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A SOURCE OF SUPPLY

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A Note on the Significance of Synthetic
Fuels and the Role of Nuclear Energy as
A Source of Supply

by

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The reasons the subject of synthetic fuels is of importance are several-fold. First, the U.S. energy economy is largely dominated by the end-use consumption of thermal energy in the form of liquid and gaseous fuels, petroleum and natural gas. It has been estimated by some that even in the year 2000 the consumption of electrical power will only make up 10% of the total energy consumed in the country. Thus, the argument put forth by fossil energy developers is that even if all the electrical energy were generated by nuclear, 90% would still have to be supplied by fossil fuel. Of course, this is somewhat distorted because it does not take into account the thermal to electrical energy conversion efficiency. Even so, the total energy supplied for conversion to electrical power would be 25% which is still a smaller fraction of the total energy budget and allows the fossil fuel developer to argue that more R&D funds should be put into fossil energy and less into nuclear. However, this thinking is still erroneous because it neglects to recognize two possibilities; one is that nuclear energy can be used to generate synthetic fuels either to extend the supply of the fossil fuel reserve or to completely replace its use and the other is that the economy would convert more to the use of electrical energy. However, even the more optimistic proponents of the

"all-electric economy" do not foresee a higher consumption than 50% of the total energy consumption in the beginning of the 21st Century. The problems of efficiency, losses and storage of electrical energy are important restraints in shifting to the all-electric economy. This leaves then a significant requirement for utilization of liquid and gaseous fuels. The emphasis on liquid and gaseous fuels as opposed to solid fuel is based on its convenience of transporting, storage and efficiency of utilization in thermal power convertors and devices.

The second argument for synthetic liquid and liquid fuels is well known, in that world natural sources of liquid and gaseous fuels, petroleum and natural gas, is limited and estimated to be fast declining. Natural gas is expected to last no more than about 20 to 30 years and petroleum no more than about 75 years. The curves for supply versus consumption are beginning to decline even now. The third realization is that the U.S. resources for petroleum and natural gas are even more limited and that we rely on foreign imports to a significant extent (15-20% of total energy) with increasing outlays of capital. Thus, the impetus to provide for synthetic liquid and gaseous fuels in the U.S. is well founded.

An examination of sources of synthetic liquid and gaseous fuels indicates that these can be produced from at least five sources: (1) Coal, (2) agricultural products, (3) solar energy, (4) waste, urban and agricultural, and (5) nuclear. These resources can be used singly or in combination in one or more processes. Coal is abundant in the U. S. and estimated to last at least several hundred years. The problem with coal is its environmental and safety hazards including extracting it from the ground and in its transportation and utilization. However, it

is available. Agricultural products are really based on the utilization of solar energy. Some people believe that energy farms could be developed. However, the inherent low intensity of solar energy deposition requires that large tracts of land are needed and the process is inefficient (not more than several percent) and time consuming. Direct solar energy either through absorbers or photovoltaic systems suffer from low efficiency, low intensity, high costs and reliability. However, developments should proceed to overcome these difficulties. Urban waste is limited (5-10% of the total energy economy) but should be included wherever possible because it serves a double purpose of waste disposal and energy recovery. Agricultural waste has great potential but suffers from similar problems as the agricultural products with the added problem of collection and transportation from widely scattered areas. Nuclear, either fission or fusion, can produce the intensity and capacity for a synthetic liquid and gaseous synthetic fuel industry, provided the problems of technology and hazards are solved.

Looking at the impact that various sources of liquid and gaseous fuels can make, it appears that coal and nuclear are the most viable and will be discussed below.

A. Coal Conversion

The basic reactions for coal gasification and liquefaction are either reaction with steam (water) or reaction with hydrogen. Generalizing the reactions:

The CO and H₂ formed in the endothermic water gas reaction with coal can be used as a gaseous fuel itself (power gas) or can be converted by numerous catalytic exothermic processes to various gaseous and liquid fuels including methane (synthetic natural gas, SNG), methanol or hydrocarbon fuels (through high pressure Fischer-Tropsch type reactions).

For methane $\text{CO} + 3\text{H}_2 = \text{CH}_4 + \text{H}_2\text{O}$ exothermic

For methanol $\text{CO} + 2\text{H}_2 = \text{CH}_3\text{OH}$ exothermic

For hydrocarbons $n\text{CO} + 2n\text{H}_2 = (\text{CH}_2)_n + n\text{H}_2\text{O}$ exothermic

In order to provide the endothermic heat for the gasification reaction, usually coal itself is burned internally with oxygen in the gasifier. Thus, about 0.5 lbs of coal is burned per pound of coal converted to gas and on the basis of a carbon balance roughly the process is 66% efficient. The reactions proceed usually in the order of 1700°F and pressures up to 150 atmospheres. The problems of high temperature, high strength materials, and capacity of gasifier reactors becomes important.

B. Hybrid Coal and Nuclear Conversion

1. The developers of the high temperature gas cooled reactor (HTGR) propose using nuclear process heat for the endothermic reactions to extend the supply of coal in conversion to liquid and gaseous fuels. However, as can be seen above, the most that coal can be extended is by 33% and for this, reactors must be made to operate at high temperature up to 1800 to 2000°F where nuclear materials problems and heat exchange problems become very severe. The hazards of radioactivity and contamination become increasingly important at these elevated temperatures. Presently, conventional coal and gas fired gasifiers suffer from material reliability problems. The main benefit is that the nuclear heat is used efficiently

and no power conversion cycles are necessary. I can understand why high temperature process heat reactors are being developed in Germany because of the limited supply of coal. In the U.S. where there is an abundant resource of coal these should be less of an incentive to employ high temperature reactors.

In the case of hydrogenation, this involves adding enough hydrogen to coal to liquify it to an oil or gasify it usually to methane (SNG). These reactions are usually exothermic and require little heat. However, hydrogen must be generated and this is usually obtained by water gasification of coal (the first reaction above). The Fossil Energy Division of ERDA is pursuing hydrogenation in many processes from light hydrogenation (Synthoil Process) to deep hydrogenation (i.e., Synthane and Flash Hydro-Pyrolysis). Nuclear heat can also be applied to water gasification of other hydrocarbon containing materials such as agricultural and urban waste. Nuclear energy can provide the hydrogen through electrolysis reactions as discussed below.

2. In addition to providing high temperature nuclear heat for the coal gasification system there is another hybrid nuclear fossil fuel process which is quite attractive.

The nuclear splitting of water (either electrolysis or thermal) can produce hydrogen and oxygen. Oxygen with water added can be used to gasify coal to CO and H₂ and provide the endothermic heat of reaction and the hydrogen can be used to further hydrogenate coal or to produce methanol.

Electrolysis	$H_2O = H_2 + 1/2O_2$
Gasification	$C + H_2O = CO + H_2$
Hi-temp Energy	$1/2C + 1/2O_2 = 1/2CO_2$
Methanol Synthesis	$CO + 2H_2 = CH_3 OH$

This system can work with any carbon containing material, i.e., coal, urban solid waste, agricultural products and wastes, etc. This is an attractive process because it combines the maximum utilization of carbon with the maximum utilization of nuclear energy.

C. Pure Nuclear Sources of Liquid and Gaseous Fuels

Coal and other natural reduced forms of hydrocarbon suffer from polluting contaminants such as sulfur, trace elements, and ash. The synthesis of liquid and gaseous fuels using nuclear energy depends basically on the decomposition of water and carbon dioxide by several different process as follows:

(a) Electrolysis	$H_2O = H_2 + 1/2O_2$	$\Delta H = +68 \text{ Kcal/coal}$
(b) High Temperature	$H_2O = H_2 + 1/2O_2$	
Thermal Splitting	$CO_2 = CO + 1/2O_2$	$\Delta H = +68 \text{ Kcal/coal}$
(c) Catalytic thermal
in a cyclical
process	$H_2O \xrightarrow{Cu, Mg, Cl_2} H_2 + 1/2O_2$	
(d) Advanced systems	1) Radiation decomposition of H_2O or CO_2
2) Ultraviolet decomposition of H_2O or CO_2
3) Direct electrolytic decomposition of aqueous K_2CO_3 solution.	

In the non-fossil nuclear system, the raw materials for synthetic fuels are CO_2 and H_2O and must come from readily available renewable sources such as air, water and earth. CO_2 can be produced by calcination of limestone

but this requires unearthing large amounts of stone, transportation expenditures and energy for its decomposition, all of which is environmentally unsound. This leaves water and air which are readily available most everywhere. The subject of extraction of CO_2 from the air or from seawater is thus extremely important and is intensively examined in BNL 20016 at great length. The basic fuels produced by splitting water or CO_2 are the gases hydrogen and carbon monoxide. These can be combined catalytically to form methane, methanol or hydrocarbons. The choice of process for production of hydrogen or carbon monoxide depends on a number of factors. The electrolysis of water is favored because it is a well-known technology and can yield high efficiencies (up to 85%). It does require demonstration on a large scale. Its main disadvantage is that it uses electrical energy. The high temperature splitting of water and CO_2 requires extremely high temperature levels ($\sim 3000^\circ\text{K}$) with its attendant materials problem. CTR fusion reactors are more suitable for these processes than fission reactors. The catalytic thermal decomposition of water has numerous disadvantages, including use of expensive chemical materials such as halogen and metals which are subject to loss, handling of large masses of recycled chemicals, recycling thermal energy to make up heat balances, corrosion problems, etc., efficiencies usually run not more than 50%. Advanced systems for CTR include high energy radiation interaction with H_2O and CO_2 in the blanket region. The direct electrolytic reduction of aqueous carbonate solution to hydrocarbon fuels is an intriguing possibility since it bypasses the need for splitting H_2O or CO_2 , and goes directly to hydrocarbons. This is the reason why we recommend continuing the research and development on the application of CTR in this direct reduction area.

It is our conclusion that the system we have proposed in BNL 20016^(1,2) to utilize CTR energy to extract CO₂ from the atmosphere and/or the ocean and combine or fix it with electrolytic hydrogen offers an advantageous alternative. It provides a non-fossil source of renewable liquid hydrocarbon fuels and feedstocks (for the petrochemical industry). It is an environmentally clean system (no sulfur, or trace metals). Furthermore, the estimates indicate that capital investments are lower than future oil and coal investments. It eliminates the dependence on foreign oil. Of course, the system is not unique to fusion reactors; it can be applied to fission and fission-fusion systems. However, the potential for fusion is a more abundant, lower cost, cleaner nuclear energy system and the ability to produce synthetic fuels extends its applicability several-fold. The unique features of fusion reactors for this purpose are the development of (1) the direct use of high energy radiation and (2) very high temperature energy for water and carbon dioxide splitting.

Some further words should be noted about hydrogen versus liquid hydrocarbon fuels (i.e., methanol) as synthetic fuels. Hydrogen gas is a good gaseous fuel. However, it has disadvantages with respect to distribution, transportation, and storage. The metal hydride storage scheme reduces the problem with storage, however, distribution or getting it to end point users is a problem and the weight of the storage system is a disadvantage. Furthermore, hydrogen does not address itself to the chemical feedstock problem. A source of carbon is required for this purpose. A supply of methanol solves this problem.

Finally, concerning the argument of an all-electric economy versus the need for synthetic fuels; the electric economy requires transmission

and storage. Transmission could be solved by superconducting lines; however, storage requires chemical or electrochemical devices such as batteries and fuel cells. Thus, we are in the chemical business anyway and there is really no such economy as an "all-electric economy." It should be noted that methanol is an excellent fuel for fuel cells so that if one wants to insist on an all-electric economy nomenclature, methanol is made by electrical power and can be considered as an energy carrier for end use either thermal or electrical.

To summarize, it is our belief that there is a definite long term need for synthetic liquid hydrocarbon fuels. This will be supplied initially by coal conversion processes. Hybrid nuclear-coal systems for conversion of coal to synthetic fuels will be based on supplying electrolytic hydrogen and oxygen using nuclear energy. Hybrid nuclear-agricultural and nuclear-solid waste conversion to synthetic fuels will also involve supplying electrolytic hydrogen and oxygen. Finally, the nuclear-air-water process for methanol synthesis provides a long-term alternative to the above systems and should be further developed, if for no other reason than to provide a strong competitive position in keeping the fossil fuel sources of synthetic fuels economically in line.

(1) Meyer Steinberg and V. D. Dang, "Use of Controlled Thermonuclear Reactor Fusion Power for the Production of Synthetic Methanol Fuel from Air and Water," BNL 20016 (April 1975).

(2) S. Baron and M. Steinberg, "The Economics of the Production of Liquid Fuel and Fertilizer by the Fixation of Atmospheric Carbon and Nitrogen Using Nuclear Power," BNL 20273.