Skip all front matter: Jump to Page 1

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Alternative Fuels
for Military Applications

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Cover photo by Tom Reynolds: X-35A Joint Strike Fighter being refueled by a KC-135 tanker.

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Summary

The U.S. Army, Navy, Marine Corps, and Air Force have all expressed a clear interest in being early users of alternative fuels in their tactical weapon systems. Doing so would supplement the services' current use of gasohol and biodiesel in administrative and other nondeployable vehicles. Congress has, as yet, not required the U.S. Department of Defense to use alternative fuels in tactical weapon systems. Nor has the Secretary of Defense issued any directives to this end. Rather, the interest in pursuing alternative fuels centers primarily on the services.

Each of the services has established programs geared toward reducing dependence on the use of fossil fuels in tactical weapon systems, such as aircraft, combat ships and vehicles, and supporting equipment. Since at least 2000, the Air Force has played the lead role in Department of Defense efforts to evaluate and test alternative fuels for military applications. It aims for the Air Force to *be prepared* by 2016 to acquire amounts of alternative fuel blends sufficient to meet 50 percent of its domestic requirements for aviation fuel. Air Force policy clearly specifies that this must be done in a manner that is cost-competitive and emits fewer greenhouse gases than fuels produced from conventional petroleum. Moreover, the alternative fuel component of the blend must be derived from domestic sources.

In October 2009, Navy Secretary Ray Mabus committed the Navy and Marine Corps to "creating a *Green Strike Group* composed of nuclear vessels and ships powered by biofuels" by 2012 and deploying it by 2016. By 2020, at least 50 percent of the energy the Navy consumes is to come from alternative sources.

With regard to the Army, it is participating with the other services in developing a fuel qualification process for the Department of Defense. It is also evaluating the performance of alternative fuels in combat vehicles and tactical power generators. The Army has not yet formally established goals for the use of alternative fuels in its combat systems.

If the services are indeed to use alternative fuels in tactical weapon systems, these fuels must be able to substitute for one or more of the three petroleum-based distillate fuels that currently support the majority of military operations: the two military jet fuels, JP-8 and JP-5 ("JP" stands for "jet propellant"), and naval distillate (F-76). From the perspective of *technical* viability, a number of alternative fuels can meet this

requirement. But uncertainties remain regarding their *commercial* viability—namely, how much these fuels will cost and what impact they may have on the environment, particularly in terms of greenhouse gas emissions. Despite these unknowns, the Department of Defense is currently directing substantial resources—both dollars and personnel—to testing and certifying alternative fuels for use in tactical systems. The services, the Defense Advanced Research Projects Agency (DARPA), and the Defense Logistics Agency Energy (DLA Energy) are also sponsoring and conducting technology-development activities aimed at identifying advanced methods of producing alternative fuels.

In this context, the Duncan Hunter National Defense Authorization Act for Fiscal Year 2009 (P.L. 110-417, Sec. 334) contains provisions (see Appendix A) calling for the Secretary of Defense to select a federally funded research and development center (FFRDC) to conduct a study on the use of alternative fuels in military vehicles and aircraft. This study was to examine several specific topics:

- Opportunities to produce alternative fuels in a way that reduces lifecycle greenhouse gas emissions, including the use of clean energy alternatives such as nuclear, solar, and wind energies for powering the conversion processes.
- The military utility of concepts for production of alternative fuels in or close to the theater of military operations compared to domestic production.
- The goals and progress of research, testing, and certification efforts by the Department of Defense related to the use of alternative fuels in military vehicles and aircraft.
- The prospects for commercial production of nonpetroleum military fuels.

Responding to Congress, the Department of Defense asked the RAND National Defense Research Institute, an FFRDC, to conduct an examination of alternative fuels for military applications. To answer the specific topics raised by Congress, RAND researchers focused on alternative fuels that might be candidates for military applications within ten years, with emphasis on those that either have been or are currently the focus of research, testing, and certification within the department. The RAND team examined economic viability, technical readiness for commercial production, lifecycle greenhouse gas emissions, and approaches that could be used to reduce those emissions. This examination benefited from recent studies completed by RAND and the National Academy of Sciences.

For its review of concepts for producing alternative fuels in theater, the RAND team drew on the experience of RAND defense analysts and active-duty military officers working as RAND fellows. To analyze the Defense Department's and private sector's efforts in the area of alternative fuels, team members reviewed available documentation and technical reports; contacted key firms; and conducted in-depth interviews with representatives of DARPA, DLA Energy, and relevant organizations in each of the services.

The findings and recommendations presented in this report are those of the research team. In some cases, these findings conflict with views held and actions taken by the Department of Defense organizations involved in alternative fuel research, testing, and certification.

Opportunities to Produce Alternative Fuels with Lower Greenhouse Gas Emissions

Fischer-Tropsch fuels are the most promising near-term options for meeting the Department of Defense's needs cleanly and affordably. The Fischer-Tropsch (FT) method was invented in Germany in the 1920s. It can produce alternative liquid fuels that can substitute for petroleum-derived civilian and military fuels, including JP-8, JP-5, and naval distillate. The method accepts a variety of feedstocks. For example, a commercial facility operating in South Africa uses coal, one operating in Qatar uses natural gas, and a small facility starting up in Germany will use biomass.

Blends of up to 50 percent FT-derived jet fuel and petroleum-derived jet fuel have been certified for use in commercial aircraft. Ongoing work by the services strongly suggests that appropriately formulated FT fuel blends can be safely used in tactical military systems as well.

Both coal and biomass are abundant in the United States. Together, they are sufficient to support a multimillion-barrel-per-day alternative fuel industry based on FT fuels. But if FT fuel production is to occur without compromising national goals to control greenhouse gas emissions, the following must hold:

- For **biomass-derived FT fuels**, the biomass feedstock must be produced in a sustainable manner; specifically, its production should not be based on practices that lead to sizable emissions due to direct or indirect changes in land use. If this is achieved, lifecycle greenhouse gas emissions can be near zero.
- For **coal-derived FT fuels**, carbon dioxide emissions at the FT fuel production facility must be captured and sequestered. If this is achieved, lifecycle emissions can be in line with those of petroleum-derived fuels.
- For **FT fuels derived from a mixture of coal and biomass**, carbon dioxide capture and sequestration must be implemented. The biomass must also be produced in a sustainable manner. If this is achieved, lifecycle emissions can be less than half those of petroleum-derived fuels. In particular, a feedstock consisting of a 60/40 coal/biomass blend (by energy) should yield alternative fuels with lifecycle greenhouse gas emissions that are close to zero.

The above approaches can result in FT fuels with lifecycle greenhouse gas emissions that are less than or equal to those of their petroleum-derived counterparts, and thereby fuels that are eligible for government purchase per the provisions of Section 526 of the Energy Independence and Security Act of 2007.

Considering economics, technical readiness, greenhouse gas emissions, and general environmental concerns, FT fuels derived from a mixture of coal and biomass represent the most promising approach to producing amounts of alternative fuels that can meet military, as well as appreciable levels of civilian, needs by 2030. But whether this technology will reach its potential depends crucially on gaining early production experience—including production with carbon capture and sequestration—in the United States. At present, no agency of the U.S. government has announced plans to promote early commercial use of FT fuels derived from a mixture of coal and biomass.

It is highly uncertain whether appreciable amounts of hydrotreated renewable oils can be affordably and cleanly produced within the United States or abroad. Hydrotreated renewable oils are produced by processing animal fats or vegetable oils (from seed-bearing plants such as soybeans, jatropha, or camelina) with hydrogen. Various types of algae have high oil content and are another possible source of oil for hydrotreatment. Fifty-fifty blends of hydrotreated oils have already been successfully demonstrated in flight tests sponsored by the commercial aviation industry. Laboratory analyses and testing strongly suggest that hydrotreated renewable oils can also be formulated for use in the Department of Defense's tactical weapon systems. Technical viability is not an issue.

The problem lies in uncertainties regarding production potential and commercial viability, especially affordability and lifecycle greenhouse gas emissions. Animal fats and other waste oils may offer an affordable low-greenhouse-gas route to hydrotreated renewable oils. But these fats and waste oils are also traditionally used in other nonfuel applications. Because the supply of these feedstocks is limited, substitutes would need to be found for use in these other applications. These substitutes may cause additional greenhouse gas emissions. Production potential is also a clear issue with animal fats and waste oils: The available supply of these feedstocks will likely limit production to no more than 30,000 barrels per day.

With regard to feedstock vegetable oils, to keep lifecycle greenhouse gas emissions at levels lower than those of petroleum-derived fuels, these oils must be derived from crops that do not compete with food production and minimize nonbeneficial direct and indirect changes in land use. Jatropha and camelina are often mentioned as ideal plants to meet these requirements, but there exists little evidence to back these claims. Even if low-greenhouse-gas approaches can be established and verified, total fuel production is likely to be limited. Producing just 200,000 barrels per day (about 1 percent of U.S. petroleum consumption) would require an area equal to about 10 percent of the croplands currently under cultivation in the United States.

Advanced approaches, such as those using algae as a feedstock, may yield hydrotreated renewable oils without the limitations and adverse land-use changes associated with seed oils. But all of these advanced approaches are in the early stages of the development cycle. Large investments in research and development (R&D) will be required before confident estimates can be made regarding production costs and environmental impacts.

Considering (1) the very limited production potential for fuels derived from animal fats and waste oils, (2) the highly uncertain prospects for affordable, low-greenhouse-gas fuels derived from seed crops, and (3) the early development status of algae-based concepts, hydrotreated renewable oils do not constitute a credible, climate-friendly option for meeting an appreciable fraction of military fuel needs over the next decade. Because of limited production potential, fuels derived from animal fats, waste oils, and seed oils will never have a significant role in the larger domestic commercial marketplace. Algae-derived fuels might, but technology development challenges suggest that algae-derived fuels will not constitute an important fraction of the commercial fuel market until well beyond the next decade.

Nuclear, solar, and wind energy technologies may offer important benefits in the production of military, as well as civilian, alternative fuels. Nuclear, wind, and solar energy offer electric power without emitting appreciable amounts of greenhouse gases. For the near- and mid-term alternative fuel options (i.e., hydrotreated oil from animal fats and vegetable oils, and FT liquids), electric power is not an important input to the production process. Electric power, however, can be used to produce hydrogen via electrolysis of water, and hydrogen *is* an important input. For example, hydrogen produced from nuclear or renewable power can be used to hydrotreat renewable oils produced from seed crops. If sufficient hydrogen is available, nearly all of the carbon in the coal or biomass feedstock to a Fischer-Tropsch plant would end up in the fuel products and not in the air, eliminating the need to capture and sequester carbon dioxide. In addition, the use of hydrogen in an FT plant could nearly triple yields of liquid fuels.

For hydrotreated oil from algae, a longer-term option, climate-friendly sources of electric power could be used directly in the processes of cultivating the algae and extracting the oil, because electricity is required for mixing, circulation, and management of water and nutrients.

But the beneficial hydrogen derived from nuclear, solar, and wind energy technologies is not an economically viable option over the near- to mid-term. The trade-off is cost: Producing hydrogen from clean sources in capacities large enough to gain the benefits described above requires very large amounts of generating capacity and would significantly increase the costs of producing liquid fuels. Considering the importance of reducing greenhouse gas emissions during the process of generating electric power for traditional uses, investments in climate-friendly power generation are already likely to be very high over the coming decades. In this context, the additional investment required to construct large amounts of generating capacity dedicated to producing alternative fuels is probably not feasible. For at least the next two decades, it is highly unlikely that hydrogen from nuclear or renewable electric-generating technologies will be a commercially viable option for producing alternative fuels.

The Military Utility of Forward-Based Alternative Fuel Production

Concepts for forward-based alternative fuel production do not offer a military advantage. Concepts have been proposed for alternative fuel production systems that could be deployed in forward operating bases or within a theater of operations. Any scheme for the production of military fuels requires a source of carbon, which can be supplied from locally available feedstocks or from military wastes. One approach would be to build an alternative fuel plant on a large barge that could be towed to a location near or within a theater of operations and connected to an undersea natural gas deposit. But this and similar floating concepts would suffer operational problems—such as securing a feedstock supply and starting up the process—that would limit their utility to long-duration deployments. In certain cases, they would require a dedicated defense. Finally, there is no evidence that a floating production plant would be less expensive than using either Navy oilers or commercial tankers to deliver finished fuel products to a forward-based oil depot.

A second set of concepts would have small-scale alternative fuel production units co-located with tactical units. From a strictly technical perspective, a number of the concepts currently being supported by Defense Department funds may be viable. But from a military utility perspective, any concepts that require delivery of a carbon-containing feedstock appear to place a logistical and operational burden on forward-based tactical units that would be well beyond that associated with delivery of finished fuels. The alternative of obtaining carbon from low-concentration sources such as the carbon dioxide in air or water would be technically daunting and prohibitively expensive.

Compact fuel production systems that would use carbonaceous military wastes are now being developed. These systems could meet a small fraction of the energy needs of a forward-based unit. They do not offer a compelling military benefit but may be a cost-effective approach to managing wastes. However, considering the complexity of equipment required to produce liquid fuels meeting military specifications in this way, these small waste-to-energy concepts are better suited for use in appropriately modified tactical power generators, as opposed to producing fuels such as JP-8 for high-performance weapon systems.

In short, traditional systems, in which fuel is produced outside the theater and then shipped in, continue to be the most practical in terms of military utility.

Goals and Progress of the Military Departments

Defense Department goals for alternative fuels in tactical weapon systems should be based on potential national benefits, since the use of alternative, rather than petroleum-derived, fuels offers no direct military benefits. While Fischer-Tropsch fuels and hydrotreated renewable fuels are no less able than conventional fuels to meet the Defense Department's needs, they offer no particular military benefit over their petroleum-derived counterparts. For example, even if alternative fuels can be produced at costs below the prevailing costs for conventional fuels, they will be priced at market rates. Also, we are unable to find any credible evidence that sources to produce jet or naval distillate fuel will run out in the foreseeable future. If conflict or a natural disaster were to abruptly disrupt global oil supplies, the U.S. military would not suffer a physical shortage. Rather, the resulting sharp increase in world prices would cause consumers around the world to curb use of petroleum products. Less usage would ensure that supplies remained available. As long as the military is willing to pay higher prices, it is unlikely to have a problem getting the fuel it requires. If problems do arise, the Defense Production Act of 1950 (P.L. 81-774) contains provisions for performance on a priority basis of contracts for the production, refining, and delivery of petroleum products to the Defense Department and its contractors.

Nevertheless, despite the absence of a specific military benefit, there are nationally important benefits to be gained from the use of alternative fuels. If the Department of Defense were to encourage early production experience, government decisionmakers, technology developers, and investors would obtain important information about the technical, financial, and environmental performance of various alternative fuel options. If favorable, that information could lead to a commercial alternative-fuels industry producing strategically significant amounts of fuel in the United States. Once established, a large, commercially competitive alternative fuel industry in the United States and abroad would weaken the ability of the Organization of the Petroleum Exporting Countries to assert its cartel power. Lower world oil prices would yield economic benefits to all fuel users—civilian and military alike. Lower prices would also decrease the incomes of "rogue" oil producers, and thereby likely decrease financial support to large terrorist organizations such as Hamas and Hizballah.

Because alternative fuel production would probably occur in diverse locations throughout the United States, a domestic alternative fuel industry would additionally improve the resilience of the petroleum supply chain, especially against natural disasters such as hurricanes.

Certain alternative fuels that can have military applications can be produced in ways that yield greatly reduced greenhouse gas emissions, in comparison with their petroleum-derived counterparts. If climate-friendly alternative fuels were available, the Department of Defense could reduce the greenhouse gas emissions from the operation of its tactical vehicles, aircraft, and supporting equipment. However, fuel use in tactical systems represents less than 1 percent of U.S. energy-related emissions of greenhouse gases. The greater benefit, again, would result if early use of alternative fuels by the Defense Department were to accelerate the use of alternative fuels in the much larger civilian marketplace.

Current efforts by the services to test and certify alternative fuels are far outpacing commercial development. With the intention of increasing their usage of alternative fuels in the coming years, the services have a range of efforts underway to test and certify FT liquids and hydrotreated renewable oils for use in tactical systems. Yet, given where industry is in the process of developing these fuels, some of these efforts—at least at the current levels of funding and personnel—may be premature.

Testing and certification of Fischer-Tropsch fuels. Commercial production of FT fuels is well established in South Africa, Qatar, and Malaysia. By 2012, global production is scheduled to be more than 350,000 barrels per day. In the United States, five plants are in the advanced stages of planning; three would use waste biomass and two would use a combination of coal and biomass. If these plants are constructed, they will be able to produce about 60,000 barrels per day of FT liquids that could be blended with military jet fuel and naval distillate. Developers of all five projects claim that they will be able to keep lifecycle greenhouse gas emissions below those of petroleum-derived fuels. But as of November 2009, none of these plants have begun final design, and most have not begun front-end engineering design.

Considering that commercial aircraft are now certified to use 50/50 blends of FT fuels, that substantial FT production is currently taking place abroad, and that the services have already undertaken extensive certification efforts, it makes sense for the Department of Defense to finish certifying the use of 50/50 blends. Completing this effort will provide additional flexibility in purchasing jet fuel in certain locations. But given the extremely small quantity of FT fuels available on the global market, there is no reason to extend this work to blends with a higher FT fuel content.

Testing and certification of hydrotreated renewable oils. Algae-derived fuel is a research topic, not an emerging option that the military can use to supply its operations, and cultivating seed oils affordably without adverse effects on climate change has yet to be demonstrated. Because the prospects for appreciable domestic production of hydrotreated oils over the next decade are so uncertain, the Department of Defense should discontinue large-scale testing and certification efforts (other than laboratory R&D). Given the growing market for these fuels in commercial vehicles and aircraft, there is no benefit to the department or the nation in proving that they can be formulated to fuel the high-performance engines in military tactical systems. If, after a few years, uncertainties regarding algae-derived fuels or seed oils are resolved, a military certification program for an alternative fuel blend may be appropriate, but at fuel blend limits that are consistent with anticipated commercial blend levels, which are highly likely to be well below 50 percent over at least the next decade.

If the Department of Defense continues to support the development of technology to produce alternative fuels, it should consider consolidating and strengthening management and shifting support to longer-term goals. Much of the Defense Department's work to develop alternative fuel production technologies is based on the unfounded assumption that the military will gain a direct benefit from having access to alternative fuels that can substitute for military fuels. Consequently, the department and Congress need to decide whether defense appropriations should continue to support activities focused on developing technology to produce alternative fuels. If Defense Department funding is phased down, consideration should be given to providing the Department of Energy with adequate resources to continue support for the more meritorious projects within the current Defense Department portfolio.

If the decision is made to continue to use defense funds for R&D of alternative fuels, the roles of the Departments of Defense and Energy should be clarified. With regard to developing technology for alternative transportation fuels, advanced technology that works for the large civilian markets for diesel and jet fuel will also work for the much smaller demand for military jet and naval fuels. For this reason, Defense Department efforts need to be integrated with the overall national energy R&D program for transportation fuels.

The Defense Department's current R&D efforts are overly focused on short-term gains, foregoing the work required for long-term progress. For the most part, the Defense Department's efforts to develop the technology to produce alternative fuels consists of a collection of independent projects, each focused on demonstrating the technical viability of a single concept for producing military fuels. Demonstrating technical viability is easy; consider the history of photovoltaic power and fuel cells. But demonstrating affordable and environmentally sound production—i.e., commercial viability—is difficult, requiring investments in exploratory and applied research dedicated to understanding fundamental problems and developing sound solutions. If the Department of Energy is unwilling to provide adequate support to applied and fundamental research in program areas in which DARPA and the services are investing, the Department of Defense should restructure or expand its efforts to create a proper balance between shorter-term engineering development projects and research directed at long-term progress.

Improved management of the alternative fuel R&D program is key to success. Alternative fuel production generally involves numerous process steps, many of which are highly complex. The construction costs for a single commercial facility can range from hundreds of millions to billions of dollars. But currently, none of the Department of Defense organizations conducting or supporting alternative fuel R&D have put in place the critical mass of expertise required to cover the broad range of technical disciplines (including experience in thermochemical or biochemical process development and process scale-up) needed for a successful technology-development program in alternative fuels.

To remedy the situation, the Department of Defense could opt to make a single organization—either in the department or one of the services—responsible for funding and managing the entirety of the department's efforts to develop alternative fuel technology. It would then be critical to staff that organization with a group of program managers whose combined technical expertise spans the scientific and engineering knowledge base critical to program success. The ability to conduct independent engineering analyses would be another essential capability.

Alternatively, the Department of Defense could assign management of its alternative fuel portfolio to one or two of the Department of Energy's national laboratories that already have the required expertise and capabilities in engineering analysis.

To cost-effectively promote early industrial production of alternative fuels, the Department of Defense needs extended contracting authority for fuel purchases. If the services are to promote early industrial experience in the production of alternative fuels, the Defense Department must obtain legislative approval to proffer longer-duration and higher-value contracts for fuel purchases. Long-term fixed-price fuel contracts should be avoided in favor of a combination of low-price guarantees and income sharing.

The Prospects for Commercial Production

Within the United States, the prospects for commercial production of alternative fuels that have military applications remain highly uncertain, especially over the next decade. Uncertainties regarding (1) the future course of world oil prices, (2) the costs of building commercial-scale facilities in the United States, and (3) the management (technical and regulatory) of greenhouse gases are impeding the large investments required to build FT production facilities. Those very small facilities that are moving forward are doing so with significant financial support from the government. It is highly unlikely that early industrial experience in the production of FT fuels, using a combination of coal and biomass and capturing greenhouse gases, will occur without government subsidies that reduce the risks to investors.

For hydrotreated renewable oils, the prospects for commercial production depend on the feedstock. For fuels derived from waste oils and animal fats, a small amount of commercial production directed at the civilian diesel fuel market is scheduled to come on line in 2010. But overall production potential in the next decade is unlikely to exceed 25,000 barrels per day.

For fuels derived from seed oils, existing federal subsidies have promoted production and use of biodiesel, which is not a hydrocarbon but rather a fatty acid methyl ester (FAME) unsuitable for military applications. Competition in the marketplace requires that customers be willing to pay a premium for hydrotreated renewable jet fuels above the going price for FAME-type biodiesel. Otherwise, renewable oil production for fuels will continue to be directed at this type of biodiesel rather than hydrotreated jet fuel, which is more costly to produce than a FAME-type biodiesel. Additionally, there is the overriding issue of whether appreciable levels of production can occur without raising food prices and causing the release of greenhouse gases through direct and indirect changes in land use.

For algae-derived hydrotreated oil produced via photosynthesis or fermentation of cellulosic materials, the scale of the technical challenge and the early development status of the enabling technology strongly suggest that appreciable amounts of commercial production are highly unlikely through 2020.

A Few Words in Conclusion

The RAND investigation was limited to alternative fuels, as opposed to the whole of energy use across the Department of Defense. But this study can be placed within the broader context of an overall energy strategy for the U.S. military. The RAND team's finding that the use of alternative fuels offers the armed services no direct military benefit is consistent with top-level findings of recent studies on military energy issues by the Defense Science Board and the JASON Defense Advisory Group: In short, the military is best served by efforts directed at using energy *more efficiently* in weapon systems and at military installations. In this regard, the services' energy programs are clearly, and appropriately, placing the greatest emphasis on measures that would increase the efficiency of energy use.