Patrick McGinn, lead scientist for the NRC's National Bioproducts Program in Microalgae Biofuels

In Full Bloom

The National Research Council's Institute for Marine Biosciences uses its resources to help companies refine new technologies

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Millions of years ago, in a carbon dioxide-dense atmosphere, massive blooms of algae covered much of our planet. Over time and through geological processes, this became buried treasure, transformed by nature into the petroleum we now extract to power our industrial economies. Today scientists are trying to capture that same energy source without having to wait millennia.

Perched among giant glacial boulders, the National Research Council's Marine Research Station, part of Halifax's Institute for Marine Biosciences, stands witness to the wind and waves pounding the granite of Sandy Cove near the mouth of Halifax Harbour. As nature reshapes the Atlantic coastline, the scientists inside explore the keys to unlocking the mysteries of this fascinating organism.

Patrick McGinn, the lead scientist for the NRC's National Bioproducts Program in Microalgae Biofuels Project, explains the increasing interest in using algae for the production of biofuel. "There's a growing realization not just among scientists but by the general public that our dependence on fossil fuels isn't sustainable," he says. "There simply won't be enough fossil fuels to keep our economy chugging along indefinitely like it has been throughout the last century." That's especially true in light of the rapid economic growth of countries such as China and India, which will demand more energy as their standard of living rises.

While biofuel has been around for decades, it only represents about 2% of the world's liquid fuel market. The United States and Brazil have both developed large national programs for producing bioethanol (the U.S. uses corn and Brazil uses sugar cane). While Brazil has essentially weaned itself from petroleum imports, the U.S. has discovered that biofuel isn't a panacea. "Growing corn as a fuel source has implications for food production, putting pressure on corn prices," says McGinn. "But there are also environmental effects to consider."

Higher corn prices are a strong incentive for farmers to plow additional land to plant more of the crop, and that land change has a CO_2 cost. He adds that some high-profile scientific publications have reported that the carbon footprint of corn ethanol is higher than originally anticipated because there's a net release of CO_2. It has made people consider second and even third-generation biological feed stocks for the fuel production, including cellulose and agricultural waste residues such as corn husks. It's still in the development stage, and yields from these feedstocks remain predictions. "What we refer to as a third-generation feedstock is what we're working on with microalgae," says McGinn.

Many microalgae are unicellular photosynthetic organisms. Like leafy plants they'll absorb carbon dioxide, and then with the sun's help turn that CO_2 into organic carbon. Some of that carbon ends up as oil. The oil that every algal cell produces is much like any vegetable oil, easily converted to either biodiesel or biojet fuel by a process called transesterification. "It's simple chemistry," says McGinn. "With little if any modification to a diesel engine, that fuel can be burned. The basic biology of how an oak tree leaf takes carbon dioxide and with light produces lipids is the same reaction as in a single algal cell."

Microalgae have other advantages over traditional feedstocks. They're much more productive, in that they grow more rapidly. A growing season for a batch of microalgae lasts about a week, whereas in Canada it would take several months before farmers could harvest an agricultural corn crop. Some strains will double two or three times every day. So you can go from dilute culture to having a fully grown culture or crop in as little as seven to 10 days.

Photobioreactors provide a controlled growing environment

Microalgae are typically grown at large scale in three ways: in a photobioreactor, in open ponds, or by a fermentation process. The NRC is using photobioreactors, which provide a controlled environment where all the growth requirements are introduced into the system. Nicknamed

“Brite-Box,” these photobioreactors are extremely productive but also expensive, small, and used mainly for research purposes.

The practical approach is likely to be large outdoor raceway ponds agitated with a paddle wheel. While they would be low cost and low energy, they would also be less productive. “One of the most important technical challenges is developing a scalable cultivation system,” says McGinn. “It’s going to have to be a system that is outdoors and uses as many free inputs as possible, such as sunlight, and is potentially fertilized and grown in municipal wastewater (for the ammonia and phosphorus) while using carbon dioxide from an industrial flue-gas stack as the Co2 input. The Co2 that would have normally accumulated in the atmosphere can be used for algal cultivation.” There are thousands of different species of microalgae, many of which thrive in seawater, which can reduce the need to use freshwater resources. “Now, if you make fuel out of algae with an industrial Co2 source, then combust it in an engine, that Co2 will still be released into the atmosphere, but at least you get two kicks at the Co2 can,” says McGinn. “You recycle it a little bit. One of the most attractive outcomes of this strategy for making biofuels is that it moves our fuel production process toward carbon neutrality, which we are currently nowhere near with fossil fuels.”

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So what makes algae so attractive? “The bottom line for algae is that it has by far the best yield of any potential oil-producing organism or plant,” says David Millar, the president and Ceo of Halifax-based Haisley Millar Consulting Group Inc. and an expert in the clean energy field. the world’s two leading oil-producing crops are camelina and jatropha, and oil yields produce about 700 to 1,000 litres of oil per hectare per year. “When you look at algae of any type, you’re up to 60,000 to 150,000 litres of oil per hectare per year, so the yield itself is way above anything plant based,” says Millar. “In fact, nothing comes close.
Algae also have a smaller land-use footprint than other biofuel crops and can fit into the current infrastructure. “The big refiners would love what’s known as a ‘drop in’ biocrude,” says Millar. “No one wants to build a new refinery; they cost billions. Ethanol does nasty things to stainless steel, but oil from algae is much closer to the fossil fuels we use now.”

The other advantage of using algae is the potential to exploit non-fuel co-products. There may be low-volume but high-value compounds that could be exploited for health benefits and commercial applications. The food industry is a perfect example, where natural products such as carageenans from seaweed have been used as emulsifiers. The Marine Research Station was originally set up to study seaweed aquaculture. Acadian Seaplants Limited, based in Dartmouth, developed its business plan and approach largely from the research that came out of the Station. Acadian Seaplants is now a thriving biotech company with a diversified portfolio of seaweed derived products ranging from food additives, animal feed, and specialty fertilizers. “We have a precedent in applying the research outcomes in algal biology to commercial applications, so there’s a potential for value-added products,” says McGinn.

“We’re keenly aware that a lot of these markets have small volumes, and that it would be easy to saturate them but it’s still worth going after them. The cost of the technology to produce the fuel from algae is expensive, so it’s essential that we use these other markets to offset these costs.”

The NRC also works with industrial partners and other research groups to develop technologies that will help the process become more efficient and viable on a large scale. The collection and sorting of local strains of algae, the ones most suited for a local environment, used to be done painstakingly by hand. A machine can now do this, paralleling the use of robotics in molecular biology. One particular industrial partner has developed and marketed solar collection and concentrating mirrored rays that are used to collect sunlight and generate energy. It’s looking to integrate this technology with a novel photobioreactor to grow microalgae.

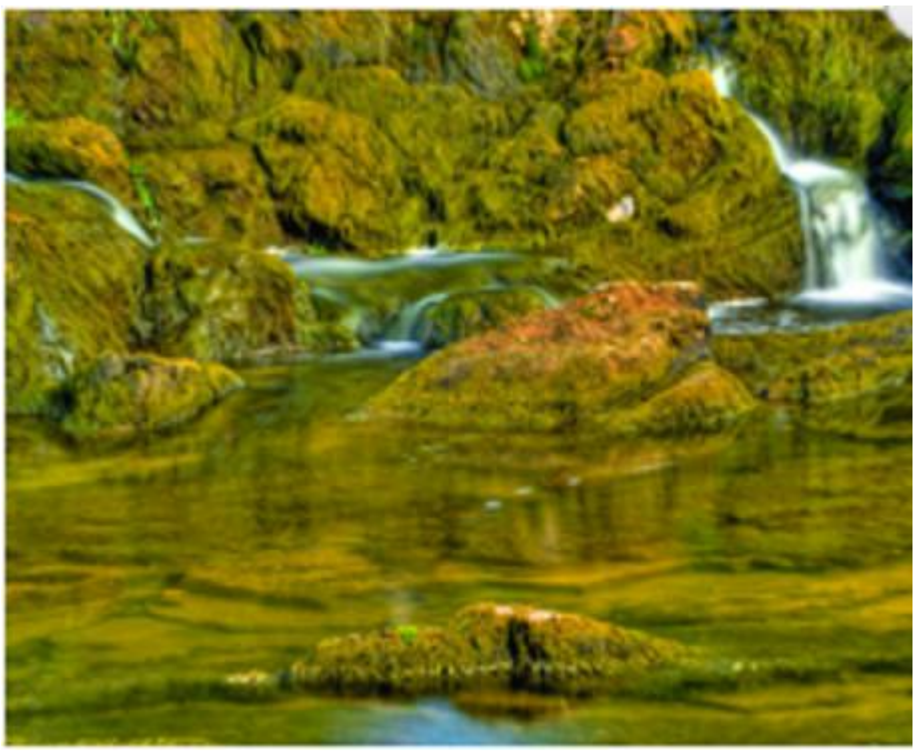
“We have another industrial partner working closely with us, Carbon2Algae Solutions Inc., which has an efficient system for dissolving carbon dioxide into algal cultures,” says McGinn. “Normally we just bubble air that’s enriched with CO2, but the bubbles formed are too big for the CO2 to dissolve efficiently. So they bring a unique ‘CO2 infusion’ technology to the table that is extremely efficient.”

The CO2 doesn’t get a chance to form bubbles, it just dissolves in the water. There’s a startling difference between how fast the culture grows when this device is used compared to growing it by traditional methods. The practical application of this promising technology is that it could be used to efficiently extract CO2 out of industrial flue gases which could then be fed to the algae to “supercharge” growth. It is these kinds of technologies which will be used on a large scale to grow the microalgae for biofuels.

Producing biofuel from microalgae is not yet cost efficient, so piggy-backing on a mature technology such as wastewater treatment might be a way to mitigate some of the high costs upfront. “If you’re going to make a lot of fuel, you’ve got to make a lot of biomass,” says McGinn. “In one of the more exciting results from our research so far, we have been able to show that algae grow really well on secondary treated wastewater. So marrying the process of, for example, wastewater treatment with algal cultivation might be a way to get the high volumes we need.” The typical rate of daily wastewater discharge from a local sewage-treatment plant, for instance, is 30 million litres. That’s an enormous quantity of algal growth medium being released into the Bedford Basin every day. “There’s a resource there that could be exploited and capitalized on,” says McGinn.

Both David Millar and Patrick McGinn agree that the main issue with algal biofuel is getting it to a sufficient scale to make an impact at a cost comparable to fossil fuel. “The ordinary consumer on the street likes all things environmental but doesn’t want to pay any more for them,” says Millar. “To minimize costs, you definitely need to look at co-locating open ponds or photobioreactors near wastewater treatment plants or coal-fired power plants to gain the CO2 and nutrients.”

Barring a major breakthrough, algal biofuel on a commercial-production scale is probably 10 to 20 years away, but many insiders are banking that it will come out on top. “I think in the long run algae is going to be the winner in biofuels, simply because a lot of things have come together,” says Millar. “It fits more naturally in the production system. It’s looking as if it’s scalable to compete at a volume comparable to fossil-based liquid fuels. It doesn’t have nearly as big a land footprint as any other contender and it doesn’t need as much water.”



Algae doesn’t have as big as land-use footprint as other biofuel contenders

A new local strain of algae with remarkably high oil content has recently been discovered by a company based in Nova Scotia, Ocean Nutrition Canada of Dartmouth, which partners with the NRC on various projects. The company is moving forward with its own algae-biofuel program, which will put the region on the vanguard of the industry.

The NRC’s microalgal biofuel project hopes to establish good working relationships with local industry leaders to set up a demonstration facility where microalgae is grown on a large scale using industrial waste. The intellectual properties generated can then be licensed to local companies, and new niche technologies can be marketed around the world.
“There is so much activity and investment going on globally in this emerging field,” says McGinn. “Given our Institute’s research in applied algal biology, our proximity to the Atlantic

Ocean, and the fact that we have the right mix of industries in our region, Nova Scotia is poised to position itself as a world leader in the development of biofuels from microalgae."