FIELD NOTES FROM THE ARIZONA BUREAU OF MINES

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ENERGY-CRISIS VS SHORTAGE

W.H. Dresher, Director

As most people are now aware, a short-term crisis exists in energy, and a long-term shortage promises to be with us unless we find additional sources of energy. Although gasoline lines are shortening – perhaps becoming non-existent in some parts of the country – a shortage still exists.

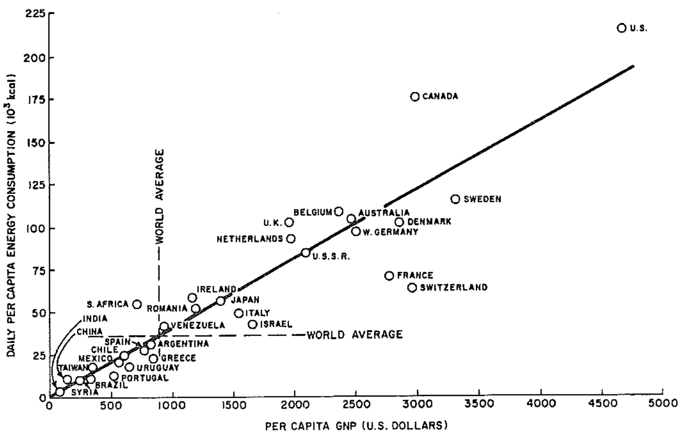

Figure 1. **RELATION OF ENERGY CONSUMPTION TO GNP FOR SELECTED COUNTRIES (1969).**

The Unites States uses approximately 30 percent of the energy of the world's total consumption, although it has only 7 percent of the world's population. We consume primarily petroleum and natural gas resources, of which we have only 2 and 4 percent of the World's energy supply in these forms, respectively. However, the U.S. does have 27 percent of the world's energy in the forms of coal and uranium. Fig. 1 shows the relationship on a per capita basis of energy consumption to gross national product for a number of countries. Though the availability of low cost energy has made our country what it is today, the question is, what is to happen when this low cost energy is no longer available?

Fig. 2 shows the progressive changes that have occurred in the pattern of use in the United States since 1850. We have had petroleum and natural gas at our disposal for a mere sixty or so years, but during this brief period our reliance upon them has been phenomenal, and we have made remarkable progress in our standard of living because of their availability. The reduction in the use of coal as an energy source was caused by the development of sources of cheaper and cleaner fuel – that is, petroleum and natural gas. Unfortunately, history does not always repeat itself as many of us are prone to believe. The reduction in our use of petroleum and natural gas as energy sources will be due to the diminishing availability of these commodities and this is happening when we do not have alternate sources of energy available. Thus, we are being forced to make decisions now that we would prefer not to make. Petroleum and natural gas have served us well, but as Figures 3 and 4 indicate, their end is in sight. While imports from foreign nations will be of assistance for some years, even these reserves are limited and becoming more precious to the countries from which they are obtained.

In regarding our predicament, it is important to separate the crisis aspect from the long term shortage aspect of the problem. The shortage aspect was both predictable and predicted by some; the crisis aspect was inevitable so long as we ignored the danger signs which have been evident for many years.

Much has been said about who is to blame for our predicament. To some extent we are all to blame – government, industry, populace – for not heeding the danger signals which have been evident since at least the early 1950's. The Paley Commission Report, "Resources for Freedom", June, 1952, forewarned the scenario we are witnessing and recommended appropriate measures to take.

The recent action by the Arab nations merely precipitated our crises. If any beginning is to be identified it probably started about twenty years ago when it was decided by a Supreme Court action to regulate the price of natural gas and to keep it at an artificially low level, thus encouraging wide-spread use of this scarce commodity. As part of the now famous Phillips Petroleum Company decision in 1954 by the Supreme Court, Justice William O. Douglas said,

"The fastening of rate regulation on this independent producer brings the production of natural gas under effective federal control, in spite of the fact that Congress has made that phase of the natural gas business exempt from regulation. The effect is certain to be profound."

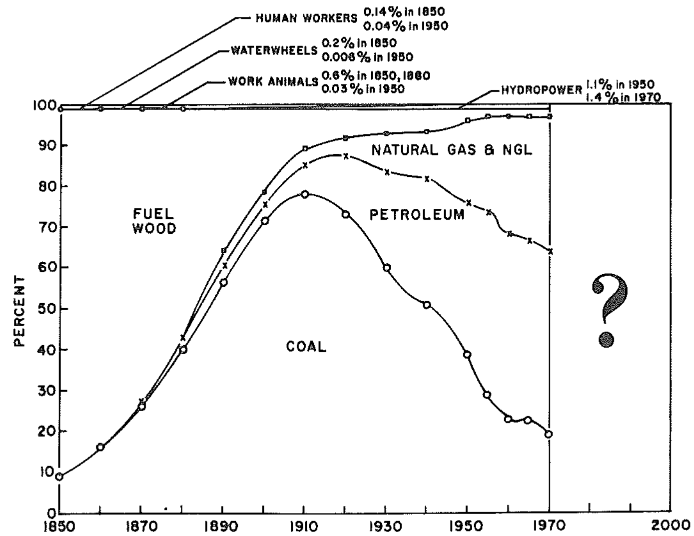

Figure 2. **ENERGY INPUT SHARES, U.S. ECONOMY, 1850-1970.**

In President Eisenhower's Budget Message to Congress on January 16, 1957, he said:

> **"Legislation freeing gas producers from public utility-type regulation is essential if the incentives to find and develop new supplies of gas are to be preserved and sales of gas to inter-state markets are not to be discouraged to the detriment of both consumers and producers, as well as the national interest."**

But regulating the production of natural gas was only one of a number of events and conditions which contributed to our dilemma – the availability of low-cost Canadian crude oil, increased cost of developing new oil wells in the U.S., the moratorium on drilling in the Gulf of Mexico and the 1960 price control on domestic crude oil, were other contributing causes. These let consulting geologist Michael T. Halbouty to say in 1960:

> **"I can safely predict that between now and 1975 we will have an energy crisis in this country. Then people will say, "The industry is to blame; why weren't we told?" Well, I'm telling them now."**

Since 1960 we have seen new refineries turned away from communities through fear of adverse environmental influence; larger and heavier automobiles have been produced which consume more gasoline than those of earlier decades and require more and more stringent anti-pollution devices. We have seen a moratorium on drilling off the Atlantic coast, a diminished drilling off the California coast, and a gross delay in the construction of the Alaskan pipeline – all because of our concern for the environment. The Tax Reform Act of 1969 which reduced the tax preference applicable to oil and gas production is credited with costing the industry $700 million dollars per year. This amount can be equated to the cost of 8000 average new wells – these were well which were never drilled because of the

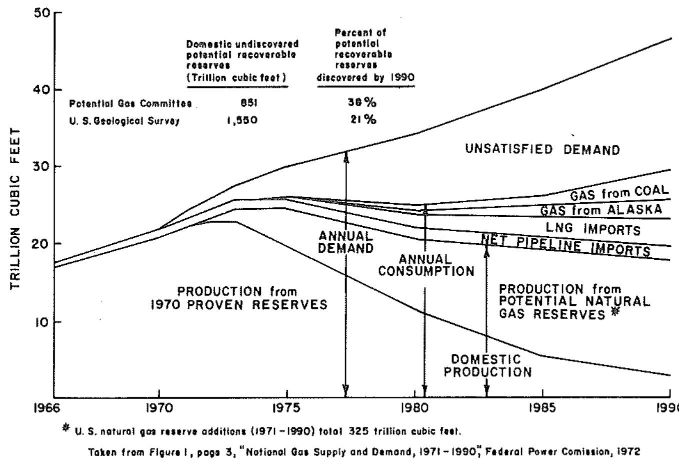

Figure 4. **UNITED STATES GAS SUPPLY — DEMAND BALANCE** (Contiguous 48 States).

increased tax burden to the petroleum industry.[1] Society of Exploration Geophysicists statistics show that over 100 petroleum exploration crews were removed from the field as a result of the Tax Reform Act of 1969. All of these events led Dr. Wilson M. Laird, Director of the Office of Oil and Gas of the Department of The Interior, to report in March, 1970:

> **"We are rapidly passing from a phase of energy abundance to one of energy scarcity. The gap between domestic supply and demand is widening so rapidly that not even the indicated production from the North Slope will be enough to restore to restore our position of self-sufficiency in petroleum energy."**

Even the Arab-Israeli situation's influence on the availability of petroleum to the United States was implied in an editorial in the June, 1969 issue of **Oil and Gas Journal**:

> **"It's been a year now since the Arab and Israeli armies fought their brief war. This anniversary offers a good chance to point out the lesson these experiences taught. The troubles proved again that heavy reliance on foreign oil is a most insecure base for this nation's energy needs."**

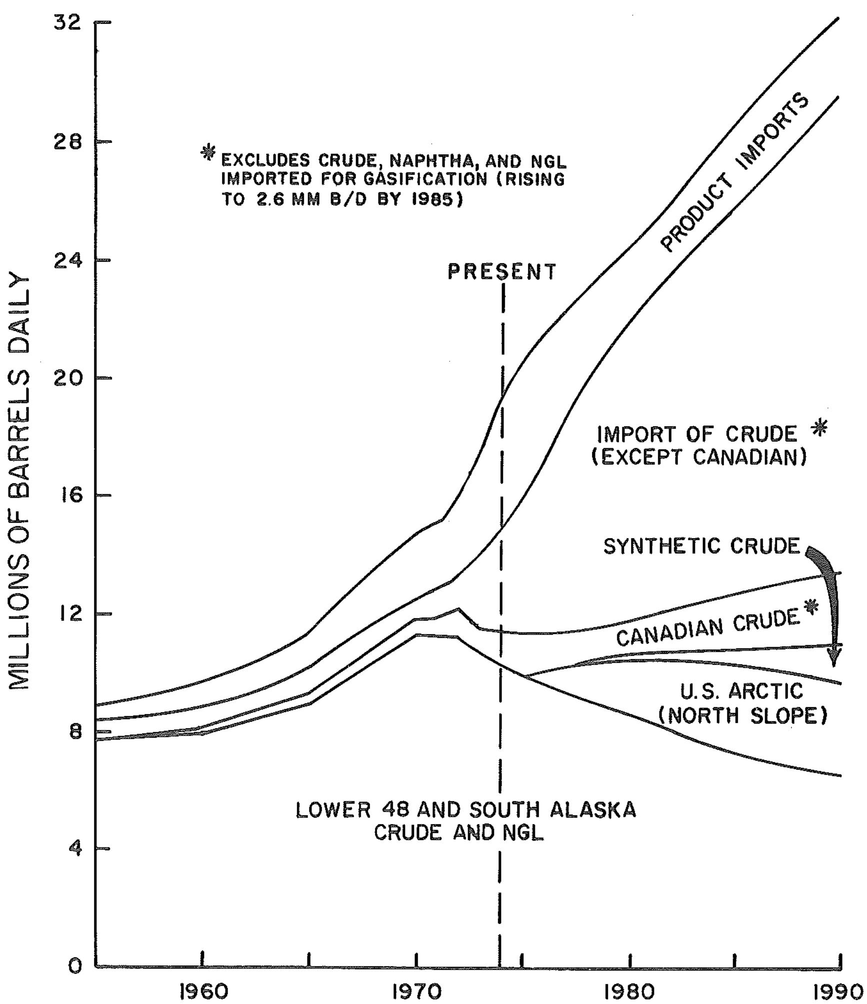

Figure 3. **U.S. PETROLEUM SUPPLY.** (taken from Chart 5 of "The National Energy Outlook," Shell Oil Companies, March 1973).

[1] **Wilson, James E., 1972, Statement made as President, American Association of Petroleum Geologists before the Committee on Interior and Insular Affairs, United States Senate, Pursuant to S.R. 45, 92nd Congress: a national fuels and energy study.**

Thus, with restrictions on the development of domestic industry, and low price levels which encourage ever-increasing usage of petroleum and natural gas, it's not surprising that we are now in the position of supplying 11 to 12 million barrels per day of our needs from U.S. refineries, the limit of our capability, and the remaining 5 to 6 million barrels per day from foreign refineries. Since we were importing only about 2.7 million barrels per day of oil from the Arab nations before the embargo, we have been able to meet our current needs by cutting out certain pleasure uses. The current shortage is roughly equal to that obtained from the Middle East. However, this deficit is destined to increase markedly in future years unless we can curb our consumption of energy and/or develop additional reserves in order to carry us until the time when our energy needs can be supplied from non-fossil fuel sources. The most immediate of these sources is nuclear power, but limitations as to its use and the long term availability of fissionable fuels are causing us to seek longer term solutions to a looming dilemma.

ARIZONA ENERGY RESOURCES

FOSSIL FUELS

Arizona has some of each of the basic fossil fuels – oil, natural gas, and coal – "fossil" because they owe their energy components to organisms, plant and animal, that occupied environments that existed many millions of years ago. Our oil and gas resources are a direct consequence of biospheric elements that thrived about 200 million years ago, whereas our coal resources, like those of many other western states, were derived from plant life that prospered about 100 million years ago. Obviously, these energy resources are more readily consumed than replenished. It is inevitable that questions will be asked and responses attempted about the reserves of energy material in Arizona and the probabilities of discovering new deposits.

According to one authority, the energy consumed in Arizona for the calendar year 1972 was equivalent to the energy contained in 21 million tons of coal, or 530 billion cubic feet of natural gas, or 94 million barrels of crude oil.[2] He further suggests that "this is about 5.5 times the energy dissipated by the water flowing over Niagara Falls in one year" and "about one four-thousandth (1/4000) of the solar energy falling on the land area contained within the state . . ." In describing the sources of energy during 1972, he allots 3% to hydropower, 21% to coal, 40% to natural gas, and 36% to petroleum. However, there was a marked shift from natural gas to petroleum products in fueling electrical generating plants in 1973. Already in 1974 several announcements of conversion to coal have been made in

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[2]Evans, D. L., 1974, Arizona's Energy – 1972: Report No. ERC-R-74001, Engineering Research Center, College of Engineering Science, Arizona State University, 6p.

NUCLEAR

STAFF, ARIZONA BUREAU OF MINES

Nuclear fuel differs from conventional fuels, such as coal, oil, and gas, in that the heat or energy produced is due to fission, the spontaneous or induced splitting, by particle collison, of a heavy nucleus or central mass of an atom rather than from combustion in the presence of oxygen. The radioactive elements uranium and thorium are the nucleus fuels being used or considered for use. Only a very small part of natural uranium will fission spontaneously but both uranium and thorium are fertile materials – that is, they can be irradiated to produce a fuel that will fission.

To date, Arizona's role in the nuclear energy field has been a relatively minor one, mainly as a source of limited tonnage of uranium ore. The Arizona Bureau of Mines has published reviews of the uranium and thorium resources of the State, and more detailed information on uranium resources of Arizona can be found in Atomic Energy Commission reports available to the public.[5, 6,]

In the future, Arizona, like most states, plans to utilize nuclear energy. One nuclear power plant being considered for Arizona would be located in the Palo summarized by the Arizona Bureau of

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[5]Butler, A. P., Jr., and Byers, V. P., 1969, Uranium in Mineral and Water Resources of Arizona: Arizona Bur. Mines Bull. 180, p. 282-292.

[6]Keith, S. B., 1970, Uranium in Coal, Oil, Natural Gas, Helium and Uranium: Arizona Bur. Mines Bull. 182, p. 103-146.

GEOTHERMAL

Interest in Arizona geothermal resources began during 1971 when State and Federal agencies, various utility companies, and private interests began geological and geophysical exploration for resources. An important review of the status of information on geothermal resources in Arizona was prepared by Dr. Jerome J. Wright of the University of Arizona in 1971 and it serves as a guide to those undertaking an evaluation of the geothermal possibilities of the State.[7] No direct evidence has been reported that confirms the existence of high temperature reservoirs in Arizona. Wright lists twelve selected areas of thermal

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[7]Wright, J. J., 1971, The Occurence of Thermal Groundwater in the Basin and Range Province of Arizona, *in* Hydrology and Water Resources in Arizona and the Southwest, Vol. 1, Proceedings of the 1971 meetings, Arizona Acad. of Sci., p. 269-290.

HYDROPOWER

Hydroelectric generators supplied about 14 percent of the total energy production in 1970 in Arizona. U.S. government-operated installations are Parker-Davis, the Colorado River Storage Project, Glenn Canyon and Hoover Dams. The remainder of the hydropower (energy from falling water) comes from the Arizona Power Company, from the Arizona Power Authority Salt River Projects dams, Coolidge Dam, and other small installations. Possibilities of additional hydroelectric generating capacity, although physically and economically, feasible, apparently are not being seriously considered for development at this time. Perhaps the Bridge Canyon Dam project could be another source of hydroelectric power for Arizona.

FOSSIL FUELS Continued

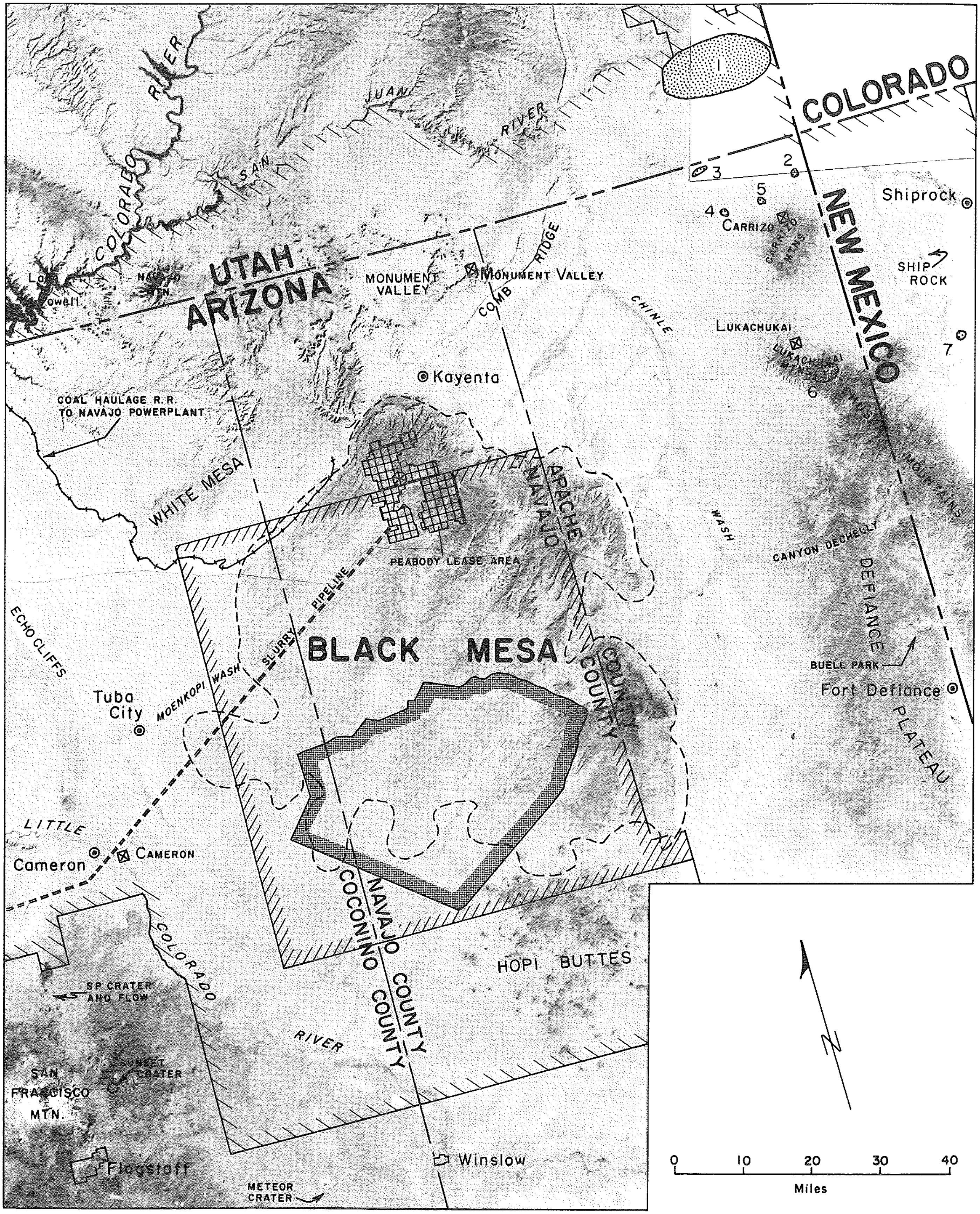

Figure 5. ERTS red band imagery (November 1972) covering 20,000 square miles of northeast Arizona and adjacent portions of Utah and New Mexico.

EXPLANATION

NAVAJO / HOPI
Joint – Use Area

HOPI Indian Reservation

NAVAJO Indian Reservation

Present location of coal stripping opperations.

Coal slurry pipeline

Major Arizona Uranium Mining districts (inactive).

Producing Oil fields.

1. Aneth
2. Teec – Nos – Pos
3. East Boundary Butte
4. North Toh Atin
5. Black Rock
6. Dineh – bi – Keyah
7. Tocito

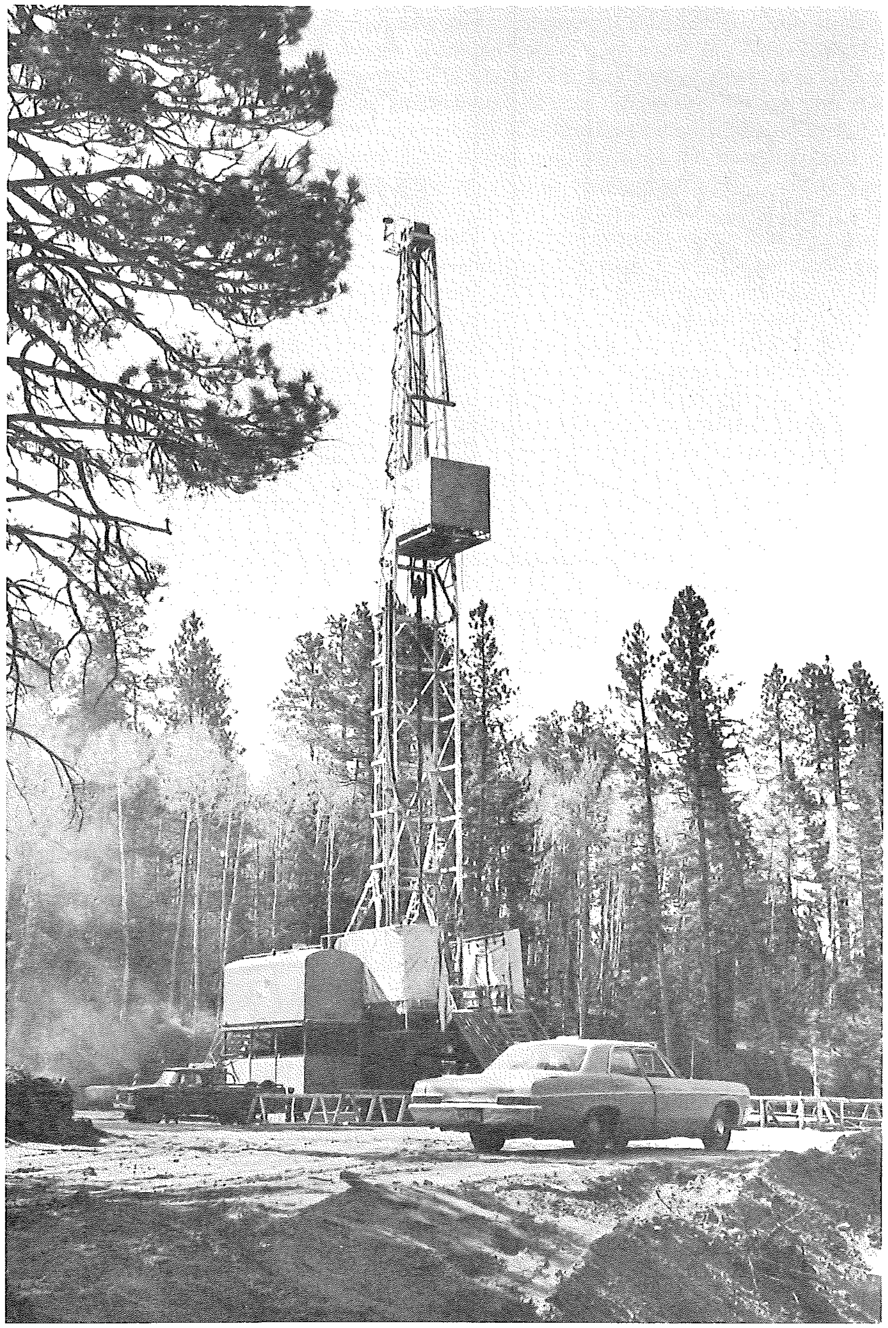

Figure 6. Oil well being drilled — Dineh-bi-Keyah oil field in 1967. Chuska Mountains, elevation above 8,000 feet.

view of natural gas and petroleum shortages.

In 1973, 29 Arizona oil wells yielded 0.8 million barrels of crude oil (2.4% of crude oil consumed in Arizona in 1972) and its only coal mine produced an estimated 4 million tons of coal which was exported to a power plant in Nevada. Commercial natural gas production was nil. Even if these indigenous resources had been used entirely in Arizona they would represent only about 20% of the energy consumed in the State in that year. From these data it is easy to see that Arizona has been importing most of its energy requirements.

All of the energy materials (oil, natural gas, coal, and uranium) currently being exploited in Arizona are in the northeastern part (Plateau Section) of the State. With the exception of the water resources of the Colorado River, all of these energy commodities fall within the jurisdiction of the Navajo Indian Tribe (some coal occurs on the Hopi Indian Reservation and also on "joint use" land that involves both the Hopis and the Navajos – See Fig. 5).

Between the first discovery in 1954 and the end of 1973, Arizona wells yielded about 14 million barrels of oil. All production is from Apache County and the largest share comes from the Dineh-bi-Keyah field (12.6 million barrels since 1967) (see Figs. 5 and 6.) Arizona's production goes to refineries in other states since Arizona has no refineries.

Known Arizona oil occurs within a small region at the extreme northeastern corner of the State (Fig. 5). This area flanks the more prodigious production of southeastern Utah. The reason for this localization of oil occurrence is logically explained once the geologic history is unravelled. The geologic history of Arizona, as presently conceived, suggests that there is no sound basis for expecting that *large* reserves of either oil or natural gas will be discovered elsewhere in Arizona. However, much remains to be learned and it is quite possible that persistent exploration (and the investment required) will lead to some addition to the State's reserves. Several general exploration possibilities have been

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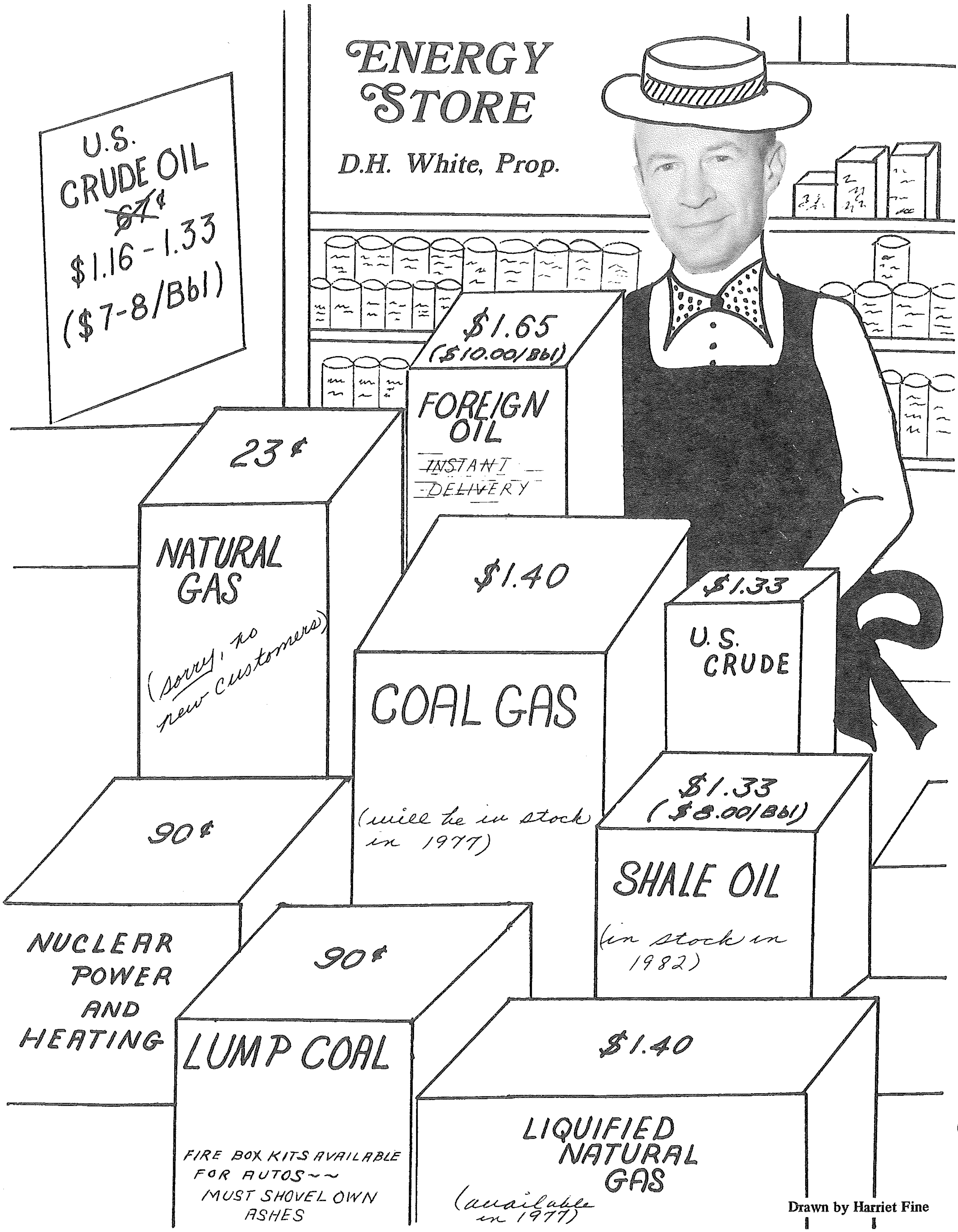

Drawn by Harriet Fine

YOUR ENERGY STOREKEEPER

One way of visualizing our current situation is for me to pretend to be your energy storekeeper. As your energy storekeeper, I have the same problems that your grocer, dress shop, auto dealer and other people might have. I must have a reliable product from a reliable source and I must be able to price my product in competition with my competitors. I have set up my energy store to provide your energy needs with boxes of energy, each of which contains a million BTU's. You may recall from your high school chemistry that a BTU is the British Thermal Unit, which means that it takes one BTU to heat one pound of water one degree farenheit. If you come into my store saying that you need ten boxes of energy each week, then I will show you my products and try to meet your needs. However, I am in short supply of some boxes of energy so you may have to take substitutes.

My most popular box of energy is NATURAL GAS which sells for $.23. However, this is in short supply and I cannot take on any new customers. The price is artificially low because the government regulates this price and Congress is reluctant to let the price seek its own supply and demand level. Next, you might be interested in my box of US CRUDE OIL (petroleum) which until recently I was able to sell to you for $.67. You will note that I have had to mark up the price to $1.16 – $1.33 because my suppliers have raised the price at their end. You may be interested in my box of LUMP COAL at $.90. If you want it for your automobile, I will also sell you at a fair price a fire box kit for conversion but you will have to shovel your own ashes from your car. Next, you might be interested in my box of NUCLEAR POWER at $.90. However, this will help you only if you live close to one of the few nuclear plants in the country. If you are desperate, I can sell you a box of FOREIGN OIL with instant delivery, but the price is $1.65.

I want you to be my permanent customer so I am trying to make my energy store as versatile as possible. Therefore, I am negotiating to add COAL GAS to my line of products. This will come from the gasification of coal. However, I warn you that I cannot sell this gas (which is equivalent to natural gas) at the old bargain price of $.23. I will have to have $1.40 a box and you can count on my having this in stock about 1977. Also, I plan to have LNG (liquified natural gas) in stock also for $1.40 a box by 1977. If you don't want to convert your auto to a coal burner, then just be patient, because I will have some good SHALE OIL in stock for $1.32 a box sometime in 1982.

I think you can see by now that I really want you as a customer, but my suppliers are not nearly as reliable today as they were just last year. I may be able to improve this situation by not being dependent on the Arab nations even for the small percentage which has brought this current situation to a head. I am also fighting hard to have my Congressmen stop regulating prices artificially so that we can get on with solving our energy problems. If you can convince me that you really need energy next week and that you will become a good customer, then I might consider letting you have one box of natural gas at $.23, three boxes of US crude oil at $1.30, and you will have to take six boxes of my foreign oil along with the other boxes at $1.65 each. Sorry, but that is just the way things are now.

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SOLAR ENERGY AS AN ENERGY OPTION FOR ARIZONA

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INTRODUCTION The sun is the most abundant energy resource available to man. The sun generates more energy in *one* second than man has used since the beginning, but most escapes unused into the depths of space. A fraction of the sunlight reaching the earth has produced the ancient coal beds and the more ancient oil and gas fields, and today produces our food and fibre crops. As we now approach the inevitable end of some of these inherited energy reserves we must learn to live on energy income.

Utilizing sunlight is not easy because of its diluteness as it arrives at the surface of the earth. The rapid approach of the long-heralded "energy crisis" makes it urgent that a new look be given to the utilization of solar energy. There are actually many ways solar energy can be used, from the growing of biological energy crops, including methane production, to technological conversion via "solar cells" or via conversion into heat. Technological conversion appears to have most promise for Arizona because of the abundance of sunshine. Arizona may therefore be the region to lead the way in the conversion of sunlight into heating, cooling, electrical power and hydrogen for the "hydrogen economy" of the future.

HISTORICAL Arizona has played a role in solar energy experiments as far back as the turn of the century. Solar-powered water pumps were located at the Tempe Crossing of the Salt River and on Dr. Chandler's farm in the 1904-6 period, only to be displaced by the more reliable "new" oil fueled pumps of the petrofuel age. The Tempe pump later did service on the McCall ranch near Wilcox.

Solar-heated and cooled houses appeared briefly on the scene in Phoenix and Tucson in the 1950's, but deficiencies in performance held back their development in view of the onset of widespread use of electrical refrigeration and natural gas heating. Renewed interest in domestic application of solar energy will now be built upon the experience of the 50's with the help of 20 years of additional technology.

APPLICATIONS Solar energy can basically be used via two avenues. The one most familiar to people is electricity from the "solar cell." It has been used for spacecraft power, but is prohibitively expensive for widespread domestic use. A major effort has been and is being made to reduce the cost of solar cells by the required factor of 100, but major technical difficulties remain to be solved. The second way is via heat, where heat would operate a steam turbine and produce electricity in the same way that present power plants operate. It also is costly because of the large collector "farms" needed, but cost reductions of only 4 or 5 are needed for it to become competitive with 1973 nuclear power.

There are less sophisticated uses of solar heat that may see early utilization. Thermal applications can be tied to certain levels of increasing technological difficulty, as follows:

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Drawn by Laurie Cook

FOSSIL FUELS *Continued*

Mines but at present remain to be evaluated more thoroughly.[3]

The State's significant coal reserves are all in the Black Mesa "basket." Black Mesa is a large physiographic feature in northeastern Arizona of about 3,200 sq. miles, approximately 3 per cent of the land area of the State but larger than the State of Delaware. Mainly in Navajo County, Black Mesa laps over into the adjacent counties of Apache and Coconino (Fig. 5.) It contains remnants of coal-bearing sedimentary rocks originally deposited in much of the Rocky Mountain region in Cretaceous time before the formation of the Rockies as we now know them. This is why the coal reserves of the Four Corners states are about the same age. Later, the Arizona portion was largely removed by erosion, Black Mesa being the remainder. Literally, billions of tons of coal have been washed to the sea via the Grand Canyon.

In 1970, Peabody Coal Company initiated mining operations near the north end of the Mesa. Pulverized coal slurry moves by pipeline 275 miles to the Mohave generating plant, just across the Colorado River in Nevada. Additional Black Mesa coal will soon move by conveyor belt and train to the Navajo power plant at Page, Arizona, near Glen Canyon Dam. Peabody Coal reserves occur within about 130 feet of the surface benath about 14,000 acres of leased ground (actually 0.7 per cent of Black Mesa's total area). Plans are to remove the coal from beneath 400 acres each year for 35 years in order to satisfy contracts with the two power plants. Peabody is recontouring and planting a variety of grasses immediately behind coal removal. (Fig. 7 & 8).

The Arizona Bureau of Mines has estimated that Black Mesa contains inferred coal reserves on the order of 20 billion tons within 1700 feet of the surface.[4] Conservatively, one ton of coal contains the gasoline equivalent of one barrel of crude oil, or one ton of oil shale. On this basis, it seems clear that, as it is for the Nation, coal is Arizona's principal known fossil fuel resource. With the exception of Peabody's limited efforts, the details of coal reserves of Black Mesa remain largely unknown.

[3]**Peirce, H.W., Keith, S. B., and Wilt, Jan C., 1970, Coal, Oil, Natural Gas, Helium and Uranium in Arizona: Arizona Bur. Mines Bull. 182.**

[4]*Ibid.*

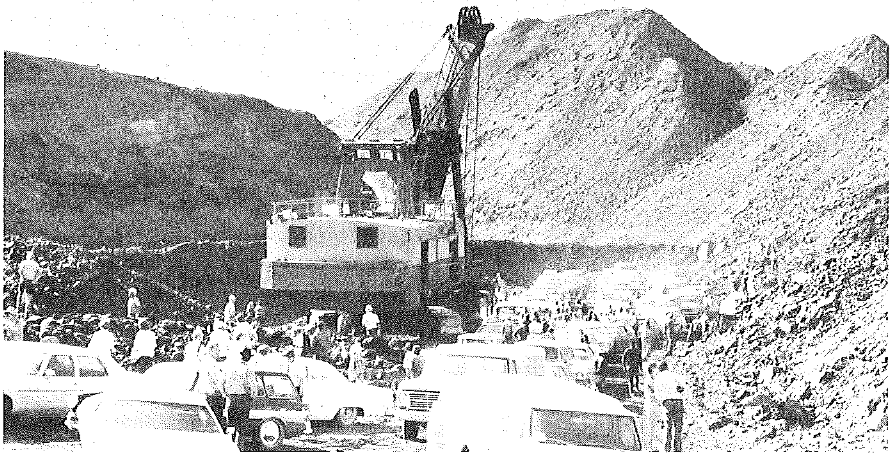

Figure 7. 1973 New Mexico Geological Society field trip to Peabody's coal mining operations on Black Mesa. Drag line uncovers coal and shovel removes it.

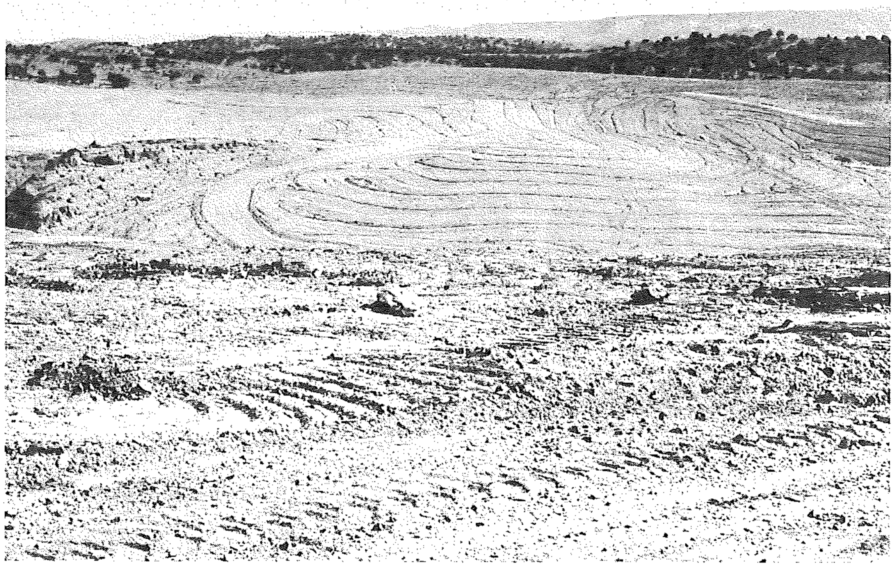

Figure 8. After coal removal, land is immediately recontoured to conform to the natural terrain and planted with many grass varieties. Looking west across part of Black Mesa. Elevation near 7,000 feet.

NUCLEAR Continued

Verde Hills about 50 miles west of Phoenix. It would have three reactors and a total generating capacity of 3.8 million kilowatts. However, it will not be operable before the 1980's.

The development of nuclear energy in the United States has centered almost exclusively on uranium as the nuclear fuel. Through 1969, the last year in which uranium ore was produced in Arizona, the cumulative output from the State amounted to slightly less than three million tons of ore containing about nine thousand tons of U_3O_8 (the usual form in which uranium content is reported). This amount was less than four percent of the total U.S. production. The reserves and potential resources of uranium in the State have not been made public in recent years. The Atomic Energy Commission includes Arizona figures with those of other states covering the Colorado Plateau or with other states having joint resources of less than four percent of the U.S. total. Our neighboring state of New Mexico, however, leads the nation with 48.96 percent of the presently commercial uranium reserves. The huge difference between the ore reserve capability of the two states can be attributed largely to the difference in geology of these two states. New Mexico has a larger percentage of host rocks which are amenable to uranium mineralization than does Arizona.

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NUCLEAR Continued

A rough estimate by the Arizona Bureau of Mines indicates that Arizona's potential reserves of uranium ore that might be produced at a reasonable price of $8 to $10 per pound of U_3O_8 would not exceed some 100,000 tons containing about 350 tones of U_3O_8. This tonnage can only be considered as *potential* at this time since there are no uranium processing mills within economic transportation distances and a large part of such reserves lies within the Navajo Indian Reservation, and thus requires the negotiations of economic viable leases before becoming available. The potential reserves of the State might double if (1) prices were to be increased; (2) lower grade material could be economically recovered, or (3) a metallurgical breakthrough permitted the recovery of the uranium from material presently difficult to process economically.

Over three-quarters of the U_3O_8 derived from Arizona ore has come from relatively small, scattered deposits in the Colorado Plateau region in the northeastern corner of the State, mainly from the Monument Valley, Lukachukai Mountains, Cameron, and Carrizo Mountains areas. The only other major producing deposit was the Orphan mine in the Grand Canyon. The deposits of the first group were in sedimentary beds, the Shinarump or Petrified Forest Members of the Chinle Formation of Upper Triassic age or the Salt Wash Member of the Morrison Formation of Upper Jurassic age. A large part of any remaining reserves and potential resources also would be in those areas but, based on past experience, the deposits also would be relatively small and scattered and any undiscovered deposits would more than likely be deeply buried and thus expensive to find and mine. The collapse-pipe deposit at the Orphan mine still has a reasonable potential but it and other possible uranium-bearing pipe deposits are not economically mineable without a nearby processing mill. Other small sedimentary deposits have been worked or found around Black Mesa and in a Tertiary basin in southwestern Yavapai County but they also are not presently economic to mine. Low grade uranium mineralization also occurs in Precambrian quartzite in the Sierra Ancha area north of Roosevelt Lake but has proven to be too expensive and metallurgically difficult to recover. No vein deposits of economically recoverable uranium have been found in Arizona. In summary, the known or potential uranium resources of Arizona appear to be relatively small and insignificant in comparison to the major uranium-producing areas in the United States.

The intense search for sources of uranium in the past thirty years increased dramatically the availability supply of domestic uranium. Producers have contracted to supply some 80,100 tons of uranium oxide (U_3O_8) for delivery through 1982 to U.S. utilities and reactor manufacturers. However, the forecast requirements for the same period are nearly *three times* that amount. Even with production from all domestic reserves and potential resources, at a reasonable price of about $8 per pound of U_3O_8, a serious deficit in domestic supplies would occur. To overcome this deficit, several possibilities can be considered. The import of foreign uranium for domestic use is not considered a likely possibility since the requirements for such fuel also are increasing world-wide. Increasing the price for U_3O_8 up to as much as $15 a pound might double the reserves and potential but still would not meet the projected requirements. The most hopeful solution would be the successful development of the fast breeder reactor by the 1980's.

The artificial production of fissionable material from fertile material is know as breeding, and when a reactor produces more fissionable material than it consumes it is called a breeder reactor. Major emphasis is now being placed on the successful development of breeder reactors. Not only will they assure a supply of nuclear fuel but also a reasonable price for such fuel. Breeder reactors could use uranium and thorium. The latter element is about three times as plentiful as uranium in the earth's crust and the reserves and potential resources of thorium in the United States that could be produced at reasonable prices appear to be much greater than those of uranium. Fissionable uranium would still be needed but the drain on uranium resources would be greatly lessened. Thorium as a source of nuclear fuel also appears to have some other distinct advantages in nuclear reactor use such as savings in fuel costs, lower operating costs, and superior safety characteristics.

Various occurrences of thorium have been noted in Arizona in pegmatites scattered across the southwestern half of the State, along fractures and dikes in intrusive rocks and Precambrian schist, and in detrital blacksand placer deposits. All these deposits are small and low grade. They would not be economic to work for thorium alone, and therefore cannot be considered as a source of energy at the present status of technology and price.

Although, like other regions, Arizona is counting on nuclear energy to *supplement* energy derived from fossile fuels, one must conclude that nuclear energy will not supply a *major* portion of Arizona's power, nor will Arizona be a *major* supplier of nuclear fuel in the near future.

GEOTHERMAL *Continued*

springs, the highest temperature recorded being 85°C with the majority being closer to 40°C. The first two holes drilled for geothermal exploration in Arizona recently reached depths near 9,000 feet in the Higley-Chandler area of Maricopa County. Information on these holes remains confidential.

Concerning the nature of Arizona thermal waters, Dr. Wright concludes that (1) their occurrence in the Basin and Range Province of Arizona is closely allied to structural elements, such as faults, and (2) in most areas it seems reasonable to expect that the waters represent the cycling of surface waters that have percolated downward. Dr. John Harshbarger, also of The University of Arizona, suggests that, although there are no known geothermal resource areas in Arizona (no surface indications of steam leakage, etc.), the occurrence of thermal waters in areas of relatively recent volcanism and faulting suggest a potential for the occurrence of geothermal energy. **8**

[8] **Harshbarger, J. W., 1972, Overview of Geothermal Resources Potential in Arizona, Arizona Bur. Mines, Fieldnotes, Vol. 2, No. 2, p. 9-12.**

SOLAR ENERGY *Continued*

Application	Thermal Need
1. Swimming pool heating	80-85°F
2. House & water heating	140-180°F
3. House refrigeration	230-280°F
4. Electrical power production	400-600°F
5. Chemical process heat	300-900°F

LIMITATIONS The regular use of solar energy faces a fundamental problem: energy must be stored for use at night and on cloudy days. Ways have been developed to store thermal energy to provide continuity, but it is expensive if many days of energy must be stored. The influence of cloudy weather has proven the major concern. Mirror and lens collectors are particularly sensitive to sky conditions as demonstrated by experiments at the University of Arizona. The development of the "planar" concept has provided a collector that works well, in theory, on most cloudy days in addition to clear days. Current experiments are being done to confirm engineering calculations on this concept. If they are successful then widespread solar energy applications will immediately become feasible since only modest amounts of energy need to be stored for night use.

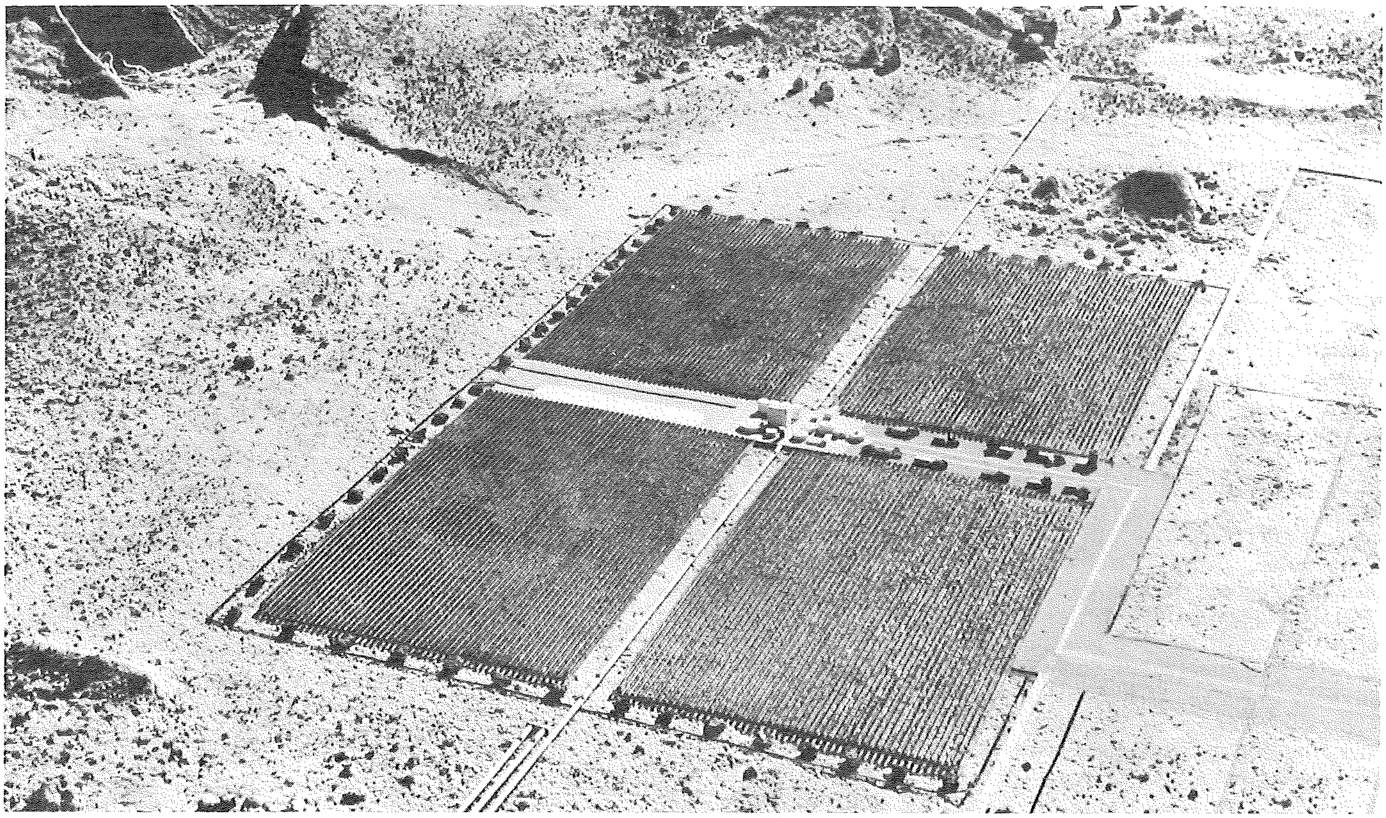

Figure 9. Model of a solar power farm.

SWIMMING POOL HEATING Swimming pool heating will be one of the first uses where fossil fuels will be denied and where widespread use of solar energy can occur. Swimming pools need large amounts of energy, more, usually, than for heating the home of the person having the of the person having the swimming pool; hence a large collector is needed. The area of the collector must be 3 to 4 times the surface area of the pool if heating to 75°F is desired in winter. Companies have marketed "small" solar heaters, but this is a deception that leads to a disappointed owner. Helio Associates of Tucson has an experimental pool installation nearing operation to establish engineering guidelines.

HOUSE HEATING House heating is another area where widespread solar energy use can occur. The collector needs to be 0.3 to 0.5 the area of the house, with a 1,000 gallon water storage tank to accumulate hot water for domestic uses also. Water is stored at 140-180°F for this application.

HOUSE COOLING House cooling has been tried by nighttime cooling of water by radiation to the sky. In Arizona it works reasonably well except in the summer monsoon season when the humidity rises. Since evaporative coolers work fine in the dry hot months radiative cooling is not really needed.

Refrigeration cycles needed to yield any-month comfort in Arizona need rather high temperatures for efficient operation. Gas absorption needs 230-280°F and this requires new solar collector technology. The selective absorber surfaces developed at the University of Arizona and Helio Associates appear to adequately handle this requirement, but a proof-of-concept installation is yet to be funded.

It it obvious that if an installation is made on a home for refrigeration that the same collector and heat storage tank can be used to provide hot water for heating the home in winter and for domestic hot water. During the change in seasons when neither heating nor cooling loads are high the excess heat energy can be used for swimming pool heating, thus using the same capital investment efficiently all year. A collector area for this type of integrated energy package is 0.5 to 0.8 the area of the home to be served.

ELECTRICAL POWER Production of electrical power requires higher temperatures,400-600°F. Attainment of these temperatures depends on more sophisticated technology than the domestic applications, but research has been completed that has established scientific feasibility of obtaining these temperatures via simple collectors with new selective absorbing coatings.

We do not feel that home generation of electric power via thermal means will be practical. Utility utilization of solar energy for power will entail rather sizeable "solar power farms" to gather the energy, and relatively standard steam power turbines to convert the heat to electricity. (Fig. 9) Partial support of this area has been received from Tucson Gas & Electric, Arizona Public Service, Salt River Project and Southern California Edison, with the balance from the National Science Foundation. Federal support for a proof-of-concept test bed has been slow in developing. We would prefer that utility and state support be combined for an early test bed to evaluate feasibility of generating electrical power from solar energy. Two types of test beds may be appropriate: 1) a thermal unit by the University of Arizona and Helio Associates, and 2) a "solar cell" test bed by Arizona State University, using their experience in this area, with an associate contractor.

DESALINATION Desalination of brackish water is a potential application of particular importance to Arizona. The technology of multiple-effect distillation using heat as a source of energy has been extensively developed under OSW programs. Solar heat could be used, but the resulting water product would be too expensive for agricultural uses in the first ten years of such a program. Dilution of Colorado River water with the pure distillate might get close to the cost objectives, and be reasonably competitive with a nuclear desalting plant. More study needs to be given to this question in the light of developing solar technology.

Other applications of solar heat for chemical processing can be envisaged, but little study has been given to this broad range of topics to the present time.

TIME TABLE Solar energy is not "instant" solution to Arizona's energy problems, but it is not as far away as some may believe. Demonstration of proof-of-concept in each case can be done within 2-5 years, but large-scale utilization depends on the complex market interplay between low volume/high unit cost and high volume/low unit cost.

Application	Time Table
1. Swimming pool heating	1 yr
2. House & water heating	2 yr
3. House refrigeration	3 yr
4. Electric power test bed	4 yr
5. Demonstration "solar power farm"	5-9 yr
6. Chemical process utilization	5-9 yr

ECONOMICS Solar energy applications have the advantage that no fuel is consumed and annual operating expenses will be low. The disadvantage is that they are all "capital intensive" since the full system cost is required on the day the system is first turned on; thus in lieu of fuel costs one faces money costs. All studies now indicate that solar energy costs will be in the range of 3 to 5 dollars per million Btu, more expensive than present fuels at 1973 prices, due largely to interest expense on the capital investments involved.

The cost barrier will inhibit early wide-spread use of solar energy appliances unless some way is found to encourage this type of investment. The encouragement could be via accelerated depreciation allowances or by direct subsidy to manufacturers to produce inexpensive units paid by a tax on the use of scarce energy fuels. One can wait for the federal government to take action in these areas, but some steps by the State of Arizona in this direction can do much to put Arizona formost in the early utilization of solar energy as a partial answer to the pending energy crisis.

In looking at a number of homes in Arizona where the owner was interested in solar energy we were surprised to see how few existing homes meet the requirements for a successful solar installation. Problems include: too many trees, the wrong orientation of the house, poor roof shapes, etc. We suspect that these factors will apply even more extensively in other parts of the country. New homes and new subdivisions offer better chances for successful solar installations.

It is our opinion that solar heating and cooling for individual homes is not going to be widely successful. People who like gadgets may find them interesting and satisfactory. Most people will not want to be bothered with them. Some who get them may be distinctly unhappy, feeling that they were the victims of oversell.

We think that solar installations will be far more successful for apartments, condominiums and commercial businesses. The larger units required will be supported by more sophisticated money management by the owner and by better maintenance. The units might be large enough to encourage operation by a utility.

In resume, the place where solar energy may ultimately have its greatest impact and benefit for this country is in electrical power production. People already use electrical energy for a vast array of needs and luxuries. If costs can be reduced for solar power it will be the ultimate answer of how to use solar energy. Solar power farms in regions away from the load centers will deliver clean energy into the electrical power grid, delivering energy with almost no perturbation of the way people live and think. A model of a solar power farm is shown in Fig. 9. The necessary technology is at hand but untested. The first demonstration units could be built with 2 or 3 years and a diligent effort would see the first commercial solar power farm in operation within a decade.

Defining Terms

What are we talking about when we say, "energy crisis", or "energy shortage"? Let's consider the perhaps obvious – but fundamental – terms involved.

ENERGY is the capacity to produce motion, or the ability to do work. It is stored in fossil fuels and uranium. And every form of matter possesses some motion, whether in a form we can see, such as a car speeding down a hill, or in a form we cannot see, such as atoms and parts of atoms. Since all matter is composed of atoms, and atoms possess motion (the ability to do work), then all matter must possess energy, or the ability to do work.

Energy manifests itself in different forms – heat, chemical, electrical or atomic. And, fortunately, energy can be changed from one form to another. But whatever form it takes, all energy is either potential or kinetic.

POTENTIAL ENERGY is stored energy that is waiting to be used. It has only the ability to do work. It is energy that we cannot see. Uranium, petroleum, coal, and natural gas are eagerly sought after because of the potential energy they contain – energy that can be released and put to use.

KINETIC ENERGY is energy that has been released and put to work. This is the form of energy we talk about most often. It is the energy of visible movement, of mechanical work. The heat which drives a piston in our cars, the steam which is formed to drive a turbine to generate electricity, or the direct combustion in a jet to propel an airplane are all examples of kinetic energy – of mechanical work.

However, we cannot change potential energy to kinetic energy if we lack the potential energy – coal, petroleum, uranium, or natural gas. Thus, we have an *energy shortage* – a shortage of potential, and therefore kinetic, energy.

PUTTING IT IN PERSPECTIVE

Conventional energy resources are based in substances that are a part of the earth. They are products of earth history and are unequally distributed in time and space. With the exception of natural surface waters, these conventional resources are not being renewed as fast as they are being depleted. Qualitatively, it can be said that the end of this road is disaster. Whether this is really a practical fact or not depends upon the answer to a "simple" problem in arithmetic, a problem in quantities, and rates. Everything else remaining equal (current economics, etc.) how long will earth energy material supplies last at the present rate of production? Production rates are matters of fact whereas supply (reserve) is a matter of cumulative judgment based upon a mixture of facts and best guesses (whose guess is best?) Sometimes we carelessly correlate the supply question with the "bottom of the barrel" concept. This is very misleading because as long as we must contend with economic factors the answer to the supply question has many answers because economic feasibility, however judged, always limits supply short of the ultimate quantities in the earth. A coal seam thirty feet thick is likely to be included in reserve calculations if it is known to exist but there are undoubtedly many tons of coal in beds two feet thick or less that are not figured in reserves. Under any given set of circumstances there is always an economic cutoff, except where desperation is a factor (Germany making gasoline from coal during World War II).

Elsewhere in this issue reference is made to a relationship between pricing policies and available supplies. Although much is said about "profits" we should realize that they accrue only after costs are met. If it costs more to produce, prices tend to go up. The reverse is that a rise in price enables one to assume additional costs, to produce that which was marginal at the previous price. Of course, evolving technology and techniques also work toward keeping moving and processing costs down. It is difficult for us to know and understand the facts about ultimate energy resource reserves, economic reserves, costs, prices and profits. It seems elementary, however, that higher prices will support production previously nonexistent as long as there is no competitive cheaper alternative. It remains to be seen what sacrifices the public will make to environmental values.

ARIZONA

What is Arizona's actual and potential energy position? Arizona is (1) a source of raw – some exported – energy materials; (2) a consumer of energy, and (3) an importer of electricity, basic fuels (coal, oil, natural gas), and refined fuels (gasoline, propane, etc.) Its imports far outweigh its exports – it is, at present, a dependent state.

The largest known potential for new supplies of indigenous conventional energy resources is coal in Black Mesa. The coal resources in Black Mesa, although potentially large, have not been assessed by normal exploration techniques. These coal resources belong to the Hopi and Navajo Indian Tribes and it is within their jurisdictions to determine whether these resources will be studied in more detail and allowed to become an eventual factor in supplying a basic raw material resource to a growing western United States. Strip mining is an environmental factor but much of the deeper Black Mesa coal likely will become available only by utilizing underground techniques.

Arizona's oil and natural gas production remains minimal and the geologic potential for the development of large supplies of these resources is not encouraging. Although the known native supplies of the ores of the radioactive elements uranium and thorium are not large, there exists a potential that will be assessed when the pricing structure proves supportive of more costly exploration efforts. The outlook for geothermal energy is not now encouraging but this resource has just begun to attract attention. Because of this, there is some potential in the unknown. Hydropower, although physically and economically feasible, apparently is not presently being seriously considered for additional development.

Less conventional methods include solar energy, which is much talked about and seems to offer a large potential in Arizona, especially in the production of electrical energy. The basic missing ingredient is funding for the research required to provide the answers essential to further evaluation of feasibility.

On the national scene, Arizona will undoubtedly benefit eventually from nuclear fusion, which is still very much in the experimental stage in the Sherwood Program at the University of California's Lawrence Livermore Laboratory. The process, which uses deuterium (a part of ordinary water) as fuel to generate electricity may be a source of unlimited energy in a few decades. Fusion requires no fossil fuel, produces no undesirable combustion products and yields very little radioactive waste. It has no weapons value, there can be no explosion, and with direct conversion to electricity, greatly increased operating efficiencies can be realized. However, there are still formidable obstacles to overcome, so this must be considered a very unconventional and very long range project at present.

FIELD NOTES
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