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Unintended Consequences: Potential Downsides of the Air Force's Conversion to Biofuels

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Unintended Consequences

Potential Downsides of the Air Force's Conversion to Biofuels

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The desire to reduce US dependence on foreign energy, ongoing environmental concerns, and the rising cost of petroleum have sparked significant development of "greener" alternative and renewable energy sources such as alcohol-based biofuels. To address these issues, the Department of Defense (DOD) has moved to diminish its reliance on petroleum for fueling aircraft and ground equipment. The US Air Force, in alignment with DOD objectives, has initiated several goals for reducing its use of energy: (1) decrease the use of petroleum-based fuel by 2 percent annually for the vehicle fleet, (2) increase the use of alternative fuel in motor vehicles annually by 10 percent, (3) certify all aircraft and weapon systems for a 50/50 alternative fuel blend by 2011, and (4) have Air Force aircraft flying on 50 percent alternative fuel blends by 2016.[1] This aggressive timetable moves the world's single largest petroleum consumer, the DOD, squarely into the alternative energies market. As the world's most prodigious fuel consumer, the DOD would likely drive segments of the aviation and motor fuels markets around the world to meet the demand for newly formulated alternative fuels and to convert existing fuel-delivery systems to support the new market. Although conversion to alternative fuels can clearly lower the production of carbon dioxide, the risks that potential fuel spills pose to soil and groundwater are only now becoming clear.

This article contends that we have not adequately addressed the potential impacts of these alternative fuels on the environment. Presently, research indicates that the risks caused by subsurface environmental contamination might actually increase with the large-scale introduction of alternative fuels. Additionally, future fuel supplies and storage systems may experience troublesome fouling due to the more biologically reactive nature of alternative fuels. Therefore, prudence demands that the Air Force use the most current research and actively support new research to understand the implications of accelerated use of biofuels, in-

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cluding environmental and other risks associated with spills and impairment of the systems that transport, store, and consume these fuels. In view of these implications, this article proposes a way ahead to ensure that large-scale incorporation of alternative fuels into the DOD's massive fuel stream does not inadvertently result in contaminated groundwater, generation of explosive gas near the thousands of DOD fuel distribution and storage facilities, or adverse operational consequences due to microbial spoilage of fuels.

Subsurface Environmental Impacts

Across the DOD, fuel systems safely move millions of gallons of fuel to and from massive above- and below-ground storage tanks, yet systemwide leaks and spills continue to occur despite over 100 years of technological development in fuel storage and distribution. Every connection along thousands of miles of pipe, every control valve, and every seam in every tank represent a potential source for leakage. These fuel spills and leaks from storage tanks, pipes, tanker vehicles, and associated equipment have contaminated soil and groundwater with a class of environmentally hazardous compounds called aromatic hydrocarbons. Of these compounds, several—including benzene—are known carcinogens.[2] In soil and groundwater, levels of aromatic hydrocarbons such as benzene and other dissolved and vapor contaminants are typically lowered through natural processes. Naturally occurring underground (i.e., subsurface) bacteria can transform hydrocarbon contaminants such as benzene, toluene, ethylbenzene, and xylene isomers (BTEX) and their breakdown products such as methane into harmless substances. Some bacteria use these organic contaminants—sometimes in combination with an oxidizing agent such as oxygen—as carbon and energy sources (i.e., "food" essential for their survival and growth).

As the field data below demonstrates, introducing alternative fuels into a leaking fuel mixture significantly modifies the complex ecological relationship among bacteria, BTEX and other contaminants, and oxidizers—increasing the possibility of groundwater contamination. Previous research on such contamination using computer modeling techniques focused on bacteria's ability to process BTEX contaminants in the presence of ethanol, a widely preferred alternative motor fuel. However, the computer models generally assumed the presence of oxidizers (oxygen) not commonly dominant in soil and groundwater at fuel-spill sites, resulting in an overly favorable view of the environmental suitability of alternative fuels.[3] Recent research reveals a more troubling picture.

A field experiment at Vandenberg AFB, California, yielded a surprising result when researchers studied subsurface contamination that might arise from a slow release of gasoline blended with ethanol into groundwater, such as might result from a hard-to-detect leak of an ethanol/gasoline mix from a fuel-storage tank.[4] The field study was designed to compare the fate of BTEX compounds with or without corelease of ethanol. Researchers conducted two experiments simultaneously in an aquifer at Vandenberg, where sulfate functioned as the predominant oxidizing agent—as was the case for many petroleum spill sites nationwide.[5] One experiment involved the nine-month continuous injection of water laced with small amounts (one to three milligrams per liter [mg/L]) of the BTEX-class compounds benzene, toluene, and ortho-xylene. The second (simultaneous) experiment in an adjacent location included 500 mg/L of ethanol with the BTEX compounds. Levels of BTEX contaminants, particularly the cancer-causing compound benzene, were monitored along with the levels of oxidizing agents (particularly oxygen and sulfate), degradation products (including methane), and, in the case of the second study, ethanol. Results for the first experiment were as expected, with the underground plume of contaminants spreading for about four months, after which the benzene contamination retracted almost completely due to biodegradation caused by naturally occurring bacteria.

The outcome of the second experiment proved striking by comparison. In the second location, where ethanol was introduced along with the benzene contaminant, the area of contamination expanded, as observed in the first experiment; however, the benzene contamination did not retract nearly as much. Benzene levels in the second experiment degraded more slowly, and copious amounts of methane were generated since the native bacteria shifted most activity to the more easily degradable ethanol. This phenomenon held true for those bacteria utilizing the commonly occurring oxidizer sulfate, as well as those microbes able to biodegrade the contaminants without an oxidizer (some of which produce methane). This result helped confirm the hypothesis that the original computer model assumptions did not apply in all instances and that results from actual field experiments provide more useful insight into the ability of natural processes to detoxify BTEX compounds in the presence of the widely preferred alternative fuel ethanol. The field experiment also demonstrated that ethanol may degrade to create significant amounts of methane. In real spills with much greater amounts of ethanol than released in the experiment, methane generation around the spilled fuel could create significant amounts and flows of this flammable gas within the soil. If the methane itself is not oxidized by native soil microbes, in some circumstances spills of biofuels might lead to explosive gas mixtures reaching building basements, buried infrastructure, or the ground's surface.

Adding ethanol to petroleum appears to slow the biodegradation rates of hazardous BTEX compounds; furthermore, contaminants exist for longer periods and travel greater distances than predicted by prior modeling. In short, this finding was irrefutable, given the clear and detailed field evidence from a site quite typical of fuel spills. We can now use more soundly based computer modeling to extrapolate from the field results to other scenarios than those examined experimentally. Air Force Institute of Technology (AFIT) researchers developed such a model, which incorporated the important processes revealed in the Vandenberg studies. Model simulations showed the long-term effect of adding ethanol to fuel. Researchers used the model to simulate two spills lasting 30 years—one for benzene only, the other for a mixture of benzene and ethanol. The model confirmed the data from the field experiment: after simulating 30 years, the benzene plume with ethanol is substantially longer than the one without ethanol.

Butanol, a type of alcohol that is an alternative candidate biofuel additive, offers a number of advantages over ethanol. Butanol's energy density is nearly equivalent to that of gasoline, while the energy density of ethanol is 34 percent lower.[6] Compared to ethanol, butanol is less volatile and corrosive, has less affinity for water, and is compatible with today's pipeline and fuel-storage infrastructures.[7] Butanol is similar enough to gasoline that it can "be used directly in any gasoline engine without modification and/or substitution."[8] Based on this fact, and in consideration of the previous field study at Vandenberg that examined ethanol's effects in groundwater, AFIT researchers conducted model simulations to investigate what would happen if butanol were used as a biofuel. Unfortunately, the use of assumptions that appeared reasonable based on past laboratory and modeling research produced a modeling prediction that butanol would have an even greater negative impact on the fate of benzene, the most hazardous compound in gasoline, than ethanol did.[9] However, researchers needed to make many assumptions to conduct the simulations. Given the importance of this problem, we believe that it merits field research in real geologic media to provide insights and confirm or refine modeling assumptions before we can make a more confident prediction of the environmental effects of fuels that contain butanol.

Biofouling Potential

In addition to effects on the subsurface environment, the increased use of biofuels may result in the seemingly curious but extremely important problem of biofouling—the microbial spoilage of fuel. The combustion characteristics of biofuels closely resemble those of petroleum-based fuels; however, their chemical compositions are quite different.[10] Biofuels (such as biodiesel) include components that are both more water soluble and more degradable by microorganisms. Currently, fuel-handling facility operators of pipelines, storage tanks, and trucks take care to minimize contact between water and fuel because of potential microbial growth at water/fuel interfaces; however, it is impossible to exclude water completely from the systems. Simple atmospheric vents and the related condensation from moist air are sources of moisture that can end up as liquid water in fuel systems. Low levels of fuel spoilage and microbial fouling, which occur now, represent persistent, sometimes critical, problems for fuel handlers. Probably no fuel system is completely free of microbes and the possibility of fuel spoilage.

Though typical practical examinations may not detect organisms in fuel, for many years AFIT has conducted laboratory and field research to investigate fuel microbial quality. AFIT and Air Force Research Laboratory researchers determined that no single organism dominated the population recovered from aviation fuel tanks and that relatively little overlap existed in the composition of microbial populations from different geographic locations or types of aviation fuel.[11] Many different species of bacteria and fungi are capable of metabolizing fuel components, resulting in significant degradation of fuel quality and potential damage to fuel system components through either plugging or corrosion problems. This fact indicates that the possible spoilage problem is multifaceted, but research clarifying the most common microbial culprits allows better insight into how to reduce the effects on fuel quality.

Increased water solubility and degradability of biofuel components magnify the potential for biofouling already seen with conventional fuels. Current nuisance problems could expand into major issues with greater use of biofuels. Fouling of storage and transport facilities could become a significant and expensive dilemma. Fouling of aircraft could have tragic consequences; indeed, in the late 1950s at least one crash was partially attributed to microbial plugging of the fuel system.[12] Fortunately, after the crash, a deicer—subsequently added to fuel—turned out to have significant antimicrobial properties, eliminating the problem for many years. Changes in fuel composition (JP-4 versus JP-8) and deicers due to toxicity concerns may have prompted a resurgence of microbial contamination. Increased biofuel usage may further enhance the possibility of microbial contamination and spoilage. Clearly, we need to identify the types of microbes likely to pose the most significant issues with new fuels before these matters become critical; furthermore, research should be able to pinpoint the optimal ways to minimize spoilage of new fuels for different fuel-handling or storage facilities. For example, high-flow systems may be relatively easy to keep clean simply because they are dynamic and because fuels move through them before problems have time to develop. Long-term static storage tanks, however, such as those associated with emergency power-generator systems, may pose serious difficulties involving contamination and spoilage.

At the very least, biofuel use will require more extensive monitoring and more rigorous housekeeping on the part of fuel handlers. Prevention of a biofuel catastrophe will demand effort well beyond the level required for oil-based fuels as well as new research to supply the knowledge base to support that effort.

Recommendations

The latest research clearly indicates that alternative fuels represent a potential threat to soil and groundwater and that biofuel spills may lead to significant generation of methane gas and extend the persistence of cancer-causing fuel compounds such as benzene in water supplies. Additionally, since benzene and other contaminants degrade more slowly in the leaking area when alternative biofuels are present, the contamination plume can spread greater distances before bacterial processes can reduce contaminant levels. Finally, because biofuels are more hygroscopic and biodegradable than current fuels, fuel users and storage and distribution systems may experience greater mission degradation due to fuel biofouling.[13] We recognize the urgency of shifting to biofuels but suggest that doing so creates an equally urgent need for research to produce the knowledge we need to adjust our fuel-management practices and safety protocols in order to maintain high standards for protection of facilities, equipment, personnel, and the environment. We thus recommend the following actions to mitigate possible contamination of groundwater and soil as well as biofouling of fuel-management systems:

1. Develop technologies to reduce, monitor, and mitigate spills and leaks, designing them specifically for biofuel distribution and storage systems. This process includes upgrading critical fittings and connections among processing, distribution, storage, and consumption facilities to ensure that the most likely sources of leaks are modified to assure compatibility with the new fuel mixture.

2. Expand research that furthers our fundamental understanding of the environmental effects and biofouling potential of biofuels.

Conclusion

The Air Force's efforts in research and development of biofuel-compatible platforms to meet the DOD's goals for decreasing its use of energy are reasonable, given the number of obvious advantages that biofuels offer. However, we do not yet sufficiently understand a number of the disadvantages of biofuels. Only when researchers challenged the assumptions of computer modeling with an actual field study at a representative test site at Vandenberg AFB did the potential for more environmental contamination appear. The study clearly showed that contamination plumes of carcinogens such as benzene could persist and expand in the presence of ethanol but disappear in its absence.[14] Similarly, field and lab research at AFIT has been a key element in understanding biofouling of petroleum-based fuels, suggesting that biofouling will become even more serious for biofuels. Because the DOD has not supported additional research on these critical topics, it is imperative that the Air Force investigate them further.

In the future, our senior leadership will confront a series of decisions regarding the type and mixture of biofuels that our ground and air fleets should use. Presently, the Air Force is conducting research to facilitate decisions in certain areas, such as compatibility of alternative fuel blends with end-user systems, motors, and turbine engines. However, researchers have yet to sufficiently explore other important questions, such as those regarding "nonobvious" environmental implications and biofouling. At a minimum, the Air Force should support additional field research to improve our understanding of the probable subsurface effects of biofuels and to create opportunities for developing new methods of monitoring and remediating such effects. The service should also continue to investigate the microbial spoilage of biofuels and develop mitigation methods. If the DOD and Air Force are compelled to use biofuels before completing more research, we recommend monitoring some of the biofuel storage and use locations in considerably more detail than normal, perhaps as an "applied research" project, to help identify and bound the significance of the issues we raise here. Only through well-controlled laboratory and field research and applied research studies will the DOD and Air Force gain insight into these matters and develop new technologies that will allow senior leadership to make informed decisions and thus avoid unpleasant surprises. ✪

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Notes

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