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TITLE: USE OF NON-PETROLEUM FUELS TO REDUCE MILITARY ENERGY VULNERABILITIES: SELF-SUFFICIENT BASES AND NEW WEAPON PROPULSION SYSTEMS

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USE OF NON-PETROLEUM FUELS TO REDUCE MILITARY VULNERABILITIES: SELF-SUFFICIENT BASES AND NEW WEAPON PROPULSION SYSTEMS

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ABSTRACT

The US fossil synfuels program may not have significant impact on domestic fuel supplies until near the year 2000, resulting in a contnuing mobility fuels vulnerability for the US military until then. But there are other mobility fuel options for both propulsion systems and stationary base-energy sources, for which the base technology is commercially available or at least demonstrated. For example, for surface propulsion systems, hydrogen-fuel-cell/battery-electric hybrids may be considered; for weapons systems these may offer some new flexibilities, standardization possibilities, and multiple military-controlled fuel-supply options. Hydrogen-fueled aircraft may provide interesting longer-term possibilities in terms of military energy self-sufficiency and multiple supply options, as well as performance specifications. These scenarios will be discussed, along with possibilities for demonstrations in the MX-system ground vehicles.

I. INTRODUCTION

The US fossil synfuels program may not have significant impact on domestic fuel supplies until near the year 2000, resulting in a continuing mobility fuels vulnerability for the US military until then. But there are other mobility fuel options for both propulsion systems and base-energy sources, for which the base technology is commercially available or at least demonstrated. In this concept paper we review some of these options and their possible military applications.

II. BACKGROUND

As illustrated in Fig. 1, the US is facing a triple-vulnerability situation at least through the 1980's:

Figure 1 here

1. According to Dr. Raymond Pollock, US Minuteman-equivalent survivors to a Soviet first strike would be about 20% today, but falling to only about 3% in 1987. The survivability curve should begin to pull upwards in the late 1980's as the MX missile system becomes operational.

2. As illustrated in Fig. 2, today the US is about 95% dependent on mobility fuels derived from petroleum.[1] About 45% of our petroleum consumption comes from imports--about half of which comes from the Middle East.[2]

Figure 2 here

This high-import dependence as a vulnerability should not be underestimated since our military, domestic emergency vehicles, farming equipment, railroads, ships, airplanes, buses, the trucking industry, and private autos are all dependent on such fuels.

Returning to Fig. 1, we see that this mobility fuels vulnerability will last at least through the 1980's and may stretch well into the 1990's before our domestic fossil synfuels program begins to have noticeable impact in offsetting imports. Since the US military purchases its fuels on the market, Curve 2 of Fig 1 also reflects the military's vulnerability to imports. And in a general way, Curve 2 of Fig. 2 reflects the mobility fuels vulnerability of each US military base. The Soviets are taking action such as aggressively developing nuclear fission energy towards being energy self-sufficient,[3] though they, too, are developing some problems with mobility fuels as illustrated in Fig. 3.

Figure 3 here

In the face of growing world population, the US Congress' OTA (Office of Technology Assessment does not expect world oil production to increase[4] suggesting that prices will continue to rise. Note also that everytime the price of fuel goes up one cent per gallon, the US annual defense budget is impacted $90 million.[5]

3. The US is also highly dependent on imports for nonfuel minerals, as shown in Fig. 1 (while the Soviets are nearly nonfuel-mineral self-sufficient[6-8]), and many

of these US imports are from Soviet Block or Soviet-influenced nations. Note that pushing for soft energy technologies may compound the US nonfuel minerals problem, since construction of soft-technology facilities can require several times the amount of materials and energy needed to fabricate them into hardware.[9]

The above background was presented to help emphasize the urgent need to take redress actions on US vulnerabilities wherever possible. We now focus on the subject of Curve 2 of Fig. 1 vis-a-vis US military strength.

III. SYNFUELS

Fossil synfuels from coal, oil shale, and tar sands are the topic of other papers at this conference, so we shall limit ourselves to a few brief remarks here.

Although it has been touted that the US has abundant coal reserves, it should be noted that a lot of the coal is estimated to be in thin deep seams, requiring more energy to mine it than you get back unless in situ extraction technologies are used. Figure 4 shows that the DOE is projecting domestic coal production to double between now and the year 2000, for domestic use (power plants, synfuels, industrial process heat). Add to that projected increases in domestic coal mining for coal exports to other nations. Professor John O'M Bockris of Texas A & M[10] estimates that if all the wish lists for

Figure 4 here

domestic coal production are fulfilled, the US high-grade coal reserves may be depleted before the year 2000.

It is estimated that the US has about 28 billion tons of oil shale, and 236 billion tons of tar sands.[11] Given environmental and regional-political (e.g., boom-town impact) considerations, plus competition between conservation efforts vs a growing number of consumers, it is not clear to us at this point in time what effect these fossil synfuels will have in bringing Curve 2 of Fig. 1 down much before the year 2000. Similar comments apply to mobility fuels from biomass.

This is not to imply that fossil synfuel programs should not be pursued, since the US needs all the help for mobility fuel supplies that it can generate.

IV. ENERGY PATHWAYS FOR THE MILITARY

Figure 5 shows a partial flowchart of possible energy pathways for the US military, excluding conventional oil and natural gas as sources, and not explicitly including synfuels from tar sands, oil shale, or biomass (--the coal-to-methanol synfuel path generically indicates such possible pathways). The DOE is spending considerable funds to develop the sources in the left column of Fig. 5, and the MX-RES office is investigating the applicability of renewable energy sources for stationary uses in the MX facilities.

Figure 5 here

Moving from left to right across Fig. 5, you can trace various pathways. You can also add pathways for tar sands, oil shale, etc., across to conventional internal combustion vehicles if you wish. We find it constructive to map such pathways for comparative analysis. We will return to Fig. 5 shortly.

We now look at various energy sources (resources) in the context of use vis-a-vis military operations and military base energy self-sufficiency. Various energy sources are given in Column A of Table 1 (please also note the footnotes), and relative qualities are indicated in the other columns. It is our understanding that the military would like for its bases (especially the non-CONUS ones) to be energy self-sufficiency we also consider the possibility of an extended "siege" (cut off from external supplies) of, say, a non-CONUS base, with the goal that the base would be fully operational during such a siege. If for such a scenario it is desirable also not to have to import (to the base) a large (volume-wise) stockpile of fuel, then when viewing Table 1 it appears that nuclear and hydrogen, possibly with some solar assist for building heating, is the desirable combination.

Table I here

Whether or not this "hard line" position or goal of having a base fully energy self-sufficient during a hypothetical extended siege is desirable may be an issue for debate elsewhere. For now, we pursue this line of thinking.

The pathways for the nuclear (plus solar add-on) and hydrogen are given in Fig. 5, and as indicated in Table I, all of the base technology exists commercially or has been demonstrated.

A small reactor would only need a partial fuel-rod change once every few months (if [illegible] frequently). A co-generation reactor could supply process heat for thermochemical production of hydrogen[12] as well as electrical power for the base (which could, in part, be used for resistance-electric space heating). But without this process heat option, another pathway to hydrogen exists via electric generation and electrolysis of water. Electrolysis equipment is commercially available today.

Existing gasoline-fueled internal combustion engine vehicles can be converted to run on hydrogen. Bottled gaseous hydrogen enables only limited range for such vehicles. But use of a Dewer (thermos bottle) with on-board liquified hydrogen (LH_2) storage enables vehicle ranges comparable to that of a tank of gasoline,[13] and refueling times only a few minutes. A "bottle exchange" is another option for rapid refueling, wherein a nearly-empty LH_2 Dewar is replaced with a full one.

On-board storage of hydrogen in metal hydrides is another option,[14] though weight and hydride recharge times are not comparatively attractive.

Electricity may also be used for electric vehicles. For non-critical vehicles where high battery weight and recharge times and range are not important, this option can be used. Numerous demonstration vehicles are operational, and some are now even commercially available today.[15]

The fuel-cell/electric hybrid also provides an interesting option for which demonstration vehicles exist.[16] In such hybrids, a small number of batteries are used for peak power demands such as acceleration, and the fuel cell provides ample power power for cruising as well as battery recharge. A fuel cell can be simply thought of as a "battery" through which you flow the chemicals from an external source; as long as the flow continues, the fuel cell will provide power.

Again, refueling times are short. And fuel cells operate with high efficiency over a broad load range--see Fig. 6.[16]

Figure 6 here

The fuel-cell/electric hybrid system also provides possibilities for propulsion system standardization via modularization. For example, one unit might be used to power a pickup truck or a van-sized vehicle, two in parallel for a one-ton-truck sized vehicle, four in parallel for a bus, etc., with interchangeable parts and common maintenance features.

In summary thus far, a military base equipped with a small nuclear powered electric generating station (perhaps with a subsurface reactor), a water well, and water electolysis and hydrogen liquefaction equipment could eventually be energy self-sufficient except for reactor fuel-shipments once every few months or so (larger commercial reactors get about one-third of their fuel rods changed once a year). This combination would not only supply base power and heat, but could also supply electricity for electric vehicles, or hydrogen for IC or fuel-cell/ electric hybrid vehicles.

Note also that consideration might be given to producing and storing excess hydrogen. That hydrogen could then be run back through a fuel cell to provide electric power for peak-power needs. Again, the base technology exists. Cryogenically cooled superconducting magnetic energy storage units may also be used to store electrical energy for peak needs.[17] Their advantage is their fast response time (1/100 sec 0-to-full power), which for military purposes may be important to keep radar and computers up during a sudden loss of normal-source power.

V. ADDITIONAL APPLICATIONS

Combat and special-purpose vehicles. As hydrogen propulsion technology advances, we forsee no reason why combat and other special-purpose vehicles could not be powered by propulsion systems like fuel-cell/electric hybrids.

Note also that mobile ground units equipped with a small nuclear power supply (or access to electric power) and an electrolysis and liquefaction unit could be used behind lines to make LH_2, provided there is a supply of water available. One can also conceive of special small ships so equipped (also with a desalinization unit on board) to make LH_2 fuel just off shore for land vehicles.

Aircraft. Per unit volume, LH_2 weighs only about one-tenth that of aviation fuel, and burns somewhat more efficiently. But per unit volume, LH_2 contains less energy. Considering these factors, it takes about 3.5 times as much volume of LH_2 to get the same range, but it would weigh less than aviation fuel.[18-21] This has led to interests in LH_2-fueled aircraft, since either heavier payloads or longer ranges may be possible. Some numbers for comparison are as follows:

FUEL	Btu/Gal	Btu/lb	lb/Gal
Gasoline	115,600	18,900	6.1
#1 Diesel	126.100	18,600	6.8
#2 Diesel	129,600	18,400	7.0
LH_2	30,900	51,600	0.6

Land bases equipped as discussed in the above section could make their own LH_2 for aircraft fuel. Nuclear powered aircraft carriers also equipped with desalinization, electrolysis, and liquefaction equipment could be self-contained, making fuel for their own aircraft.

Ships. Non-nuclear powered ships could be powered by LH_2 fuel cells, with nuclear-powered fuel manufacturing craft strategically located on the oceans.

VI. LH_2 COSTS

The cost of LH_2 is a function of how the H_2 is produced. For LH_2 where the H_2 is made from natural gas,[22] the current delivered price to Los Alamos, NM via truck from Los Angeles, CA (Δ~1,000 miles) is \$3.66/ gal gasoline equivalent. But with market expansion, one estimate by Donnelly of Aerospace Corporation[23] for the cost of LH_2 is \$1.13/gal gasoline equivalent. Calculations by Baker of Union Carbide confirm those estimates.[24]

Another DOE cost comparison[25] puts hydrogen (via electrolysis) at \$10-20/MM Btu compared to gasoline from oil at \$9.37/MM Btu (~\$1.17/gal, regulated).

Some worst-case numbers that we've seen are shown in the top of Fig. 7.[26] "Basic differences of opinion has developed between Boeing and Lockheed as the two companies attempt to soidify their positions on the subject of liquid hydrogen fuel for future-generation aircraft.....They agreed (despite differences of opinion for near-term commercial aircraft needs) that liquid hydrogen offers advantages over the other alternatives studied in terms of minimum noise and air pollution, improved aircraft performance with lighter aircraft weight, reduced runway requirements, and safety in terms of fire and explosive hazards...."[27]

The lower half of Fig. 7[28] gives some other cost comparisons for producing hydrogen by various processes. For example, the General Electric SPE (Solid Polymer Electrolyte) process cost estimates give \$13.62/ MM Btu,[28] which is getting competitive with gasoline. (Note: These are estimates for commercial retail costs that can be divided by ~2.5 to obtain costs of producing and distributing it yourself.)

Figure 7 here

Other cost estimates[29] place the total delivered commercial cost of LH_2 from a cogeneration steam-iron (coal feedstock) process compatible with the graph in the lower half of Fig. 7.

A fundamental question that the military must address is "What is the DOD willing to pay (i.e., request funds from Congress) for military energy security/self-sufficiency?" Is it in the national interest for the military to pay a bit more, if necessary, for its energy if it can be energy secure?

VII. ENTRY PROGRAM

Refer again now to Fig. 5. At selected military bases, the DOD could begin almost immediately in obtaining some operational experience at the right of Fig. 5, with a few electric vehicles, hydrogen IC vehicles, or fuel-cell/electric hybrids; for the latter two, fuels are commercially available today in limited quantities. Note also that the same fuel cell can be run on methanol-air or hydrogen-air. Vehicle selection might include a few base taxis, some maintenance vehicles, and some delivery trucks for starters.

If results of such a small-scale demonstration program are favorable, then the fleet conversion could be expanded, along with obtaining commercially available electrolysis and liquefaction equipment if that pathway in Fig. 5 is chosen; fuel cells might also initially be run on methanol synfuel. The point is that an entry program could start almost immediately beginning at the right of Fig. 5, later working "backwards" towards the left, towards energy self-sufficiency (if the nuclear and solar paths are taken), or initially using one of the other supply options of Fig. 5.

Given the charge of the MX-RES Project Office to explore possible use of emerging renewable energy sources for base electric power and building heating, the concept of also considering alternative propulsion systems for MX-base general-purpose vehicles has been raised, and was discussed in a workshop on the subject held at the Los Alamos Scientific Laboratory on October 22-23, 1980. The 53 attendees were mostly DOD and DOE personnel. Some summary comments from that workshop are as follows:

> MX may provide an interesting test bed. Since detailed facility designs have not yet begun, options for alternative vehicles could be designed in now rather than retrofitted later. It is unlikely that alternative vehicles will be commercially available for the construction phase of MX, but possibilities may exist for the operations phase. Electric vehicles may be suitable for uses confined to the operating base. IC hydrogen and fuel-cell/electric hybrids (LH_2 or methanol) appear more useful for trips to the clusters where vehicle range becomes important. Some vehicle testing on existing bases might be considered (as discussed above) to obtain some operational data. Initial attention should be focused on non-special-purpose vehicles. Once the technology for such vehicles is stimulated, even if commercial production cannot meet demands for the first generation of MX operational phase vehicles (4-7 year vehicle lifetime), by the time the first generation of vehicles needs to be replaced, production capability might well meet second generation needs. A more thorough assessment is needed, looking at MX vehicle requirements (types, quantities, range, load, frequency of use, etc.) vis-a-vis the state of technology of non-petroleum-fueled propulsion systems. Possible future expanded use at other military bases may not only move the military towards energy self-sufficiency, but may also serve as a catalyst for other sectors in the US.

VIII. SUMMARY

We suggest looking at a military base in terms of an integrated energy system.

The approach outlined above is directed towards moving the US military in the direction of energy self-sufficiency, without having to rely on frequent deliveries of military fuels from off-base sources. The process of moving towards military energy self-sufficienty will be an evolutionary one, and synfuels may find applications in the transition. Figure 5 outlines some of the pathways and options, with the nuclear and hydrogen pathway likely yielding the best possibility for ultimate self-sufficiency.

Questions of trade-offs in economics vis-a-vis the value of energy self-sufficiency need to be addressed.

When fossil synfuels for mobility fuels run out (--they will sooner or later--), then the world will eventually have to turn to hydrogen. The base technology exists today for hydrogen-fueled ground vehicles If it is decided by strategists and decision makers that costs do not outweigh the importance of military energy self-sufficiency, then a transition to hydrogen-fueled propulsion systems could begin almost immediately to start obtaining some operational experience. Although this may initially be on a small scale, it may help catapult us into the ultimate generation of fuels, preserving petroleum and "synthetic petrochemicals," for the non-fuel petrochemical industry for making fertilizers, and materials such as advanced plastics that might be used as substitutes for certain materials derived from non-fuel minerals--see Curve 3 of Fig. 1.

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1. Graph from ~~Dr. A. R. Landgrebe~~, ~~US Department of Energy~~. ~~See Ref. 15~~.

2. See "Energy Statistics," a quarterly publication of the Institute of Gas Technology, Chicago, Il, 60616.

3. The Soviet Energy System: Resource Use and Policies, by L. Dienes and T. Shabad, John Wiley Publishers, NY, 1979.

4. "World Oil Outlook Bleak at Best," news release, Oct. 20, 1980, Congress of the United States, Office of Technology Assessment.
5. US News and World Report, November 10, 1980, pg. 23.

6. "Mineral Self-Sufficiency--The Contrast Between the Soviet Union and the United States," by S. D. Strauss, Mining Congress Journal, Nov. 1979.

7. "Managing Critical Materials in the '80's," by J. J. Piepgras and H. J. Metz, Metal Progress, March 1980.

8. "Afghan Oil, Minerals are Honey to Russian Bear," by Dr. J. F. Shroder, Albuquerque Journal newspaper, Jan. 27, 1980.

9. For a summary see: "US Energy Sources and Materials Needs," by David A. Freiwald, Los Alamos Scientific Laboratory Brief No. LASL-80-10, April 1980.

10. John O'M Bockris, Department of Chemistry, Texas A & M University, College Station, TX 77843.

11. SYNFUELS newsletter, Oct. 10, 1980, pg. 7.

12. "Thermochemical Cycles: A New Method of Producing Hydrogen," by K. E. Cox, Los Alamos Scientific Laboratory Mini-Review No. LASL-80-26, August 1980.

13. "A Liquid-Hydrogen-Fueled Buick," by Walter F. Stewart, Los Alamos Scientific Laboratory report LA-8605-MS, November 1980.

14. "Hydrogen Storage in Metal Hydrides," by J. J. Reilly and G. D. Sandrock, Scientific American, February 1980, p. 118.

15. Contact BOB KIRK ~~Dr. Albert R. Landgrebe~~, US Deparpment of Energy/CS/AT, 600 E. Street, NW, Washington, DC 20585, for a summary of DOE's electric vehicle program.

16. "The Case for Fuel-Cell-Powered Vehicles," by J. B. McCormick and J. R. Huff, Technology Review, August/September 1980.

17. "Superconducting Magnetic Energy Storage," by W. E. Keller, Los Alamos Scientific Laboratory Mini-Review No. LASL -78-81, September 1978.

18. "LH_2 Airport Requirements Study," edited by G. D. Brewer, Lockheed-California, National Aeronautics and Space Administration report no. NASA-CR-2700, March 1976.

19. "An Exploratory Study to Determine the Integrated Technological Air Transportation System Ground Requirements of Liquid-Hydrogen-Fueled Subsonic, Long-Haul Civil Air Transports," prepared by The Boeing Company, National Aeronautics and Space Administration report no. NASA-CR-2699, September 1976.

20. "An International Research and Development Program for LH_2-Fueled Aircraft," recommended by the Hydrogen in Air Transportation Ad Hoc Executive Group, W. M. Hawkins (Lockheed Corporation), Chairman, July 1980.

21. "Hydrogen in Air Transportation," proceedings (in English) of an International Symposium by that title, co-sponsored by the West German DGLR and DFVLR, the American Institute for Aeronautics and Astronautics, and the International Association for Hydrogen Energy, held in Stuttgart, Germany, September 11-14, 2979.

22. "Hydrogen - Buy It or Make It?" by L. C. Bassett and R. S. Natarajan, Chemical Engineering Progress, March 1980, pg. 93. (Delivered price of ~\$19/MM Btu.)

23. "Study of Hydrogen-Powered vs Battery-Powered Automobiles," by J. J. Donnelly, Jr. et al, Aerospace Corporation report No. ATR-79 (7759)-1, Vol. 2, May 1979.

24. "Economics ~~Enemies~~ of Hydrogen Production and Liquefaction Updated to 1980," by C. R. Baker, Linde Division, Union Carbide Corporation, Tonawanda, NY, 14150, NASA Contractor Report 159163, November 1979.

25 ~~24~~. Data from Eugene Ecklund, DOE/CS/TP, 5H046, US Department of Energy, Washington, DC 20585.

26 ~~25~~. Summary of a Boeing study reported in SYNFUELS, October 17, 1980, pg. 7.

28 ~~26~~. Paper No. 7 in Ref. 21: "Hydrogen from Fossil Fuels," by Derek P. Gregory and Paul B. Tarman, Institute of Gas Technology, Chicago, IL 60616.

29 ~~28~~. Numbers from a September 30, 1980 proposal submitted to US Department of Energy by General Scientific Company (E.H. Erath, President), 810 S. Flower St., Los Angeles, CA 90017.

27. "Forecasters Projecting Stabilizing Fuel Situation", Aviation Week and Space Technology, Nov 3, 1980, in particular see pg 65.

TABLE I

	A Source/ Resource	B Technology Status		C Longevity of US Resources[c]	D Suitability for Military-Base Self-Sufficiency[g]	E Direct Type Use		F Relative Production and/or use Pollution
		Known	Emerging			Mobility	Stationary	
1.	Oil	✓		No	Only with large On-Base Stkpile	✓	✓	High
2.	Natural Gas	✓		No	-	✓	✓	Low
3.	Coal	✓		Moderate	-		✓	High
4.	Nuclear	✓		Yes (with breeder)	Yes		✓	Low
5.	Solar	✓	(✓)[b]	Yes[d]	Partly		✓	Low
6.	Wind	✓		Yes[e]	Limited		✓	Low
7.	Biomass Fuels	✓		(Yes)[f]	Limited		✓	Moderate
8.	Hydro	✓		Yes	Limited		✓	Low
9.	Oil Shale Fuels		✓	Moderate	Only with large On-Base Stkpile	✓	✓	High
10.	Tar Sands Fuels		✓	Moderate	-	✓	✓	High
11.	Coal SNG and Liquid Fuels		✓	Moderate	-	✓	✓	High
12.	Geothermal	✓		Yes (HDR)	Limited		✓	Low
13.	OTEC		✓	Yes	Very Limited		✓	Low
14.	(Hydrogen)[a]	✓		Infinite	Yes	✓	✓	(Low)[h]

Footnotes:

[a] Hydrogen is not a source. It is a carrier. Energy is needed to make it.

[b] Photovoltaics is emerging.

[c] Looking at a several-decade time horizon.

[d] Diurnal plus seasonal variations.

[e] Highly variable except in a few places.

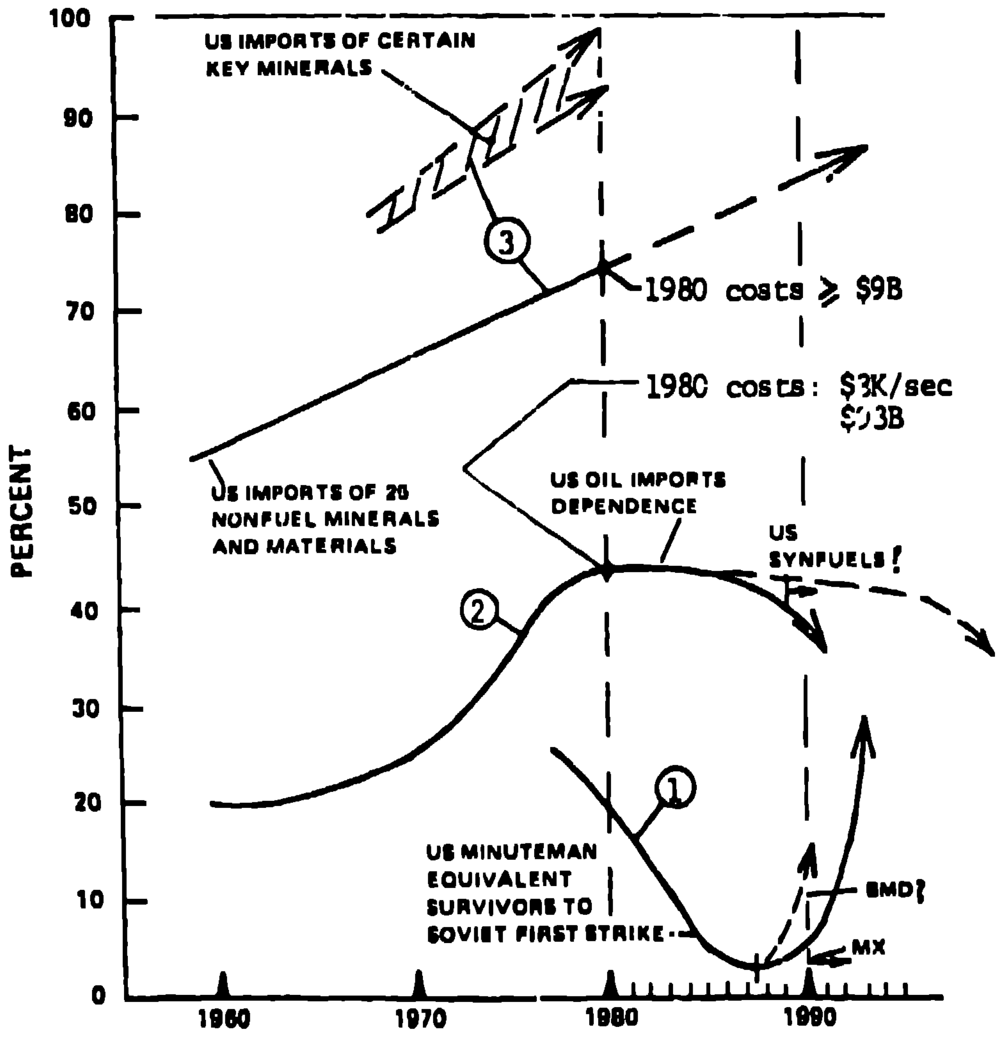
[f] Questionable best use given the world food situation.

[g] I.e., for a base to be energy self-sufficient if cut off from fuel supplies for several weeks.

[h] Products of use are H_2O vapor and traces of NO_x. If H_2 is made from fossil sources, pollution may result from these sources; if made from nuclear or solar, the source will be pollution-free.

Fig.1

US Vulnerabilities for the 1980"s



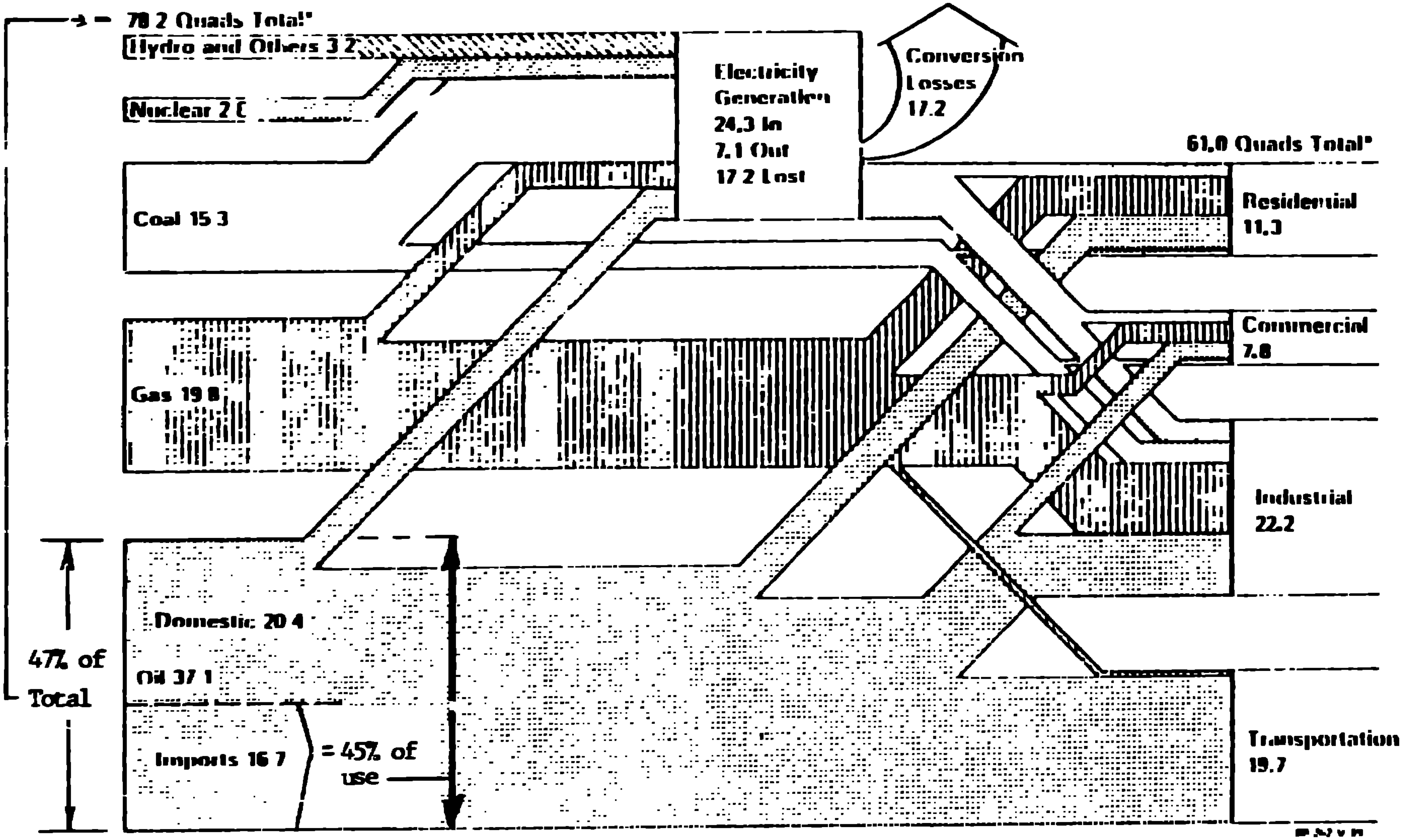
① "Ballistic Missile Defense--A Quick-Look Assessment" Dr. Ray Pollock, LASL report LA-UR-80-1578 (June 1980).

② DOE data.

③ Data from "Managing Critical Materials in the 80's", J.J. Piepgras & H.J. Metz, <u>Metal Progress</u>, March 1980.

Fig. 2

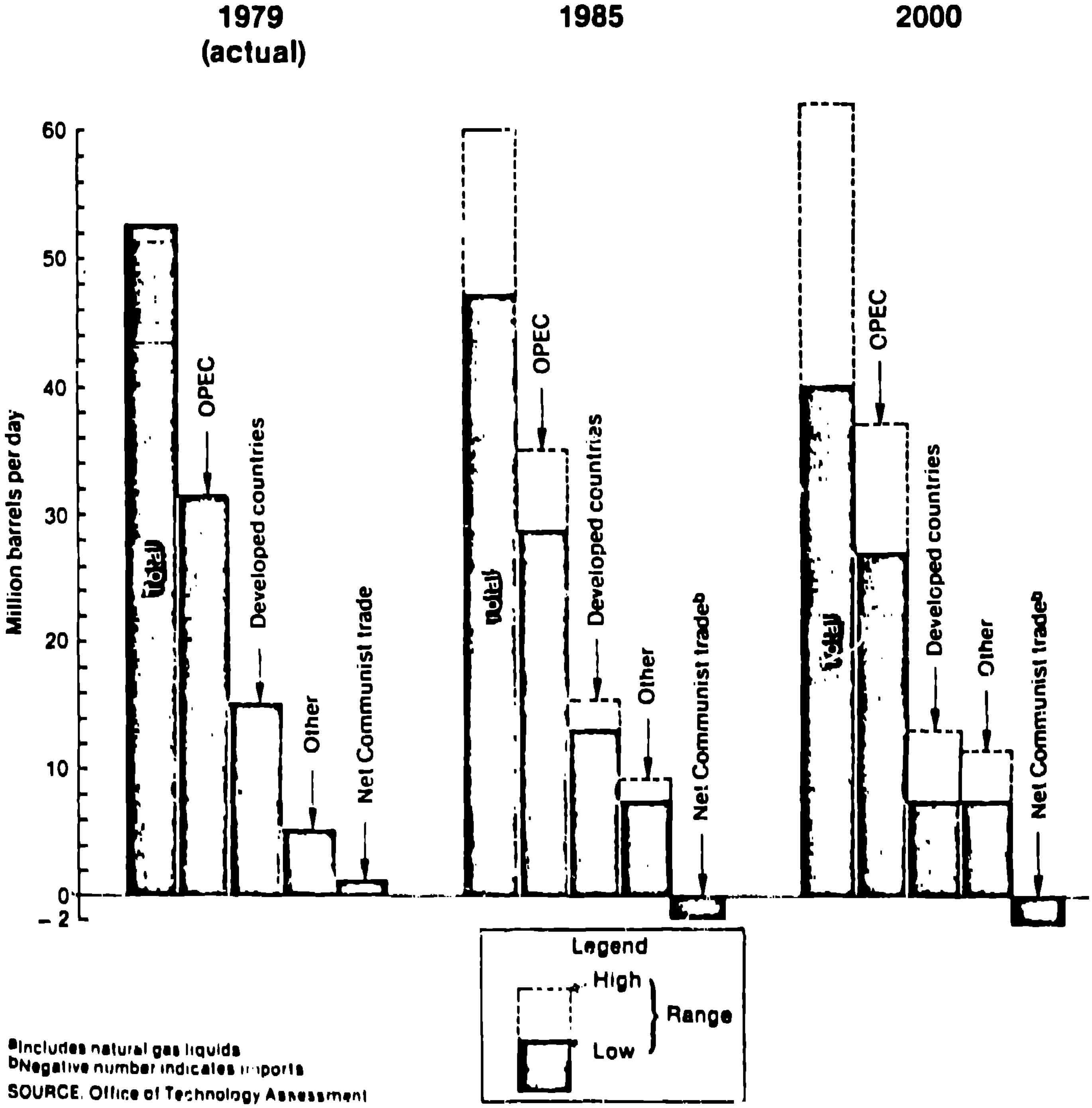
1979 U.S. Energy Consumption (Quadrillion Btu's)



*Excludes 1.8 quads of biomass used in the pulp and paper industry not currently accounted for in DOE statistics

Fig. 3

Projections of Non-Communist World Oil Supplies[a]

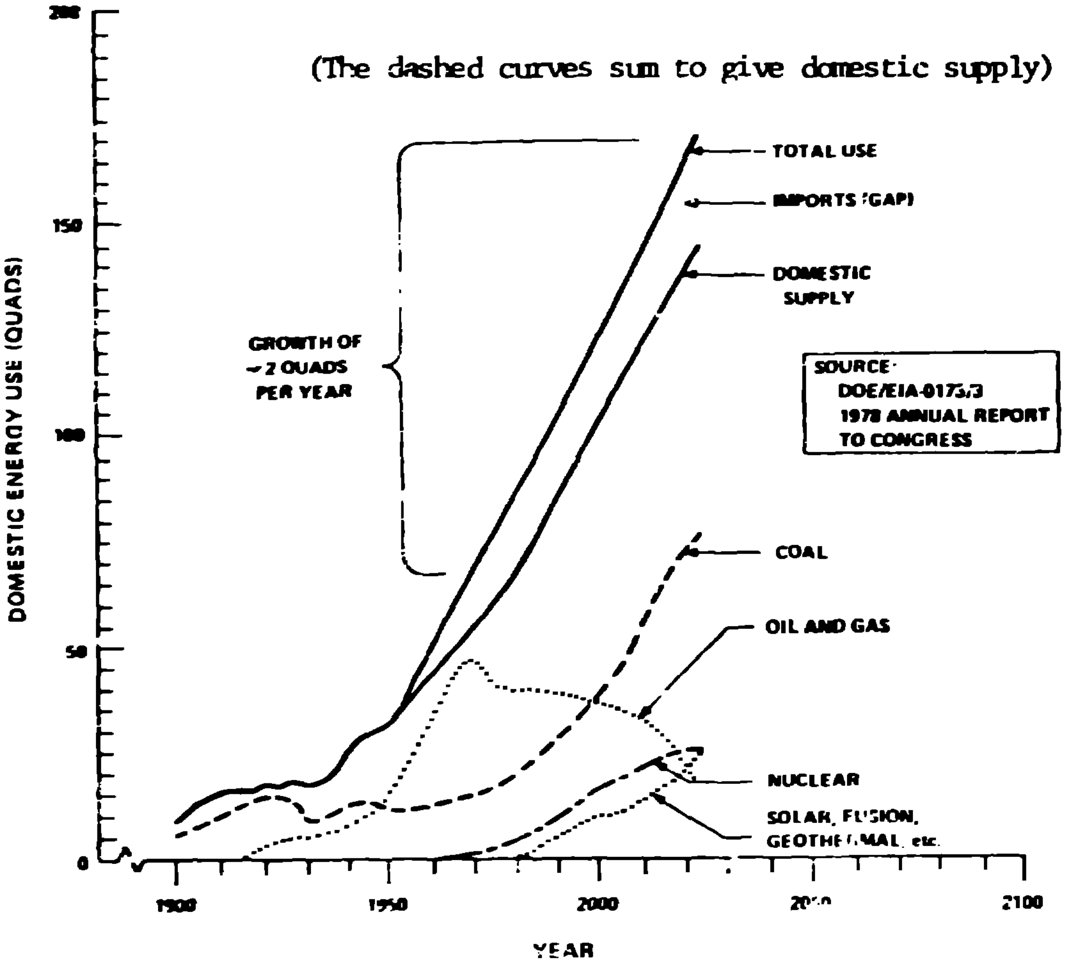


[a] Includes natural gas liquids
[b] Negative number indicates imports

SOURCE: Office of Technology Assessment

Fig.4

U. S. ENERGY SOURCES



(The dashed curves sum to give domestic supply)

SOURCE:
DOE/EIA-0173/3
1978 ANNUAL REPORT
TO CONGRESS

Fig. 5

PARTIAL FLOW CHART OF FUEL PATHWAYS FOR VEHICLES USING ALTERNATIVE FUELS

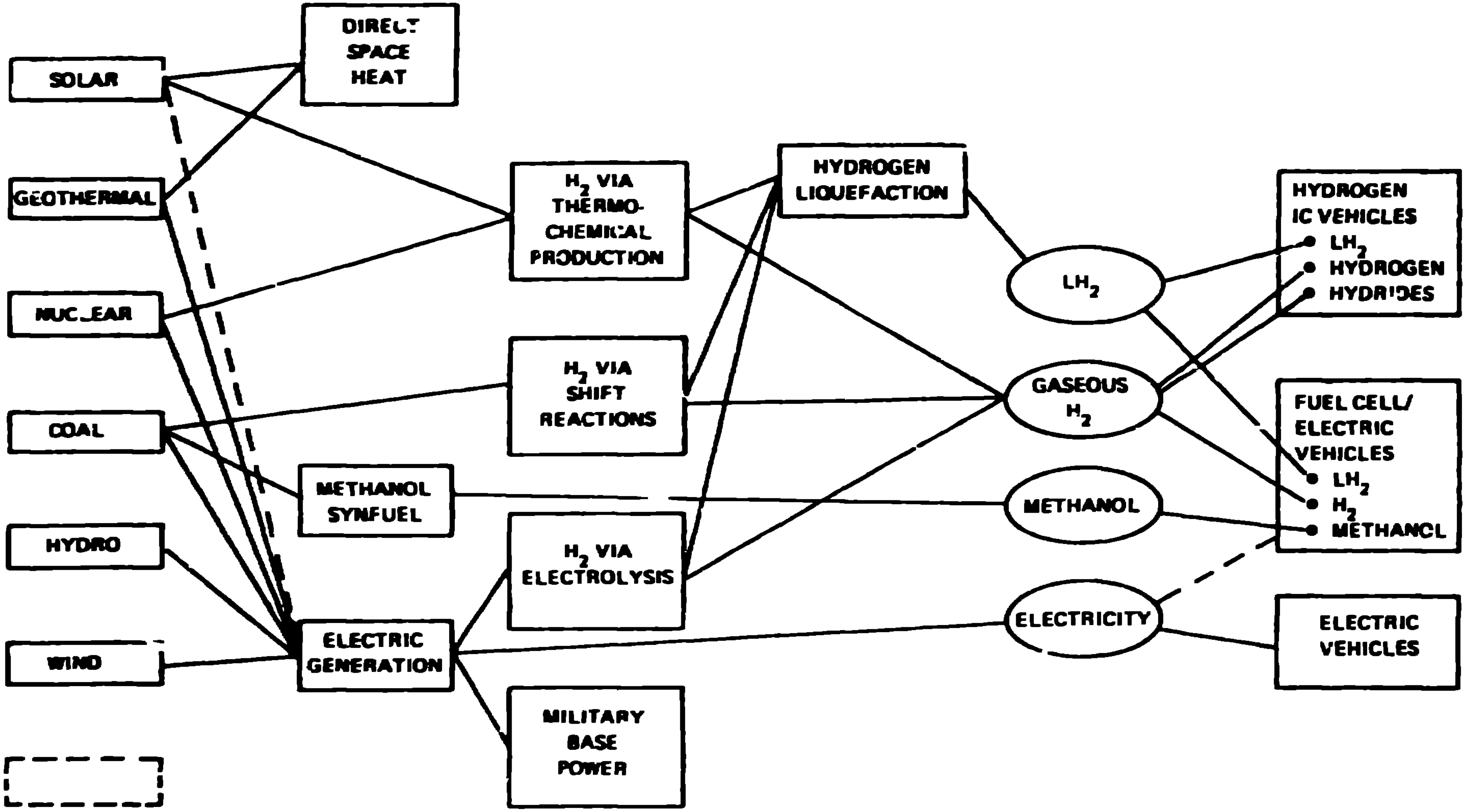
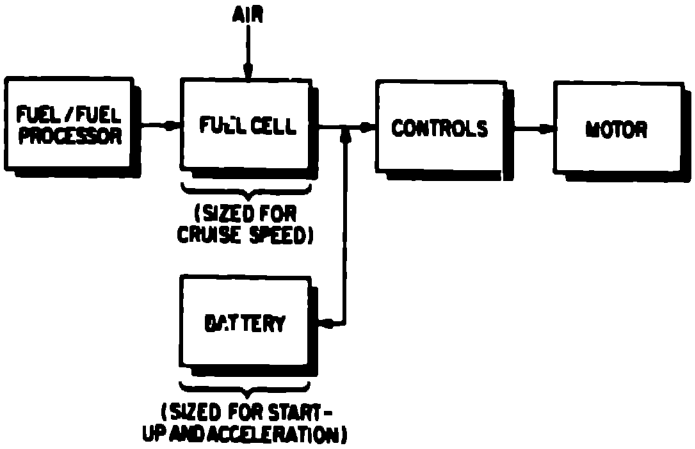
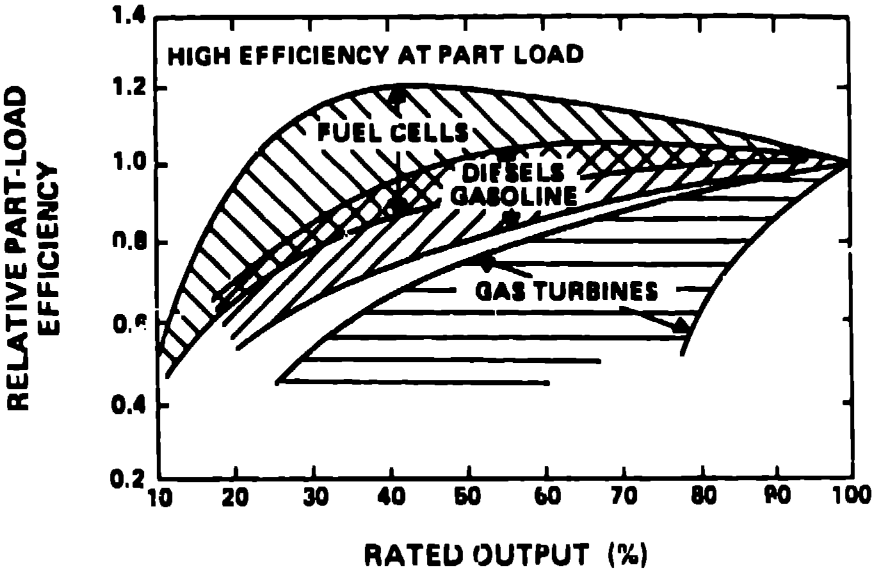


Fig.6

Fuel-Cell/Electric Hybrids and Fuel Cells





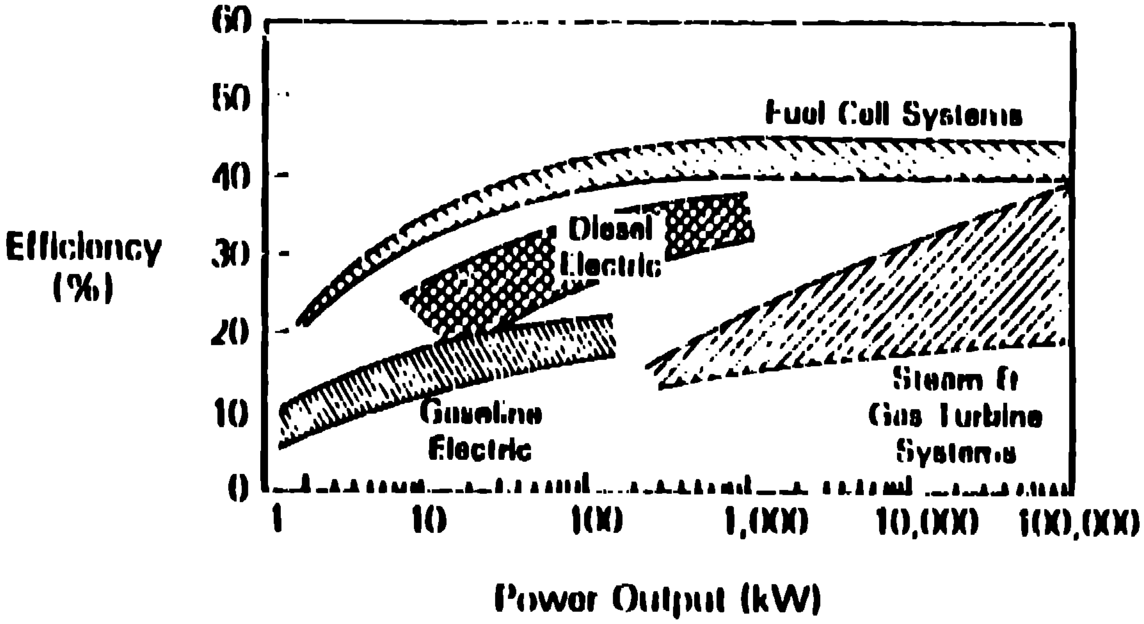


Fig. 7

SYNFUELS, and DATA ON HYDROGEN PRODUCTION