

A microscopic view of green algae cells, showing a network of bright green, interconnected filaments against a dark blue background. The cells are highly detailed, with visible internal structures and a glossy, reflective surface.

BIO FUEL

WRITTEN AND PHOTOGRAPHED BY LEWIS CARLYLE

FROM ALGAE TO JET FUEL

Biomass and the future of propulsion energy

SOME DAY JETS WILL

THE ENERGY UTOPIA Sunlight radiates across the unforgiving desert landscape of northern Arizona. The red rock mesas of Monument Valley tower above the long glistening rows of glass greenhouses which span all the way to the horizon and beyond. The translucent solar panels which cover the roofs of each building collect energy while still allowing light to pass through, where it shines upon pools containing billions of gallons of bright green water. These indoor photo-bio reactors grow a hybrid strain of genetically engineered marine algae which photo synthetically converts sunlight into long hydrocarbon molecules. The result is a form of oil, that when refined, burns hotter and cleaner than gasoline. The year is 2185 and the violence which surrounded the final years of oil depletion in the Middle East still lingers in the memories of those who witnessed the end of the fossil fuel era. Overhead, an airliner paints a long white contrail across the sky as it heads for Los Angeles. The bio-fuel burning in its scramjet engines was produced from this very facility not five months earlier. The CO₂ emissions from the expended fuel are expelled into the atmosphere and gradually fall back to earth, where they will be consumed by the latest batch of algae and re-forged through photosynthesis into the fuel of tomorrow. The energy cycle continues. Sustainable. Renewable. Never ending.

THE FUTURE OF BIO-FUELS

Jump back to present day to a laboratory in the Air Force Academy's Department of Biology. A collection of beakers filled with bright green liquid bask in the sunlight emanating from a row of windows. Dr. Don Veverka is director of the Life Sciences Research Center at USAFA and he is passionate about renewable energy. Funded and supported by the Air Force Office of Scientific Research and Air Force Research Laboratories, he has taken part in a nation-wide study to obtain bio-fuel from algae. If mastered, the process could save the world from its dependence on oil, but a lot of obstacles stand in the way, and the prospect of sending F-16s into combat on jet fuel derived from pure algae is still a long way off.

"The idea of using algae as a source of energy for transportation fuels actually came about quite a few years ago," Dr. Veverka begins. "The Department of Energy developed the Aquatic Species Program during the OPEC energy crisis in the 1970s and algae was one of the alternative fuel sources that the ASP was looking into. The problem was, once the energy crisis ended and gas got cheap again, all the alternative fuel research got mothballed and put on a shelf." Veverka rests a hand on the desk. "Fast forward three decades and we're right back where we started. In searching for sufficient energy for this country,

our interests in algae have reawakened."

Veverka illustrates that the current Cadet Wing had not yet been born when the OPEC energy crisis took place. Still, that hasn't stopped them from taking a strong interest in the future of the nation's energy. "Cadets join us as juniors for an independent study course," Veverka says. "They are assigned a mentor scientist and are then given little pieces of the research project to work on. This year Kris Morehouse and Mike Wojdan are our cadet investigators."

The concept of renewable energy made from plants has been around a long time. Henry Ford, founder of Ford Motor Company once had plans to run his fleet of Model-T's off of ethyl alcohol, and is famous for quoting "There is fuel in every bit of vegetable matter that can be fermented. There's enough alcohol in one year's yield of an acre of potatoes to drive the machinery necessary to cultivate the fields for a hundred years." While Ford's math may have been based off the agricultural model of 1925, the basic concept still rings true today.

"There is the old food for fuel argument," Dr. Veverka explains. "The agricultural resources that could be used to produce food are now being diverted to making fuel for this country. This is why the algae is being looked at with

RUN ON SEA WATER

DID YOU KNOW?

Algae belong to a group known as Protists, which include a wide range of uni and multicellular organisms that exhibit plant (photosynthetic, like algae) and animal like (heterotrophic, like protozoans) characteristics. The common denominator is that they are all eukaryotic; their cells contain a defined membrane bound nucleus with organelles. Algae are very diverse and can encompass a wide range of specimens, from the microscopic unicellular types under investigation at the Air Force Academy to the visible kelp and seaweed one observes in lakes and oceans. Over 40,000 species of algae have been identified with many more yet to be identified. Major groupings include green, golden, red, brown, and blue-green (which are considered another organism, cyanobacteria).

such interest. I can get a lot more bang for my buck with algae than I can with food stocks.”

Veverka's interest in these little green single celled organisms is shared by scientists around the nation for several reasons. To begin, algae is a naturally occurring organism that has lesser commercial value as a food source, which means it can be cultivated without causing national food prices to increase. Furthermore, algae does not require the same amount of land, nor share the same soil cultivation and pesticides cost factors of other terrestrial based crops.

Veverka continues, “There are thousands of different species of algae and these organisms are very good at photosynthesis and growing in large numbers.” He explains that the species scientists are most interested in are the ones which are most prolific at producing oil. “Algae produce an oil which is quite convertible to the types of fuels we put in our gas tanks.”

If that's the case, why aren't we skimming off algae-laden sea water and putting it into our cars today? Why suffer from sticker shock at the pumps when the world's oceans are teeming with endless volumes of oil-producing algae? To answer this, one must first understand the challenges today's scientists are facing.

The oil that Dr. Veverka refers to is a byproduct of the algae's metabolism and it comes in the form of long molecules called hydrocarbon chains; these chains consist of many carbon atoms strung together. One of the biggest issues scientists face is extracting these fuel molecules from the organisms which produce them. This process is further complicated by yet another challenge: extracting the organisms from the water they live in. “In order to get to the solid biomass,” Veverka says, “you have to extract

the water, and this can expend a lot of energy.” The scientist explains that there are several methods used to separate the algae from the water they live in, including centrifuge devices which spin the biomass free of its watery environment, and chemical catalysts which cause the algae to voluntarily expel the oils they produce. As gas prices rapidly approach four dollars per gallon, these are challenges the scientific community is willing to take on.

Algae isn't the only bio-fuel that scientists are studying today. Research labs across the nation are working with everything from corn and soy beans to peanut and palm oil. Algae is particularly attractive because it boasts higher yields of oil and does not interfere with food production.

Back in the Academy's bio lab, Dr. Veverka brings to light one of the more vital mission elements of his research: *finding the best species of algae for the job of producing energy*. “The key,” Veverka says, “is to narrow our search down to a select few species of algae that are very favorable for producing oil. The idea is to have a product that produces a lot more energy than we put into harvesting it. One particular species under investigation is the freshwater green algae *Scenedesmus obliquus*. It appears to be very hardy and robust under a variety of environmental conditions and preliminary work seems to indicate it will produce fair amounts of algal lipid under tightly controlled conditions.”

Veverka explains that there are three general types of algae: marine algae, found in the oceans; brackish algae, occurring in deltas and estuaries; and fresh water algae, living in lakes and rivers. “They all seem to be fairly consistent in oil produc-

FUEL

tion; that is, there isn't currently a species that jumps out in front of the rest. They all seem to have advantages and disadvantages depending on which type of oil you want to produce."

The USAFA bio lab is collaborating with Air Force-funded Dr. Jürgen Polle from Brooklyn College. "Dr. Polle has bio-prospected several thousand strains of algae all over the country," Veverka says. "He then screened those strains down to about 20 species which really do a nice job of producing oils. He has given the Air Force Academy about ten strains to work with. At the Academy, we'll use environmental regimes such as varying light, temperature and nutrient ratios to push these promising strains to greater oil accumulation and then closely analyze the composition of oils produced."

Once the search for the elite in oil-producing algae has been honed down to a select few, the next step in this fledgling energy paradigm begins. In farming, happy, healthy crops produce better yields. The same is true of algae, which means the science of providing these organisms everything they need to produce oil is of critical importance.

Veverka explains that there are two ways to manipulate algae into producing more oil. The first is to alter the species genetically, and the second is control environmental factors to favor faster growth and better production. "There is a degree of genetic manipulation that is occurring at research centers around the country. Here at the Academy, we're just

working with naturally occurring algae." The doctor indicates the incubation growth chamber to his left. The large enclosed device contains several beakers of green algae gently rocking back and forth on a motorized platform. "I can artificially manipulate the light and the temperature in this chamber. Depending on the right combination of environmental factors, I can actually get the algae to produce more oil than they naturally would."

Dr. Veverka cites another strategic partner in the Academy's algae to fuel endeavors, Dr. Terence Evens of the United States Department of Agriculture. Dr. Evens has hypothesized that there is a more efficient way to grow algae. His theory involves controlling the trace amounts of minerals and nutrients that are introduced into the algae's nutrient medium. By steadily revising these ingredients while monitoring growth results, Evens speculates that scientists will soon arrive at a recipe that will help algae to grow and thrive better than ever. The Academy currently uses some of his software models for cultivating their own algae.

Eventually, once theory and research have provided more answers to the biological questions, the task of developing viable production facilities will come into play. Does it take an ocean's worth of algae to accommodate our energy needs? Or merely a few swimming pools? How do we manage production, allocate farming space and extract oil without putting in more energy than we get out? These are the questions

Dr. Don Veverka is director of the Life Sciences Research Center at USAFA.



BIO

that scientists are working on today, and there are a number of great ideas in the making.

Dr. Veverka points out, “There’s an on-going debate as to whether we should grow algae outdoors in race-way ponds, or indoors in photo-bio reactors. Outdoors, we have to rely on the natural environment to provide our growing conditions, whereas indoors we can control those elements exactly to our specification.”

Naturally, these two growing options have their trade-offs. While outdoor facilities can utilize unlimited free energy from the sun, they also suffer from cloudy days and cold winter months. Indoor facilities can provide ideal growing conditions year-round, but running photo-lighting arrays and heaters costs money. Veverka suggests that perhaps a hybrid of indoor-outdoor facilities may be a good alternative.

“The beauty is that algae are very good at what they do,” Veverka says. “Under the right conditions, it’s very efficient in terms of capturing energy from the sun and producing oil. For every few hundred acres of corn, we could probably get away just a couple acres of algae ponds to produce the same amount of oil.”

Not all algae are created equal and each produces oil with a slightly different hydrocarbon chain. Likewise, not all machines are created equal, and high performance systems such as jet engines require fuel with a much different chemical composition than engines for machines such as tractors or trains. Scientists speculate that with the help of genetic technology we will some day be able to engineer algae to produce a specific type of oil for a specific type of machine.

The Air Force is looking at various blends of bio-



The bioreactor uses a photo array of LED lights to simulate sunlight, providing needed energy for the algae to perform photosynthesis. The fermentation chamber carefully controls the influx of nutrients and minerals to stimulate maximum growth.

FUEL

COOL CLEAN TECHNOLOGIES

Jon Wikstrom, '84, is President and CEO of Cool Clean Technologies, an Egan, Minnesota company that uses recycled carbon dioxide for solvents, cleaners and renewable energy technology. Currently partnered with USAFA as a research collaborator, CCT uses liquid CO₂ as the primary ingredient for extracting oil from the dried biomass obtained from the Air Force Academy's research labs. Unlike other biomass oil extraction methods which use methanol or benzene—which are carcinogenic—CO₂ acts as a solvent and can be used to safely remove oil from algae. Cool Clean Technologies provides yet another step in the environmentally conscious production of energy from biomass.

fuels grown from renewable sources such as camelina, pennycress and algae. These Hydrotreatable Renewable Jet Fuels are tested and in some cases even flown in live exercises. In March of 2010, the Air Force successfully tested a 50/50 blend of biomass with conventional JP-8 jet fuel to fly an A-10 Thunderbolt II from Eglin Air Force Base in Florida.

“The next big step is scaling this technology up,” Veverka announces. “We need to go from being able to produce thousands of gallons of fuel to millions of gallons of fuel. When you think about the petroleum refining capabilities in this country, that infrastructure took a lot of time to get to the capacity we're at today. Getting the bio-fuel industry up to that level will take a tremendous investment.”

The Air Force's research into alternative fuels also comes with certain environmental advantages. Current fossil fuels spew greenhouse gasses into the atmosphere at an alarming rate. Biomass, such as algae, actually consume greenhouse gasses such as CO₂ during photosynthesis. “We're very interested in knowing where our net carbon capture capability stands,” Veverka says. “There are discussions going on

as to whether or not this process achieves net-sequestering of carbon gases. The general consensus for now is that we're probably not pulling any extra carbon out of the atmosphere; but at least we're not making it any worse. And that's a step in the right direction.”

It is no mystery that conventional fuels such as oil and coal will some day be gone. In fact, today's fossil fuels are merely the ancient remnants of Paleozoic algae and other biomass which undertook the same processes scientists are attempting to cultivate today. “From an evolutionary standpoint,” Veverka concludes, “things always change—they have to in order to survive.” Ironically, this phrase rings true for more than just algae. If our dependence on fossil fuels does not change soon, we may be in for dire circumstances. Our transition to renewable energy must therefore be pro-active, rather than reactive. It would be very unwise to wait until the last drop of petroleum is used up before we begin focusing on bio-fuels and other sustainable energy. If there is to be hope for the future, it rests with the innovation of today. ▣