SCRIPPS INSTITUTION OF OCEANOGRAPHY

explorations

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Scientists take aim with tiny algae and their giant promise as the biofuel solution of the future.

**BELL-BOTTOMS... DESIGNER JEANS... DISCO... BIG HAIR... GAS SHORTAGES—** some icons of the 1970s are etched in the memories of those old enough to remember. A few styles, to the dismay of many, have come back in vogue—oil-related crises among them. Anxiety over the yo-yo of fuel costs returned in 2008, illuminating the dark side of our continued oil addiction.

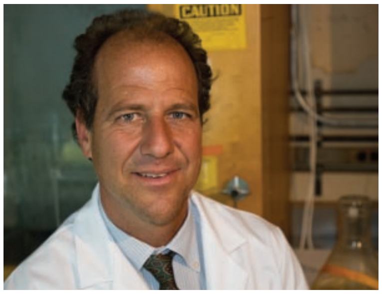
Out of the '70s oil crisis came U.S. government funding for research evaluating the prospects of new fuel sources derived from terrestrial plants such as corn and soybeans, as well as algae. But when oil prices plummeted in the late 1980s and '90s, interest in such biofuel programs waned. Now 21st century gas prices—which bolted to more than $4.50 a gallon in California earlier this year—have sparked a renaissance in the search for new biologically based energy solutions.

Today, the most fervent attention in biofuel development has shifted from soil to the sea, and specifically to marine algae. Scientists at Scripps Institution of Oceanography at UC San Diego, along with researchers at UCSD's Division of Biological Sciences, are part of an emerging algal biofuel consortium that includes academic collaborators, CleanTECH San Diego, regional industry representatives, and public and private partners.

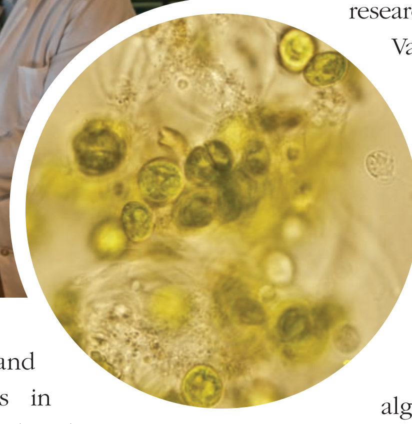
# GREEN BULLET

Mario C. Aguilera


**Above and Right,** *Greg Mitchell and his colleagues are hoping algae, cultured by the flaskful in Scripps labs, will help provide the science behind a new fuel source derived from the ocean.*



**Left and Below**, *In his Scripps laboratory, biologist Greg Mitchell studies various species of marine algae for their potential as a new biofuel source.* **Below Right**, *A microscopic image depicts an algal culture under invasion by contaminants.*



Scripps scientists see algae as a "green bullet," science and society's best hope for a clean bioenergy source that will help loosen dependence on fossil fuel, counteract climate warming, and power the vehicles of the future.

## TEN TIMES MORE POTENT

Scripps biologist Greg Mitchell's interest lies in Earth's basic energy patterns and how sunlight drives fundamental biological functions and energizes the world's ecosystems. He has built his science career on researching photosynthesis, the process in which green organisms integrate sunlight, carbon dioxide, nutrients, and water to produce oxygen and carbohydrates, creating biomass.

Since he arrived at Scripps in 1987, Mitchell has kept close tabs on advancements in studies of algae as a potential source for biofuels, including landmark experiments by the U.S. Department of Energy's National Renewable Energy Laboratory, a research and development facility. Scripps Professor Emeritus Ralph Lewin had a hand in these efforts in the early 1980s when he successfully grew marine algae for biofuel in experimental ponds.

As funding for such projects evaporated in the 1990s, Mitchell never took his eyes off the field. Marine algae are the most efficient organisms on Earth for absorbing light energy and converting it into a natural biomass oil product, the biofuel equivalent of crude oil.

"Algae yields five to 10 times more bioenergy molecules per area, per time, than any terrestrial plant," said Mitchell, a native of oil-rich Houston, Texas. "Nothing else comes close."

From a sustainability perspective, algae hold the upper hand against other biofuel candidates, such as corn and soybeans. Marine algae can be grown on barren desert land using seawater, averting competition with cropland and the need for large amounts of precious fresh water for irrigation.

Since they require carbon dioxide for growth, algae are inherently carbon neutral, and they can suck up $CO_2$ directly from industrial pollution sources. They can feed off the nutrients in discarded wastewater and the rich protein left over from algae harvests can be converted to animal feed.

"There is still a lot of work to do, but algal-derived biofuels have the potential to become a major source of transportation fuel," said Bernard Raemy, executive vice president of Carbon Capture Corporation, a company growing algae in ponds for biofuel research in California's Imperial Valley desert.

Raemy acknowledges that a string of challenges lie ahead, but with appropriate investment he believes a new algal biofuel industry, could be built within 10 years.

"Given their advantages, I believe marine algae are not only the most promising option for bioenergy fuel, but the *only* option that can scale up massively at the global level," said Mitchell. "There is no silver bullet when it comes to energy, but there is a green bullet, or rather a green missile."

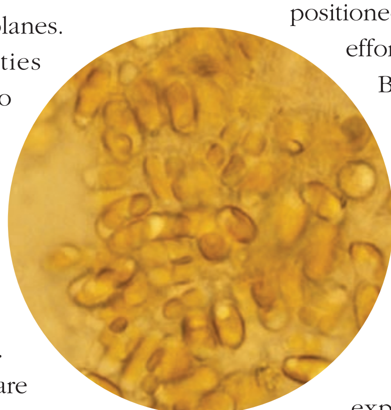
**Right and Opposite**, *At Carbon Capture Corporation's desert biofuel development facility, algae are grown in seawater ponds and dried on mesh netting.*

## GREEN FUEL

The prospect of squeezing billions of gallons of biofuel oil from marine algae is enticing, but to transform tiny lime-green-colored plant-like organisms into a viable and realistic fuel option, they must be tested and grown on a massive scale. Intermediate-sized, and

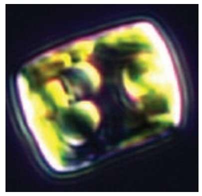
eventually immense, algae production sites will be required to produce sufficient quantities of biodiesel fuel in cars, trucks, and airplanes.

Such facilities are beginning to emerge, featuring farms with vast ponds capable of churning out hundreds of pounds of algal biomass per day. But these facilities are in their formative stages and face an array of problems. Operators must select which species of algae are the best candidates for



biofuel output and deal with the threat of contaminants that invade algae ponds and disrupt growth.

In 2005, as gas prices continued to rise and long-term oil supplies grew increasingly suspect, interest in algal biofuel research began to stir. Mitchell, who spent years promoting algal biofuel but was largely dismissed, jumped in with zeal. He began organizing meetings and coordinating efforts with national and international algal



biofuel stakeholders.

At the same time, Mitchell's laboratory began evaluating various species of algae for their biofuel potential. Today, the lab is evaluating algal growth scenarios and resultant biological models, or test cases, which could be applied in algal pond farms.

Scripps Oceanography, UCSD, and San Diego in general are uniquely positioned to lead algal biofuel efforts, according to Mitchell. Besides his laboratory, efforts have emerged across Scripps, including initiatives by scientists William Gerwick, Mark Hildebrand, Mike Landry, Brian Palenik, and Maria Vernet.

"By virtue of the expertise found at Scripps and UC San Diego, this region has a fundamental critical mass of talent that's not available anywhere else," Mitchell said.

## BIOMEDICINE TO BIOFUEL

Up one floor from Mitchell's office inside Scripps Oceanography's Sverdrup Hall is William Gerwick's bustling laboratory, part of Scripps' Center for Marine Biotechnology and Biomedicine.

A 1981 Scripps Ph.D. graduate in oceanography who returned as a professor in 2005, Gerwick is one of several researchers at Scripps searching for new biomedical products from ocean resources to help treat human diseases such as cancer.

Two years ago Gerwick and graduate student Cameron Coates, began applying the tricks of the marine drug discovery trade to algal biofuel development.

"Algae are my life," said Gerwick, who believes algal biofuel development will require expertise across several disciplines. "There is an amazing transformation happening at the moment with a groundswell of interest in new energy sources."

Gerwick's team deciphers the structures of molecules and probes the metabolic processes that produce unique and sometimes medically promising compounds. Such expertise could similarly help unlock the mysteries of algae's biofuel potential.

The organism's energy sources reside in its production of lipid oils, or fat molecules, that store energy. Algae

**Top left**, *Biofuel development travels from fresh algae culture at left to dried algal biomass, then to crude extract.* **Top right**, *Lipids fill the cell of a diatom.* **Middle left**, *Microscopic algae.* **Below**, *Researchers Cameron Coates (left) and William Gerwick.*

produce and store globules of lipids in a fashion similar to the way fat is generated and accumulated in human bodies. A relatively simple chemical process turns the solid lipid globules to liquid. A few more steps convert the liquid to biodiesel fuel for cars and trucks, and, in the near future, jet fuel. Because algae reproduce quickly—they can double their numbers in a single day—it's believed they can more efficiently produce many more gallons of oil per acre than any other source.

Gerwick's team is also using an imaging technique called mass spectrometry to explore the inner workings of organisms at the molecular level. The tool is helping the scientists determine the mechanisms of the genes that produce lipid molecules in the hopes of boosting lipid oil production by adding certain molecules to algal cultures.

"We have tested about 15 different ways for eliciting (lipids)," said Gerwick. "We see some evidence in which we were able to greatly expand their growth rate and production of oils. It's early, but I'm excited."

## PONDS OF PROMISE, NOT POND SCUM

Like Gerwick, Scripps biologist Mark Hildebrand only recently initiated algal biofuel studies in his laboratory at Scripps.

Hildebrand is optimistic about algae's contribution to future bioenergy solutions, but he is realistic about the challenges ahead. And he is especially sensitive to misinformation being generated to the public about algae and biofuel. He particularly winces when he comes across public descriptions of biofuel algae as "common pond scum."

For the record, many algae targeted for biofuel inhabit the sea, rather than terrestrial ponds. And the algae Hildebrand studies, tiny algae called diatoms, are far from scummy. He is quick to point out, backed by striking nano-scale images of the one-celled organisms, that they, in fact, can be quite beautiful.

**Below**, *Mark Hildebrand examines the biofuel potential of diatoms, microscope algae that grow in a variety of ornate shapes.*

He and members of his lab are probing a catch-22 presented in algal biofuel research. Algae mainly produce desired lipid oils when they are starved for nutrients. Yet if they are limited in nutrients, they don't grow well. Give them a healthy diet and they grow well, but they produce carbohydrates instead of lipids.

Thus Hildebrand is investigating how genes are turned on, or "expressed," in lipid production.

"If we can grow cells under conditions where they are not making lipids and another batch where they are, we can compare changes in gene expression patterns and that will help us identify the genes that are induced when lipids are produced," said Hildebrand.

Hildebrand uses fluorescent dye to measure lipid content and is developing genetic manipulation tools to induce or repress the expression of these genes. He is also studying how the cell is "partitioning" carbon between lipids or carbohydrates, in hopes of metabolically engineering the cell to use more carbon for lipid synthesis.

Such investigations and others by his colleagues are vital, Hildebrand said, in order to lay a badly needed basic research foundation for the emerging algal biofuel industry.

The upside of algae, Hildebrand maintains, is that lipids have shown great promise as a robust energy source. Oils derived from certain algae species have already been converted to fuel. Now it's a matter of economics and the engineering needed to ramp up to large-scale production.

"We know almost nothing about how lipids are synthesized and where the gene regulation is occurring. It's like proposing to develop agriculture without understanding how plants grow," said Hildebrand. "We'll need to keep coming up with new solutions because new problems will need to be addressed. That's the beauty of basic research."

View the complete multimedia presentation of this story at explorations.ucsd.edu.

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