TECHNOLOGICAL FEASIBILITY OF ALTERNATIVE ENERGY SOURCES

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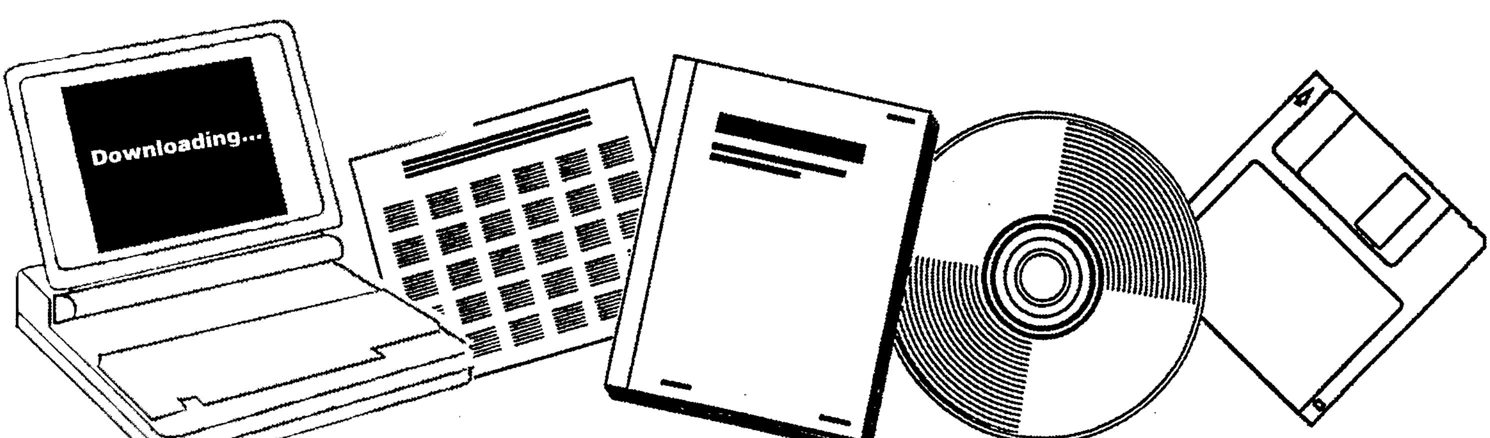

USAWC RESEARCH ELEMENT

TECHNOLOGICAL FEASIBILITY OF ALTERNATIVE ENERGY SOURCES

By

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The US energy shortage is discussed. The technology of coal gasification or liquefication, shale oil from oil shale, and geothermal energy recovery is presented in sufficient detail to show feasibility of these as energy source alternatives to petroleum crude.

Technical trade publications data show that essentially all necessary process technology is known, although important improvements are possible, and have been proved at pilot plant scale. Conversion of coal to energy offers the best opportunity for rapid development as a broad, in-house US energy source. The

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Introduction

Many points of view have been belabored in public detail as to the "hows" and "whys" of the current energy posture of the United States. While these factors may be subjects for debate, the "what" is crystal clear. United States public and private demand for all forms of energy has grown beyond the capability of supply. Over-demand had been creeping up on us for a long time.[1,2] The last week in November, 1973, it was at once made painfully obvious when Middle East crude oil shipments to the Free World were halted.

The real problem seems to be that no significant segment of U. S. activity appears voluntarily willing to reduce consumption enough to pull energy demand back into line with supply. American tradition and the U. S. economy has, deeply woven into its fabric, the idea that human activity of any kind (standard of living, business activity, even leisure-time preoccupation) is on the "right" track only when it is growing in size and/or quantity and at an ever increasing rate even at the expense of efficiency. Thus, one can predict a near certain increase in demand for energy in a variety of forms.

Under these conditions, energy shortfall was predictable (to what now is evident as good accuracy) from simple arithmetic projections a considerable time ago. Coupled with scientific curiosity, the need prospects led to numerous but scope limited research efforts. These produced the crude outlines of possible technology to such alternative energy sources as solar radiation, wind, hydromagneto plants, tidal movements, coal or near coal, nuclear fission or fusion, hydrocarbon bearing shale, and faster more efficient recovery of known petroleum crude deposits. In each case, exploratory research defined the concept to the extent that the individual and specific problems became evident.[3] For example - - plants for conversion of coal to fuel gas and/or other hydrocarbons has been operating for decades, particularly in Europe. Until the recent crude oil crisis, these alternatives had the common problem of high relative cost per energy unit. The Arab crude oil embargo and the consequent crude oil price increase can be characterized as the catalyst to the development in detail and broad field implementation of those alternative energy sources which are now becoming realistically competitive to petroleum crude on the basis of cost per unit of energy.

This paper arbitrarily limits itself in scope. Nuclear fission is not considered for discussion because of the state of the art. While fission technology is still to some degree in a state of development, extensive field application has already clearly shown this alternative to be a significant, viable, and cost competitive energy source. Nuclear fission as an energy source is already in being and, therefore, not considered as a new alternative. This paper further limits itself to only those alternatives for which the technology is essentially all known and has been proved at least through pilot plant stage. There is room for some difference of judgement as to what constitutes successful pilot planting stage development. The pilot plant data must have been judged to be adequate and sound enough to make scale up to large, field production plants imminently possible. Raw material availability must be such as to permit practice of the technology for a period in excess of a hundred years. This paper will discuss coal, shale, and geothermal sources as the long range alternatives for energy.

Resources

To understand the problems of U. S. energy supply, one needs to consider the nearly incomprehendable magnitude of quantity of energy used. The combined consumption of energy as fuel and feed-stocks in the U. S. during 1973 was some 8.6×10^{16} British Thermal Units (BTU).[4] The total world energy use rate is about three times the U. S. rate.[5] About seventy five percent of U. S. energy is produced from natural gas and petroleum crude, about twenty percent from coal, about four percent from hydropower, and all the other sources (including nuclear sources) produce about one percent. At the present use rate, oil, gas, and tar sources have an estimated use lifetime of about 64 years.[6] Coal has a similar lifetime of 300 years. Some fifty percent of the world's coal is located in the U. S. Shale is estimated to have a conservative yield somewhat greater than the world's entire known crude oil reserves. Geothermal sources are variously estimated at a 50 year to unlimited (renewable) similar lifetime. Incidentally, solar and nuclear fusion (not technically feasible as energy sources at present) have excellent potential because of their unlimited lifetime as a resource. The major role of coal as energy source is that of raw material to produce liquid and gaseous streams for feedstocks and/or secondary conversion to heat. Perhaps the most significant consideration of energy resources, aside from the questions relating to magnitude and location of source deposits, is that of energy conservation. It has been estimated that diligent application of known conservation techniques could reduce the growth rate for energy demand enough to defer until about the year 2000 the energy consumption rate currently predicted for 1985.

Coal Gasification and Liquefaction

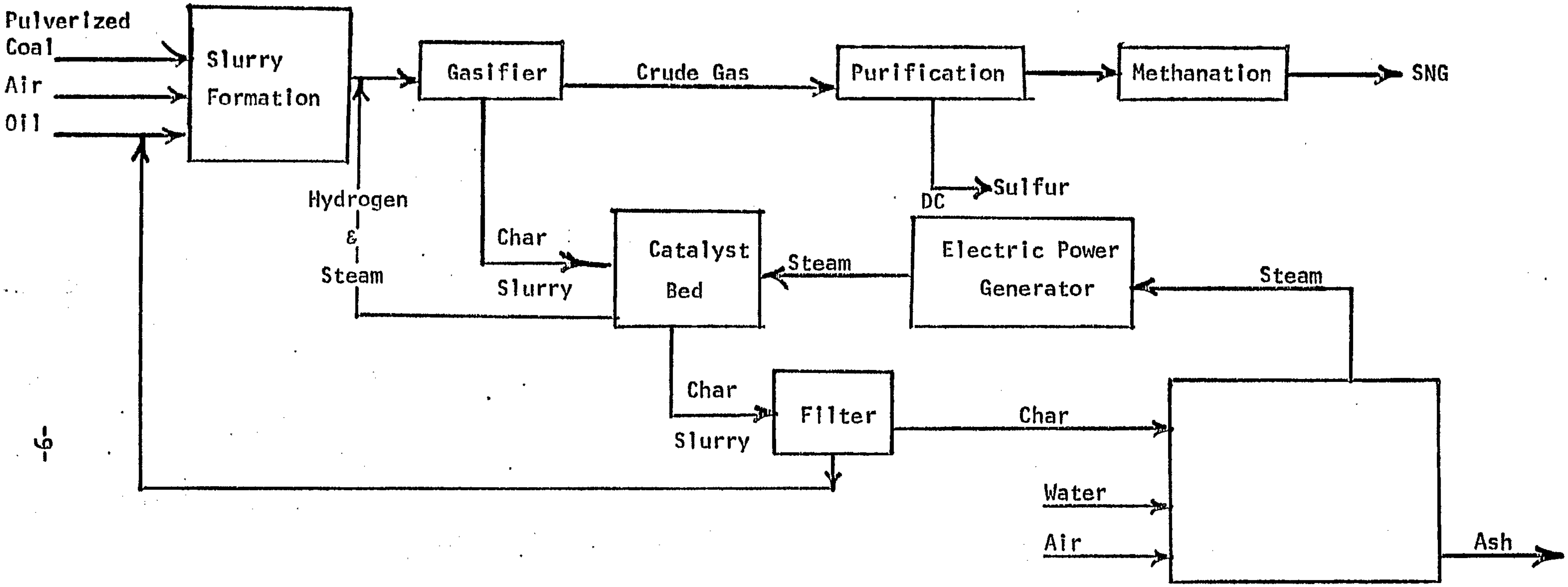
Of the many process variations for coal gasification, the older, established processes - Lurgi, Koppers-Totzek and Winkler - involve partial oxidation. Coal, super heated steam, and oxygen are mixed in a gasifier to produce a mixture, containing carbon monoxide and hydrogen, called synthesis gas. This gas can be used as fuel (560 BTU/ft^3) or as feedstock to make methanol and ammonia. These are the so-called first generation processes.[7] They have been developed, proved, and used to varying degrees of utility for some thirty years.

More recent modifications are designed to increase the heat content of the gas and produce liquid hydrocarbons in addition to the gas. The approach involves, in general, hydrogenation of the fuel gas produced from the older processes to produce methane which is blended with synthesis gas to raise its BTU value to 900-1000. In Figure 1, pulverized coal is slurried in a light oil and fed into a gasifier. Hydrogen and steam are added and the mixture heated to 700-815^{o}C at 1000-1500 psig. pressure. The hydrogen, produced on the site from char, reacts with coal products to produce methane. The process of Figure 2 differs in that liquid byproducts are obtained. Useful finished products such as benzene, toluene, and xylenes can be recovered by fractional distillation.

Use of high temperature, gas-cooled nuclear reactors as the heat source has been proposed. Gas and liquid product yield improvements up to 30% over those currently being obtained in pilot plants are projected.

A key feature of the gasification approach to using coal as a general energy source centers around BTU content versus utility. Synthesis gas (500-600 BTU per cubic foot) can readily be used as general process fuel or to generate electric power.[9] However, home heating plants require 900-1000 BTU/ft^3 gas. Conversion of the burner units to accommodate the gas with lower heat content would be a major expense for homeowners. Methanation of the syn-

FIGURE 1



SLURRY CRACKING
(HYGAS)[8]
ARROW DIAGRAM
(BLOCK FLOW DIAGRAM)

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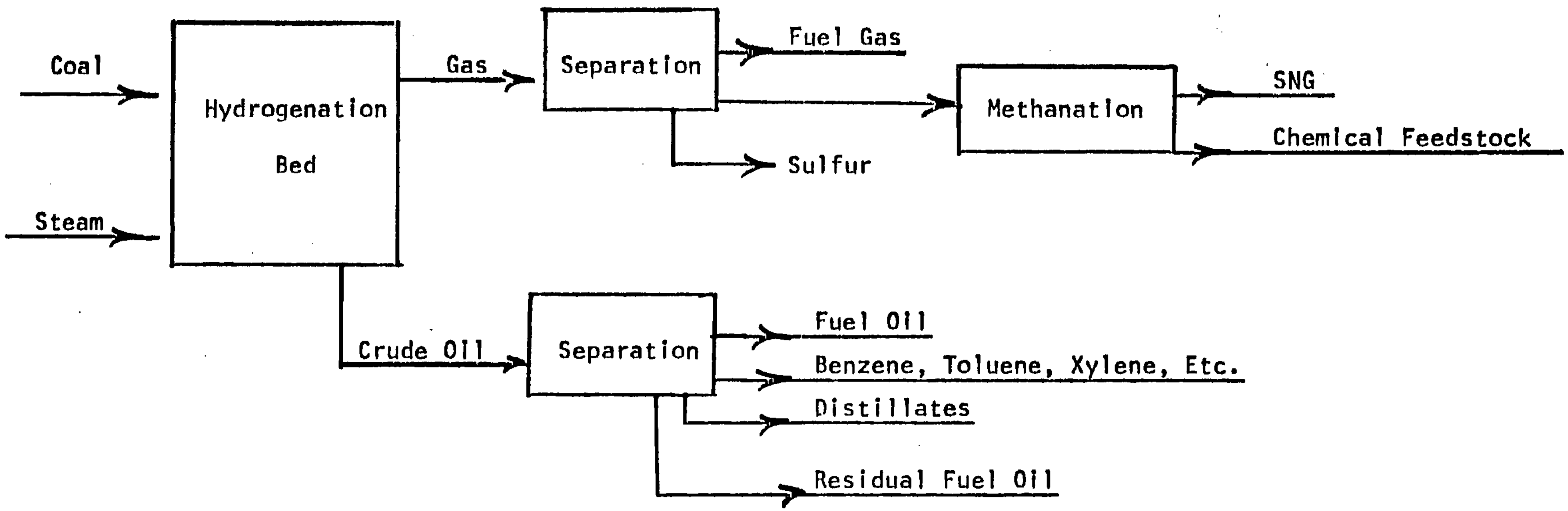
FIGURE 2



ARROW DIAGRAM

FLUID BED CRACKING

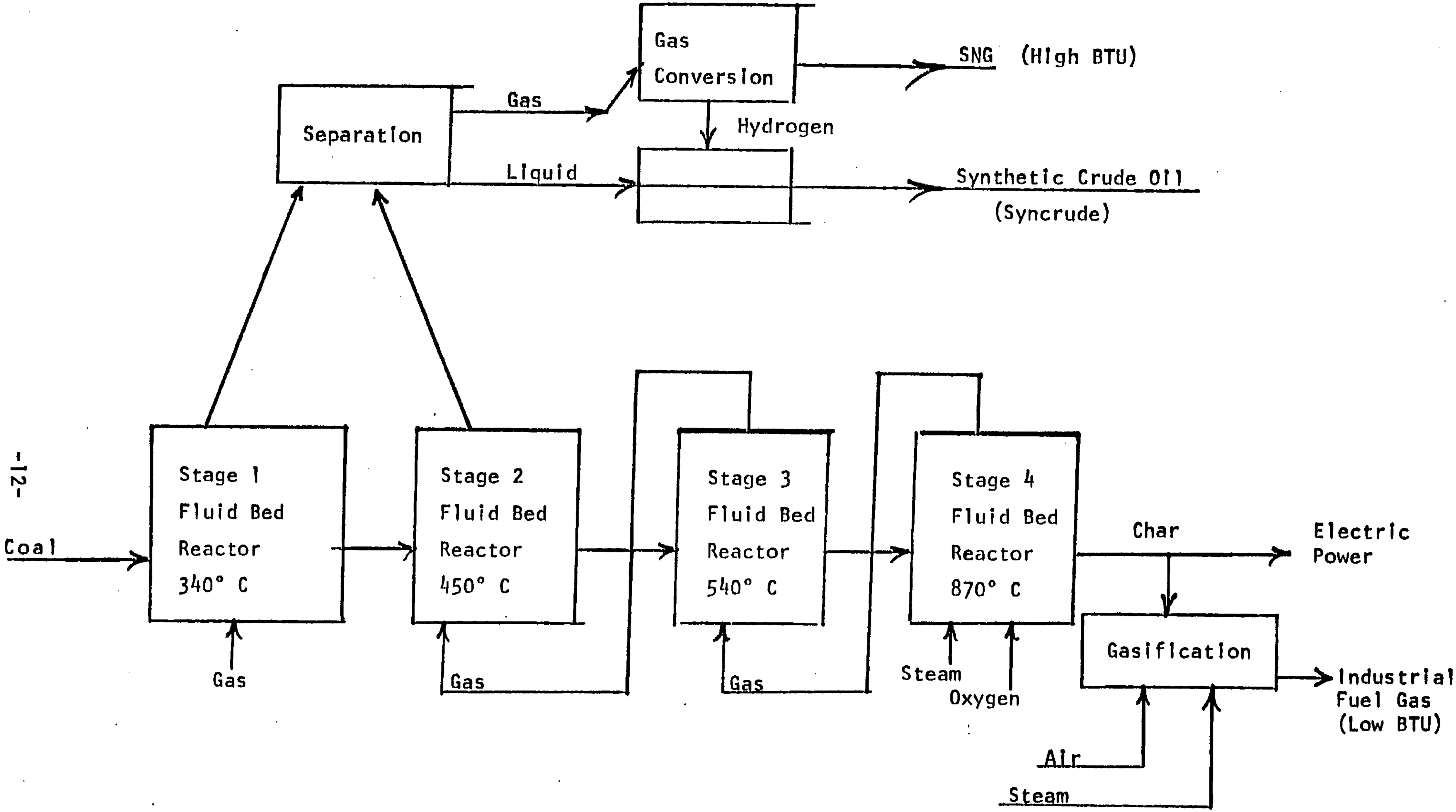
(COALCON CO.)

thesis gas is needed to raise its heat content to the higher level of natural gas now in use. A major problem in the gasification of coal is that 14.4 million gallons per day of water are needed for a 250 million cu. ft. per day production plant. Major coal deposits which would logically be used in these plants are located in areas (North Dakota, for example) where water is in relatively short supply. Process improvements are needed to accommodate this situation.

Liquefaction of coal differs from gasification only in that the process conditions are chosen so as to maximize the yield of liquid products. Fairly significant yields of gaseous byproducts are also obtained. Pilot plant proved processes for liquefaction include: FMC's Char Oil Energy Development (COED) process shown in Figure 3, Hydrocarbon Research's H-Coal process shown in Figure 4, and Pitsbury and Midway's Solvent Coal Refining (SCR) process shown in Figure 5. Liquefaction has several advantages over gasification: (1) Energy conversion efficiency is higher - about 78% versus about 60% for gasification; (2) Liquids are more easily stored for later use, thus production scheduling is not necessarily regimented by instantaneous use demands; (3) Liquids are more economically transported to a use site; (4) Liquefaction has a lower water demand; and (5) Liquids are cheaper to use as industrial turbine fuel.

Liquefaction processes, as shown by Figures 3 to 5, are essential pyrolysis of pulverized coal in a series of fluidized beds in

FIGURE 3



COED PROCESS [10]

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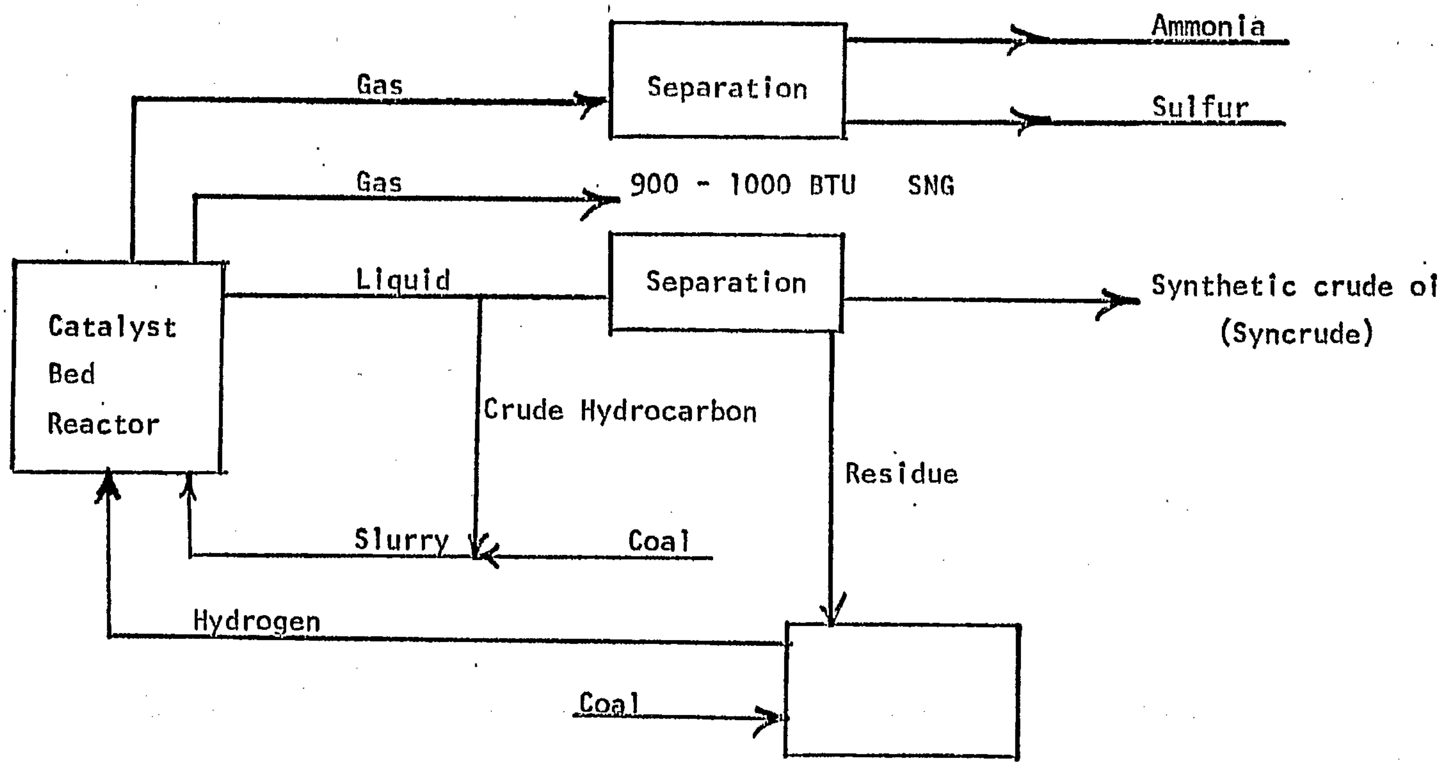
FIGURE 4



H-COAL PROCESS [10]

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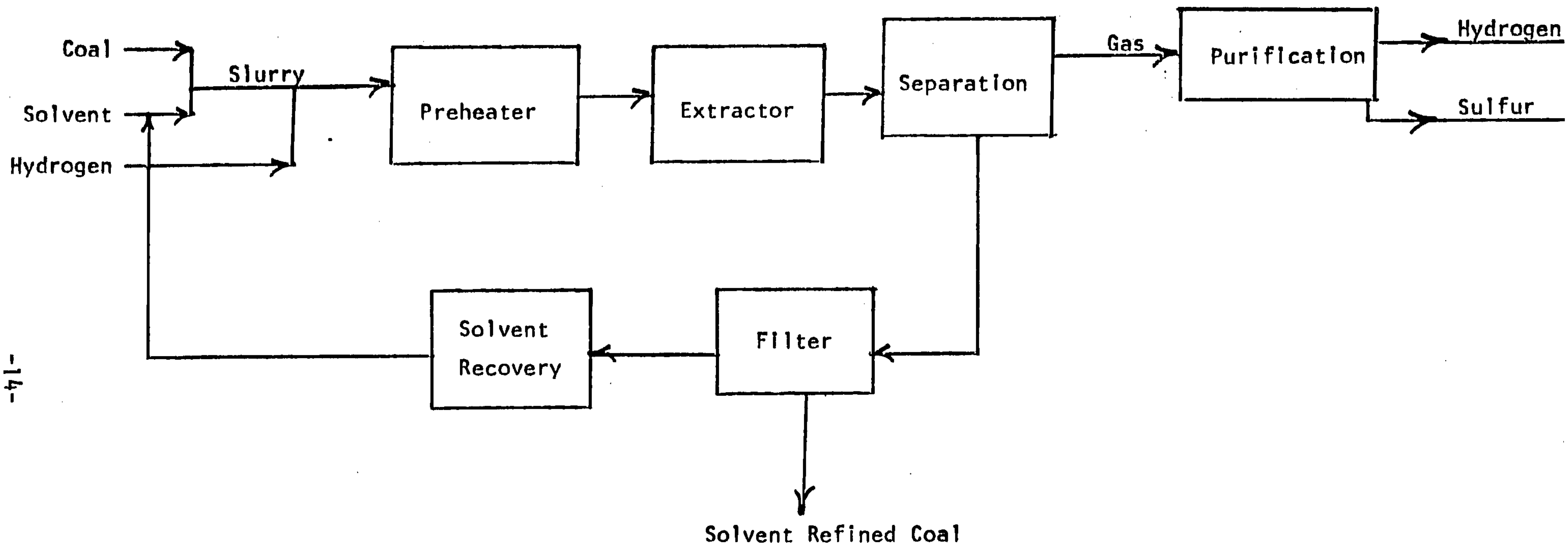
FIGURE 5



SRC PROCESS [10]

increasing temperature sequence to drive off volatiles as they are formed from the solid coal. Char, which remains, is used as fuel for conversion to electric power. Some char is used to produce hydrogen, which is fed into the fluid bed reactors to enhance the conversion of coal to liquid hydrocarbon. In the process, some of the hydrogen is also used to produce methane, raising the heat content of the synthesis gas. These processes have been validated in pilot plant operations of plants ranging in size to convert from 25 to 1600 tons of coal per day. Yields have varied, depending on the product mix. Typical yields have been 4 bbl crude oil per ton or a combination of one barrel crude oil, 9000 ft^3 SNG, and 1000 lb. char per ton. The crude oil has been found to be essentially equivalent to petroleum crude.

The problems that remain are concerned with the methanation process by which the heat content of the fuel gas is raised from about 500 BTU/ft^3 to about 1000 BTU/ft^3. Removal of entrained solid particles (ash and char) from the product gases is the other main problem. Solutions to both problems have been worked out at pilot plant scale, but improvements are deemed necessary for scale up to large scale production.

As already stated, the economic comparison of converting to energy as compared to petroleum crude sourced energy has changed. The price of foreign crude oil has raised the price of all crude oil, even much of the domestic supply, to $10-11 per bbl. The economics of coal derived energy has been fairly well discussed in many of the cited references in the bibliography. There is good agreement that costs of coal products, based on equivalent barrels of crude oil, are $8-9 per bbl., including cost of capital. This is a comparison quite obviously favorable to coal conversion. The rub is that of assembling the huge amounts of risk investment capital needed to get plants into production. This is true of other alternative energy systems, such as oil shale, as well.

This being the case, government and industry need to carefully consider the parameters and ramifications before implementing. Because this approach offers more diverse opportunity for success or partial, intermediate success stages, coal conversion to energy and raw materials is judged the best recommendation for large scale development. For example, even if it turns out that only part of the total conversion scheme really works out well, products from the several intermediate process stages could make the operation at lease somewhat profitable. It must quickly be pointed out, however, that oil shale retorting and geothermal energy systems, discussed later in more detail, need to continue to be developed, either as back-up alternatives or to augment coal conversion in the future. Likewise, nuclear fussion and solar radiation, among others, need to be researched as possible long range alternatives. Such an orderly progression of research and development would be in consonance with current Federal research funding support plans.

Several scale-up plants for coal conversion are at the advanced planning stage. Typical plants would consume some 2500 tons of coal per hour and generate some 500 million cubit feet of SNG per day. The sheer bulk of coal solids to be handled in such large scale production plants is a new kind of problem. It is precisely such engineering and construction problems which will require most of the relatively long estimated lead times before large scale plants can be expected to be on stream. Estimates range from 1980 to 1985 as operational target dates.

Crude Oil from Shale

U. S. Bureau of Mines has been active in oil-shale research for at least 50 years. Greatest activity and progress has occurred since 1944. Pilot plant verification was essentially complete by 1956. The key reason why development of the process was stopped was inability of the product to compete with the cost of crude oil at that time. The recent OPEC price increases have changed that. A pilot plant in Brazil is producing 1000 bbl/day crude oil at a cost of $6-7 per bbl compared to the $10-11 per bbl being paid for petroleum crude.

The hydrocarbon in the shale from which the crude oil is obtained is known as kerogen. It is a high molecular weight polymer which breaks down, on heating (retorting) above 850°F, to the components shown in Figure 6. It can be shown that this is a typical range of products which could be expected from the mild acid hy-

Figure 6

Distribution of n-paraffins in oil-shale

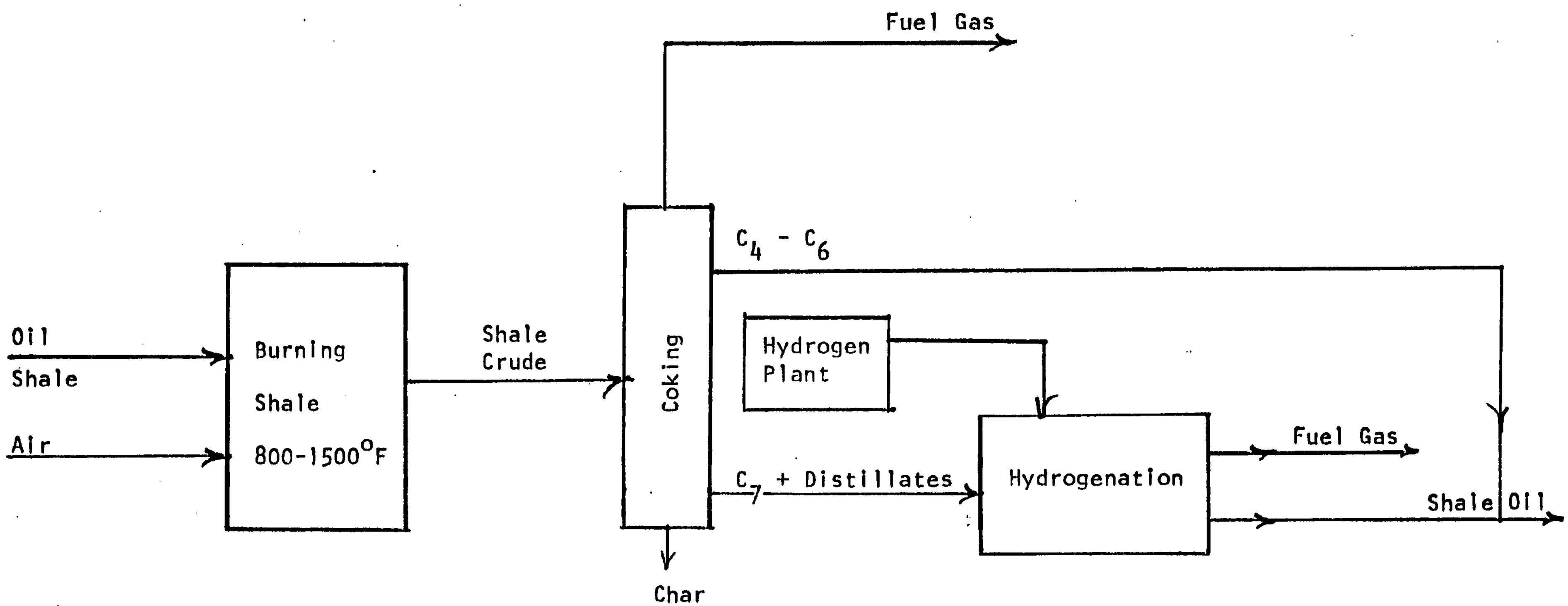
Carbon Number	% Paraffins
13	0.2
14	0.3
15	1.3
16	10.7
17	12.3
18	3.6
19	5.7
20	4.0
21	6.8
22	9.0
23	6.4
24	3.5
25	6.0
26	2.7
27	7.4
28	2.6
29	10.7
30	1.4
31	3.6
32	0.1
33	0.8
	99.1

drolysis or by enzymatic action on the chlorophyll in plant life deposits.

The retorting of oil shale offers two generalized approaches. One can either mine the shale, crush it, and retort it in an above-ground plant, or one can retort in situ. Figure 7 shows a block flow diagram of a typical process. The composition of the shale oil can be altered by retorting at different temperatures. At temperatures near 900°F, one gets mostly olefins, such as ethylene and butadiene - highly useful petrochemical building blocks. As the temperature is increased, one gets increasing proportions of aromatics (ring compounds) until at about 1500°F one gets essentially product consisting entirely of benzene and toluene. Economically useful shales contain between 15 and 140 gallons crude per ton, averaging, depending on area location, about 25 gallon/ton of total kerogen content. Of this, some 50-75% is typically recoverable as shale oil. The rest is carbon coke. Specifically, the shale rock is crushed to 1.5 - 3.5 inch diameter particles. The kerogen is ignited, using outside fuel, air being added to support combustion. The kerogen melts, crude shale oil drains off and flows out, leaving carbon coke. The coke is ignited by the advancing fire front, retorting the entire charge.

In situ retorting differs from the above system only in that the shale rock is broken up by nuclear detonations some 2500-3000 ft. underground. Retorting is then carried out in the ground,

FIGURE 7



OIL SHALE RETORTING

using only slightly modified techniques to those already outlined. A typical example would be twenty nuclear shots (five at a time) which should yield 150,000,000 bbl crude oil at 100,000 bbl per day for four years (50% recovery).

Known deposits in the U. S. are extensive. Bitumin content of the useful deposits varies a fair amount - from 15 to 140 gallon/ton of shale. Using conservative factors for deposit size, bitumin content, and recovery efficiency, this calculates to show a reserve of more than four trillion barrels of shale oil - equivalent to petroleum crude. This, in turn, is greater than all the world's know petroleum crude reserves. Other countries have oil shale deposits and have done some recovery research on them. But nowhere else are these deposits anywhere nearly as significantly large as in the U. S. It has been estimated that the cost of a barrel of oil shale crude would be $7-8 per bbl compared to the present $10-11 per bbl of petroleum crude.

Geothermal Energy

The geothermal energy alternative represents perhaps the most thoroughly proven system for energy recovery. One plant in northern California is in operation (400-mw.). Other, smaller, plants are in operation in new Zealand, Mexico, Japan, Russia and a few of lesser significance.

Geothermal energy systems are those based on dry steam type, hot water type, hot rock type, and geopressured water type. The dry steam type simply taps subterranian steam sources which are fed to well known conventional thermal electrical power plants. The principles of application are straightforward and well known.

The hot water system utilizes a series of heat exchangers to produce steam which is then fed to conventional thermal electric power plants - the same as above. The only real problem here is the corrosive nature of the dissolved substances in the hot water. These have been overcome by proper choice of materials of construction. There exists the added potential for salt and mineral recovery.[12]

Hot rocks as a source of energy are a little different. Several wells are drilled into the hot rock and the rock formations between them fractured by injection of cold water. Water is then circulated up and down the wells and through heat exchanger equipment on the surface to generate steam which can be used in conventional thermal electric power plants. The hot rock system is estimated to have an order of magnitude greater potential as an energy source than all the dry steam and hot water types combined.[13]

Geopressured fields are a mixture of natural gas and hot water. These exist at much greater depths. The natural gas can be easily separated and the hot water used as above. It has been estimated that up to 400,000 megawatts of electrical power could be produced from geothermal sources.[14]

Summary

It can be seen that the technology for deriving energy from coal, oil shale, or geothermal sources is fairly comprehensive to the point of pilot plant scale. Indications are that large scale implementation is now principally a matter of committing capital and then executing the plant construction and start-up. Overall, the data appear to recommend coal as the most favorable alternative for several reasons. The processes for coal conversion offer the most versatile (fail safe) intermediate stages where economic success would be assured even if further implementation were stopped. By-product utility from coal conversion makes this approach a better integrated system. Raw material resources are more favorable for the coal conversion system.

Nevertheless, we need to insure a balance of energy sources to guard against "single-source-trap" sort of problems. Oil shale retorting and geothermal systems need to be given continued R & D support, even if at a lower tempo, to provide for this. In addition, the longer range alternatives, such as nuclear fussion and solar sources, must not be overlooked or ignored if the U. S. hopes to continue its established growth pattern.

FOOTNOTES

1. "A Time of Learning to Live with Less", Time, 3 December 1973, p. 29.

2. "What Went Wrong", Time, 10 December 1973, p. 49

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9. "Gasification Stokes the Fire under Coal's Comeback", Chemical Week, 19 December 1973, p. 41.

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