THE NAVY'S ENVIRONMENTAL MAGAZINE

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from seed

to supersonic

How Camelina Powered the Navy's Premier Fighter Jet

on 22 April,

Earth Day 2010, what appeared to be a routine flight of a Green Hornet—the F/A 18 E/F, the Navy's premier fighter jet—attracted hundreds of onlookers, including Secretary of the Navy Ray Mabus. This time, for the first time, the jet was powered with a 50/50 blend of biofuel and petroleum-based fuel. The flight, one of a series of test flights held in early 2010 at the Naval Air Station (NAS) in Patuxent River, MD (Pax River), marked the first time ever that an aircraft has flown faster than the speed of sound on a fuel mix that is 50 percent biomassed derived. And this is how it happened.

the basics about the Navy Fuels Team

THE NAVY FUELS TEAM IS part of the Naval Fuels and Lubricants Cross Function Team. The team is comprised of technical experts from across the Navy. Officially chartered in 1999, the team includes representation from the aviation, ship, logistics, research and operational communities. The Team's mission is to provide a single source of fuels-related technical expertise, guidance and solutions to all levels of the Navy.

The road to the series of test flights started back in 2008 when the Navy Fuels Team began to test small quantities of biofuels in its Pax River laboratory. Based on this testing, a procurement specification for the jet propulsion 5 (JP-5) biofuel was developed and the team was on the road to the testing of the F/A-18 fighter jet, also known as the Green Hornet. Secretary Mabus's announcement of the Navy's energy goals, designed to lessen the Navy's dependence on foreign oil, spurred the team on and they accelerated their efforts in October of 2009.

The Navy's Procurement Specification for a Biofuel

"The Navy Fuels Team has the job of taking the fuels that various manufacturers and refiners are producing and getting them approved," stated Rick Kamin of the Navy Fuels Team.

"We wrote a procurement specification that specified the performance properties for the biological component of the aviation fuel blend," he continued. The biomass component of the new fuel had to meet the following requirements:

1. It had to be a drop-in replacement for the petroleum-based fuel.
2. It must meet or exceed the performance requirements of the petroleum-based fuel. (There must be no notable operational differences.)
3. The biofuel must be able to be successfully mixed or alternated with petroleum fuel.
4. The biofuel must require no modifications or enhancements to the configuration of the aircraft or ship.
5. The biofuel must require no modifications or enhancements to the Navy's existing fuel storage or transfer infrastructure.

"Although, we were looking for a sustainable plant—and/or algae-derived oil—that was not competitive with food crops, we did not specify that it needed to be a camelina-based fuel," explained Kamin. But camelina seemed to be a logical choice.

Kamin sent the procurement specification for JP-5 jet fuel to the Defense Logistics Agency (DLA) Energy (formally known as the Defense Energy Support Center), which has the responsibility of purchasing fuel for the Department of Defense (DoD). (For more information about DLA Energy, see our sidebar entitled, "The Basics About the Defense Logistics Agency Energy.") An open solicitation

was put forth to the energy industry to develop and produce a suitable fuel, and in 2009, a contract for almost 600,000 gallons of biofuel (190,000 gallons for the Navy and 400,000 gallons for the Air Force) was awarded to Sustainable Oils, Inc.

Because the procurement specification stipulated that the biological component of the blend must not compete with food crops, traditional materials or "feedstocks" such as corn or soy were not appropriate. Because it is a dedicated energy feedstock, camelina met the requirement.

This Thing Called Camelina

The oils that come from crushing the camelina (*Camelina sativa*) seed (a type of mustard plant) are structurally more similar to petroleum than other bio-based products. Used by the ancient Romans as lamp oil, camelina oil was produced in Europe and Asia throughout the 19th century for a variety of mostly industrial applications. After World War II, however, the crop fell out of favor and has since been largely regarded as a minor non-food crop in Europe and a weed in North America.

Camelina moved to the forefront of the renewable fuels scene only two years ago. Its advantages include the fact that it is best grown in rotation with dryland wheat during the part of the cycle where the land would otherwise lie fallow (uncultivated). As a result, camelina does not compete with

Camelina sativa.

USDA-NRCS PLANTS Database / Britton, N.L., and A. Brown. 1913. An illustrated flora of the northern United States, Canada and the British Possessions. 3 vols. *Charles Scribner's Sons, New York. Vol. 2: 157. Courtesy of Kentucky Native Plant Society.*

An F/A-18 Super Hornet strike fighter, dubbed the "Green Hornet," conducts a supersonic test flight. The aircraft is fueled with a 50/50 blend of biofuel and conventional fuel. The test, conducted at NAS Patuxent River, drew hundreds of onlookers, including Secretary of the Navy Ray Mabus, who has made research, development, and increased use of alternative fuels a priority for the Department of the Navy.

Liz Goettee

the basics about the Defense Logistics Agency Energy

WITH HEADQUARTERS IN FORT BELVOIR, VA, DLA Energy exercises procurement and sales responsibility for crude oil for the Department of Energy's Strategic Petroleum Reserve, a program used to store crude oil as a buffer against potential national energy emergencies.

DLA Energy's mission is to provide DoD and other government agencies with comprehensive energy support in the most effective and economical manner possible. DLA Energy directs the DoD organization responsible for purchasing and managing all petroleum resources used by the U.S. military. In addition, DLA Energy guides the growing mission of total energy support by developing strategies to buy and sell deregulated electricity and natural gas to DoD and other federal agency customers. DLA Energy also directly supports DoD's initiative to privatize the military base infrastructure that distributes those utilities (in addition to lighting, heating, air conditioning and water/wastewater systems).

Camelina seeds.
Courtesy of Sustainable Oils, Inc.

RIGHT: Camelina (early stage shown here) requires less fertilizer and herbicides than traditional crops, is an excellent rotation crop with wheat, and can also grow on marginal land.
Courtesy of Sustainable Oils, Inc.

food crops, and requires little irrigation. It has even been shown to enhance the yield of subsequent crops by up to 15 percent. In addition, the oil it produces is more cold-tolerant than other biofuel feedstocks. (Note: For more information about camelina, see the Energy Daily web site at www.energydaily.com/reports/Camelina_Biodiesel_A_Reality_999.html.)

In the words of John Williams, spokesman for Sustainable Oils, "Camelina is the world's first dedicated energy feedstock."

Turning Mustard Seed into Jet Fuel

Early on, Sustainable Oils recognized the potential that camelina oil had as a feedstock for biofuel. The company, a joint venture between Seattle-based Targeted Growth (a biosciences company) and Houston-based Green Earth Fuels (a biodiesel production facility), researched and pioneered the seed's use for producing biodiesel.

As scientists and engineers from Targeted Growth were trying to figure out ways to increase the yield of crops that were used for both food and fuel (crops such as corn and soy), a team of their researchers decided to look at the problem in reverse. According to John Williams, Targeted Growth's researchers realized, "There's no doubt that agriculture and biology can play a role here. But we've been looking at this the wrong way. Instead of looking at what we're already growing, we should be looking at the desired end product and figure out what we should be growing."

Camelina is the world's first dedicated energy feedstock.
John Williams

Camelina seeds typically contain more than 35 percent oil and are high in omega three fatty acids. This makes the energy crop a good fit for jet fuel (as well as biodiesel), but the meal is also a valuable co-product as a good option for livestock feed.
Courtesy of Sustainable Oils, Inc.

Targeted Growth's scientists looked at a variety of different raw materials for feedstocks for producing biofuel including switchgrass, sorghum, different types of corn, and camelina. They settled on camelina because it doesn't compete with food crops and it is easy to cultivate (with existing equipment) as well as other factors. "We joke that camelina is the meaner, older brother of canola," says Williams. "Camelina oil is very high in omega three fatty acids. But for all its productive qualities, it doesn't taste very good. That's why it's never entered the agricultural mainstream." The "meal" from camelina, however, can be cycled back into the food chain as a feed for livestock and poultry once the oil is extracted.

Because camelina fits so well into crop rotation, "It offers farmers a way to make some money during a time when they would leave their land fallow or planted with a cover crop that doesn't generate significant revenue," stated Williams.

Navy & Other Federal Agency *energy goals*

THERE HAS BEEN NO SHORTAGE of new federal energy policy in recent years. The Energy Policy Act of 2005, The Energy Independence and Security Act of 2007, Executive Order 13423, renewable energy provisions in the National Defense Authorization Act of 2007 and the Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding all contributed substantial new requirements. The policies invoke wide-ranging and aggressive energy and water initiatives, such as:

- Reducing installation energy consumption per square foot 30 percent by 2015 relative to 2003.
- Reducing installation water consumption per square foot 16 percent by 2015 relative to 2007.
- Requiring Leadership in Energy and Environmental Design Silver or higher certification for new facilities.
- Constructing new facilities 30 percent more energy efficient than American Society of Heating, Refrigerating and Air-Conditioning Engineers standards.
- Reducing fossil fuel use in new and renovated buildings by 55 percent by 2010 and 100 percent by 2030.
- Metering all facilities with advanced time-of-use electrical meters.
- Purchasing Energy Star or Federal Energy Management Program-designated equipment–written justification required to deviate.
- Generating/Procuring renewable energy equal to 25 percent of electrical energy consumed by 2025.

At the October 2009 Navy Energy Forum, Secretary Mabus announced the following goals for the Department of the Navy (DON):

1. By 2020, 50 percent of total DON energy consumption will come from alternative energy sources.
2. By 2020, DON will produce at least 50 percent of shore-based energy requirements from alternative sources; 50 percent of DON installations will be net-zero.
3. DON will demonstrate a Green Strike Group in local operations by 2012 and sail it by 2016.
4. By 2015, DON will reduce petroleum use in the commercial vehicle fleet by 50 percent.
5. Evaluation of energy factors will be mandatory when awarding contracts for systems and buildings.

Farmers harvest a field of camelina on the northern Great Plains near Great Falls, Montana.
Courtesy of Sustainable Oils, Inc.

Targeted Growth proceeded to research the seed, conducting non-genetic breeding techniques to produce an "elite" camelina seed—one that produces more oil per acre, requires less fertilizer, and performs better under extreme temperature variations than the original seed. The "elite" seed was introduced to Montana in 2007.

Since Targeted Growth was not in the business of producing biofuels, they realized that they needed to establish a second company to take the "elite" camelina seed that they had engineered and get it into production. For this task, the company joined with Green Earth Fuels to form Sustainable Oils as the marketing arm for the new seed.

Producing Camelina Oil

Camelina seeds are crushed using existing equipment and technology, and are converted through the same refinery process used for soybean and canola oils. Called transesterification, this process combines natural feedstocks such as vegetable oils or animal fats with a short chain alcohol in the presence of a catalyst.

Targeted Growth's original intended purpose for the camelina oil was for use in vehicle diesel engines but not jet engines. To re-purpose the oil, they turned to Honeywell's UOP for the knowledge and technologies necessary to process oils into jet fuels.

The Honeywell/UOP Connection

UOP, LLC—a Honeywell company—develops and licenses processing technologies to the refining, gas processing, and petrochemical production industries.

UOP had already established a track record in the biofuel industry. Its green division, formed in 2006, worked with European energy company Eni, to develop a process to convert vegetable oils and waste into a green diesel fuel.

Working with the camelina oil provided by Sustainable Oils, animal fats from Cargill, and algae from Solazyme

Camelina oil is very high in omega three fatty acids.

John Williams

This particular F/A18F, commanded by Lieutenant Commander Tom Weaver, successfully tested a 50/50 blend of camelina-based and petroleum-based fuel on Earth Day 2010.

(among others), UOP engineers designed a process that utilizes traditional refinery hydroprocessing technology—a process that could easily be adopted by American refineries using existing equipment.

Refining the Oil

The refining process for camelina and other plant-based oils works as follows:

First, the oils are cleaned to remove impurities using standard oil cleaning procedures. The oils are then converted to the shorter chain diesel-range paraffins (chemical compounds that consist of hydrocarbon and hydrogen) using UOP's Green Jet Fuel Production Process. This hydroprocessing process (called Deoxygenation) converts natural oils by removing oxygen molecules from the oil and converting any olefins to paraffins by reaction with hydrogen. The removal of the oxygen atoms raises the heat of combustion of the fuel and the removal of the olefins increases the thermal and oxidative stability of the fuel. A second reaction, called Selective Hydrocracking, then isomerizes and cracks the diesel range paraffins, breaking them down into smaller paraffins with carbon numbers in the jet range. The third and final Product Separation phase separates the products of the hydrocracking process into end products—light fuels, green jet fuels and green diesel.

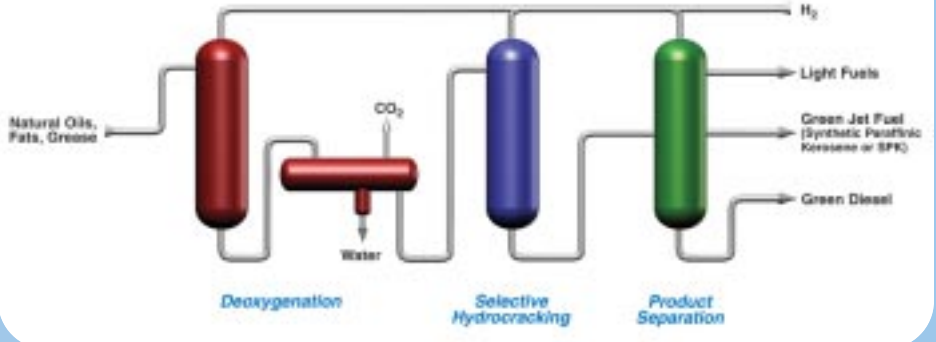
The end product is a synthetic paraffinic kerosene fuel that contains the same types of molecules that are typically found in conventional petroleum-based jet fuel.

"Green jet fuel is able to address several requirements," said Jim Rekoske, Vice President & General Manager of Renewable Energy & Chemicals for Honeywell's UOP. "First, the fuel had to meet the Navy's flight specifications. Secondly, the fuel could not require any changes to the engine or airframe. Finally, the formula had to be generated from a sustainable, non-food feedstock."

The new fuel succeeds on all three fronts:

1. It meets and in some cases exceeds the Navy's procurement specification.
2. The 50/50 blend (renewable product to petroleum) provides the necessary aromatics required in today's jet engines.

UOP's Green Jet Fuel Production Process



3. The process can be utilized to convert a wide range of non-food feedstocks including camelina, jatropha and algae.

"The camelina used for the Navy flight is only one feedstock option," says Rekoske. "It's available in the U.S. now, but oils extracted from various other sources such as algae and jatropha [a plant that grows well in tropical climates] can also be used as feedstock for biofuel production. The process is feedstock-agnostic, meaning that producers can select the ideal feedstock depending on their location, availability or cost."

Rekoske also stated that although the initial formula requires 50 percent petroleum-based fuel, there is a possibility of a 100 percent sustainable biofuel in the future—technology could be available as soon as 2014.

The Testing Begins

Per the biofuel procurement specification developed by the Navy Fuels Team, Sustainable Oils produced the necessary amount of camelina oil and shipped it to UOP's seed processing plant in Bayport, TX. In turn, UOP used their patented *Green Jet Fuel Production Process* to refine the camelina oil into biofuel. UOP produced 40,000 gallons of biofuel and delivered it to the Navy Fuels Team in Pax River. Then, it was time to subject the biofuel to rigorous testing.

"We had a very ambitious timeline," said Kamin. "From the receipt of the fuel, we wanted to complete testing in the Green Hornet in less than six months."

The first step was to conduct a full laboratory evaluation to compare the biofuel with the performance parameters outlined in the procurement specification. Navy chemists blended the biofuel with the petroleum-based JP-5, then initiated a series of chemistry and property analysis tests to validate that the blended fuel matched the performance of the JP-5 fuel. "This is a two-part process," stated Kamin, "First you need to conduct 'performance to specification' tests and then 'fit for purpose' tests."

The 'fit for purpose' properties testing involved 20 to 30 different tests that analyzed properties and chemistries that are outside the limits of the specification. "These 'fit for purpose' tests are critical since all of the Navy's systems have been designed around petroleum," Kamin explained. "There are a number of properties that are inherent to petroleum-based fuels for which we don't regularly test during procurement. It is those properties, not explicitly referenced in our biofuel procurement specification, that we needed to test under the 'fit for purpose' mantle. These tests would cover the entire range of purposes for which the fuel may reasonably be used and provide the fuels chemists and engineers with the confidence that the fuels will perform as expected when used in subsequent component and system tests."

"We wanted to make sure that the biofuel had the same properties that we have come to expect of petroleum-based fuels," Kamin continued. "For example, the dielectric constant of the biofuel is important for the purposes of tank gauging". The F-18 uses a capacitance gauging system

There is a possibility of a 100 percent sustainable biofuel in the future—technology could be available as soon as 2014.

Jim Rekoske

Liz Goettee

which is calibrated for the dielectric properties of petroleum-based jet fuels. If the dielectric constant of the biofuel is not the same as petroleum-based jet fuel, the F/A-18's tank gauging systems will provide incorrect fuel quantity readings to the pilot.

After laboratory tests were completed, testing of individual components and the jet's engine began. At this stage, the Navy team expanded to include engine experts, fuel control experts and combustion experts among others. "As you move away from the laboratory and closer to the aircraft, the composition and size of your team expands," said Kamin. Two component tests and one of the two engine tests were performed at General Electric—the manufacturer of the F/A-18's F414 engine.

"We conducted a 500-hour test of the fuel control unit to see if the biofuel had any impact on any of the materials contained in the unit," said Kamin. "This unit is a complex series of valves and orifices that meter and control the flow of fuel to the engine. This system ensures that the right amount of fuel is sent to the engine based on the throttle settings set by the pilot," he explained.

The other component that was tested was the combuster. This is where the

The Green Hornet's *green initiatives*

AS THE PREMIERE TACTICAL AIRCRAFT of the U.S. Navy, the F/A-18 Green Hornet is the focal point of various energy and environmental initiatives. For years, the team has focused on reducing or eliminating hazardous materials, identifying material reduction and recycling opportunities, and identifying and addressing environmental health and safety concerns.

New technologies are at work to make the F414 engine more efficient. Testing of some engine efficiency upgrades (an advanced aerodynamic compressor and high pressure turbine, ceramic matrix composite turbine blades, and performance seeking engine controls) was conducted in November 2010. Air emission and fuel consumption reductions are the goal of the trapped vortex combustor technology. This technology initiative supported by PMA265 has demonstrated reductions in greenhouse gases (carbon monoxide, nitrogen oxides [42 percent reduction], and unburned hydrocarbons [17 percent reduction]) with no loss in engine performance. Other efforts to reduce energy consumption include minimized hot pit refueling at NAS Lemoore and Fallon, and enhanced simulation capabilities. Mike Rudy estimated, "The Green Hornet's carbon footprint will be reduced from all of these energy initiatives. We expect fuel consumption reduction by 27 million gallons per year and greenhouse gas emission reductions by 300,000 metric tons annually." The use of the camelina biofuel reduces conventional aviation fuel use by 50 percent and reduces carbon emissions by 80 percent on a lifecycle basis.

For more insights into the Green Hornet's other green initiatives, see our cover story entitled "Green Hornet Team Achieves Environmental Breakthroughs: Program Office Implements Green Technologies Without Compromising Aircraft Performance" from the spring 2007 issue of *Currents*. To subscribe to the magazine or browse the *Currents* archives, visit the Naval Air Systems Command's environmental web site at www.enviro-navair.navy.mil/currents.

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fuel is atomized and burned providing the energy to propel the aircraft.

The component and engine tests confirmed the initial results from the laboratory tests. The components and engines didn't "know" the difference between the petroleum- and bio-based fuels. "The performance of the bio-based fuel was well within the tolerance that was expected. Everything operated exactly as we expected," said Kamin.

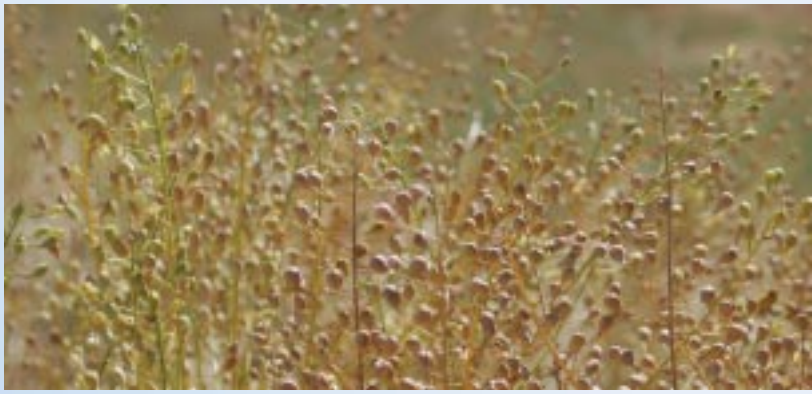
A flight clearance package was prepared that summarized all of the technical data that was collected during laboratory, component and engine testing. The performance monitors need to be confident based on the results of the testing and data contained in the flight clearance package, that the aircraft won't be exposed to any undue risk.

Once flight clearance was obtained, the effort was turned over to the VX-23 squadron and the Naval Air Systems Command's Flight Test Team who were responsible for conducting the flight test.

Why the Green Hornet Program?

"PMA-265 was a logical program to test this new batch of camelina-based biofuel," according to Mike Rudy, PMA265's Environment, Safety and Occupational Health Coordinator. "We have our own jet engine test cell. We use it to run our engines through all sorts of performance parameters. We also have lot of experience studying the components of the engine to see what sort of impact there might have been during the course of the tests," said Rudy.

"The F414 series engine is also known to be extremely reliable," explained Rudy. "We have a large database of tests on this engine, including things like the rotors, the turbine blades and the combustor—those components have been analyzed and reworked where necessary. Any problems have been analyzed then corrected. We also have a relatively large number of test



aircraft here at Pax River. And our Green Hornet team is located here at Pax River and has a recognized environmental track record. So it made perfect sense for us to test the camelina-based biofuel."

The Earth Day demonstration flight at Pax River on 22 April 2010 was one of 16 test flights conducted on the F/A-18E/F that demonstrated the performance of the biofuel blend over the entire aircraft flight envelope. The event drew hundreds of onlookers, including Secretary Mabus, who observed the flight from a Project Engineering Station at the air station's Atlantic Test Range. After the jet landed, he met the pilot, Lieutenant Commander Tom Weaver, of Billerica, MA.

"The aircraft flew exactly as we expected—no surprises," said Weaver, in a Navy announcement. "The fuel works so well, all I needed to do was fly the plane."

"We observed no operational difference with the biofuel," confirmed Mike Rudy. "It accelerated properly, it decelerated properly. There were no flame-outs. All functional checks were nominal [normal]."

> Our Navy, alongside industry, the other services and federal agency partners, will continue to be an early adopter of alternative energy sources.
>
> *Secretary Ray Mabus*


Courtesy of Sustainable Oils, Inc.

"The alternative fuels test program is a significant milestone in the certification and ultimate operational use of biofuels by the Navy and Marine Corps," remarked Secretary Mabus. "It's important to emphasize the Navy's commitment to reducing dependence on foreign oil as well as safeguarding our environment. Our Navy, alongside industry, the other services and federal agency partners, will continue to be an early adopter of alternative energy sources."

The flight test report is currently in final review so it would be premature to quote results. However, all the data analyzed to date have shown that the 50/50 biofuel JP-5 blend operated no differently in the aircraft than 100 percent petroleum-based JP-5.

The Future

The program's goal is to incorporate the 50/50 blend into the Navy's JP-5 aviation specification by early 2012. Planning is already underway to expand testing to a number of other Navy and Marine Corps tactical systems. MH-60 Seahawk helicopter testing was conducted in November 2010 with tests on the V-22 Osprey tiltrotor aircraft and other systems in the works for 2011.

"The plan is to qualify JP-5 for all programs," states Rudy. "These programs will be qualified to use the 50/50 blend and will eventually move to 100 percent biofuel when it becomes available," Rudy continued.

Energy & Environmental Benefits

Though the impetus for the development of the new biofuel was to lessen the Navy's dependence on foreign oil, the new fuel has environmental benefits as well.

"Camelina fuel has been demonstrated to reduce carbon emissions by 80 percent," stated John Williams. These emission reductions will be realized over the long run, due to the fact that biomass sources absorb carbon dioxide while growing and can have higher energy content than fossil-based fuel. The use of use biomass sources as aviation biofuel could potentially save millions of tons of aviation greenhouse gas emissions.

The Big Picture

Now that camelina and other sources have been successfully tested in the F/A-18 as well as other commercial and military aircraft, the industry has a challenge to produce enough renewable fuel to support the eventual demand for the 50/50 blend.

"Camelina is the first of the biofuel stepping stones," says Rudy. "It is scalable today and has been proven. In the future, other feedstocks, such as algae, will complement production to efficient levels. "

At the present time, there is no commercial scale production infrastructure in place. All the fuel procured for testing to date was produced in pilot scale operations, which, as in all new technology, resulted in higher costs. Currently the Department of Energy, Department of Agriculture, Defense Advanced Research Projects Agency, and industry are aggressively working to commercialize the technology and drive the economies of scale to enable these fuels of the future to be produced in quantities sufficient to make them competitive with petroleum.

Even more so than camelina, algae can be grown in the most hostile of regions such as deserts, so it doesn't infringe on land set aside for food crops. It doesn't require fresh water to flourish, and can thrive in salt water or even wastewater.

The Navy's Vision

"The Navy has always led in energy change," Mabus said, noting that it switched from sails to coal-fired power in the 1850s, from coal to oil in the early 1900s and from oil to nuclear in some vessels in the 1950s. "Every single time we did that, there were people who said we were taking proven technology and trading it for an unproven one, and (putting the operations at risk). Every single time they were wrong." (Source: The Billings Gazette web site at www.billingsgazette.com/news/state-and-regional/montana/article_c32a96a2-4cce-11df-ab60-001cc4c03286.html. Used with permission.) ⚓

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