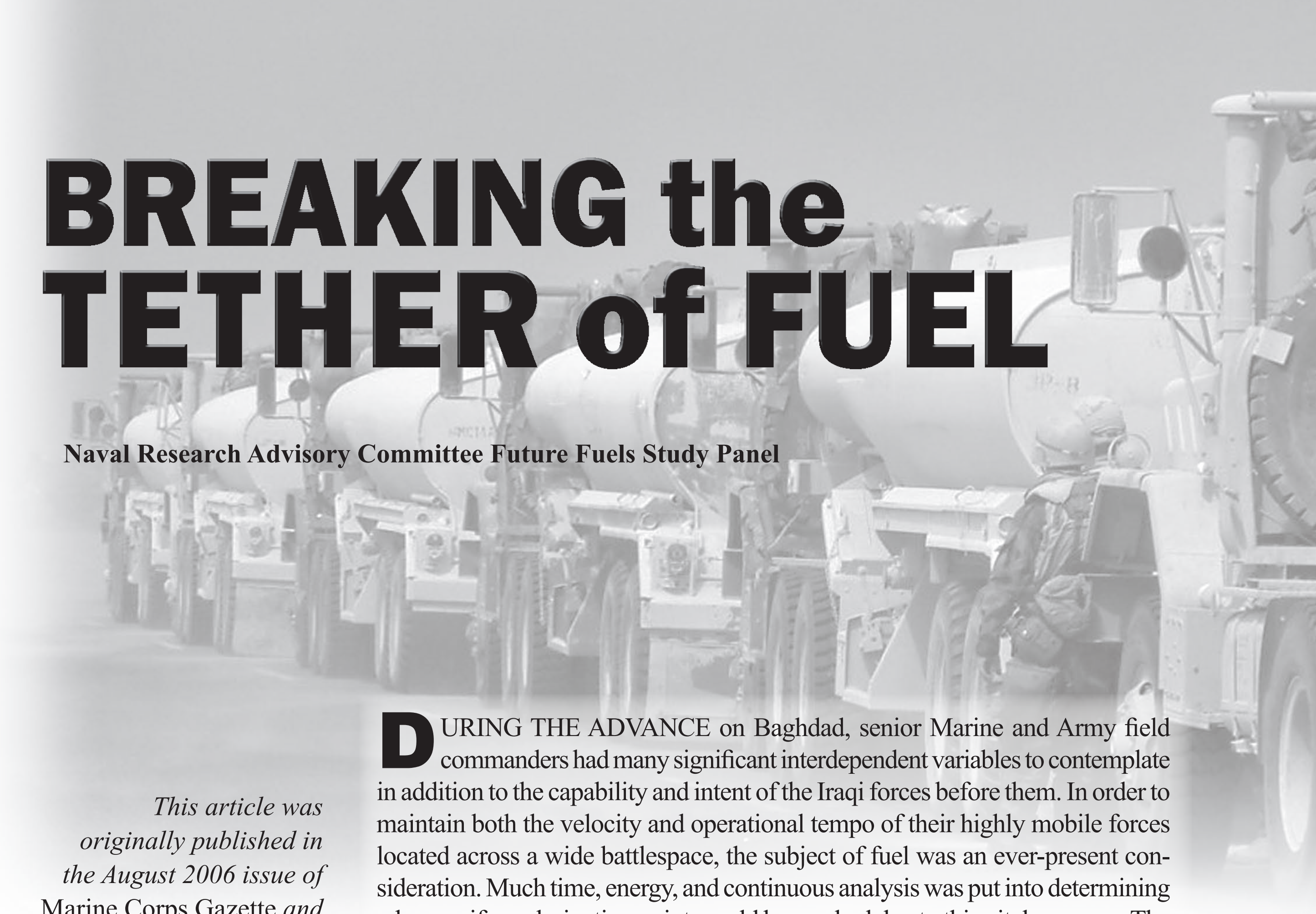
BREAKING the TETHER of FUEL



Naval Research Advisory Committee Future Fuels Study Panel

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The Naval Research Advisory Committee is the senior scientific advisory group to the Secretary of the Navy, the Chief of Naval Operations, the Commandant of the Marine Corps, and the Chief of Naval Research on matters relating to research and development. The committee provides independent problem assessment, recommendations, and/or alternatives to resolving research and development issues and problems within the Navy and Marine Corps. More information about NRAC is available at their web site at <http://www.onr.navy.mil/nrac>.

PHOTO: Fuel trucks belonging to Combat Service Support Battalion -10 convoy north to Iraq during Operation Iraqi Freedom. (DOD)

DURING THE ADVANCE on Baghdad, senior Marine and Army field commanders had many significant interdependent variables to contemplate in addition to the capability and intent of the Iraqi forces before them. In order to maintain both the velocity and operational tempo of their highly mobile forces located across a wide battlespace, the subject of fuel was an ever-present consideration. Much time, energy, and continuous analysis was put into determining when, or if, a culminating point would be reached due to this vital resource. The challenge, "unleash us from the tether of fuel," came from Lieutenant General James N. Mattis, Commanding General, Marine Corps Combat Development Command, and his Operation Iraqi Freedom experience as Commanding General, 1st Marine Division. Mattis' challenge was taken on by John Young, then-Assistant Secretary of the Navy (Research, Development, and Acquisition), who directed that the Naval Research Advisory Committee (NRAC) identify, review, and assess technologies for reducing fuel consumption and for producing militarily useful alternative fuels, with a focus on tactical ground mobility. Technical maturity, current forecasts of "market" introduction, possible operational impact, and science and technology investment strategy were considered.

The most telling characterization of fuel usage came from the Marine Corps 2003 Marine Expeditionary Force (MEF) Study. This study showed that almost 90 percent of the fuel used by MEF ground vehicles would accrue to tactical wheeled vehicles (TWVs), including HMMWVs, 7-ton trucks, and the logistics vehicle system. Moreover, the study showed conclusively that combat vehicles (e.g., M1A1 tanks, light armored vehicles, and assault amphibious vehicles), although fuel guzzlers individually, as a fleet consume a relatively minor fraction of the fuel. Consequently, TWVs became the primary target for fuel economizing.

Findings and Recommendations

The principal findings and recommendations of this study fell in two main time frames—the near term and the mid-to-far term. Each of these is discussed below.

While the panel identified no single near-term action that would achieve the goal of reducing fuel consumption by 50 percent or eliminating the tether of fuel, the panel found a way to improve efficiency (hybrid-electric vehicle technology) and improve fuel utilization on the battlefield (dynamic fuel management). To ensure that operational commanders are better able to achieve their missions, system engineers and designers need to work with military users to better design future vehicles with increased fuel efficiency to maximize combat power. For the Marine Corps to take advantage of these opportunities it must commit to the development of the hybrid-electric architecture for TWVs and the development of sensor and communications systems to enable operational commanders to manage fuel allocation and resupply in real-time during combat operations. Near-term responses for these two areas are as follows.

Figure 1 describes the architecture and benefits of hybrid-electric vehicles. Series hybrid-electric drive vehicles offer the most effective and efficient way to meet the fuel challenge. In contrast with the all-mechanical approach, the series hybrid vehicle architecture utilizes a single engine power source and a single electric generator that provide all power for vehicle transport (propulsion) as well as for auxiliary electric power. Since the hybrid architecture no longer requires use of very heavy mechanical clutches, transmissions, and drivetrains, the engine can operate at an ideal speed independent of vehicle speed, thereby significantly improving fuel efficiency. Improved fuel economy, as much as 20 percent or more, can significantly reduce the existing MEF shortfall in fuel as well as reduce the expeditionary footprint.

A series hybrid-electric architecture of the type described above would provide the greatest flexibility for vehicle design, since much of the space- and weight-consuming aspects of conventional mechanical power distribution systems (i.e., driveshafts and transmission/differential gearboxes), can be eliminated. This is a true open architecture for vehicle designs that has significant potential for improving overall system and passenger survivability. The ability to distribute and locate critical components to less vulnerable positions on the vehicle, combined with the inherently redundant nature of a series hybrid propulsion system, greatly improves overall system survivability. The integration of survivability capsules or "blast buckets" for passengers would also become more achievable. Presently, such an approach becomes operationally unsuitable when placed above a conventional drivetrain. The overall height of the vehicle is a dramatic limitation for both mobility and transportability. But with no intervening shafts and components running the length of the frame, these capsules can be "nested" such that present suitability issues are eliminated. These basic advantages, combined with the significant available excess electrical power to operate active and passive vehicle defense systems, make the hybrid a great choice for improved survivability.

Component elements of this architecture would include primary power sources, such as diesel-electric generator sets and distributed electric motors at the drive wheels for propulsion and braking, as well as onboard weapons systems, sensor systems, and communications systems modules. Such a standardized common power structure would also provide an extensible framework into which new technologies could be integrated as they mature.

- **Vehicle design flexibility**
- **Power distribution flexibility**
  - **traction power**
  - **mission payloads**
  - **mobile electric power**
- **Improved survivability**
- **Inherent modularity improves maintainability and upgradability (readiness)**
- **Design growth to emerging electric sources (e.g., fuel cells)**

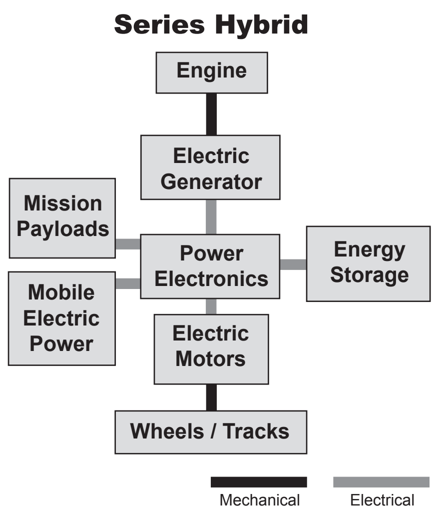

Figure 1. Hybrid-electric vehicle (HEV) architecture.

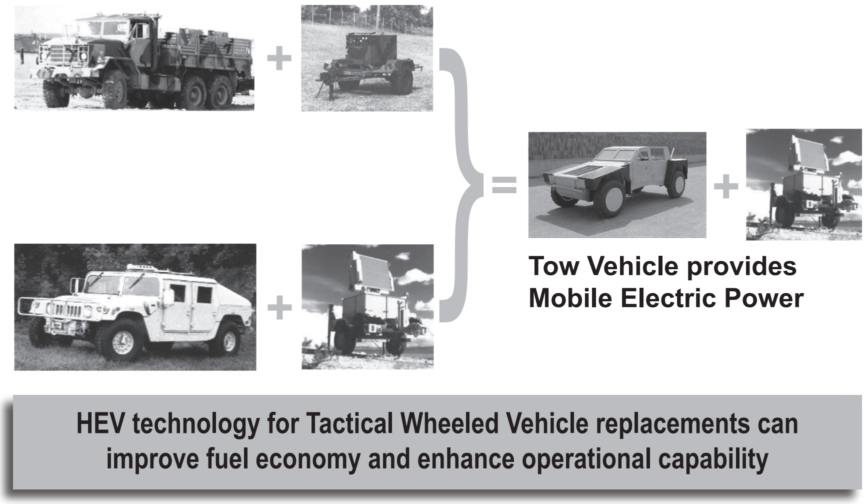

Figure 2. HEV electrical power reduces expeditionary footprint.

This framework would provide much more flexibility in terms of integration of required payload and mission packages. In addition, the series hybrid-electric vehicle architecture provides "exportable" mobile electric power as an integral part of the vehicle using the same common electric power infrastructure.

The fastest growing requirement on the battlefield is electric power. From the power requirements of the individual Marine to the increasing power requirements for sensors, weapons, and armor systems, the need for ubiquitous electric power as the force maneuvers to its objective is burgeoning. The current solution is towed generators that literally double the amount of wheeled equipment that must be accommodated by the logistics system as well as the tactical vehicle fleet. As illustrated in Figure 2, effectively making the towing vehicle the generator, due to its ability to shift its propulsion electric power to conditioned field-usable electric power, cuts the number of systems, simplifying the logistics and operational problem.

Improving the management of fuel resources on the battlefield can lead to a significant extension of operational reach and enhance tactical success. To deliver fuel in the most efficient and timely manner to dispersed units across the battlespace, several fundamental elements of information must be known. These include the location and fuel status of each tactical vehicle, including all types of refueling assets; the location of both friendly and enemy forces; and a detailed knowledge of the terrain in the area of operations. The ability to see in real-time the fuel picture of all assets in the battlespace, combined with the ability to dynamically reallocate petroleum assets as combat operations evolve, can greatly improve the efficient delivery of this scarce and critical resource.

To substantially improve fuel management during combat operations, a combination of new hardware and software tools formed into a system will need to be introduced into the ground combat element. A near-term opportunity is found in the automatic fuel status reporting requirement. Commercial fuel reporting systems like those found in the trucking and railroad industries may serve as an initial model to be adapted for military use. The study panel was made aware of an ongoing project within the Marine Corps that was evaluating a specific technical approach. These activities should be supported and the field of evaluation expanded. Application to all mobility assets of the ground combat element must be included and not limited to only fuel transportation systems. A dynamic allocation system includes the automatic vehicle location/fuel status reporting segment, but goes a considerable step further. A complete fuel management system must include, at minimum, the ability to fuse the friendly and enemy situation, as well as integrate the topography of the area of operations. These are the critical parameters necessary to properly create and evaluate real-time fuel reallocation courses of action. The dynamic allocation system should have the ability to create these initial courses of action for evaluation by the commander and his staff. It is recommended that these two activities not wait to be pursued and fielded until the wider "autonomic logistics" effort is complete, but rather form a key domain element that can be integrated as a module when an autonomic logistics system is eventually fielded.

Alternate Fuels

In the mid-to-far term and separate from the hybrid-electric vehicle discussion above, numerous alternative fuels are being evaluated across the spectrum of power and energy density to satisfy national fuel needs. Fuels may either be derived directly from natural resources (e.g., petroleum, natural gas, or uranium) or by a method of storing energy in a more convenient form (e.g., alcohol from biomass or hydrogen from electrolysis of water). In order to minimize transportation and onboard storage requirements, high-energy density fuels are essential, and as such, stored energy density is a useful metric for comparing various fuels. Since fuels may be solid, liquid, or gaseous, both energy per unit mass and energy per unit volume are important. Figure 3 compares the energy densities for various fuels (relative to that of gasoline). Liquid hydrocarbon fuels, such as diesel, represent the highest energy density fuels available for ground transportation. (A chemist asked to develop the ideal transportation fuel stated that the result would be a liquid hydrocarbon.) Currently, these fuels are obtained from refining (mostly imported) petroleum. This resource faces ever-increasing global demands and is dwindling. Critical U.S. refineries are almost all in coastal regions that are subject to both weather disasters and terrorist actions. Petroleum must be replaced with a suitable substitute. Fortunately, the United States has large deposits of coal and shale oil (see Figure 4).

The United States' future dependence on liquid hydrocarbon fuels without abundant domestic crude oil supplies will not be unprecedented. In pre-World War II Germany, Franz Fischer and Hans Tropsch developed a process to produce liquid hydrocarbon fuel from coal. The so-called Fischer-Tropsch (FT) process supplied a substantial fraction of Germany's transportation fuels after Allied actions threatened the output of the Ploesti oilfields and refineries. South Africa was unable to import crude oil in large quantities during the apartheid era, and consequently, all of South Africa's vehicles have been powered by FT-generated fuels derived from low-grade coal for nearly 50 years. Sasol's FT plant in Secunda, South Africa, produces 150,000 barrels of manufactured fuel per day. FT fuel production is mature technology. China, which also has abundant domestic coal, has purchased essentially the entire world output of coal gasifiers for the past several years to produce fertilizer via the FT process.

The flow chart in Figure 5 shows an integrated gasification FT fertilizer power plant proposed

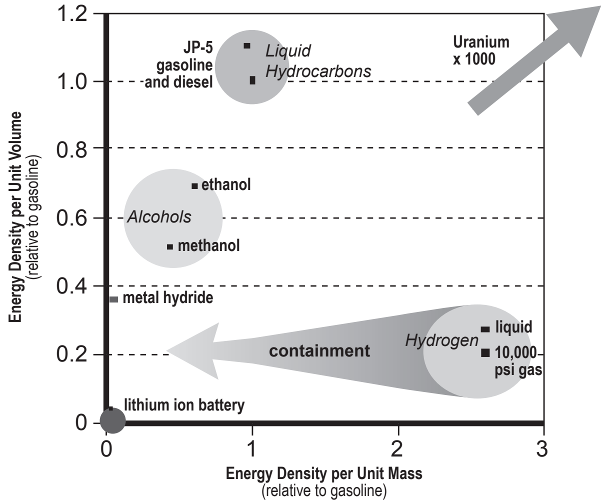

Figure 3. Energy density of fuels.

- **Liquid hydrocarbon fuels have ideal properties and are needed as transportation fuels for the foreseeable future**
  - **Oil-derived fuels primarily imported and will become increasingly scarce**
  - **Existing refinery infrastructure**
    - **Predominantly coastal and vulnerable**
    - **Operating at capacity**
- **Alternative: Fuel efficiency, domestic resources, interior production**

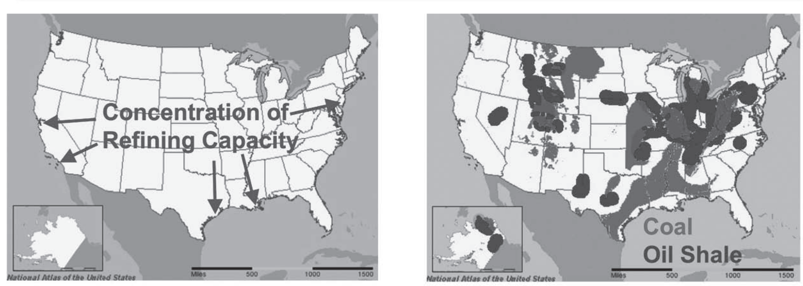

Figure 4. Mid-to-far term fuel strategy.

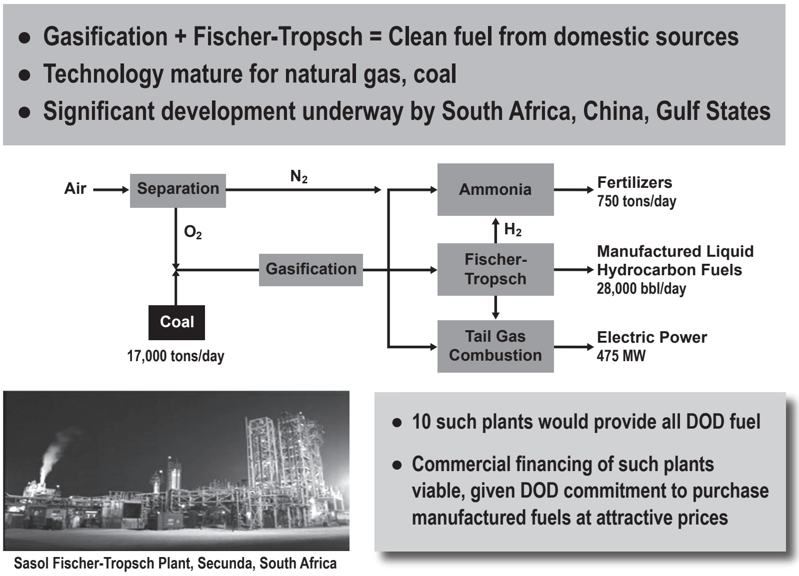

Figure 5. Manufacturing fuel to spec.

by Baard Generation (a 20-year-old producer of small- to medium-scale project-financed power plants). From 17,000 tons per day of low-grade coal, the plant would produce 28,000 barrels per day of liquid hydrocarbon fuel, 750 tons per day of ammonia, and 475 megawatts of net electrical power. Importantly, the gasification process serves to separate the sulfur and heavy metal contaminants found in low-grade coal (which makes it undesirable as a raw fuel). Thus, the liquid hydrocarbon fuels produced from coal via gasification and the FT process are intrinsically clean. Use of such fuels will minimize emissions (sulfur and particulates) from internal combustion engines.

The Baard proposed plant described above would cost approximately $3 billion and employ about 200 full-time staff. Baard envisions building such plants near rich low-grade coalfields, areas that are typically economically depressed since emission controls have made such coal economically unattractive for power production. Although such plants are relatively small, it would only take about 10 of them to supply all of the Department of Defense's (DOD's) liquid hydrocarbon fuel requirements. Baard claims that commercial financing of such plants will be possible, with adequate internal return on investment and revenue/debt margins. This change in posture need not be funded by the government (and indeed, to realize the full potential of this approach, the government could not afford to capitalize the needed changes in infrastructure); the rising price and increasing scarcity of crude oil will motivate commercial firms to invest in manufactured fuel infrastructure. DOD could, however, catalyze commercial development of this highly desirable infrastructure by making a long-term commitment to purchase liquid hydrocarbon fuels at attractive prices.

Summary

In response to Mattis' challenge to unleash us from the tether of fuel, the panel determined that the tether is still there but has found a way to lengthen it through hybrid-electric vehicle technology and untangle it using dynamic fuel management. Hybrid-electric drive vehicles offer the most effective and efficient way to accomplish Mattis' goal. Improved fuel economy, as much as 20 percent or more, can significantly reduce the existing Marine Expeditionary Force shortfall in fuel as well as reduce the expeditionary footprint. From the perspective of the farther term, the United States is in the fortunate position of having domestic resources that will, with the development of appropriate infrastructure, enable the continued use of liquid hydrocarbon fuels, without the economic and security disruptions attendant with the import of crude oil as the primary feedstock. DOD needs to commit now to procuring manufactured liquid hydrocarbons for the long term as an assured supply of fuel, at lower than current market price to encourage commercial financing, to push technology, and to help motivate the building of the necessary manufacturing and distribution infrastructure. ***MR***

Authors' Note: Statements, opinions, recommendations, and/or conclusions contained in this article are those of the NRAC panel and do not necessarily represent the official position of the U.S. Navy, U.S. Marine Corps, or the DOD.