Unlikely Fuel Source Makes Waves

Re-engineered Bacteria Aims to Offer Cleaner, More Sustainable Propulsion in Jets, Missiles

By Rob Perry and Peter Fitzpatrick

Researchers at the Naval Air Warfare Center Weapons Division (NAWCWD) in China Lake, California, have developed a process to convert waste material into high-performance jet fuels.

With support from the Office of Naval Research (ONR), ONR Global (ONRG) and the U.K. Royal Air Force, Dr. Benjamin Harvey, a senior research chemist at NAWCWD, and scientists from the University of Manchester and C3 Biotech in the U.K., are developing a hybrid biological/chemical process that uses Halomonas—bacteria found in seawater—to generate a "platform" chemical, which can then be converted into jet, diesel, gasoline or even missile fuel.

Conventional biofuels require large tracts of land, carbon-intensive fertilizer and lots of fresh water. Whether it is a field of corn to make ethanol or palm trees to create palm oil, as many as 100 million acres would be required to generate enough material to satisfy the U.S. demand for jet fuel. In contrast, the use of waste biomass as a feedstock eliminates the need to plant additional acreage. Further, macroalgae (seaweed) can potentially be used as the carbon source for this technology.

Halomonas is salt-tolerant and can not only grow in solutions containing high salt and pollutants but is also able to grow at a wide range of temperatures and pH conditions, which can limit the growth of other microorganisms. Because of these characteristics, Halomonas provides a sustainable and robust "microbial chassis" that does not require potable water or expensive sterilization protocols.

"By re-engineering the microbe's genome to alter its metabolism, scientists can convert waste biomass into precursors for the production of different types of fuels," said Dr. Kristy Hentchel, ONR program officer for bioengineering and biomanufacturing. "For the fleet, the use of Halomonas makes conducting these processes possible at sea, forward operating bases or coastal locations."

Professor Nigel Scrutton and his team at the University of Manchester and C3 Biotech have engineered Halomonas to produce various molecules, including a sweet, floral-smelling terpenoid called linalool, which is also found in many flowers and spice plants.

"The equipment and process used for biosynthetic production of linalool is similar to that used for making beer," said Dr. Patrick Rose, the ONR Global science director for synthetic biology. "Sustainable production of linalool on an industrial scale will require two main components—large fermentation vessels and an accessible carbon-rich feedstock derived from agricultural, forestry or even solid municipal waste streams."

In parallel, Harvey and his team developed a method to convert linalool into jet fuel using various catalysts. One catalyst can produce a high-density fuel useful for missile or rocket propulsion; another process produces diesel fuel, while yet another generates a high-performance drop-in jet fuel—all from the same starting point of biomanufactured linalool.

"By integrating different catalysts and conditions we can exert exquisite control over the fuel product distribution, which means no changes to existing vehicles or platforms will be required," Harvey said. "We are creating designer, biosynthetic, drop-in fuels that have higher energy densities, lower viscosities, cleaner combustion profiles and reduced long-term maintenance costs compared to conventional jet fuels."

Much of the initial work on linalool was focused on the production of missile fuels, but in recent years the project has expanded to include high-performance jet fuels.

"We're packing more energy into the fuel tank, which allows the aircraft to go farther," Harvey said.

U.S. Navy photo by Deirdre Patin

Dr. Luke Keller, a National Research Council postdoctoral fellow, synthesizes a biosynthetic fuel in his laboratory at the Naval Air Warfare Center Weapons Division (NAWCWD) in China Lake, Calif.

U.S. Navy photos by Deidre Patin

Chris Walkling, a chemical engineer working in the NAWCWD research department, conducts a distillation of a biosynthetic fuel component.

"The benefits to the warfighter are clear. If we can provide them with biosynthetic fuels that outperform those derived from petroleum and can be produced domestically or in the field on-demand, we are giving them an advantage over their adversaries."

"We can optimize the properties of the final blend to enhance the capability of modern engines. These fuels have applications for jet aircraft, unmanned aerial vehicles (UAVs), helicopters and ground vehicles. We're not only interested in maintaining our capability but enhancing our capability with these fuels."

One of the fuel products generated by Harvey's team exhibits up to 17 percent higher volumetric energy density compared to conventional jet fuel, which can enhance the range of aircraft and UAVs. A flight test with a UAV using an optimized jet fuel derived from linalool is scheduled for December in the U.K.

Rising Potential in Cost Reduction, Deployment and Other Uses

The timeline to get to commercial production of the drop-in biosynthetic fuel largely depends on funding.

"The biotechnology is at an advanced stage and ready for scale-up. The chemical conversion process has been demonstrated at the laboratory scale and is ready for transition to a pilot plant," Harvey said. "Integrating the two components and optimizing the final fuel blend is the current focus. Once we are able to make significant quantities of fuel we can engage with Department of Defense (DoD) partners, the Federal Aviation Administration (FAA) and other stakeholders to qualify these fuels for use in both military and commercial aircraft."

Harvey says that at this stage of development, it is difficult to put a price tag on the linalool-derived jet fuel. The team and its partners are currently working to establish multi-year programs focused on transitioning this technology out of the laboratory and demonstrating a small footprint (shipping container), mobile and modular system with integrated synthetic biology and chemical catalysis process steps. These systems could be deployed to forward

From left, Dr. Luke Keller, National Research Council postdoctoral fellow, Dr. Ben Harvey (team lead), senior research chemist and associate NAWCWD fellow, and Chris Walkling, NAWCWD chemical engineer, are working to produce a cleaner burning biosynthetic fuel that can be generated from waste biomass by a hybrid biological/chemical route utilizing bacteria found in seawater.

operating bases or areas that import their fuel (e.g. Hawaii, Guam) and produce fuel continuously.

Since an aircraft carrier averages 3 million gallons of jet fuel in storage and the size of a facility needed to generate that much synthetic fuel would be enormous, Harvey said, rendering production of synthetic fuel at sea impractical. However, Harvey said deploying the modular systems at forward operating bases or remote locations and using locally sourced carbon-containing materials including seaweed, wood or waste biomass to constantly produce the synthetic biofuel is a more realistic scenario.

"One of the advantages of generating fuel in theater is the dramatically reduced logistics costs," Harvey said. "For example, in remote forward operating bases the cost of jet fuel is $400 a gallon just because of transportation costs, the security costs to get the fuel caravan out there, etc. By producing it in theater from local resources, you're saving a ton of money."

Although the current work with linalool is focused on producing fuels, Halomonas can also be engineered to produce chemicals, pharmaceuticals and polymers. The latter could be used in combination with additive manufacturing technologies such as 3D printing.

"As an example, consider when a component breaks on a system at a forward operating base and the technician needs a new part. The base is equipped with a biosynthetic reactor 'programmed' to make a recyclable polymer. The reactor produces the polymer, the technician takes that polymer to a 3D printer and prints a new part," Harvey said. "Under this paradigm, the whole process might take a day or two, while under a conventional scenario that part may have taken a month or more to arrive."

Current supply chain issues due to the COVID-19 pandemic highlight the need to develop a resilient and dynamic supply chain, particularly for the DoD.

Harvey sees a bright future for biosynthetic jet fuels.

"The benefits to the warfighter are clear. If we can provide them with biosynthetic fuels that outperform those derived from petroleum and can be produced domestically or in the field on-demand, we are giving them an advantage over their adversaries. Advanced development of this technology will simultaneously improve Naval readiness and capability while reducing net greenhouse gases and enabling sustainable operations around the world."

Rob Perry is editor and staff writer for Naval Aviation News. Peter Fitzpatrick is a writer and photographer with Naval Air Systems Command Public Affairs.