Director of Transportation conduct experiments with the public to determine the feasibility of a gasoline-alcohol fuel blend.

South Carolina

H.B. 2443—passed 1979.

Provides that gasohol be sold tax-free until October 1, 1979; imposes a 6-cent per gallon tax from October 1, 1979 to July 1, 1985, and a 7-cent per gallon tax from July 1, 1985 to July 1, 1987; provides for removal of these incentives if loss of revenue totals $5 million.

South Dakota

H.B. 1064—passed 1979.

Gasohol Tax Exemption - 5 cents. The gasohol tax exemption applies to a 10% blend of alcohol derived from agriculture and forest products.

Tennessee

H.J.R. 161—passed 1979.

Creates a special joint committee to study the development and use of methanol as an alternative fuel.

Texas

H.B. 1803—passed 1979.

Provides for state loans for establishment of plants to manufacture fuel from renewable resources, $25,000 may be loaned to any one legal entity and $500,000 may be loaned to a small business corporation. The total unpaid principles balance shall not exceed $15 million.

H.B. 1986—passed 1979.

Provides for annual alcohol manufacturers permit of $100. A Texas Legislative Council preliminary draft provides an alcohol users license of $10, an alcohol fuel manufacturers license of $25, an agriculture fuel marketing license of $50, and a beverage alcohol manufacturers permit of $1,000.

Washington

S.H.B 302—passed 1979.

Exempts B&O Tax on alcohol manufactured for gasohol when alcohol is sold to another person in Washington. Does not apply to out-of-state sales.

Wyoming

H.B. 114—passed 1979.

Gasohol Tax Exemption - 4 cents. Sales of gasohol would be subject to a 4-cent per gallon tax rather than an 8-cent per gallon tax until July 1, 1984.

TABLE A-1. SUMMARY OF STATE ALCOHOL FUEL EXEMPTIONS

STATE	STATE GASOLINE TAX	STATE GASOHOL TAX EXEMPTION
Arkansas	.095	.095
Colorado	.07	.05
Connecticut	.11	.01
Indiana	.04	.04
Iowa	.10	.07
Kansas	.08	.05
Louisiana	.08	.08
Maryland	.09	.01
Montana	.09	.02
Nebraska	.105	.05
New Hampshire	.10	.05
North Dakota	.08	.04
Oklahoma	.065	.065
South Carolina	:10	.05
South Dakota	.09	.04
Wyoming	.08	.04

CAN FLUOROHYDROCARBON ELASTOMERS USED IN OILFIELD SERVICE BE IMPROVED BY VARYING CARBON BLACK TYPE?[*]

D. E. Cain[+], L. A. Peters[‡], and T. L. Pugh[‡]

ABSTRACT

Elastomers for oilfield seals are often specified by hardness and generic type. Experienced compounders recognize that hardness of a seal can be achieved by many different formulations. The filler type and amount plus the cure system in these formulations have the most profound influence on the hardness. Carbon black and finely divided minerals are the most common fillers used in elastomer compounding.

This investigation evaluated the influence of the effect of carbon black particle size in fluorohydrocarbon formulations. Several fluorohydrocarbon compounds were formulated with carbon black types ranging from N330 to N990. These compounds were aged by exposure to aqueous hydrocarbon and gaseous fluids, which were intended to simulate oilfield environments. Changes in the physical properties of these compounds were determined and tabulated for comparison.

[*] Energy Rubber Group Meeting, September 25, 1986, Houston, Texas

[+] D. E. Cain, Wellhead Equipment Division, FMC Corporation.

[‡] L. A. Peters, Central Engineering Laboratories, FMC Corporation.

[‡] T. L. Pugh, Production Research and Development, Conoco, Inc.

CONCLUSIONS

- Fluorohydrocarbon elastomers used in oilfield service can be improved by varying the carbon black type.
- As the carbon black particle size in fluorohydrocarbon elastomer compounds of equal hardness is decreased the required percentage of filler by weight is reduced.
- Testing has shown that 90 Durometer compounds of Viton AHV exhibited improved physical properties with the use of smaller particle size carbon black.
- These improved physical properties are generally maintained following exposure to several aqueous hydrocarbon and gaseous fluids.
- The compression set of these compounds decreased as carbon black particle size was reduced.

BACKGROUND

Elastomers are used in oilfield seals because of their ability to store energy due to their characteristic elasticity and large strain behavior. A typical oilfield seal application would include a requirement to seal pressure in an annulus between two concentric metal surfaces. Appendix I explains why elastomer materials are useful in the construction of seals.

Two types of elastomer seals are common in oilfield service including interference seals such as O-rings and compression seals such as packers or slab packings. The force required to establish an interference seal is caused when the seal element is forced into a restricted space. The force required to engage a compression seal is a result of squeezing the seal element in a confined space. Effects which lower this force or displace the seal material can lead to seal failure.

Five main causes for the failure of oilfield elastomer seals are: Gas Permeation or Blistering, Compression Set, Thermal Stress caused when confined elastomer seals are heated and cannot expand, Thermal Degradation, and Chemical Degradation. Due to the large number of high pressure gas applications in the oilfield, gas blistering has become an important area of focus. When gas pressure is released from a sealed system and the seal contains dissolved gas, bubbles, cracks, and blisters can form in the seal structure. The seal will eventually fail if sufficient damage occurs.

V. Cox[2] (Shell UK Research) and D. L. Potts[3] (BP/UK) presented papers concerning this phenomenon at the 1985 Offshore Engineering Conference in Aberdeen. D. H. Ender[1] (Shell Development Company) wrote a paper titled "Elastomer Seals" concerning this phenomenon which appeared in the January issue of Chemtech. D. Hertz[5] wrote another paper titled "The Hidden Cause of Seal Failure" concerning this phenomenon for the April 9, 1981, issue of Machine Design.

Cox[2] described the testing of a new fluorohydrocarbon seal material available from Dowty Seals. We were interested in the composition and the principles underlying the performance of this material in order to apply it to a recent oilfield application where gas blistering was anticipated.

Three different fluorohydrocarbon elastomer candidates were evaluated for this seal application. The subject materials were ranked based on their resistance to gas blistering and damage. The prime candidate material had a slightly higher hardness of 90 Shore A which was not surprising.

When these three materials were subjected to Thermogravimetric Analysis (TGA) for compositional estimation, it was surprising to find that the 90 Durometer material contained lower levels of carbon black filler than the two softer materials. It was theorized that this was likely accomplished by the use of small particle size carbon black fillers. Patel and Brown[9] have written a paper that outlines the various properties of carbon black fillers and their effect on reinforcement. Thus, an investigation was initiated to determine the effects of the carbon black filler on the resistance of fluorohydrocarbon elastomers to oilfield environments.

Fluorohydrocarbon elastomers have been the elastomers of choice for sour or high temperature oilfield service. With this in mind, a series of Viton AHV and Aflas 100H materials were compounded using various levels of filler and different carbon black particle size to achieve the same hardness. The physical properties of these materials were measured as received, after heat aging, after oil immersion, and following several autoclave exposures intended to simulate oilfield service. These test results support the conclusion that varying the carbon black filler type can improve a fluorohydrocarbon elastomer compound.

COMPOUND EVALUATION TESTING

This test program was designed to identify the original physical properties at ambient temperature and elevated temperature, to fingerprint, and to evaluate the effect of aging on the elastomer compounds of interest.

Step 1: Original Physical Properties and Compound Fingerprinting

1. Hardness Shore A, ASTM D2240
2. Tensile Strength, Ultimate, ASTM D412
3. Elongation to Break, ASTM D412
4. Modulus, 100%, ASTM D412
5. Compression Set, 72 Hours, 350°F, ASTM D395
6. Thermogravimetric Analysis (TGA), Gross Percent Composition
7. Infrared Spectrophotometry (IR), Base Polymer Verification
8. Specific Gravity

Step 2: Elevated Temperature Physical Properties

1. Repeat Tests 1-4 as outlined in Step 1 at 250°F.
2. Repeat Tests 1-4 as outlined in Step 1 at 350°F.

Step 3: Post Aging Physical Property Testing

1. Tests 1-4 were repeated as noted in Step 1 above plus weight/volume change following the exposures outlined below.

	TEMPERATURE (°F)	PRESSURE (KSI)	TIME (DAYS)	EXPOSURE
1.	350	N/A	5	Air
2.	350	N/A	5	ASTM Reference Oil #3
3.	350	2.5	5	95% ASTM Fuel B, 5% H_2O with $CH4/CO_2$ (90/10) gas overpressure.
4.	350	2.5	5	90% ASTM Fuel B, 5% NACE B corrosion inhibitor, 5% H_2O and gas overpressure as outlined in 3 above.
5.	350	2.5	5	5% NaCl brine with gas overpressure as in 3.
6.	350	2.5	5	5% (5% NaCl) brine, 95% ASTM Fuel B and gas overpressure as in 3.

NOTE: All % are by volume of liquid.

COMPOUND FORMULATION

The compounds referenced in this paper are outlined in Table I. In order to maintain final compound hardness of 90 Shore A, it was necessary to change the level of carbon black accordingly.

TABLE I

FLUOROELASTOMER COMPOUNDS 90 DUROMETER SHORE A	V5	V6	V7	V8
1. Viton AHV	100	100	100	100
2. Carbon Black Type	N990	N762	N660	N330
3. Carbon Black Level	55	37	28	20

NOTE: Levels in parts per hundred rubber (PPHR), by weight.

Curative and Process Aids:

VC-20, 2.0, VC-30, 6.0, MAG D, 3.0, $CA(OH)_2$, 6.0, and Carnauba Wax, 1.0

Curing and Postcuring:

10 minutes at 350°F and then 24 hours at 450°F.

TEST RESULTS

The results of testing the subject compounds may be summarized as follows:

- o Physical properties were improved as carbon black particle size was reduced.

    a. Tensile strength increased at no sacrifice in ultimate elongation (Figure 1).

    b. Compression set is improved (Figure 2).

- o There was a slight improvement of physical properties, as measured at elevated temperatures, as carbon black particle size was reduced (Figure 3).

- o In general, resistance to thermal and chemical environment follows the same increasing trend observed with original physical properties (Figures 4 and 5).

  The presence of 5% NACE B amine corrosion inhibitor had a severe effect on Vinylidene-Fluoride-containing fluoroelastomers, supporting the results previously reported by Ray and Ivey[4] and Watkins[6]. There was considerable blistering and cracking of the tensile specimens exposed to the corrosion inhibitor (see photos on pages 16 and 17).

- o There was no measurable volume swell advantage with decreasing particle size (Figure 6). This was probably due to compensating effects of increasing rubber content and increasing crosslink density as illustrated in Figure 7.

SUMMARY

- Fluorohydrocarbon elastomers used in oilfield service can be improved by varying the carbon black type.

- As the carbon black particle size in fluorohydrocarbon elastomer compounds of equal hardness is decreased, the required percentage of filler by weight is reduced.

- Testing has shown that 90 Durometer compounds of Viton AHV exhibited improved physical properties with the use of smaller particle size carbon black.

- These improved physical properties are generally maintained following exposure to several aqueous hydrocarbon and gaseous fluids.

- The compression set of these compounds decreased as carbon black particle size was reduced.

- Parallel studies with Aflas 100H are continuing.

- Another evaluation will be completed to determine the influence of the effect of carbon black structure and non-black fillers on Fluorohydrocarbon Elastomer Formulations intended for Oilfield Service.

ACKNOWLEDGMENT

We wish to thank Conoco, Inc. and FMC Corporation for their cooperation and support during the development of this paper. Kirkhill Rubber Company of Brea, California, supplied the test slabs and buttons used during the testing outlined by this paper. Also, we wish to thank Virginia Nielsen and Lori Garcia for their careful experimental work required for this paper to be complete.

BIBLIOGRAPHIES

1. David E. Cain, of FMC Petroleum Engineering Group, is the Group Engineering Wellhead Product Group Leader in Houston, Texas. He received a BSME and MBA from the University of Houston and is a Professional Engineer with registration in Texas. He has eight years of mechanical design experience with a focus on elastomer and metal-to-metal seals. He is a member of NACE and ERG.

2. Loretta Peters, of FMC Central Engineering Laboratories, is the Polymer Characterization Supervisor, Materials Engineering Laboratory, in Santa Clara, California. She received a BS in Chemistry from Mapua Institute of Technology, Manila, Philippines, an MS in Polymer Chemistry and an Ed.D from the University of Kentucky. She has eight years of experience in polymer characterization work at Boeing Commercial Airplane Company and FMC. She is a member of NATAS, ASTM Committee E-37 on Thermal Measurements, and ACS Rubber Division.

3. Thomas L. Pugh, of Conoco, Inc is a Research Associate Production, R & D, in Ponca City, Oklahoma. He received his BS/MS/PhD at Wayne State University in Detroit. His experience includes 29 years of research and technical service in Elastomers at DuPont, three of those focused on Oilfield Applications. He transferred to Conoco in 1985 and is a member of ERG, NACE, SPE, and ACS Rubber Division.

REFERENCES

1. D. H. Ender, "Elastomer Seals", Chemtech (January 1986).

2. V. A. Cox, "Explosive Decompression in Oilfield Elastomers", a paper presented at the discussion forum organized by the Plastics and Rubber Institute on Offshore Engineering with Elastomers: Seals in the Oilfield Environment, Aberdeen, Scotland (June 5-6 1985).

3. D. L. Potts, "Explosive Decompression Resistance of Elastomers in Gas Duties", paper #21 presented at the forum on Seals in the Oilfield Environment, Aberdeen, Scotland (June 5-6 1985).

4. T. W. Ray and C. E. Ivey, "Effects of Organic Amine Inhibitors on Elastomers", a paper presented at NACE Corrosion 84 (April 1984).

5. D. L. Hertz, Jr., "The Hidden Cause of Seal Failure", Machine Design (April 9, 1981).

6. M. J. Watkins, "Watch Out for Elastomer-Inhibitor Incompatibility", Petroleum Engineer International (April 1984).

7. D. E. Hull, "Oilfield Media Profile of Tetrafluoroethylene-Propylene Copolymer", a paper presented at the 124th ACS Rubber Division Meeting, Houston, Texas (October 1983).

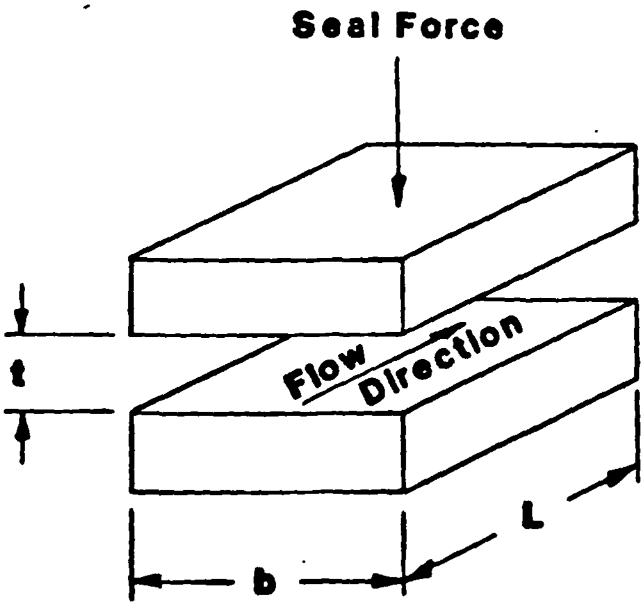
8. J. C. Vicic, "Testing in Oil and Gas Applications", a paper presented to the Polyurethane Manufacturers' Association in The Woodlands, Texas (April 1984).

9. A. C. Patel and W. A. Brown, "Carbon Black Structure and Viscoelastic Properties of Rubber compounds", Rubber World, April 1986.

APPENDIX I

To help explain some of the mechanics of seals and why elastomer materials are useful in their construction, consider an idealistic model of fluid flow between two parallel plates in close proximity to each other. Flow only occurs across "b" and in the direction of "L" in this model.

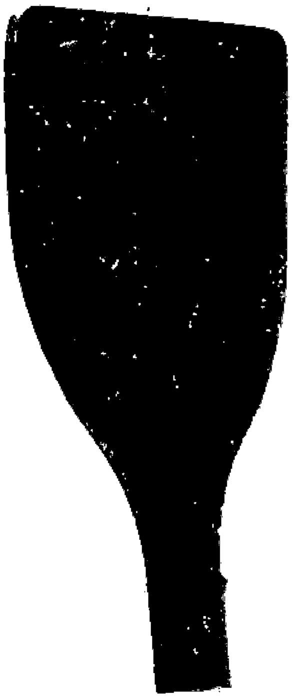
The flow of a fluid between these two parallel plates may be reduced by moving the two plates closer together. The flow relationship is governed by the equation: $G = (t^3 \times P \times b) / (12 \times L \times u)$ where G is the flow rate, P is pressure, u is the fluid viscosity, t is the distance between the plates, L is the length of the flow path between the plates, and b is the width of the plates. Assuming these two plates are perfectly flat, rigid, and have smooth surfaces, then a seal or zero fluid flow between the plates may be achieved by reducing t to zero.



LAMINAR FLOW BETWEEN
TWO PARALLEL PLATES

Unfortunately, in the real world, seal surfaces have waviness, roughness, imperfections, and are not rigid. This means fluids could flow between two parallel plates due to the gaps and permeable area caused by surface waviness, imperfections, and roughness, even if t is equal to zero. A seal may still be achieved by applying a force between these two plates until the surface imperfections are compensated for by local yielding and deflection. If the two plates are made of metallic materials with relatively high yield strength, low strain behavior, and low elasticity compared to elastomers, then the required force to cause local yielding will be very high. Also, the low strain characteristic of metals means a very small deflection in the "t" direction can cause a large drop in bearing stress and result in a leak.

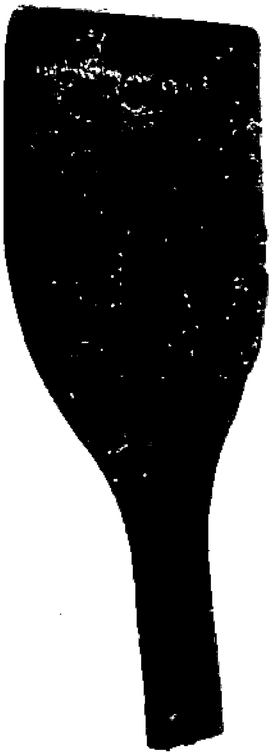
Now assume that a sheet of elastomer material is placed between the two metallic parallel plates. The elastomer material with its high strain to stress relationship will easily deflect and compensate for the surface imperfections in the plates at a much lower force. Also, the elastomer characteristic of large strain means that small deflections in the "t" direction will not result in a leak. Consequently, many seal applications incorporate elastomer seals.



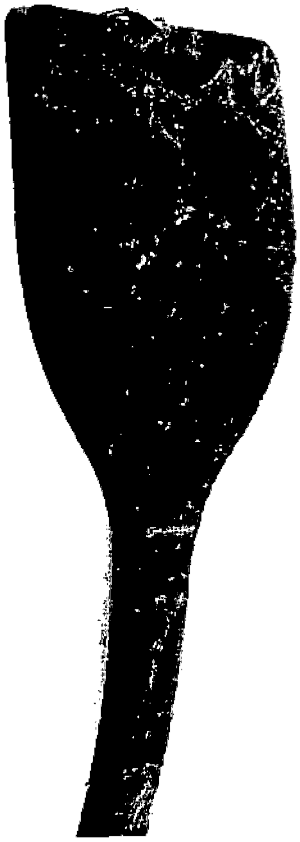
V5

V6

MAG = 1.8X



V7



V8

MAG = 1.8X

V5

V6

MAG = 5.8X

V7

V8

MAG = 5.8X

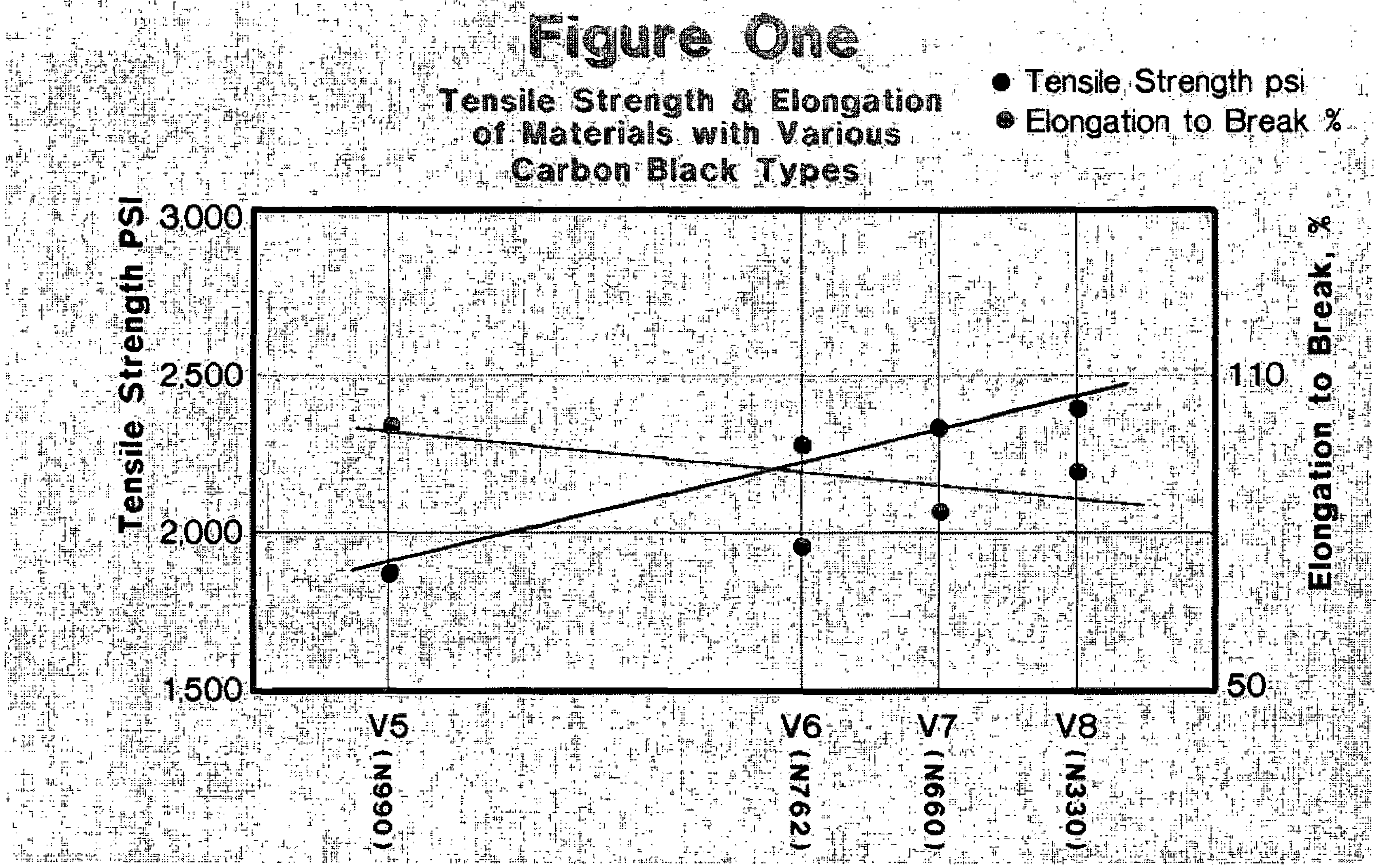
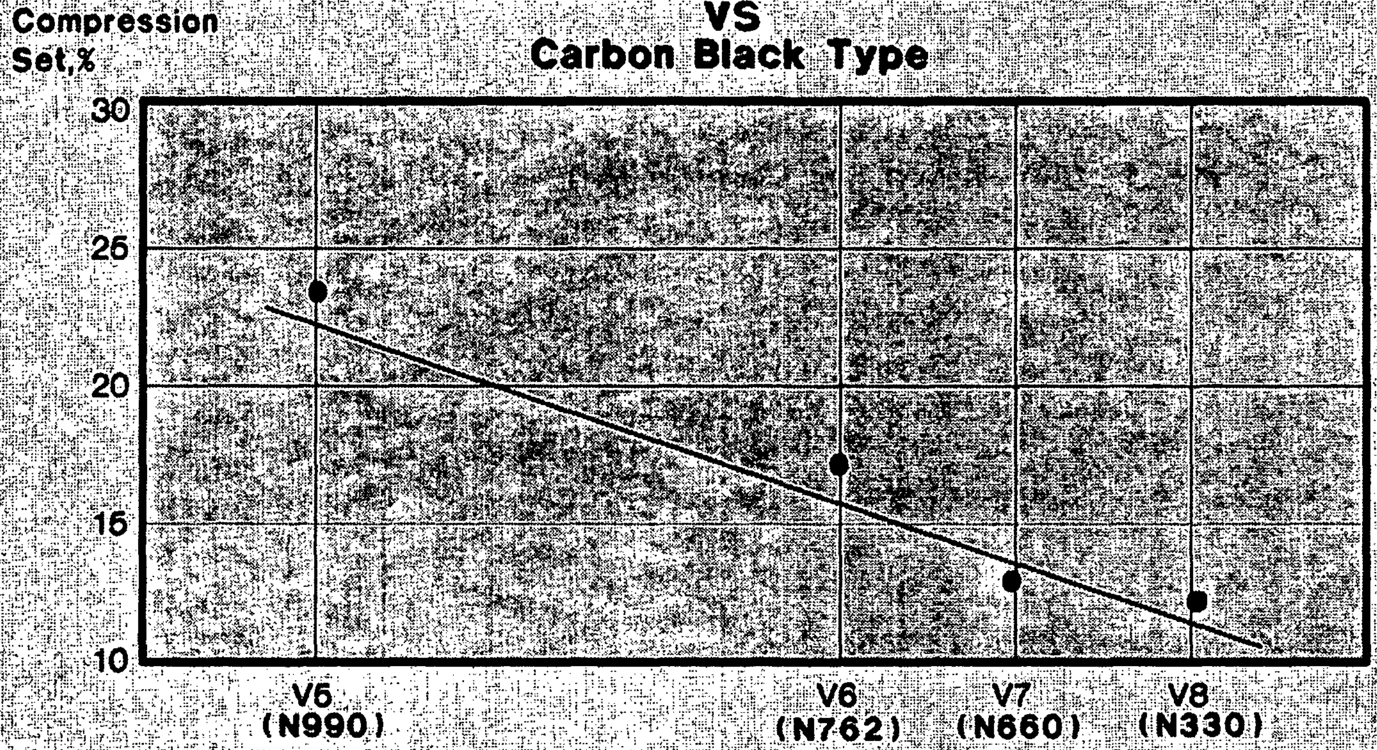


Figure One

Tensile Strength & Elongation of Materials with Various Carbon Black Types

Figure Two



Improved Compression Set
VS
Carbon Black Type

Figure Three

Elevated Temperature Properties

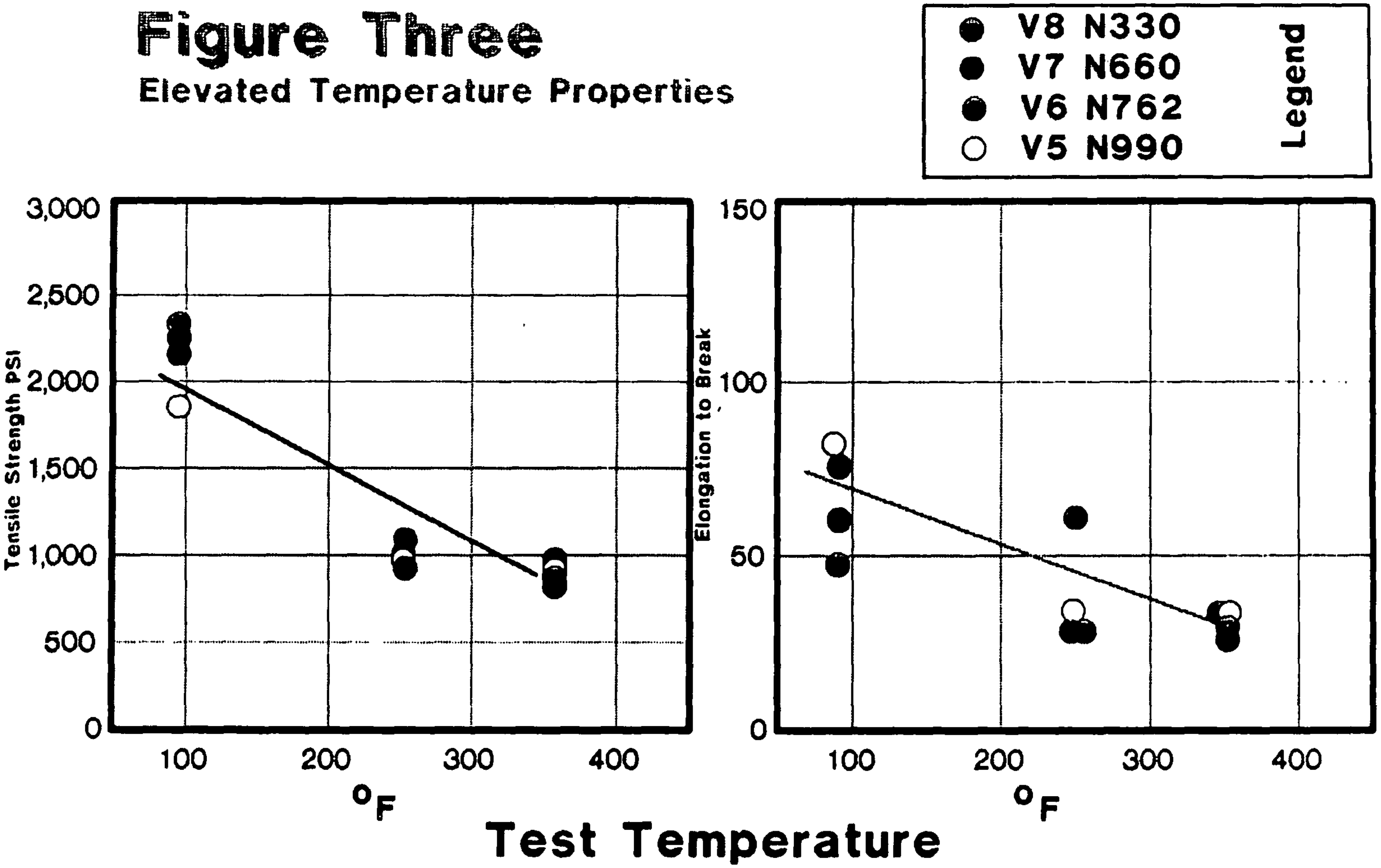


Figure Four

Tensile Stength-Orginal & Post Autoclave Exposure

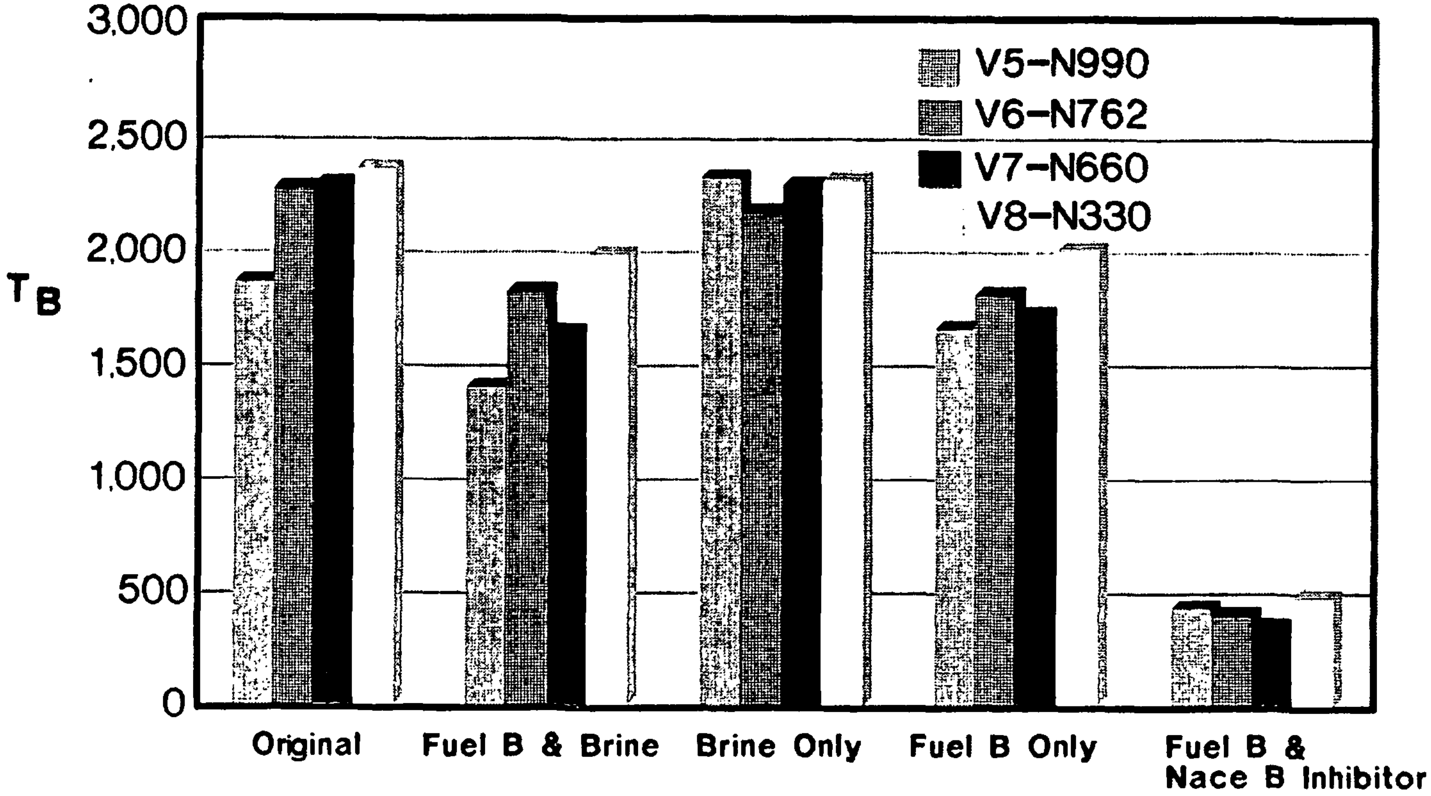


Figure Five

Original & Post Aging Tensile Stength

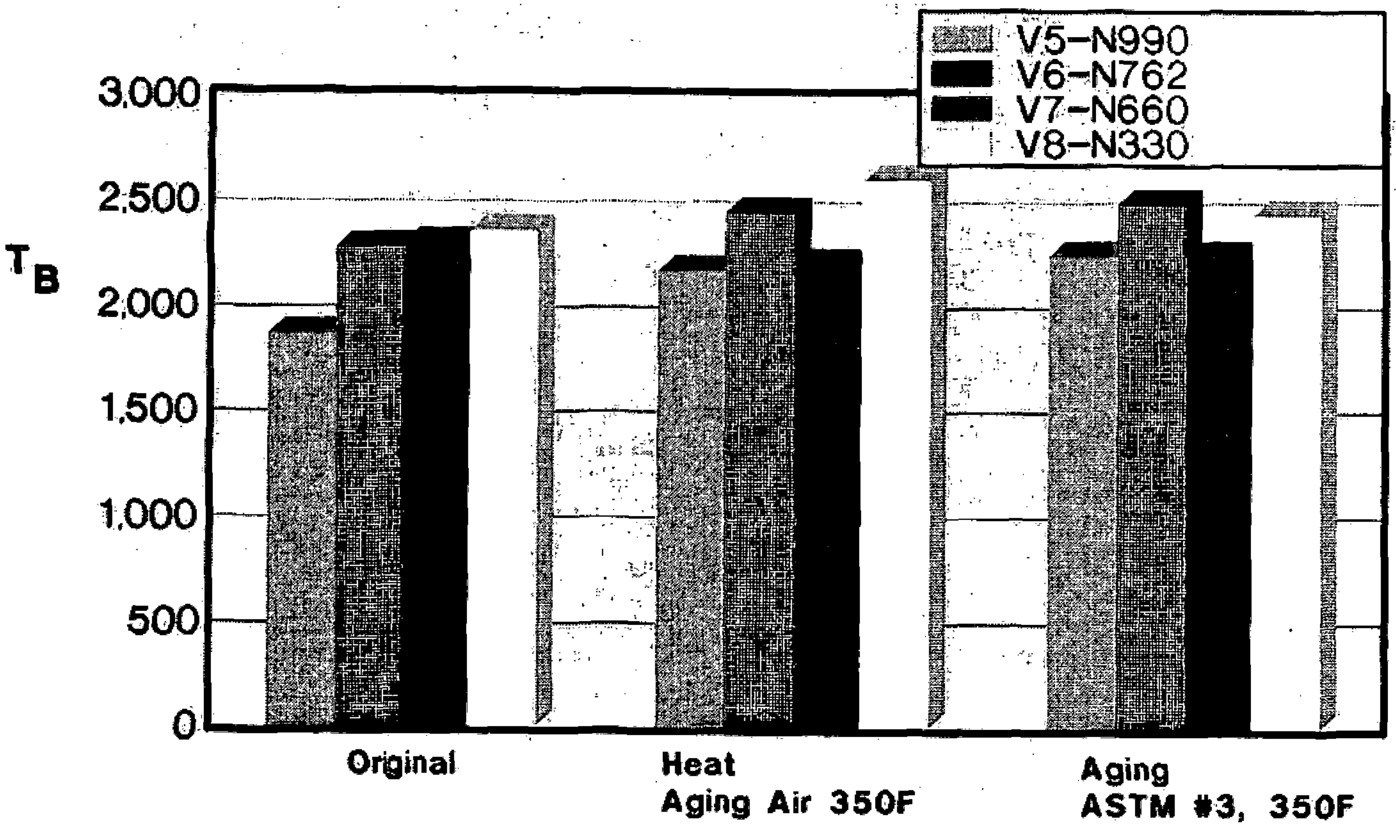


Figure Six

Volume Swell Following Fluid & Gaseous Aging

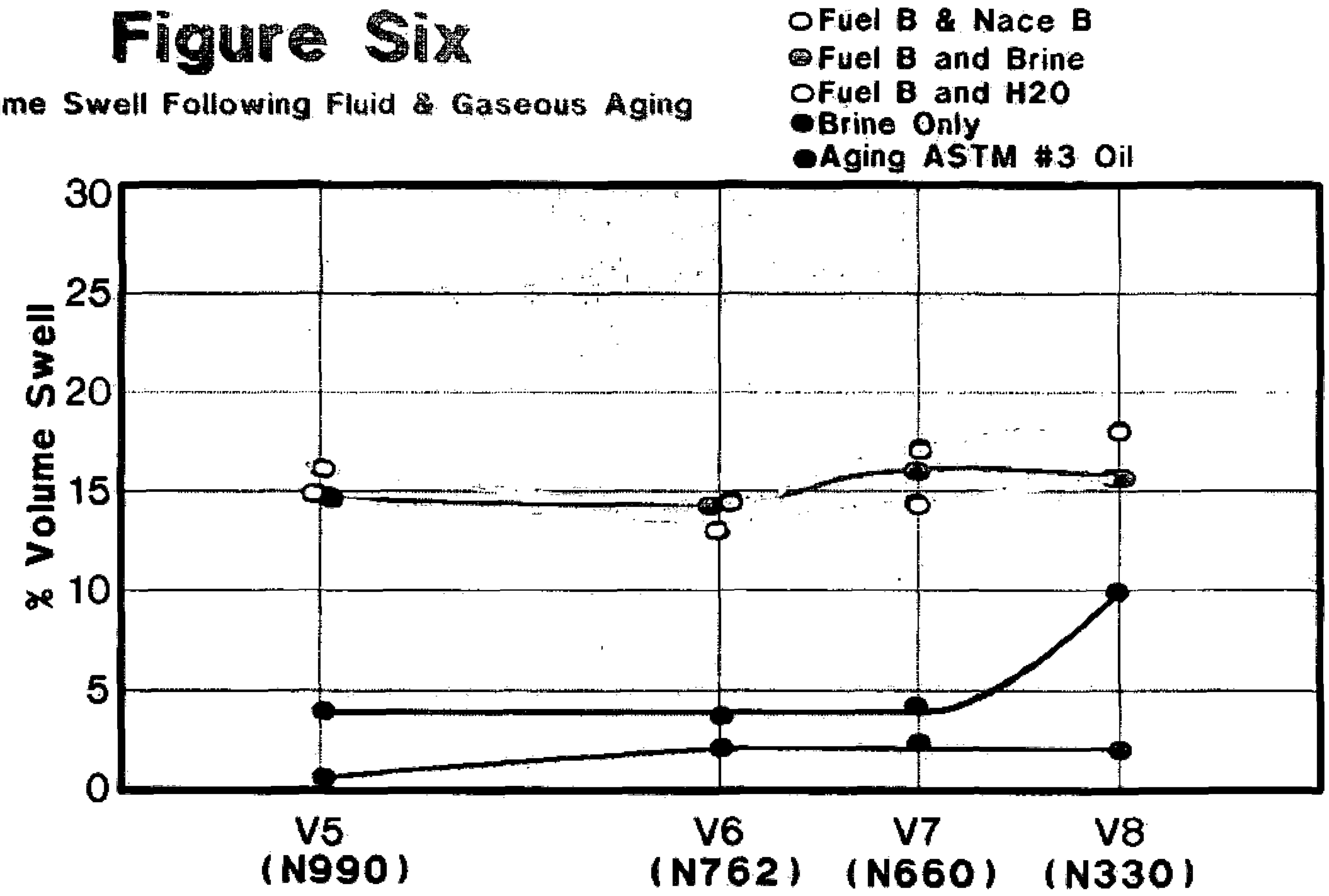
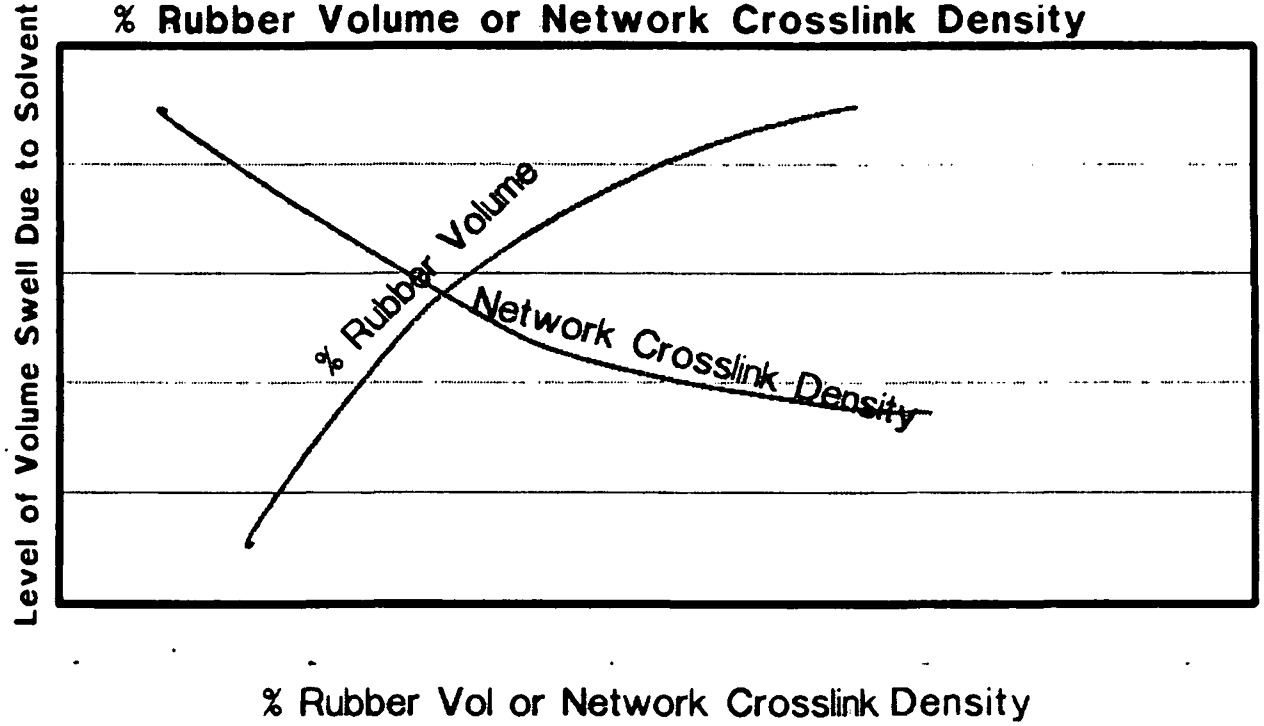


Figure Seven

Projected Effects on Volume Swell Due to % Rubber Volume or Network Crosslink Density



HYDROTHERMAL POWER CO., LTD.

Post Office Box 2701
Paso Robles, CA 93447

ROGER S. SPRANKLE
General Partner
(805) 239-3521

Library

November 27, 1985

Dr. Phillip Wright
Earth Science Laboratory
University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, UT 84108

Dear Dr. Wright:

The report on international testing along with the enclosed test result analysis was to be presented at the canceled DOE Conference. If interested, I have copies of the test report.

Additional analysis of the test results will undoubtedly provide a greater understanding into the prime mover capabilities. However, I firmly believe that the current conclusions will remain basically unchanged. The prime mover is ready for long term commercial usage.

This letter is an inquiry into the availability of a resource where arrangements could be made to put the prime mover to work. Many currently unused geothermal resources would surely benefit from the demonstrated abilities of this prime mover. The prime mover is versatile and I would welcome the opportunity to detail its capabilities for any specific site or application.

If I can be of any assistance, please advise.

Sincerely,

Roger S. Sprankle
General Partner

Enclosure

HELICAL SCREW EXPANDER POWER PLANT
MODEL 76-1
TEST RESULT ANALYSIS

November 3, 1985

by

ROGER S. SPRANKLE
General Partner
Hydrothermal Power Co.
P. O. Box 2701
Paso Robles, CA 93447
805/239-3521

As stated in the test reports[1,2] on the Helical Screw Expander, Model 76-1 was purposely manufactured with abnormally large clearances. These clearances are more than five times larger than normal for this class of turbomachinery, and it was known that attractive machine efficiencies would require mineral deposition to close the clearances. The impact of these oversized clearances and the resulting leakage is revealed in the following analysis.

The data was obtained from the New Zealand test results at a time when the internal clearances were known to be free of any mineral deposition.

Figure 1 contains test data of machine efficiency plotted against the effective fluid volume ratio. Along the right part of the curve, towards point 5, where the high volume ratios occur, the machine becomes increasingly unable to fully expand the fluid across the rotor, resulting in underexpansion and operation known as square card with its known losses. Thus a greater and greater pressure drop occurs from the exit rotor pocket into the exhaust. Along the left of the curve, towards point 1, with low volume ratios, the machine increasingly overexpands the fluid. Thus the exit rotor pocket pressure becomes lower than the exhaust. Near the center of the curve, a point is reached where the machine fully expands the fluid across the rotors and the exit rotor pocket unfolds into the exhaust with no pressure change.

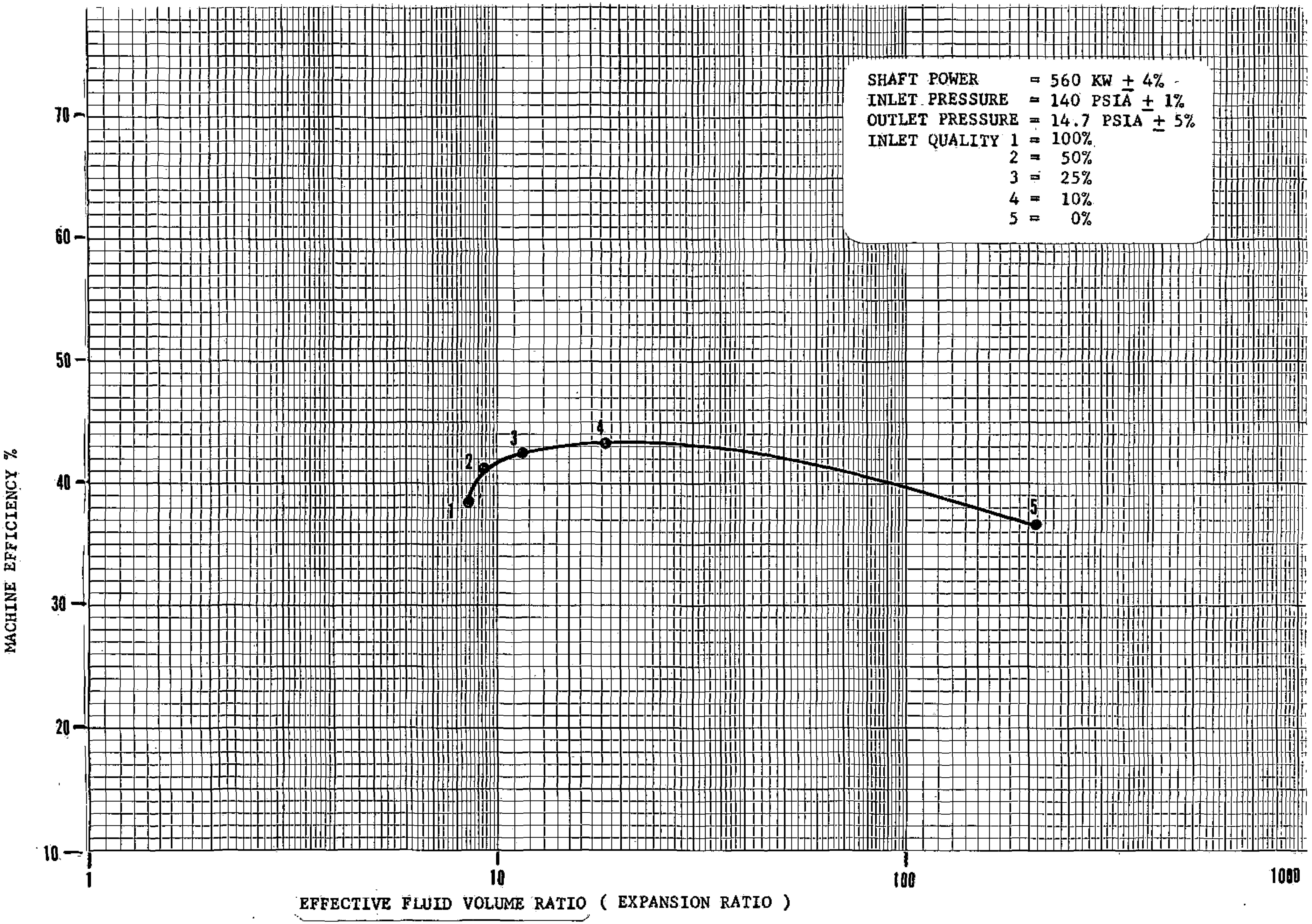
Figure 2, containing the same test data, shows machine efficiency plotted against effective fluid volumetric flow. Again we see the effects of underexpansion along the curve toward point 5. Here, the increasing pressure drop and resulting expansion is shown as increasing volumetric flow. The most important information revealed occurs at full expansion. By definition, at full expansion the exit rotor pocket volumetric flow equals the exhaust volumetric flow - except for leakage. As shown, greater than half the flow through the machine is leakage. With the clearances reduced to a range considered standard for this class of machinery, by a design change or mineral deposition, the leakage rate can be expected to be less than 15% of the total flow.

Figure 3 provides insight into the relationship between clearances and machine efficiency. The figure is from Dr. O. E. Balje and his work on turbomachinery.[3] In the figure, families of machine efficiency are drawn for three different rotor clearances. The rotor length to diameter (L/D) curves are slightly displaced because the diameter is changed (to change the clearance) for each family of curves. Model 76-1 has a leakage gap to rotor diameter ratio (S/D) greater than .004, which is four times larger than the worst case shown on the graph. As can be seen, clearances have a major impact on machine efficiency.

The leakage problem with Model 76-1 makes further analysis of the test results difficult. Leakage is not only a function of clearance, but also a function of clearance distribution through the machine. In addition, pressure drop and distribution across the machine is a factor. Two phase flow also influences leakage. In Figure 2, there is a drop in machine efficiency when going from 50% quality to all steam. The disappearance of liquid phase sealing is clearly evident.

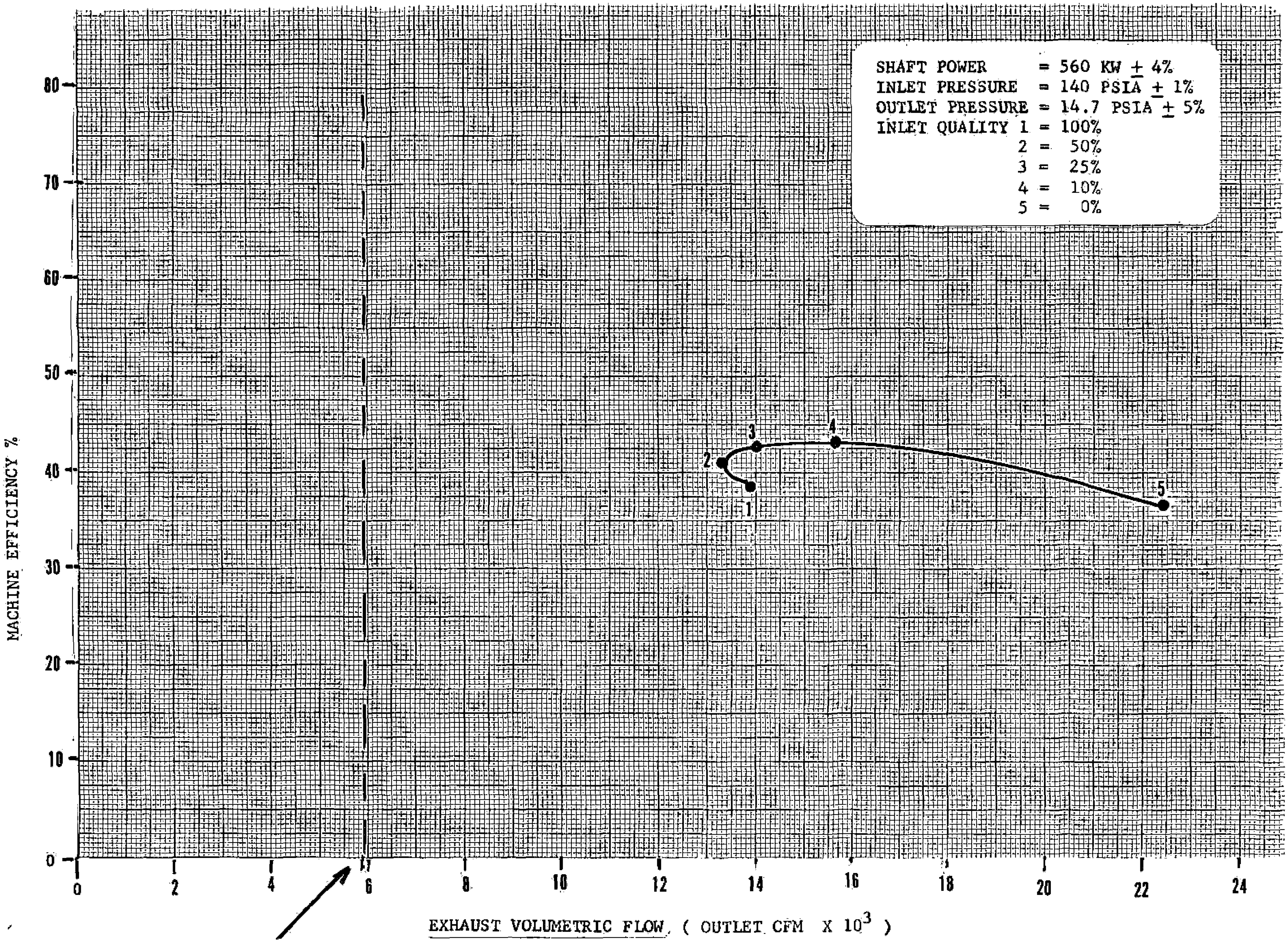
Even though further analysis is made difficult to precisely characterize the prime mover[4] and display its capabilities on a universal diagram of specific speed and diameter, some conclusions are possible.

1. Model 76-1 machine efficiencies of greater than 70% can be expected over a broad range of conditions up to 1,000 KW, the maximum tested output.
2. Equally high machine efficiencies can be expected with condensing operation, although at power levels less than 1,000 KW.
3. The dynamic losses at higher tip velocities has not been determined. However, in the range tested the machine is commercially viable.
4. Practical machines with power outputs greater than 20 MW are feasible.
5. Long term commercial operation is needed to answer practical utility questions.



FROM NEW ZEALAND TEST DATA @ 3333 RPM

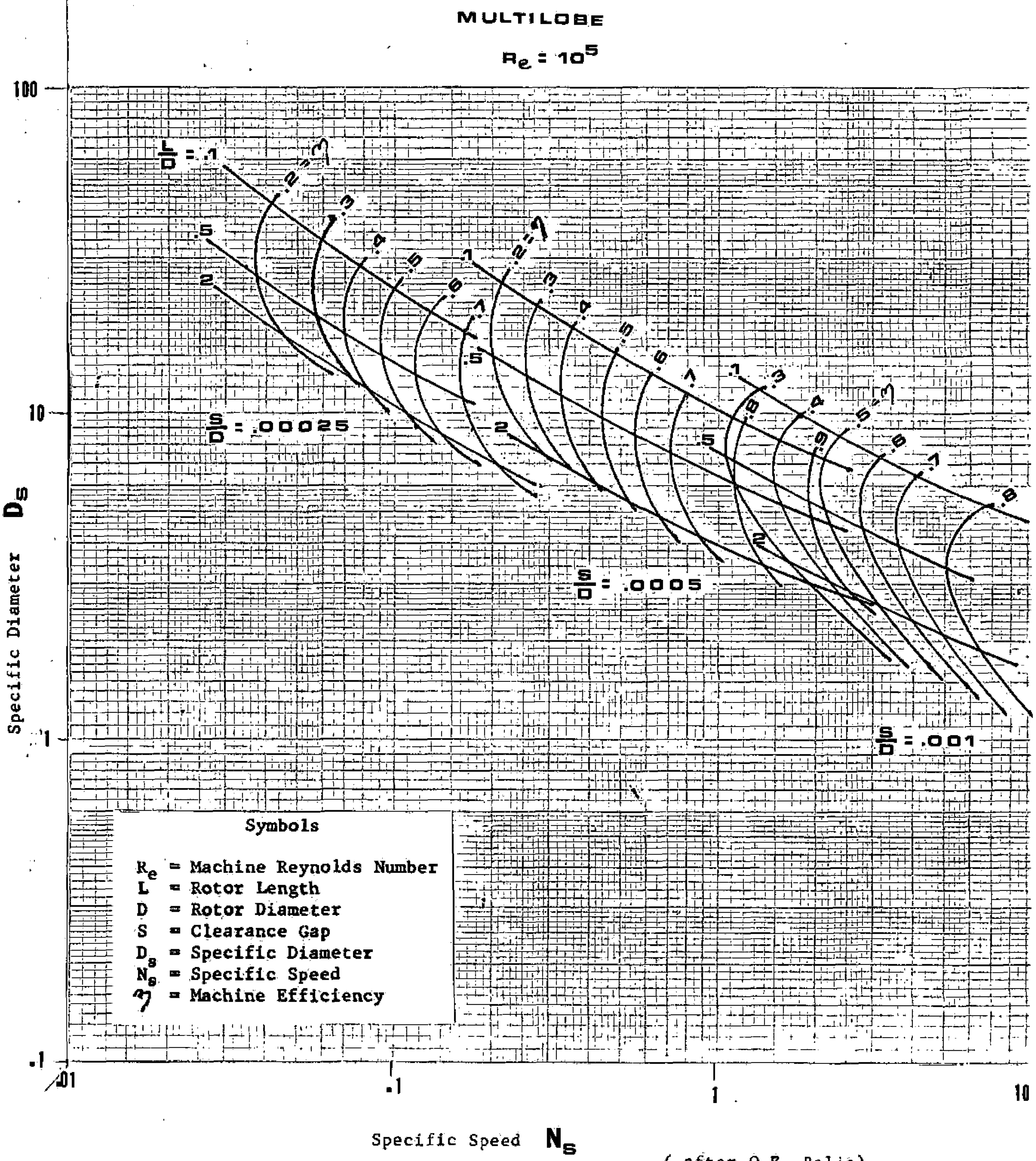
FIGURE 1.



POSITIVE DISPLACEMENT FLOW
@ ROTOR POCKET EXIT @ 3333 RPM

FROM NEW ZEALAND TEST DATA @ 3333 RPM

FIGURE 2.



(after O.E. Balje)

Figure 3.

References

1. Helical Screw Expander Evaluation Project Final Report, Richard McKay, March 1, 1982, JPL Publication No. 82-5; DOE/ET-28329-1, Distribution Category UC-66D. This report may be ordered under the DOE Accession No. DOE/ET-28329-1, or the NASA Accession No. N82-22659, from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

2. International Test and Demonstration of a 1-MW Wellhead Generator: Helical Screw Expander Power Plant, Model 76-1, Final Report, Richard A. McKay, June 1, 1984, JPL Publication No. 84-29; DOE/ET-37116-2, Distribution Category UC-66df.

3. O. E. Balje, *Turbomachines: A Guide to Design, Selection and Theory*, John Wiley & Sons, Inc., 1981.

4. U.S. Patents 541,854 and 3,751,673 and foreign patents held by Hydrothermal Power Co., Ltd.

Proceedings - Mineral Econ. Symposium Nov. 1977 - AIME

IMPORTANCE OF PHYSICAL PARAMETERS IN PETROLEUM SUPPLY MODELS

L. J. Drew, E. D. Attanasi, and D. H. Root,
U.S. Geological Survey

I. INTRODUCTION

The world's initial endowment of crude oil is for practical purposes fixed and only sufficient as a major energy source for three or four generations. To us who live in the period of large scale petroleum production, however, the industry is of great importance. If the entire history of the world-wide petroleum industry is to be modeled from the spudding of the first wildcat well to the plugging of the last stripper well, then the model must assume zero production at the beginning and at the end. During this period, exhaustion (diminishing returns to exploration and production effort) is inescapable. Diminishing returns to exploration can be temporarily reversed by occasional giant discoveries made during the initial exploration of frontier areas. The declining production rate from known fields can be masked by bringing large new fields into production. Studies of the industry in a large region over the short term need not take into account exhaustion in either exploration or production because its effect is gradual. If a petroleum study is restricted to a small region, say a single productive formation, then only a very short-term study can safely ignore exhaustion. For example, the amount of petroleum discovered by the first 500 exploratory wells in a formation is typically much greater than the amount discovered by the next 500 exploratory wells. If the region under study contains many productive formations then the effect of exhaustion on the discovery rate (bbl/well or bbl/meter) is erratic because as some formations are being exhausted other new ones are just beginning to be explored. Consequently, the overall discovery rate can increase though typically this increase is short lived.

Several petroleum industry models that use both physical and economic data and assumptions are analyzed below. Substantial differences exist in the structure of these models and also in the type of forecasts they are intended to produce. The National Petroleum Council model (F.E.A., 1974) used a discovery rate curve extrapolation approach along with numerous economic and physical assumptions to forecast petroleum liquids production within a specific 15-year time period (1974-88). The econometric models developed by Fisher (1964) and MacAvoy and Pindyck (1975) were designed at least in part to estimate the responsiveness of future discoveries to changes in price. The discovery process models developed by Arps and Roberts (1958), Barouch and Kaufman (1977), and Drew, Schuenemeyer, and Root (in press) are based on purely the physical attributes of the discovery process. The prediction of future rates of discovery produced by discovery process models can be used with engineering-cost analysis to predict the marginal cost of future discoveries.

II. FORECASTING MODELS

National Petroleum Council Model

The model developed by the National Petroleum Council and modified by the Federal Energy Administration (F.E.A.) for Project Independence (F.E.A., 1974) was intended to forecast U.S. petroleum liquids production for the 15-year period from 1974 through 1988. The fundamental physical data used in the model are annual average discovery rates measured in barrels of oil-in-place discovered per foot of exploratory drilling for 12 onshore and offshore regions in the United States. Extrapolations of the discovery rates were used to forecast the quantity of oil-in-place that would be discovered in each region by a given amount of exploratory drilling.

Recovery factors for each of the 12 regions were assumed for primary, secondary, and tertiary recovery techniques. Annual production in each region was assumed to be a fixed fraction of proved reserves. The costs of exploration, development, and production were also assumed for each of the 12 regions. Additional costs of secondary and tertiary recovery were also assumed along with discount rates, interest rates, and tax rates. For each of the 15 years and 12 regions a target amount of exploratory drilling was chosen. However, only that amount of drilling which was profitable under the physical and economic assumptions was assumed to be done.

For various oil prices, the model calculated what exploration would actually take place, what would be discovered, and, finally, how much would be produced annually from each region. The main conclusions were that at constant real oil prices the U.S. could maintain petroleum liquid production (including natural gas liquids, tar sands, and heavy oil) at about 9 million or 10 million bbl/day from 1974 through 1988. Moreover, if the real price of oil were increased by a factor of 3.75, then U.S. petroleum liquids production could be increased from 10.5 million bbl/day in 1974 to 16.4 million bbl/day in 1988. Overall liquids production for the 15-year period at the high price level was forecast to be 70.1 x 10^9 bbl -- 1.1 x 10^9 bbl from tar sands and heavy crude, 48.5 x 10^9 bbl of conventional crude oil, and 20.6 x 10^9 bbl was to be natural gas liquids.

The complexity and detail of the assumptions that were used in making these projections present an apparently formidable barrier to checking whether or not these projections are reasonable. This complexity can be circumvented by considering the physical aspects of petroleum exploration and production. Economic data and assumptions were used in the model primarily to predict the amount of exploration that would be carried out, so that one can restrict one's attention to the question of whether or not the predicted exploration would lead to the predicted production. The exploratory drilling that was to bring about the additions to proved reserves sufficient to allow production to increase from 10.5 x 10^6 bbl/day to 16.4 x 10^6 bbl/day was assumed by the model to be about 175 x 10^6 m (575 x 10^6 ft) over the 15-year period 1974-1988. Slightly more exploratory drilling was done in the U.S. during the 15-year period 1959-73 when U.S. production of crude oil was 43.4 x 10^9 bbl and proved reserves were increased by 4.8 x 10^9 bbl indicating that total additions to proved reserves were about 48.2 x 10^9 bbl. The model predicts that crude oil production will increase from 8.09 x 10^6 bbl/day in 1974 to 10.9 x 10^6 bbl/day in 1988. To reach this higher production level, proved reserves must not be permitted to decline, thus total additions to proved reserves between the beginning of 1974 and the end of 1988 must be at least equal to production in this period or 48.5 x 10^9 bbl. Thus, the model forecasts that a slight decrease in the rate of exploratory drilling will be accompanied by a slight increase in the rate of additions to proved reserves. It is hard to see how such an increase in the rate of additions to proved reserves can be maintained during such a long period.

In order to support the production predicted by the model, the additions to proved reserves of natural gas liquids must be proportionately even greater than the additions to proved reserves of crude oil. From 1959 to 1974, U.S. production of natural gas liquids was 9.0×10^9 bbl and proved reserves increased by 0.251×10^9 bbl, from 6.20×10^9 bbl to 6.46×10^9 bbl, so that total additions to proved reserves of natural gas liquids were 9.25×10^9 bbl. The model forecasts that production will increase from 1.92×10^6 bbl/day in 1974 to 5.06×10^6 bbl/day in 1988. If we assume a proportionate increase in proved reserves, then proved reserves of natural gas liquids must increase from 6.46×10^9 bbl to 17.0×10^9 bbl. The total additions to proved reserves as calculated by adding the increase in proved reserves to the cumulative production during this period sum to 31.1×10^9 bbl. This amount represents over 3 times the additions to proved reserves made in the 15 years prior to 1974.

Additions to proved reserves are, of course, not the same as discoveries, nonetheless, the FEA forecasts could only come true if a considerable increase in the discovery rate were maintained for the 175×10^6 m of exploratory drilling. A model which is intended to describe petroleum exploration over a period which includes this much exploratory drilling cannot ignore the fact of an overall declining discovery rate in oil and gas, as can be seen by examination of the discovery rate for the lower 48 states presented by Hubbert (1967, p. 2223).

The Fisher Model

The first widely publicized econometric model of the oil industry was authored by Fisher (1964). He used three equations to predict the annual number of wildcat wells drilled, success ratio (proportion of wildcat wells that resulted in a discovery), and the average size of predicted discoveries. The product of these three variables yields the supply of new reserves. Fisher distinguished between exploration at the extensive margin (i.e., frontier areas) and at the intensive margin (i.e., partially explored areas). Exploration at the intensive margin is very sensitive to short-run economic conditions, yields relatively small discoveries, and has low risks. Discoveries at the extensive margin are characterized by being large and by having relatively high risks. Fisher asserted that short-term reaction to increases in price results in a shift of exploration to the intensive margin.

The most important physical parameter that Fisher attempts to deal with, average deposit size of oil deposits discovered in period t (S_t), is predicted from the following equation:

Average oil Dep. Size, S, in period t,

$$S_t = \frac{\alpha_0 S_{t-1}^{\alpha_1} F_{t-1}^{\alpha_2}}{N_{t-1}^{\alpha_3} P_t^{\alpha_4}} \qquad (1)$$

where: F_{t-1} is the previous period's success ratio, N_{t-1} is the average size of natural gas deposits discovered in period t-1, and P_t is the price of oil in period t. All the parameters, α_i, are positive.

This relationship suggests that the average size of a new discovery is directly related to the size of deposits discovered in the previous period and to the previous period's success ratio and is inversely related to the average size

Why inverse to price? because of short run effect!

of natural gas deposits found in the previous period and the current price of oil. Because Fisher also found the price and success ratio to be directly related, he claimed that the initial effect of increases in the price of oil is to shift exploration to the intensive margin, thus producing lower risks and relatively small discoveries. The estimated short-run price elasticity, 0.3, indicates a modest price responsiveness of reserves from new discoveries.

Although the model may have not been constructed to predict petroleum supply, the estimated price responsiveness of new reserves (which is the sum of the price coefficients in the three-equation model) has been misused by applying it to long-run supply problems. Nothing in the structural equations of the model reflects the finiteness of the physical resource base. Moreover, in order to increase the number of observations, time series data for various regions were pooled using regional dummy variables. Variation in the historical price data used by Fisher were probably more the result of differences in the quality of the oil than the incremental production costs. Erickson and Spann (1971) elaborated on Fisher's original formulation by including an equation for predicting the average size of natural gas deposits using the same specifications.

The MacAvoy and Pindyck Model

MacAvoy and Pindyck (1975) also developed an econometric model of the petroleum industry to predict future supply of natural gas. Like Fisher, they modeled the reserves from new discoveries by predicting the number of wildcat wells to be drilled, success ratios for oil and gas exploration, and the average size of oil and natural gas discoveries. The structural equation yielding the predicted average size of the new discoveries in period t (S_t) has the following functional form:

$$S_t = S_R e^{WR(-\alpha_0 + \alpha_1 D_1 + \alpha_2 D_2 + \alpha_3 D_3 + \alpha_4 X - \alpha_5 PG_R + \alpha_6 PO_R)}$$

$$\text{with } X = (PGO_o - XO - CQ_o)/PGO_o \qquad (2)$$

where: S_R is the average discovery size in the previous 3 years, WR is an index of the number of successful oil wells in the reference period immediately preceding the current period, D_1, D_2, and D_3 represent respectively dummy variables for South Louisiana, the Permian district, and a single large area covering East Texas, Kansas, and Oklahoma, PO_R is a 3-year average of oil prices, and PG_R is a 3-year average of natural gas prices. The variable X, an index of oil depletion, is specified as a function of PGO_o, an estimate of original oil in place for the production district; XO, end-of-year oil reserves; and CQ_o, cumulative production. The specification of the model asserts that the predicted average size of new oil discoveries is directly related to the price of oil (the reverse of the previous model) and inversely to the price of gas and advancement of depletion (which leads X to decrease). Because price is directly related to deposit size and inversely related to the success rates, MacAvoy and Pindyck assert that their formulation is able to capture long-run supply adjustments.

Comparison of historical data with the model predictions indicates that the model substantially overestimated the price responsivness of new reserves. Pindyck (1976) revised the model to correct this problem and used different equation specifications for predicting the average size of new oil and gas discoveries. In particular, the size equation for newly discovered oil deposits has the form:

$$S_t = e^{(\theta_0 + \theta_1 D_1 + \theta_2 D_2 + \theta_3 D_3 - \theta_4 CW_t)} \tag{3}$$

where S_t is the predicted average size of oil discoveries for period t; D_1, D_2, and D_3 are the same regional dummy variables used in equation 2; and CW_t is the cumulative number of exploratory wells drilled at period t. Average oil deposit size is completely divorced from price and steadily decreases with the cumulative number of exploratory wells drilled. However, the equation used to predict the average size of newly discovered gas deposits still included price and took the following form:

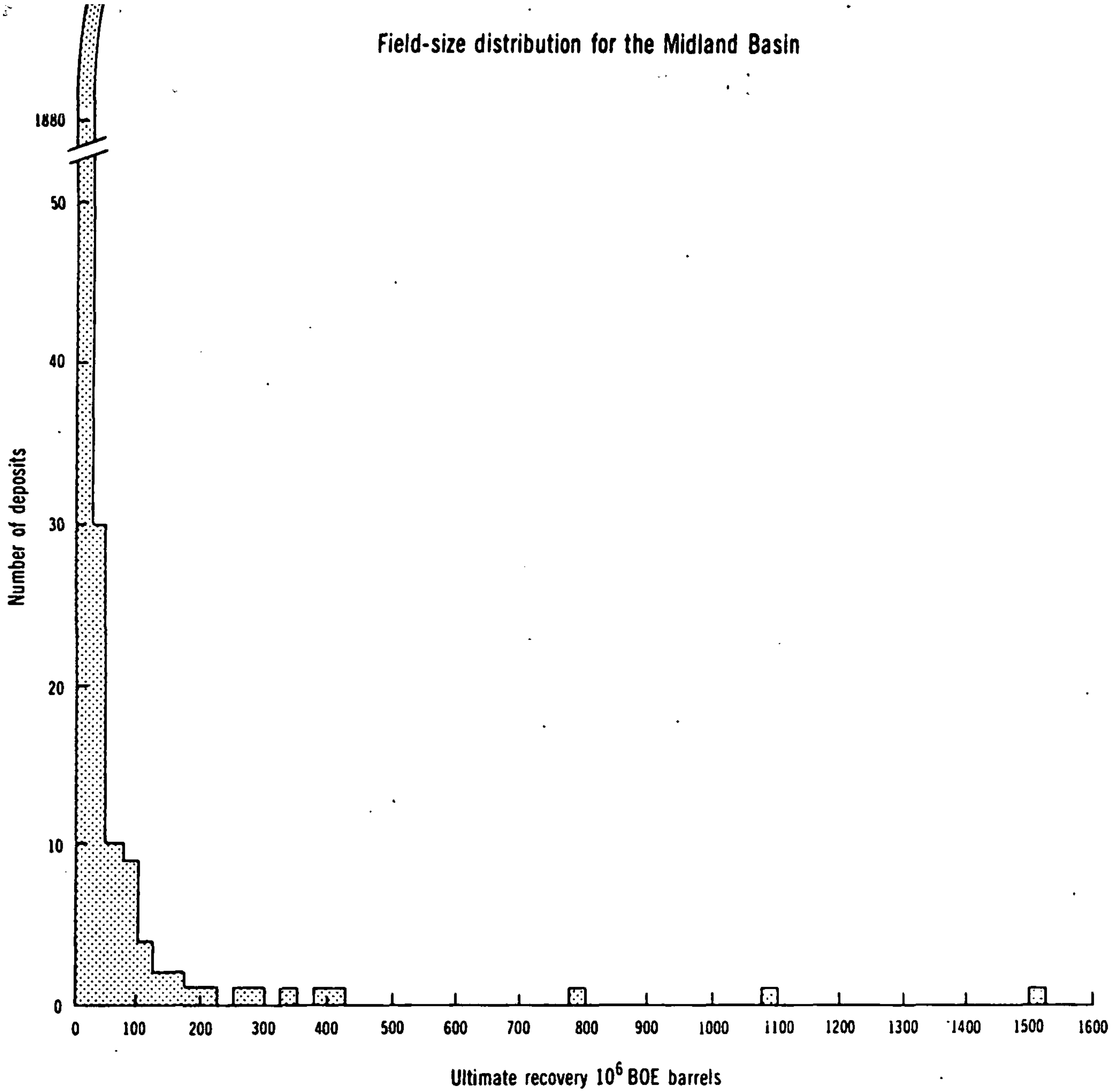
$$N_t = e^{(\beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 PG_R - \beta_5 PO_R - \beta_6 CW_t)} \tag{4}$$

where N_t is the predicted average size of natural gas discoveries and PG_R and PO_R are reference prices for gas and oil respectively. The predicted average size of gas discoveries is inversely related to the price of oil and the cumulative number of wells drilled and positively related to the price of gas. The difference in the specification of the oil and gas equations reflects the belief that physical depletion is the only relevant factor in the expected size of new oil discoveries but that economic variables, i.e., the price of oil and gas, determine expected size of new gas discoveries. In this paper we argue that physical parameters characterizing the level of exhaustion in the area being explored are the appropriate data on which to base predictions of the expected sizes of discoveries of both oil and gas.

III. TWO IMPORTANT EMPIRICAL OBSERVATIONS

Our assertion that an equation used to predict the average size of discoveries must explicitly specify some form of decline (such as that shown in equation 3) is based upon generalizations drawn from two empirical observations. The first of these observations is that within any petroleum province and within exploration plays, in particular, the size distribution of deposits is highly skewed, i.e., there are many small deposits and only a few large deposits. It is not uncommon to find that of the several hundred deposits that may occur in any given region, most of the petroleum is contained in only the few largest deposits. The second observation is obtained from analyzing historical discovery time series data which shows that the larger deposits tend to be discovered early in the exploration of any region. Coupling these two ideas together, we have a physical basis for the specification of a model of the discovery process.

In order to develop these ideas more fully, we will examine in detail a field size distribution and discovery table from the highly explored Midland Basin. This basin is located in Western Texas and covers approximately 91,000 km^2 and is a sub-basin of the much larger and highly prolific Permian Basin. The size distribution of the ultimate recoverable petroleum in the 1,957 deposits that were found through the end of 1974 is shown in Figure 1. In this figure,



Field-size distribution for the Midland Basin

Figure 1.

the highly skewed nature of the size distribution of deposits is clearly demonstrated. The implication of the order of deposit discovery becomes apparent when the relative proportions of the aggregate volume of petroleum is tabulated according to deposit size (Table 1). The largest single deposit in this basin contains 13.4 percent of aggregate petroleum which occurs in the 1,957 total deposits discovered through 1974. The 12 largest deposits contain 51.3 percent of the total. Another comparison which illustrates the highly skewed character of this size distribution is that there is more petroleum in the two largest deposits in this basin than in the 1,890 deposits in the 0-25 million barrel class. The order of discovery of the few large deposits that occur in any given region then, plays a central role in determining on either a temporal or per well basis the rate of return to exploratory drilling. The largest deposit in the midland basin was discovered in 1948 when only 2,012 (12.6 percent) of the total 16,014 exploratory wells drilled through 1974 had been drilled. All 18 deposits that each contain 100 million barrels or more were discovered by 1954 when 5,937 (37.1 percent of the 1974 total) exploratory wells had been drilled. Between 1955 and 1974 an additional 1,352 deposits were discovered with the drilling of an additional 10,077 exploratory wells. On the average, however, these subsequent discoveries were small (Figure 2). This pattern of observed events in the Midland Basin is similar to that in other regions such as the Denver Basin, offshore Gulf of Mexico, and the North Sea.

IV. DISCOVERY PROCESS MODELS

A generalization can be drawn about the physical nature of the discovery process from the type of empirical results discussed above which can be used to specify analytic models of the discovery process. Each of the discovery process models that have been developed to date, while having different structures and different output formats, use the central assumption that the larger the deposit the more likely it is to be discovered earlier in the discovery sequence. The model constructed by Barouch and Kaufman (1977) uses the additional assumption that the size distribution of deposits is lognormally distributed. The discovery process models developed by Arps and Roberts (1958) and Drew, Schuenemeyer, and Root (in press) do not require the size distribution to have a specific form, but instead estimate the form of this distribution as the drilling process unfolds.

but could use lognormal initially

The Barouch and Kaufman Model (1977, 1978)

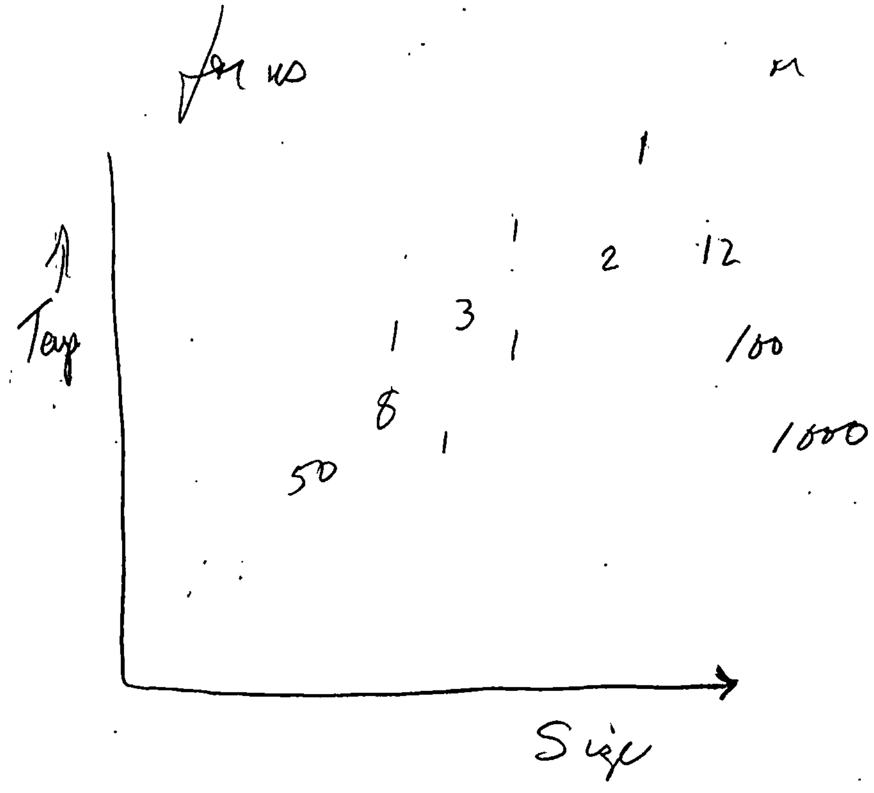
In this model, it is assumed that the size distribution of the parent population of petroleum deposits in any homogeneous unit (exploratory play) is lognormal. The sizes of deposits that occur in a play are then a finite number of values selected independently from the lognormal parent population. It is further assumed that the exploration process can be described by sampling from this finite population proportional to size and without replacement. Given the results of the exploratory drilling within any partially explored exploration play this model can be used to estimate the mean and variance of the parent population and the number of deposits in the play. With estimates of these parameters the model can then be used to estimate the expected size of each new discovery in the remainder of the exploration play.

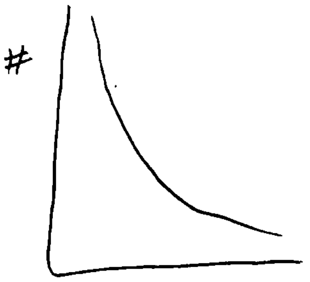
Table 1. - Proportion of Aggregate Petroleum in the Midland Basin Contained in Various Size Classes of Deposits

Size Class 1/	Number of Deposits in Class	Percent of Total in Class	Cumulative Percent
1,500-1,525	1	13.4	13.4
1,075-1,100	1	9.6	23.0
775- 800	1	6.9	29.9
400- 425	1	3.6	33.5
375- 400	1	3.5	37.0
325- 350	1	3.0	40.0
275- 300	1	2.7	42.7
250- 275	1	2.3	45.0
200- 225	1	1.9	46.9
175- 200	1	1.6	48.5
150- 175	2	2.8	51.3
125- 150	2	2.4	53.7
100- 125	4	4.1	57.8
75- 100	9	6.8	64.6
50- 75	10	5.6	70.2
25- 50	30	9.4	79.6
0- 25	1,890	20.4	100.0
TOTAL	1,957	100.0	

discontinuous classes

1/ In millions of barrels of oil equivalent.





BTU's reflect size + temp.

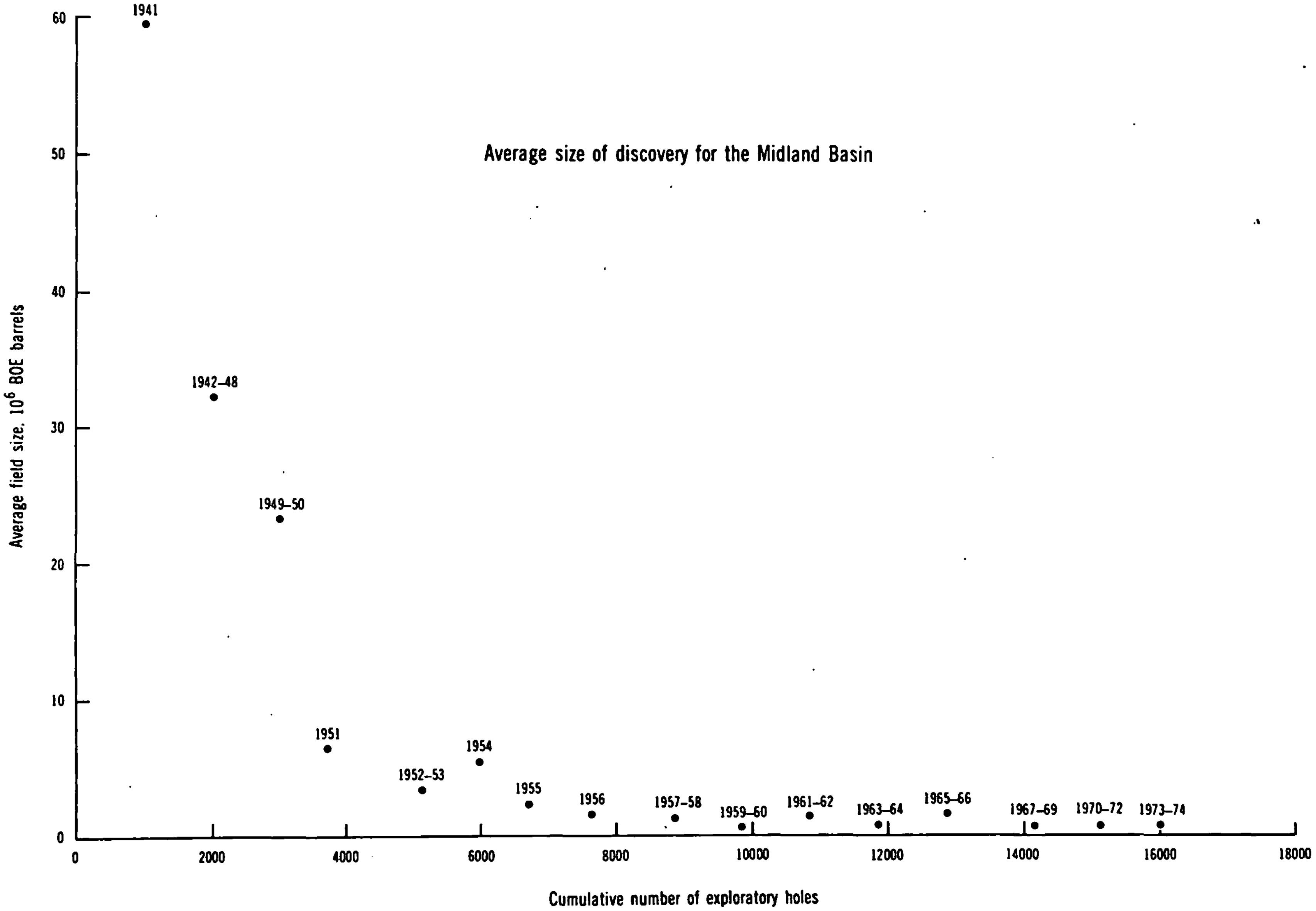

Average size of discovery for the Midland Basin
Average field size, 10^6 BOE barrels
Cumulative number of exploratory holes
0
10
20
30
40
50
60
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
1941
1942–48
1949–50
1951
1952–53
1954
1955
1956
1957–58
1959–60
1961–62
1963–64
1965–66
1967–69
1970–72
1973–74

Figure 2.

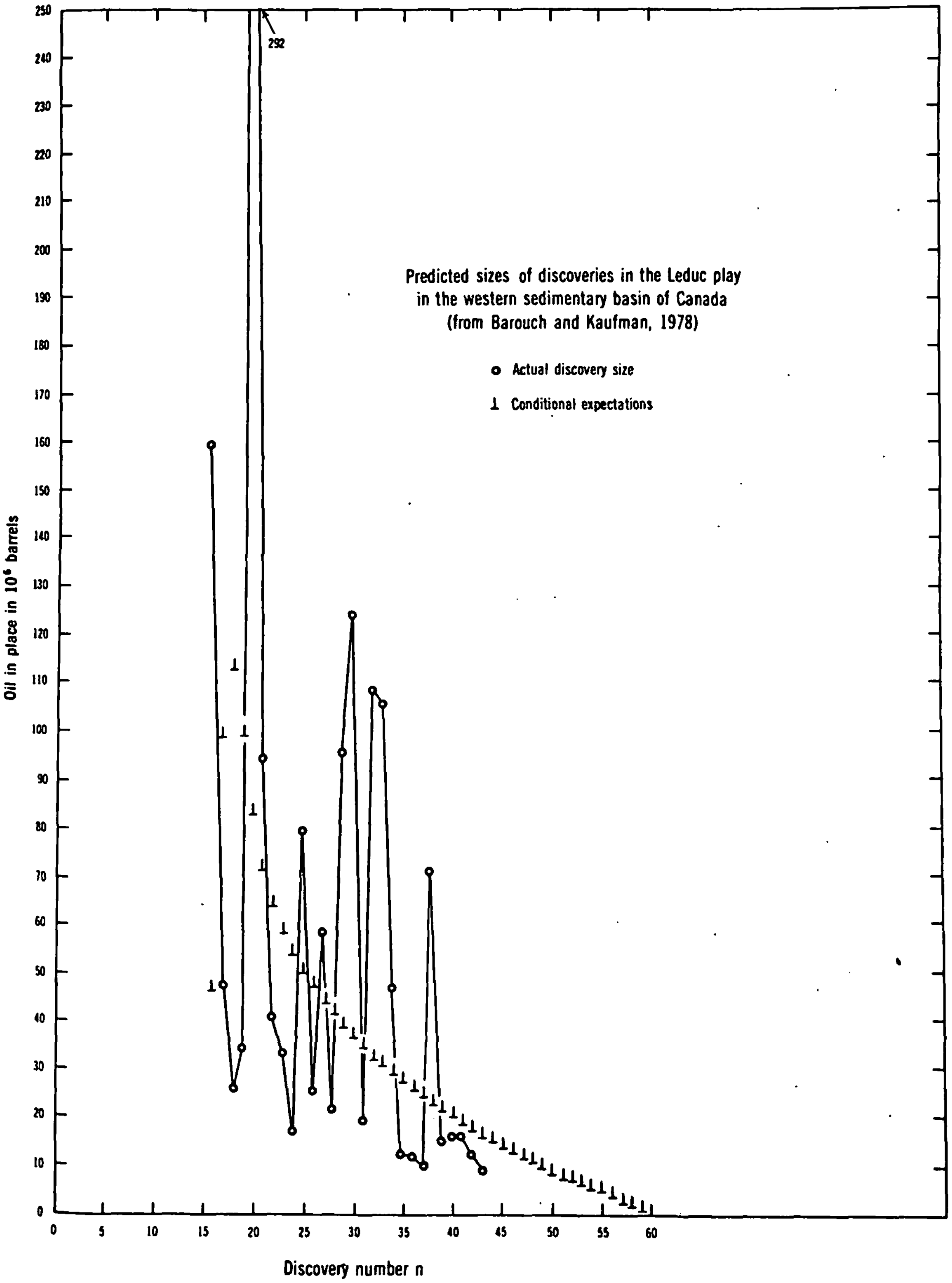

Predicted sizes of discoveries in the Leduc play
in the western sedimentary basin of Canada
(from Barouch and Kaufman, 1978)
o Actual discovery size
⊥ Conditional expectations
292
Oil in place in 10⁶ barrels
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
0
5
10
15
20
25
30
35
40
45
50
55
60
Discovery number n

Figure 3.

For example, using the ordered sizes of the first 15 discoveries in the Leduc reef play in the western Canadian sedimentary basin this model was used to predict the sizes of the 16th through the 55th discovery in this play (Figure 3). Comparing the amount of petroleum actually discovered in the 16th through the 43rd discovery (the most recent discovery in the play) the model was found to predict the total volume of petroleum contained in these 28 discoveries to within 7 percent of what was actually discovered.

Recognizing that a model of this type, which is specified purely as a function of physical variables, can produce such an accurate forecast of future events, yields the type of evidence which implies that an average size of discovery equation such as that arrived at by Pindyck (1976) (equation 3) is not unreasonably specified. This is not to say that the translation of the type of prediction produced by the Barouch and Kaufman model into the average size of discovery equation specified by Pindyck does not require the use of assumptions or qualifications. For example, Pindyck's equation (equation 3) can be determined only to the first approximation by applying a constant success ratio to the series of expected size of discoveries produced by the Barouch and Kaufman model (Figure 3). The success ratio equation required to cast the predictions made by the Barouch and Kaufman model into an average size of discovery time series equation obviously requires additional empirical study. The important point is that given the physical nature of the discovery process, a declining rate of expected return to exploratory drilling is a fundamental physical principal. Therefore, whether a discovery process model is designed to produce forecasts in terms of (1) the average size of discoveries, (2) barrels of petroleum discovered per wildcat well, or (3) barrels of petroleum discovered per meter drilled, the equation linking the chosen expected value of the dependent variable must be specified as a declining function of cumulative exploratory effort.

The Arps and Roberts Model (1958)

This discovery process model has the appealing attribute that the success ratio is determined endogenously rather than being assumed after the fact as in the previous model. This model, however, requires the use of additional information about the discovery process; in addition to a partial time series of sizes of discoveries, the corresponding time series of number of wells that led to these discoveries is also required.

Given this additional information, a model can be specified to produce estimates of the expected number of discoveries to be made within any individual deposit size class as a function of any increment for future exploratory drilling. The form of this model is as follows:

$$F_A(w) = F_A(\infty)\left(1 - e^{-\frac{CAw}{B}}\right) \tag{5}$$

where:

$F_A(w)$ = the number of discoveries in areal size category A expected to be made with the drilling of w cumulative exploratory wells.

$F_A(\infty)$ = the ultimate number of deposits to be discovered within a size class with average areal extent over the class equal to A areal units.

Schematic diagram for the Arps and Roberts discovery-process model after w exploratory wells have been drilled

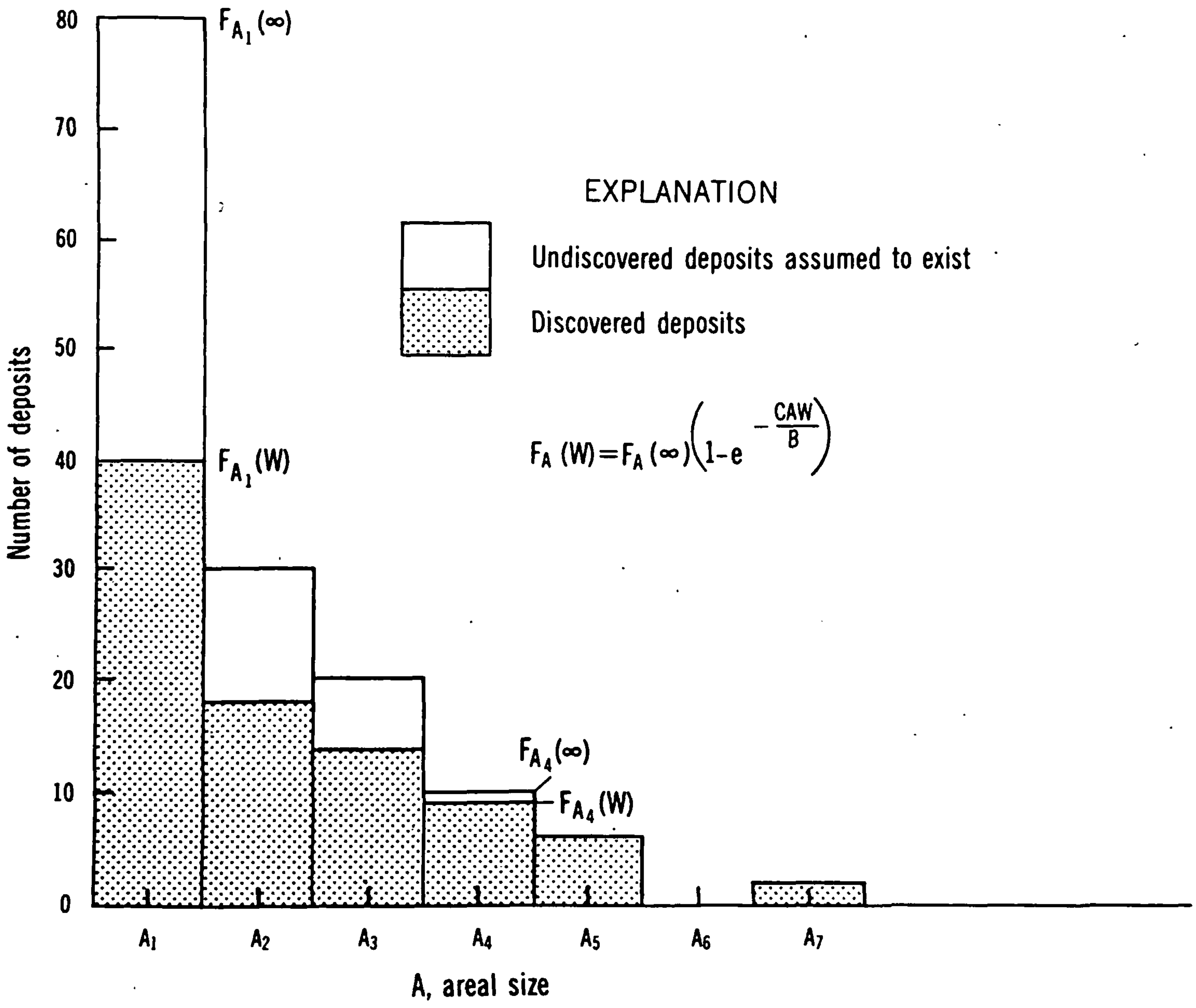


Figure 4.

B = the effective size of the basin, i.e., that region within which explorationists will ultimately be willing to site exploration wells.

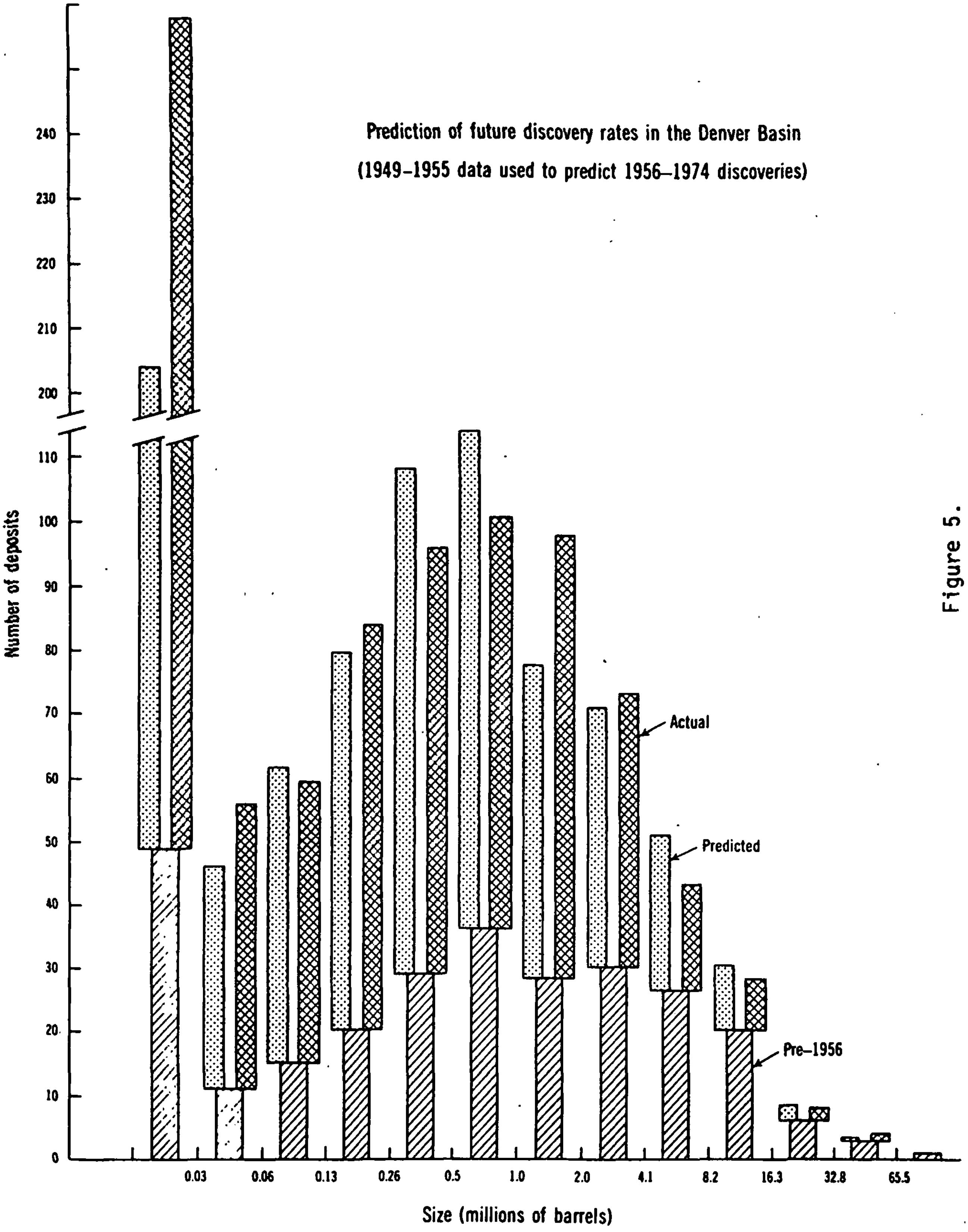
C = the efficiency of exploration; for the case of random drilling C=1; if exploratory drilling is carried out twice as efficiently as random drilling C=2; etc.

In order to demonstrate how this model captures the central elements of the discovery process, we have constructed the following example: assume that the hypothetical population of deposits, $F_A(\infty)$ shown in Figure 4 exists in a region of size B. By the time w exploratory wells have been drilled in this region, this discovery process model will typically reveal a pattern of discovery such as is shown in Figure 4, where it is assumed that say 50 percent of the deposits in the smallest size class A_1 have been discovered. At this same level of exploratory drilling, 90 percent of the deposits in the A_4 size class have been discovered. The levels of discovery in the intermediate size classes, A_2 and A_3, are between 50 and 90 percent complete and it is beyond 90 percent for all larger classes. Thus, the phenomenon of declining rate of return to exploratory drilling is then clearly specified in the model.

economics of size deem unimportant

The forecast of future discoveries produced by this discovery process model differs substantially in form from the type of forecast produced by the Barouch and Kaufman model. Rather than having to obtain a discovery success ratio from outside sources of information in order to determine the returns to any increment of future exploratory drilling, the Arps and Roberts model produces a forecast of the expected sizes of future discoveries directly as a function of any prescribed increment of future drilling. To produce such forecasts for any given partially explored region, values for the two parameters (B, basin size, and C, exploration efficiency) must first be determined. In the Denver Basin where Arps and Roberts first tested their model they were able to use their extensive knowledge of the petroleum geology of this basin to make what have proved in retrospect to be very accurate estimates of these two parameters. The values of these parameters that they chose were used by the authors along with the discovery and drilling data for this basin to produce the forecast shown in Figure 5. Using only the first 6 years of the discovery and drilling data (1949-1955) for the Cretaceous Dakota Sandstone exploration play, the model produced a very accurate estimate of the levels of discovery in each size class in this basin for the subsequent 19-year period (1956–1974), when nearly 9,000 additional exploratory wells were drilled and nearly 700 additional discoveries were made.

This model has also been tested in two additional regions (the Midland Basin and Gulf Coast-OCS) in which multiple exploration plays have occurred (Drew, Root, and Bawiec, unpublished). Using the initial portion of the historical discovery time series in both of these regions, this model produced an accurate forecast of subsequent discovery events. Because of the complexities introduced into the discovery time series by simultaneous unfolding of multiple exploration plays, a somewhat larger initial segment of data was required to estimate the model parameters than in the Denver Basin, where only a single exploration play occurred.



Prediction of future discovery rates in the Denver Basin

(1949–1955 data used to predict 1956–1974 discoveries)

Figure 5.

The Drew-Schuenemeyer-Root Discovery Process Model

Commonly an analyst will not have access to as extensive knowledge of the exploration geology of the region in which he wishes to forecast the future size distribution of discoveries as Arps and Roberts did in the case of the Denver Basin. It was with this concern in mind that Drew, Schuenemeyer, and Root (in press) developed a discovery process model in which both B, the effective basin size, and C, the efficiency of exploration, can be estimated for the initial subset of drilling and discovery results within a region. Once these parameters have been estimated, the future size distribution of discoveries can be forecast for any prescribed amount of future exploratory drilling in the region. This model is based upon the concept of the area of influence of an exploratory hole developed by Singer and Drew (1976).

This model is given by the equation,

$$F(A) = 1 - \left(1 - \frac{E(A)}{B}\right)^{C(A)} \tag{6}$$

where:

F(A) = the fraction of the deposits of size A which have been discovered by the time E(A) square units of the region have been exhausted.

B = the effective basin size.

C(A) = the efficiency of exploration for deposits of size A.

The statistical procedures used to estimate the three parameters of this model—B, E(A), and C(A)—are outlined in Drew, Scheunemeyer, and Root (1978) and their derivations are presented by Root and Schuenemeyer (1978). The predictive power of this discovery process model has been tested by using the same set of historical data for the Denver Basin as was used to test the Arps and Roberts model. Using the 1949-1955 portion of the discovery time series, this model was found to produce an accurate forecast of the number of discoveries to be made in each deposit size class during the 1956-1974 portion of the discovery time series in the basin.

V. COMPUTATION OF INCREMENTAL COST FUNCTIONS FOR NEW DISCOVERIES AT THE REGIONAL LEVEL

Given that the discovery process models described above have been shown to produce accurate forecasts of future discovery events at the exploration play and regional levels, we can posit a rationale for producing a marginal cost curve for new discoveries. In economic theory the standard marginal cost curve expresses the cost of additional output per unit time. In contrast, the marginal costs described below represent the incremental costs per unit of cumulative output (reserves) and are therefore more properly described as incremental finding and production costs. By setting the analysis at the regional level, the physical features of the discovery and development process which are specific to each region can be isolated and analyzed.

If the discovery process model is used to predict a size distribution of deposits that are to be discovered with a given search effort, the marginal finding and production costs can be calculated separately for each deposit and then aggregated. Marginal finding costs can be calculated from the accumulated oil that is found and the average cost per exploratory well. Because the discovery process models of the type mentioned earlier are generally identified with a specific geologic play, costs of exploratory wells should be very similar. As the particular petroleum province becomes exhausted, that is, as the cumulative number of exploratory wells increases, a given increment in wildcat drilling will result in discovery of a smaller aggregate amount of oil as the frequency distribution of discoveries shifts toward smaller deposits. Therefore, the mechanical nature of the discovery process model allows one to calculate the expected marginal finding costs for any increment in exploratory wells.

The predicted size distribution of discoveries can be used for calculating field development and production costs for future discoveries. Because the productivity of development wells for primary recovery from large deposits is greater than that of smaller size deposits, field design specifications and costs calculated on the basis of physical characteristics of the deposit size classes will capture economies of scale that are present in the production of oil. The particular deposit size class is also important in determining the economic viability and unit costs of implementing a secondary or enhanced recovery program. In particular, for both the primary and secondary recovery unit cost calculations, which are made by assuming a set of physical characteristics that are typical of a deposit of that play and size class, the field development design is easily specified. Engineering costs (investment and operating) of producing the oil can then be calculated on the basis of that design. As physical exhaustion progresses, the size distribution of new discoveries predicted by the discovery process model will shift toward smaller deposits and calculated marginal costs of producing future deposits will increase. Consequently, the discovery process model, by predicting the size of forthcoming deposits, permits the costing procedure to capture the rising marginal production costs that result from physical exhaustion of the petroleum province.

VI. CONCLUSION

This discussion has pointed out the importance of including appropriate physical parameters in models designed to characterize the future supply of petroleum. To some extent these remarks can also be applied to mineral supply modeling because deposit size distributions (of contained metal) for other minerals are highly skewed and because there appears to be little physical evidence of a relation between the grade and tonnage of copper ore bodies (Singer, Cox, and Drew, 1975). As exhaustion of an area proceeds, the physical size distribution of remaining deposits declines systematically. If petroleum supply models are to be used for predicting future discoveries, ways must be found to capture analytically these systematic changes. Discovery process models such as those presented here appear to provide the means for characterizing such changes.

References

Arps, J. J., and Roberts, T. G., 1958, Economics of Drilling for Cretaceous Oil on East Flank of Denver-Julesburg Basin: American Association of Petroleum Geologists Bulletin, vol. 42, no. 11, p. 2549-2566.

Barouch, E., and Kaufman, G. M., 1977, Estimation of Undiscovered Oil and Gas in Mathematical Aspects of Production and Distribution of Energy, Proceedings of Symposia in Applied Mathematics, Vol. XXI, American Mathematical Society, p. 77-91.

Barouch, E., and Kaufman, G. M., 1978, The Interface Between Geostatistical Modelling of Oil and Gas Discovery and Economics, Journal of the International Association for Mathematical Geology, vol. 10, no. 415 (in press).

Drew, L. J., Root, D. H., and Bawiec, W. J., 1978, Forecasting the Rates and Sizes of Future Petroleum Deposits Discoveries in the Permian and Gulf Coast OCS Basins: U.S. Geological Survey Circular (in press).

Drew, L. J., Schuenemeyer, J. H., and Root, D. H., 1978, Resource Appraisal and Discovery Rate Forecasting in Partially Explored Regions, Part A - Application to the Denver Basin: U.S. Geological Survey Professional Paper (in press).

Erickson, E. W., and Spann, R. M., 1971, Supply Response in a Regulated Industry: The Case of Natural Gas: Bell Journal of Economics and Management Science, vol. 2, no. 1, p. 94-121.

Federal Energy Administration, 1974, Project Independence Blueprint - Final Task Force Report: Oil, Possible Levels of Future Production: Washington, D.C., U.S. Government Printing Office, 162 p.

Hubbert, M. K., 1967, Degree of Advancement of Petroleum Exploration in the United States: American Association of Petroleum Geologists Bulletin, vol. 51, no. 11, p. 2207-2227.

Kaufman, G. M., Balcer, Y., and Kruyt, D., 1975, A Probabilistic Model of Oil and Gas Discovery: in Haun, J. K. (ed), Methods of Estimating the Volume of Undiscovered Oil and Gas Resources, American Association of Petroleum Geologists, Studies in Geology, No. 1, p. 113-142.

Fisher, F. M., 1964, Supply and Costs in the United States Petroleum Industry: Baltimore, Johns Hopkins University Press, 177 p.

MacAvoy, P. W., and Pindyck, R. S., 1975, The Economics of the Natural Gas Shortage (1960-1980): Amsterdam, North Holland, 259 p.

National Petroleum Council, 1972, U.S. Energy Outlook, Washington, D.C., 200 p.

Pindyck, R. S., 1976, Higher Energy Prices and Supply of Natural Gas, unpublished manuscript, M.I.T., Cambridge, MA, 36 p.

Root, D. H., and Schuenemeyer, J. H., 1978, Resource Appraisal and Discovery Rate Forecasting in Partially Explored Regions, Part B - Mathematical Foundations: U.S. Geological Survey Professional Paper (in press).

er, D. A., Cox, D. P., and Drew, L. J., 1975, *Grade and Tonnage Relation-*
s Among Copper Deposits, U.S. Geological Survey Professional Paper 907-A,
.

ger, D. A., and Drew, L. J., 1976, The Area of Influence of an Exploratory
e: *Economic Geology*, vol. 71, no. 3, p. 642-647.

Reprinted from
14 January 1977, volume 195, pages 206-207

SCIENCE

SUBJ
ENER
OGG

Design Services
998 Church St., Apt 27
Ventura, CA 93001

The Civil Engineering Laboratory told me you might be interested in this reprint, and that you had inquired about Ref. (1). There have been two more recent technical papers on the OTGHPP -- a report and a fairly long paper delivered at a symposium on OTEC in New Orleans, March 1977.

Ocean Thermal Gradients—A Practical Source of Energy?

In "Ocean thermal gradient hydraulic power plant," Beck (*1*) describes a scheme for extracting power from the ocean thermal gradients, a very important subject. He suggests introducing warm surface water through a restriction in the lower end of a vertical pipe, which leads to a closed, direct-contact spray condenser, cooled by water from lower ocean depths. Cavitation would occur in the restriction and steam bubbles would be formed, which would then travel up the vertical pipe, carrying water with them (as in the well-known air-lift pump) to a height of hundreds of feet.

There are a number of fallacies in this concept. Ignoring the energy required to pump the low-temperature subsurface water up to the condenser, the inefficiencies of direct-contact spray condensers, the energy required to remove air from the condenser, and the energy required to move water through the restriction, it should be noted that any vapor bubbles formed in the restriction would collapse immediately after entering the high-pressure zone just above the restriction, near the bottom of the vertical pipe. Vapor bubbles are, therefore, simply not available to provide pumping action as in the air-lift pump. Vapor bubbles would be created by boiling near the top of the vertical pipe as the warm water enters the condenser. These vapor bubbles would be available to lift the water, but then only a few inches, assuming reasonable driving temperatures such as 80°F for surface water and 40°F for subsurface water. This few inches of water, rather than a few hundred feet, is the only head available to drive a turbine to extract the energy.

One might suggest that entrained or absorbed air would be separated from the warm surface water by the cavitating restriction, and that it would provide the bubbles needed for an air-lift pump. Ignoring the fact that not enough air could be provided by this means, it should be noted that any air entering the system must be pumped from the condenser to maintain its pressure near that corresponding to the condensing steam temperature. The energy required to remove this air from the condenser is more than the potential energy stored in the water raised by the air-lift pump. Therefore, we cannot get something for nothing, using the air-lift principle.

In the report "Foam solar sea power plant," Zener and Fetkovich (*2*) propose a direct-contact spray condenser in a containment shell, which creates a low pressure that draws the warm surface water about 30 feet above sea level. At the low pressure, the warm water is said to "foam." The low-density foam elevates water to great heights, where foam breakers remove and collect it, and it then flows through a turbine. The assumption that a foam would be created and sustained during its vertical travel is questioned. It appears that the vapor bubbles formed would grow and break as they reach the liquid surface. Adding foaming agents would be impractical and polluting. A second problem with the concept is that the warm surface water, raised 30 feet above sea level, would cool as it vaporizes and would therefore require a circulation system to maintain its warm condition and allow the foaming process to continue. However, if this were the only problem, it would not be insurmountable. The real question is, how do you get water to foam rather than bubble?

Unfortunately, extracting useful energy from ocean thermal gradients still presents a series of gigantic conceptual problems.

J. O. Henrie

24847 Jim Bridger Road,
Hidden Hills, California 91302

References

1. E. J. Beck, *Science* **189**, 293 (1975).
2. C. Zener and J. Fetkovich, *ibid.*, p. 295.

1 September 1976

I should like to thank J. O. Henrie for his comments on the ocean thermal gradient hydraulic power plant (OTGHPP) scheme (*1*, *2*), and particularly for his timing. A year ago many of his points would have been unanswerable.

Most of Henrie's predictions seem to be wrong according to my present understanding, some of which is incorporated into an unpublished report (*3*). Many of the engineering details are not reported in (*3*), having been developed later than the work reported, but I will attempt to provide some of that information here.

Considering Henrie's points, but not necessarily in his order, my present understanding is that the micronuclei inherent in dirty water would be activated by diffusion of dissolved air, in the first of two stages of bubble formation. Actual formation of steam bubbles occurs either very high in the cavitating venturi or, more probably, in the first part (in a fraction of an inch) of the pump tube proper through precipitous growth by evaporation. This is discussed in some detail in (*3*). While the notion that air in an air-lift pump or steam in a steam-lift pump carry water with them may be descriptive, it is more accurate to say that the water, containing most of the moving mass, is elevated to a useful height by buoyancy. While elevations of hundreds of feet are theoretically possible, a practical height of a floating system might be much less for stability reasons, as stated in (*1*). A height of perhaps 150 feet seems reasonable, but is undetermined at this time.

We cannot ignore the power required to bring the cooling water from ocean depths, but condensation should require an acceptable and fairly small portion of the power produced. The mass ratio of the water elevated in the steam-lift pump to the water used for condensing may be well over 200 to 1, because of the very large specific volume of the steam formed and so the relatively small amount of condensing water required to condense it. For effective operation of the OTGHPP, steam bubbles, wherever formed in the system, cannot be allowed to collapse, but the application of well-known design principles assures their nurture the full height of the steam-lift pump. Vapor bubbles must be available over the useful portion of the steam-lift pump tube to develop a low-density leg; vapor bubbles must be available for the system to work. But it *has* worked on a small scale, very convincingly (*3*). And the few inches of useful pumping head predicted by Henrie has been vastly exceeded, even in a small, high-friction system. The Civil Engineering Laboratory demonstration experiment (*3*) had a total height above water level of about 10 feet and a useful net working head of about 6 feet, boiling seawater from about 210°F.

Air leakage into the system is not seen as a problem in the large, simple system under consideration, which has few penetrations, no valves, and so on, in contrast with conventional vacuum systems in steam power plants. The few gasketed closures or sealed penetrations that will be used can all be protected with cold water seals. However, dissolved air is carried into the system by the water and at least partly released in the nucleation process. In fact, without dissolved air, the formation of steam bubbles is theoretically not feasible. This air would provide a trivial part of the buoyancy for lifting water, and a similar negative lift during its removal in a Taylor air compressor (*4*), where there would be a slight but finite reduction in the density of the water going to the hydraulic turbine.

I am not sure what Henrie means by "inefficiencies of direct-contact spray condensers," but available design information (*5*) predicts that with the crudest of approaches, effective condensing can be realized in simple equipment, and very close temperature approaches are possible if desired and economically justifiable. The friction in the nozzle-venturi-diffuser section is easily calculated and, in large diameters, is almost negligible. When compared with the uncertainties in the friction losses in the two-phase flow, it is trivial at this point in the refinement of the design equations.

In summary, the steam-lift pump, the completely new component in the OTGHPP (*2*), has been convincingly demonstrated on a small scale. Theoretical projections to the large sizes of potential interest in producing the large blocks of power needed are all optimistic. Nevertheless, we should not become overly euphoric until the scaled-up experiments have been done.

Earl J. Beck

Design Services,
998 Church Street, No. 27,
Ventura, California 93001

References

1. E. J. Beck, *Science* **189**, 293 (1975).
2. ______, U.S. Patent 3,967,449, 6 July 1976.
3. ______, "Nucleation of steam bubbles for the OTGHPP," unpublished report of the Civil Engineering Laboratory, Port Hueneme, California.
4. L. S. Marks, Ed., *Mechanical Engineers' Handbook* (McGraw-Hill, New York, ed. 4, 1941).
5. T. Baumeister, Ed., *Standard Handbook for Mechanical Engineers* (McGraw-Hill, New York, 1958, 1967).

9 November 1976

Henrie is correct in identifying the foaming of seawater as the crucial process in our scheme for extracting power from the ocean thermal differences. As has been demonstrated by Abe (*1*), both natural and artificial seawater are quite foamable, in contrast to the essentially zero foamability of tap water. Whether seawater foam is sufficiently stable to operate our proposed solar sea power plant must, of course, be demonstrated. If experiments designed to settle this question are successful, we believe no further conceptual problem will block the economic extraction of power from the ocean thermal gradients.

Clarence Zener

Carnegie-Mellon University,
Pittsburgh, Pennsylvania 15213

John Fetkovich

Department of Physics,
Carnegie-Mellon University

Reference

1. T. Abe, *Pap. Meteorol. Geophys.* **5**, 240 (1955).

26 October 1976