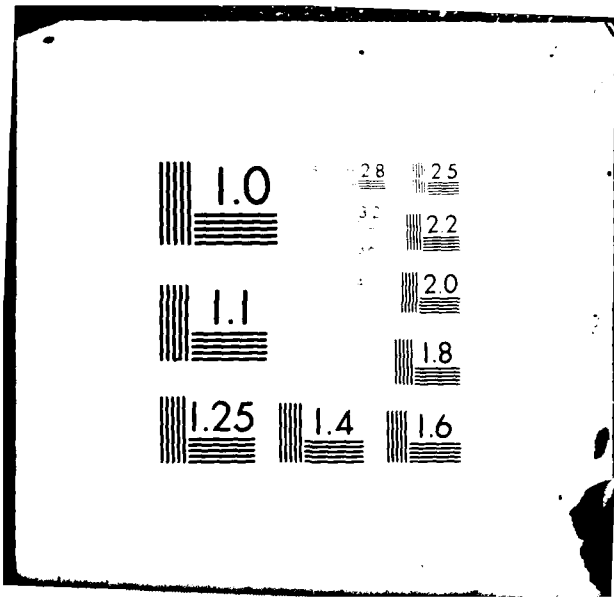


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MOBILITY FUELS FOR THE NAVY

THE OUTLOOK FOR MOBILITY FUELS

A decade ago the Navy experienced few problems with the cost and quality of the fuel its ships and aircraft used. Oil was cheap and high-quality distillate fuel was readily available and could be allowed to replace lower quality ship fuels.

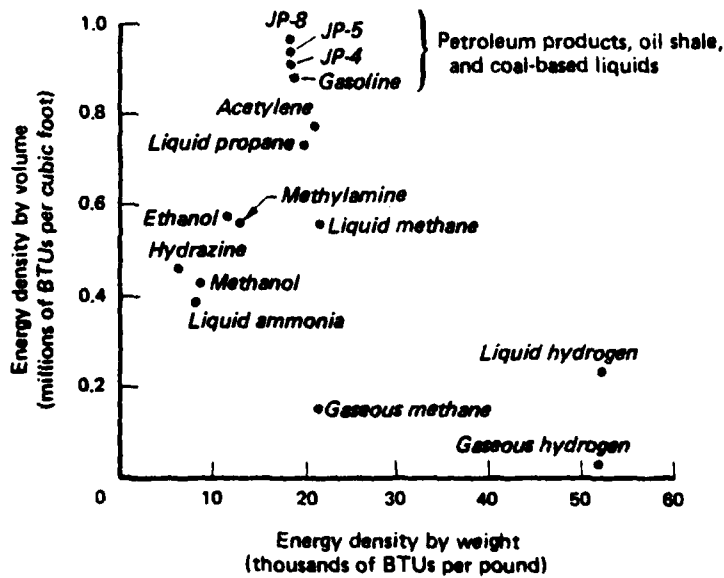
During the 1970s, the situation changed dramatically. Crude oil prices shot up, thereby increasing the relative importance of fuel in operating and support costs. For example, the percentage of direct operating and support costs attributable to fuel rose over the period 1973 to 1980 from about 5 to 33 percent for representative ships and from about 10 to 38 percent for typical aircraft. Also, lower quality crudes became more prevalent on the world market as the search for oil began to include heavier crude oil from new sources, such as Alaska, and from older fields, through use of enhanced recovery techniques. This led to lower fuel quality. Quality here is used to mean the characteristics of a fuel relative to well-refined petroleum products that determine how it burns. The trend toward higher prices and lower quality will continue in the future.

Another major change in Navy fuels will occur with the introduction of synthetics produced from shale, tar sands, and coal over the next few decades. Synfuels will most likely be mixed with petroleum-derived products, so that the chemistry of future fuels will be more complex than it is today. This will have a profound effect on the engines that burn these fuels.

An even more radical change would result from the widespread use of other energy sources. Hydrogen and alcohol are two substances mentioned frequently. Although it would certainly be desirable to supplement dwindling petroleum reserves with other sources of energy, a number of problems would first have to be solved before alternative fuels could be employed on a large scale. Some of these are mentioned in the following section.

ALTERNATIVE MOBILITY FUELS

Many substances have been suggested as candidate fuels to replace oil. Some of the more likely candidates are arranged in figure 1 according to two important properties: energy density by weight and by volume. For ships and aircraft, the amount of energy that can be released from a given volume of fuel is a more relevant parameter than the energy density by weight. This is because these vehicles are primarily volume limited, which means that their drag (and consequently their fuel consumption) is related more to their volume than their weight.



Source: [1]

FIGURE 1: ENERGY DENSITY, PER MASS AND PER VOLUME, OF VARIOUS CANDIDATE FUELS

Hydrogen exhibits by far the greatest energy content by weight of any fuel, because it is so light. Although this characteristic makes it an excellent rocket propellant, that does not imply that it should be the choice for ships or aircraft. Even in liquefied form, its energy density by volume is so low that a hydrogen-fueled vehicle would require a fuel tank four times the size of the tank in a comparable petroleum-fueled vehicle to achieve the same range. Alternatively, the range of the hydrogen burner would be limited to one-quarter the range of the latter.

As figure 1 shows, petroleum-derived fuels and the synthetics have greater energy content per volume than the alternatives. Another advantage of petroleum and close substitutes lies in their greater availability. It is true that both hydrogen and alcohol have potentially abundant resources bases. Hydrogen gas can be released from seawater, and ethyl alcohol (ethanol) can be fermented from grain. However, processes used to produce fuels from these sources are quite energy intensive and are not economically viable at present. Other substances generally are even less readily available, at least in usable form.

There are two more problems that argue against the extensive use of fuels radically different from oil. First, many candidate fuels are difficult to store and handle. Some compounds are very toxic, corrosive, reactive, or explosive, while others, such as liquid hydrogen and liquid methane (essentially liquefied natural gas), are cryogenic

and therefore require special precautions and excessive insulation. Second, widespread use of exotic fuels would require adapting or replacing engines and supporting infrastructure that have been designed for oil.

A recent study of alternative fuels for the maritime industry by the National Academy of Sciences [2] concluded that synfuels, which essentially mimic petroleum, are the only alternatives that are expected to be burned in commercial ships and aircraft powered by gas turbines through the year 2000. The study also predicted that some types of diesels and steam powerplants could potentially employ solid coal or coal-oil slurries. However, because of the advantages of petroleum and synfuels, they will remain the mainstay of both civilian and military fuels through at least the next few decades. Other energy sources are possibilities for a more distant future, when the proper infrastructure has been built up and engines have been adapted.

LOWER FUEL QUALITY

Although the primary Navy fuels during the next few decades will be produced from oil or synthetic substitutes, they will not be identical to today's distillates. The quality of the crude oil on the world market has already begun to deteriorate, due to a change from predominantly sweet (low-sulphur), light crudes to a greater percentage of sour (high-sulphur), heavy crude oil. These lower quality sources require more extensive processing to yield high-quality distillate fuels for ships and aircraft (DFM and JP-5, respectively).

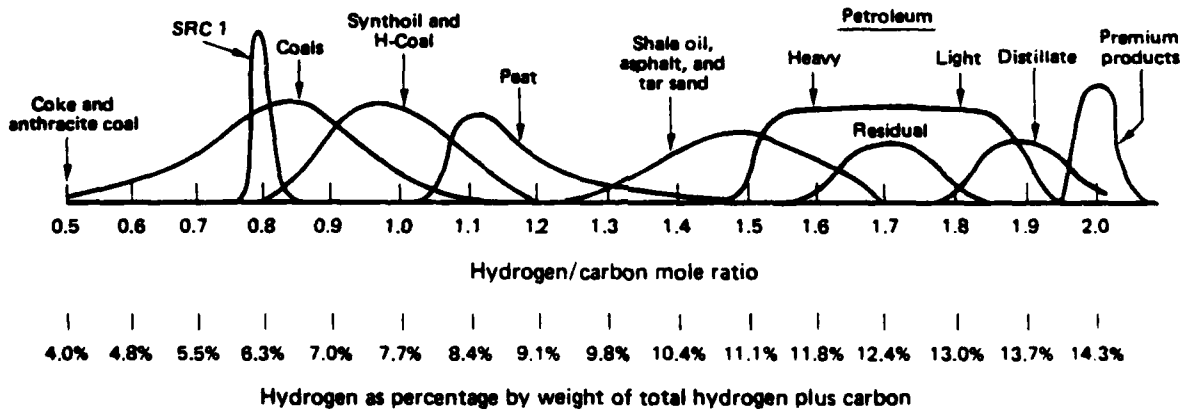
Synthetic crudes obtained from shale oil, tar sands, and coal must be processed even more than residual or heavy oil. This requirement is illustrated in figure 2 by the extent to which the hydrogen-to-carbon mole ratios of these hydrocarbon sources have to be upgraded to provide distillate-grade fuel. Either extensive hydrogenation (hydrogen addition) or pyrolysis (carbon removal) steps would have to be performed, especially to use coal. These completely different processing techniques would, in turn, require substantial technological and economic investments.

Many feedstocks also contain high levels of containments, such as sulphur, ash, nitrogen, and heavy metals. The quantities of these contaminants should be greatly reduced in additional processing operations, because some can poison refinery catalysts, while others cause pollution or contribute to engine corrosion. Although additives are frequently employed to help counteract these and other problems, additives themselves can produce undesirable side effects.

In theory future energy sources could be processed sufficiently to produce high-quality distillates, but in practice this will not be accomplished, due to prohibitive costs. Since the Defense Department accounts for only about 2.5 percent of total U.S. oil consumption, it cannot exert enough influence on the oil market to force producers to provide high-quality fuel at lower prices for the military. In fact, many refineries that now supply military fuels are small and cannot perform the hydrotreating or hydrocracking steps necessary to upgrade

Note:

SRC 1, Synthoil, and H-Coal are names of representative hydrogenation processes that convert coal to a higher grade of solid or to liquids or gases.



Source: [3]

FIGURE 2: HYDROGEN CONTENT OF VARIOUS HYDROCARBON FUEL SOURCES AND PRODUCTS

low-quality sources. Thus, in the future, virtually all fuels will be higher priced but still be lower in quality than they are now.

EFFECTS ON ENGINES

As fuel quality declines, problems with engine maintenance and reliability will increase. Some of the factors that bring this about are discussed briefly here. Many fuels have a prevalence of long-chain hydrocarbons. These chemicals raise fuel viscosity and cause restricted fluid movement and perhaps clogging within fuel filters or small engine passages. Furthermore, these heavy hydrocarbons, along with aromatics and other ring structures, increase corrosion or erosion rates in diesels and gas turbines, because they do not burn completely. When they are present in significant quantities, smoking can occur as well. Contaminants remaining in the fuel after processing can also speed up the rate of corrosion or erosion.

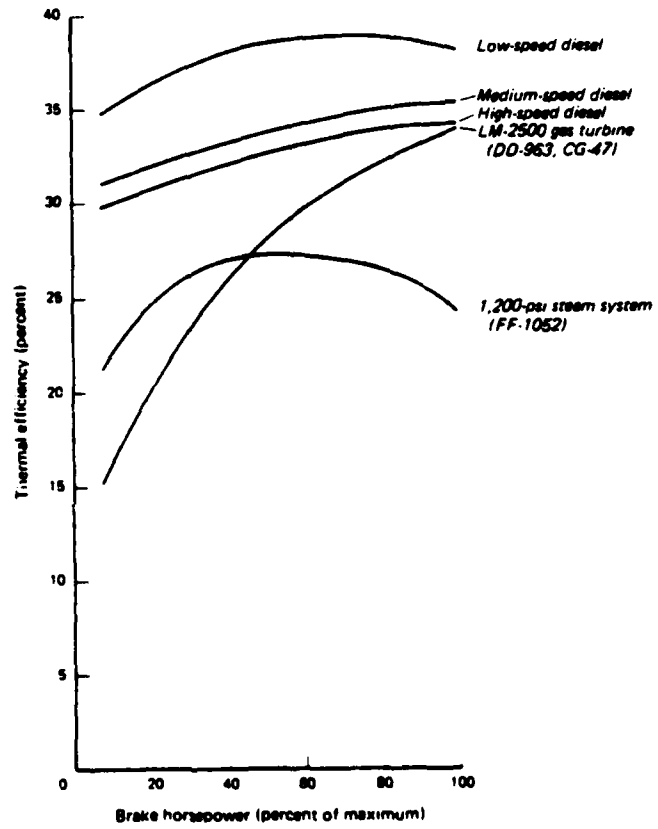
The engines most susceptible to these problems are aircraft gas turbines, because their components are very complex and built to fine tolerances. A study by Pratt and Whitney Aircraft [4], for example, has concluded that commercial gas turbines would probably be severely affected by high aromatics levels in distillate fuels. The study also anticipated that the use of a specific low-quality fuel would increase smoke and emission levels and drastically shorten the life of certain engine components--by about 40 percent for combustor liners and up to 60 percent for turbine airfoils. High levels of sulphur and heavy-metal contaminants would probably result in additional damage.

Most other engine types are less sensitive than gas turbine engines to fuel quality variations. Marine medium- and high-speed diesels can be designed to be somewhat more tolerant of low-quality fuel. Low-speed diesels are substantially more resistant, primarily because their larger combustion zone allows for more complete burning. However, this greater size, in conjunction with increased weight and noise, is disadvantageous, especially for warships. Steam powerplants, in particular those ordered since the mid-1960s, are the least sensitive of all marine engines to low-quality fuels. In fact, existing steam plants could probably be adapted to burn coal-oil slurries, while future ones may even be designed for pulverized or stoker coal.

An additional advantage of diesels and steam plants over gas turbines is their greater fuel efficiency during cruise operations (15 to 20 percent of full load). This is illustrated in figure 3. Diesels are more efficient even at high-power settings.

CHANGES TO FUELS

Interrelationships between the price and quality of fuel have already been noted. Fuel availability is another factor in this equation. The quality demanded by Navy specifications for any fuel type has quite an effect on the amount of that fuel the refiner can produce from a given crude. Exxon has estimated that JP-5 production could be boosted about 40 percent by increasing the freeze point 10°F above the present value of -51°F [6]. Similarly, a 10°F reduction in the flash point from 140°F would allow about a 25-percent increase in yield. Of



Source: [5]

FIGURE 3: THERMAL EFFICIENCIES OF PROPULSION SYSTEMS

course, other considerations, particularly safety, impinge on decisions to change fuel specifications.

As fuel quality declines, both specifications and engine designs will have to be modified to accommodate this change. In addition, specifications have to reflect the fact that fuel chemistry itself is undergoing change, so that new problems have begun to arise. Recently, batches of DFM and JP-5 that passed inspection have been associated with fuel filter clogging and excessive smoking. The mechanisms of these effects are not clearly understood. As synfuels are introduced, the variety of chemicals in fuels will be greatly expanded, and this will cause a new range of problems.

Besides modifying the specifications of current fuels to address the issues of price and availability, other ways might come from changing the types of fuel burned. The Navy could attempt to switch to fuels in civilian use. Number 2 diesel oil is similar to the ship fuel DFM, while Jet A-1 is not unlike the aircraft fuel JP-5. Another approach could involve the use of just one type of fuel for both ships and airplanes. This would reduce storage and handling costs, perhaps enough to offset the modest differential of 5 cents per gallon between JP-5 and DFM that existed in October 1981.

These are just a few of the means to deal with changes in fuels. As fuel quality degrades, the Navy will have to expand its current efforts in this area. A far-reaching research and development effort and prudent planning will hedge against uncertainties in the quality, quantity, and price of future fuels.

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