Algae Biofuels in Texas

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Abstract

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Texas – the energy center of the world – is emerging as a pioneer in algae biodiesel research and production. There are a number of reasons for this. Texas is the largest emitter of CO2 in the country, and efforts are being made to reduce the state's dependence on fossil fuels. Also, algae – robust and promising organisms – need non-arable land, lots of sunlight and brackish/waste water, along with CO2. Texas has all of these in abundance, plus universities and algae start-ups that are doing crucial R&D in this field. But Texas faces many challenges and algae biofuels could just as easily disappear into obscurity because of biological and engineering problems in cultivating the algae, and extracting and refining the oil. Add competition from other renewables such as wind and solar energy the powerful oil and gas industry. Although the Obama administration has has promised to give clean energy a boost, Texas is still not pushing the right political buttons. The state government seems reluctant to take the issues forward. However, Texas stands at the cusp of becoming either a launch pad or leader in algal biodiesel production. If commercial production launches at a couple of billions of gallons a year with a dollar a gallon, it means additional billions for the Texas economy.

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They say it's a miracle fuel. A couple of billions of gallons of oil from microscopic green slime with the potential to replace fossil fuels. Algae are revolutionary plants from which you extract oil to make biodiesel. Although algae are proven to be nutritionally and pharmaceutically potent, an entirely new breed of biologists, engineers, venture capitalists and entrepreneurs are now braving the traditional U.S. fuels industry forces to tap into the potential of algal biofuels. And the battle is right here in Texas. The destiny of the land of oil, cattle and cowboys is now intertwined with that of pond scum.

Texas – the world's energy center – is emerging as a pioneer in algal biodiesel research and production. Because it's the largest emitter of carbon dioxide in the country, the state is trying to reduce its fossil fuels dependence. Algae – robust and promising organisms – thrive on non-arable land, with lots of sunlight and brackish or waste water, and carbon dioxide. Texas has all these in abundance, plus universities and algae start-ups doing crucial research and development in this field.

However, Texas faces many challenges and algal biofuels could just as easily disappear into obscurity because of biological and engineering problems in cultivating the algae, and extracting and refining the oil. Add competition from other renewables such as wind and solar energy and from the well-established and powerful oil and gas industry. And although the Obama administration has promised to give clean energy a much-needed boost, Texas still is not pushing the right political buttons. The state government seems reluctant to take the issue forward. However, Texas stands at the cusp of becoming either a launch pad or leader in algal biodiesel production. If commercial production launches at

a couple of billions of gallons a year with a dollar a gallon, it means additional billions for the Texas economy.

Algae, the green gold

Biofuels in the U.S. are mainly produced from feedstocks such as corn and soybeans. Such first generation biofuels have received criticism recently because of their non-sustainability, environmental impact and effect on world food supplies. Algae, on the other hand, have proven to be optimum feedstocks for biodiesel, synthetic gasoline, diesel, jet fuel and hydrogen. Certain types of algae are oil-rich organisms. Their oil content typically ranges from 20 to 50 percent, depending on the species. Algae-based biofuels appeal because they grow fast, they consume carbon dioxide during photosynthesis, they grow in many regions and conditions, including on non-arable land and in salty water – thus they don't compete with freshwater resources. Compared to other terrestrial crops, algae grow very fast and can be harvested much more frequently, sometimes two or three times a day.

"The reason algae is so interesting is because on paper it looks very good," says Michael Webber, assistant professor in the Department of Mechanical Engineering and associate director of the Center for International Energy and Environmental Policy at the University of Texas at Austin. "Theoretically, it's highly productive per acre – anywhere between 500 and 15,000 gallons a year." It also avoids some moral dilemmas – the use of

food crops for fuel or for food, or if you're using fresh water or arable land. "Algae have been growing for billions of years so it's very robust whether you want it to grow or not," Webber says. "It would reduce CO_2 emissions as it uses carbon dioxide. And it helps displace petroleum." Algae are six or seven times more effective than terrestrial plants in taking up carbon dioxide.

Algae production uses low energy – they can produce oil that can be made into electricity to power the plant where the refining occurs. "The main issue is we're using a crop that emits CO_2 when burned but that CO_2 does not come from carbon that was derived from geologic sources; it's from renewable sources," says Bob Avant, bioenergy program director at Texas A&M University. "We're simply reusing the carbon instead of pumping it out of the ground – that's a big difference. We know it will reduce the carbon footprint depending on the right production system."

Most terrestrial crops can produce about 100 gallons per acre per year of lipids (cells with stored fat). Cotton produces somewhere around 40 gallons per acre, soybean around 15 gallons, and castor probably can go up to 200 gallons. But algae average 2,000 to 5,000 gallons, with a theoretical maximum of about 15,000 or 20,000 gallons. "But that means everything needs to be perfect," Avant says. "So our thinking is that a practical, sustainable quality of production is somewhere around 5,000 gallons per acre."

"I'm a part of Big Oil and when I see biofuels and I see something that works, I want to buy, to own it and run it," says Ron Henson, former vice president of Earthrise, a

California company that makes algae natural foods. “Most biofuels are not a good deal; they drive up food prices. Algae grow in salt water and pollutants from city wastewaters, and animal feedlots can be used as fertilizer.”

Thomas Gieskes, former vice president of the Houston-based Organic Fuels, an algae biodiesel company, also attests to the potential of the plant as an alternative and green biofuel. Organic Fuels, started in 2005, currently makes small quantities of algae biodiesel, but a pilot plant in Texas is in the works – a bio-refining facility that could make commercial quantities of algae biodiesel in the next few years. Gieskes’ company is one of many in Texas as well as the whole country that are experimenting in this emerging energy source.

The potential for biofuels has not gone unnoticed by the federal government either. In 2007, Congress enacted the Energy Independence and Security Act, which includes the Renewable Fuel Standard. The RFS mandates production of up to 36 billion gallons of renewable transportation fuels by 2020, of which 21 billion gallons per year must come from advanced feedstocks, with 5 billion gallons a year potentially from algae. “With the RFS, we’re working to get algae actually included in the renewable energy portfolio,” says Thomas Byrne of Byrne & Co. Ltd., a consultation firm for renewable energy companies. “We’re only a small part of it right now and we’d like to be able to be part of the 21 billion gallons and not just a billion or two.” The act aims to increase domestic biofuel production from a number of feedstocks beyond corn and soybeans. Possibly, algae.

Alga trumps other feedstocks in many aspects. Higher-oil-content plants such as jatropha and palms fare better than corn or soybeans by requiring 34 percent and 11 percent of our current cropland, but are not necessarily compatible with U.S. climate. Microalgae, however, with varying oil contents would require less than 6 percent of the amount of land used for crops. According to the Department of Energy's National Renewable Energy Laboratory's estimates, corn has an oil yield of 18 gallons an acre per year, cotton and soybean are 35 and 48 gallons respectively, while microalgae with 50 percent oil content yields 10,000 gallons of oil per acre per year. "Arid land that a farmer owns on which they earn only $400 to $500 an acre by growing soy or canola, with algae they can make $5,000 per acre," says Barry Cohen, director of the National Algae Association (NAA).

Although a veritable miracle fuel, algae require complicated processes for cultivation and oil extraction. Algae cultivation systems for algae mainly run along two lines: ponds and photo bioreactors. Pond systems require giant lakes to be built across many hectares of land, through which CO_2, water and nutrients are pumped for the algae to grow. Photo bioreactors are a series of tubes through which algae are circulated in water along with regular doses of CO_2, nutrients and sunlight. Both methods have pros and cons.

Photo bioreactors incur huge construction and installation costs but limit problems of contamination from invasive species and also provide higher yields. They are are made up of a series of closed tubes through which the algae is circulated. Ponds, on the other hand, are easier and cheaper to build (like constructing a giant lake) but require vast tracts

of land and water resources. There's also the danger of invasions from other plant species and temperature cannot be regulated. However, 98 percent of current algae cultivation in the U.S. uses pond systems. "The robust affordable simplicity of ponds looks appealing to me," engineering professor, Webber says. "Photo bioreactors look very expensive to me.

But Cohen, from the NAA, feels the best method is closed photo bioreactors. "They produce minimum 50,000 gallons per acre per year and up to a few hundred thousand gallons per acre per year," he says. As Big Oil companies seek to reduce the high offshore-onshore production and drilling costs, open pond systems make more sense as they are cheaper even if they generate only around 8,000 gallons of algae per acre per year. Some 15 to 20 such pond systems operate in the U.S. right now, according to Cohen.

Once the algae are cultivated and harvested, problems occur in extracting the oil and refining and blending it. The most common oil extraction methods involve drying the algae and then adding solvents or enzymes, or applying pressure and heat. "Some algae secrete ethanol – they sweat it, which is then treated and refined and processed to blend into gasoline," says Jerry Brand, director of the Culture Collection of Algae at UT Austin (UTEX). "It's an expensive process but that way you can use a large percentage of the whole alga."

It all comes down to growing the right strain of algae in the right condition and for the right price. Whether companies use ponds or photo bioreactors, heat or solvents, algae biodiesel needs to be taken to a commercialization level, both profitable and environmentally sound. If you wanted to supply the entire U.S. with fuel from algae, and everyone drove diesel vehicles, it would probably take up one whole western state like New Mexico – not feasible without solving the problem of space. Enter, Texas.

The Texas story

The state provides the perfect landscape to determine the amount of algae-based biofuels that can be produced. Texas has an abundant supply of resources conducive to growing algae, as well as decades of experience in the energy industry. “It’s not so much about the connection between Texas and algae but between Texas and energy,” says Brand, the director of UTEX.

The well-established Texas oil and gas industries possess significant knowledge and expertise in refining and processing. “This is a center for pipelines, and blending and refining and distribution, sales and marketing and research,” Webber says. Although fuels currently produced are petroleum-based, the same companies involved in the production will have a hand to play once biofuel production starts. The lessons learned in Texas can be applied to the large-scale production of algae biodiesel anywhere in the world. “If you

want to get biofuels blended and distributed you're going to have to talk to Texas companies," Webber says. "We have the recipe [for blending and refining]."

"The energy industry is centered here in Texas," says David Wogan, a UT Austin engineering graduate student who has co-authored a paper on Texas' algae biofuel potential for Austin Technology Clean Energy Incubator. "We handle a quarter of the country's refining capacity." This capacity has given Texas a solid knowledge base in industry and academia. "Houston is also the energy capital of the world and you can benefit from a lot of the infrastructure like docks and tanks and pipelines and this is a good location logistically," he says.

Texas also has many industrial plants that produce a lot of carbon dioxide – a vital component of algae cultivation. Depending on future carbon legislation, carbon credits could be big business for people who produce a lot of carbon. "Maybe you're an electrical utility and instead of just emitting CO_2 into the air maybe you feed it to the algae producer and you get credit for that," Wogan says.

Texas is the biggest consumer of petroleum and emitter of greenhouse gas emissions in the U.S. We pollute more than some nations combined. Texas consumes almost 17 billion gallons of gasoline and diesel per year and emits nearly 192 million metric tons of CO_2 from transportation sources. So Texas has an interest in exploring cleaner fuel technologies and investing in ventures that reduce fossil fuel emissions.

“As the world's third largest producer of crude oil, largest producer of natural gas, and second largest producer of coal, our domestic production of traditional energy sources will continue to play an important role in our energy supply,” says Congressman Mike Conaway, R-Midland. “Developing carbon capture and storage, clean coal, biofuels, and other clean fossil fuel technologies will help us utilize these critical fuel stocks and our fossil fuel based infrastructure in a more environmentally responsible manner, while providing critical increases in production capacity.”

Much of Texas’ collective wealth of knowledge in algae biofuels can be attributed to its universities. They conduct significant research and development crucial to the commercialization of the industry. UT Austin is home to the world’s largest algae collection, headed by Jerry Brand, the director; there are almost 3,000 strains available for supplies to companies, researchers and universities.

Texas A&M University also is heavily involved in algae biofuel research. “We have a major program in algae biofuels – a $7 million program that is looking at a systems approach to algae production from the screening of algae to the extraction of the oil from the algae itself – the lipid extraction,” says Avant, bioenergy program director at Texas A&M. “It is a fairly comprehensive systems approach that focuses on the production side of it in terms of the algae production in the field.”

The main resources required for sustainable algae growth are sunlight, CO_2, brackish or saline water, land and nutrients like phosphorus and nitrogen. Texas has all these

resources in significant quantities, providing an opportunity to grow algae for biofuels on a large scale. “We have been blessed with a lot of sun, a lot of water, and a strong business climate, an ample and skilled workforce, and a great demand for energy,” says state Senator Kirk Watson, D-Austin. “All of these are critical components to developing a biofuel industry.”

Certain parts of the state host optimum climatic conditions for large-scale algae production. “The extreme southern tip of Texas has marginal weather compared to southwestern California and southeastern Arizona,” says Henson of Earthrise. “That area probably is the best place for algae production in the U.S.” Also, a substantial part of West Texas is ideal for algae cultivation, according to Henson. There are huge tracts of land, otherwise unfit for agriculture, sunny weather throughout most of the year and brackish or saline water. The rest of Texas also has abundant water resources in the form of underground saline aquifers. Wastewater from city sewage treatment plants can also be supplied for algae cultivation.

Texas’ algae biodiesel potential has not gone unnoticed by the business world. Interest in algae biofuels has translated into rising investments in research institutions and start-up companies. Government agencies have provided research funding many universities to produce algae for military aircraft uses while venture capital firms have invested in smaller start-up companies. Venture capital investments in biofuels increased from $2 million in 2004 to more than $200 million in 2008, according to DOE estimates.

Some of the prominent algae-biofuel start-up companies in Texas are Valcent Energy, PetroSun Biofuels, Organic Fuels and Sunrise Ridge Algae. El Paso's Valcent produces algae biodiesel using vertical photo bioreactors. Partnering with Canada's Global Green Solutions, they have opened a $3 million algae cultivation plant in Anthony, outside of El Paso. Houston's Organic Fuels, partnering with UT Austin's mechanical engineering department, is experimenting with extracting oil from algae using a high-energy voltage charge. Sunrise Ridge of Austin has a pilot plant partnering with the city's wastewater treatment facility, cultivating algae for oil extraction. All are focused on commercialization of technology to produce algae on a large scale.

For example, when Houston-based Organic Fuels first started production of biodiesel in 2005 – according to former Vice President Thomas Gieskes – the company experimented with other feedstocks, such as vegetable oil, palm oil, etc., but ultimately found the production processes unsustainable. With the help of Texas universities as well as emerging technologies used by other companies, Organic Fuels transitioned into using algae as a feedstock. Although the company still produces small quantities of the oil, it focuses on commercialization, and Gieskes hopes that the industry could mean something significant to the state economy.

A viable and fully commercial algae biofuel industry in Texas could translate into significant contributions to the state's trillion-dollar economy. "It could mean a lot of money for Texas and a lot of jobs," UT Austin engineering student Wogan says. "Best-case scenario in Texas is 3 to 12 billion gallons worth of algae oil. You're looking at

billions of dollars." But this is subject to the availability of algae feedstocks at price levels that would be profitable for companies and allow the industry to operate at full capacity.

According to Texas A&M University research, based on the total biodiesel production capacity of Texas in 2008 - 536 million gallons per year – the directly resulting industry profits are $2.4 billion alone. The total economic impact is $3.7 billion annually for the industry if you include the profits of related industries. At 536 million gallons per year, around 10,000 jobs can be created throughout the Texas economy. While the impact of the Texas biodiesel industry on the Texas economy is significant, if related industries could (like pharmaceuticals, fertilizers, nutraceuticals, animal feed) also benefit the impact on the state's economy would be even greater.

"Texas cattlemen should be the ones looking into this," Earthrise's Henson says. "Biofuels from feedlots and dairies and piggeries." The methane emitted by cows can be converted into a biofuel or burned to produce electricity. There are nutrients in manure from animals that can be used to grow algae, which feed on these nutrients. The meal from the algae oil extraction process can be fed right back to the animals or burned again as fuel. "In an integrated approach, Texas should be leading the way," Henson says. "You got quite a few cows out there."

Not quite there yet

But Texas faces challenges on the technological and economic fronts – challenges faced by the industry as a whole in the U.S. Not enough algae oil quantities are being produced to qualify as large-scale production. “If you want a 100-liter flask, then yes there is production,” Texas A&M’s Avant says. “Right now we’re talking about the order of a few gallons to maybe a few tens of gallons – but in terms of being able to go out and buy quantities of algae oil right now, it’s just simply not possible because nobody has reached that level of production yet.”

The algae biofuel industry is very small right now; production levels are at a few gallons of algae oil a year. Although many start-ups are partnering with major oil companies and universities, algae biodiesel production is still at a nascent stage. Most of the algae industry in the U.S. is concentrated in pharmaceutical and nutraceutical applications to make shampoos, food supplements, vitamins and so on. “In terms of big companies, not a lot of people are doing it,” says Wogan, UT engineering student. “It’s just a lot of small-scale farms and start-up companies trying to figure it out. Nobody really knows what the processes are or how much it costs.”

Experts consider California, New Mexico, Arizona and Texas to be the forerunners in algae energy research. Florida, Louisiana, Colorado and Hawaii are also home to university and industrial algae research. The southern parts of the U.S. dominate this field

possibly because of the co-location of optimum resources needed for algae cultivation – tremendous amounts of open, unutilized land and warmer climates.

But many disagree that Texas is one of the leaders in the algae biodiesel field. "There is a $66 billion algae oil market and a $50 billion biomass market out there," Cohen from the NAA, says. "California, New Mexico, Arizona, Louisiana, Florida, the Carolinas, Pennsylvania are all the top producers of algae biofuels. Texas is not one of them."

A number of nationwide projects have moved to the pilot and demonstration stage of algae biodiesel production. Algenol Biofuels in Florida will be using bioreactors filled with saltwater to cultivate blue-green algae to produce ethanol. PetroAlgae, another start-up, has a demonstration facility in Florida that makes biodiesel. Sapphire Energy, one of the most promising companies in this field, will produce gasoline and jet fuel from its algae process in its demonstration plant in New Mexico. HR BioPetroleum is in the process of constructing and operating commercial algae facilities in Hawaii by partnering with Royal Dutch Shell. Other noteworthy companies are XL Renewables in Arizona that has established a biomass production center for biodiesel and feedstock purposes; they hope to be commercially viable by this fall. Solix Biofuels' pilot facility in Colorado makes oil from microalgae and expects to produce 3,000 gallons of oil per acre, per year by 2010. Solazyme from California also makes algal biodiesel and hopes to build a commercial plant by 2010. OriginOil is another California company that uses photo bioreactors to produce algae oil.

John Carey of *Business Week*, who often writes about the American biofuel industry, says that there's a lot of hype around algae and there are many companies trying to raise money and make it seem as if they're on the verge of making a breakthrough. "But in talking with the oil companies like Shell and BP, who have evaluated all the companies, they were a little less sanguine about the pace of the industry," he says. "In some cases, they thought that a lot of the approaches wouldn't even work out in the long run."

Others liken this to an initial phase of excitement, which is what typically happens when an opportunity is identified. "Unfortunately, there are so many reports that algae produce 5,000 or 10,000 gallons of oil per acre," says Ben Cloud, COO of the Arizona algae biodiesel company, XL Renewables. "The truth is that combination does not exist yet. There's just too much speculation." The industry is finding it difficult to attract investment consistently because the initial expectation of high yields and high oil content has not been realized because of technological difficulties. And now it's dropping back down to a more realistic approach to producing and understanding algae biodiesel.

"What has happened is that some of the people/companies crying the loudest for financing may not have had a viable business model anyway," Henson says. "As with any new and developing technology, when all kinds of groups are going after it in all kinds of different ways looking for financing, you'll always have some who really don't know what they're doing. They don't understand algae and it's so easy for people to become confused."

Business Week's Carey says that right now the algae biofuel industry in the U.S. is in the angel money phase. Angel money comes from individuals who have significant amounts of money that they invest quietly in concepts that they either believe in or have a moral feeling for. Venture capital groups, on the other hand, are the big investors with equity funds from a number of investors. "There has been a little bit of a bubble where the companies who got in early got the funding and then [investors] sort of pulled back," Carey says. "So now there's more skepticism out there. It's clearly more difficult to raise that kind of capital now."

But these companies get support from many quarters, such as the Air Force and the commercial airline industry. The Air Force uses the most amount of energy than any other U.S. government body, so it's trying to reduce its carbon emissions by investigating biofuels. The commercial airline industry, too, has been a big sponsor of algae biofuels as potential jet fuel. Airlines have tested liquid jet fuel made from organic feedstocks. But some processing still needs to be done since not all algae oil is the same: It differs in fuel quality.

Significant public investment also has come from the Department of Defense's Defense Advanced Research Projects Agency and the military. The Department of Energy and the Department of Agriculture also have awarded grants and loan guarantees to help particular projects. For these reasons many people think that the algae industry is booming and that Texas is a key player as people come to the state to learn about algal production. "There are a number of individuals out there with very significant programs

that in the next year or two years will be on the verge of producing significant amounts," says Avant from the bionenergy program at Texas A&M.

Gieskes' company Organic Fuels in Houston, for instance, is building a pilot plant under a Department of Energy grant. The DOE currently encourages industry companies to integrate their biorefineries, where feedstocks can be used to produce biodiesel and resulting by-products can be used in related industries. Gieskes hopes the company can combine ethanol production with algae biodiesel production. "Ethanol is produced through fermentation and in fermentation you co-produce CO_2 – for one pound of ethanol you produce one pound of carbon dioxide," Gieskes says. "So by integrating these two processes we can take a feedstock such as sugarcane or sorghum or corn to produce ethanol – co-produce animal feed which is then fed in a feedlot to cows." The animals' manure can then be used as a nutrient source to grow algae using the carbon dioxide from the ethanol production. Such integration may key the survival of these companies.

"The most promising companies are the ones that can make stuff other than fuels – some of those products are higher valued," Carey says. "There are a bunch of interesting niches that algae companies are going to come into." Many companies soon will have to determine if the algae that they cultivate will give the highest profits from using it as a fuel only. It is possible that they might discover a more profitable uses such as burning algae biomass directly to make electricity to power cars rather than as fuel. Maybe fuel will not be the best use; maybe it will be used by refineries to make plastics and other chemicals. The advancement of technology will determine this in the next few months.

“All the companies right now in algal biofuels are on the cutting edge,” Henson says. “But the cutting edge is also the bleeding edge. So it’s like any other high-risk technology.”

The science of it all

Algae may be a miracle crop yielding an abundance of oil, but the biological and engineering hurdles are the main things standing in the way. Avant narrows down the challenges to eight: three related to biology and about five connected to engineering. “The biological aspects are to identify the right algae to operate 365 days a year – screening algae for the production of biomass,” he says. “Then there are issues of what alga strain yields lipids and then the biological performance of the algae itself that might relate to how easy it is to extract the oil from the algae cells.”

Algae require vast swaths of land, if grown in open pond systems – land that could instead be used for crop cultivation. Add the right weather, water and nutrient conditions. “Out in the open it’s very hard to prevent practical things like contamination,” says Carey, a writer at *Business Week*. “And once you have the algae grown it’s sometimes difficult to extract whatever you want out of it. You have to break up every individual cell wall of each algae cell and that will take up a lot of energy.”

Once the cultivation method has been determined, there is the problem of extracting the oil from the algae, and figuring out what to do with the resulting by-products. “Algae have a lot of protein and other [chemicals] in it that one has to deal with,” says Brand from UT Austin. “If you start calculating the amount of oil that’s processed by even one of the small refineries down in south Texas, you have to take away trainloads of algal waste products every month; at least maybe even every week. So what do you do with that?”

If the resulting waste has nitrogen and phosphorus in it, it could be used as a fertilizer, but it may also be a product that can cause environmental contamination. If only algae crops are grown in Texas, it might have serious implications for the native environment.

Different strains of algae produce different types of oil, not all of which may be conducive to making biodiesel to fuel engines. “Algae makes the kind of oil that we want when it’s stressed – so if you deprive it of nutrients or sunlight – it makes a different kind of oil that we want and it stores it as fat or an energy reserve,” UT engineering student Wogan says. “So you have to balance growing it really quickly with producing the right kind of oil we want. It doesn’t do that automatically [in its natural environment].”

Algae produce oil very inefficiently. They first produce carbohydrates and proteins for growth and when they can’t grow anymore they produce oil. “Web sites out there are talking about 80 to 100 grams per square meter per day yield with 50 percent oil content,” Earthrise’s Henson says. “Now I’ve seen algae be produced at that high rate of

growth but not with those kinds of oil yields. High rates of growth and increased oil production are not compatible." This is because slow-growing algae produce the kind of oil we want, while fast-growing algae may not produce the kind of oil we want. A balance needs to be achieved.

Logistically, co-locating water, land, CO_2 and refining capacity in Texas is an enormous hurdle. Although the state has all of these in adequate supply, getting them together in one place to minimize time and cost is the real challenge. "The easy part is that we have [CO_2] here in Texas right now and we know where it is." Wogan says. "The main challenge is where to grow the algae and making sure you co-locate all your resources."

Cultivation of algae in photo bioreactors has its own set of problems. Photo bioreactor systems, although more effective in growing algae, require huge capital investment. "The lowest cost of production with [photo bioreactors] is $100,000 per acre to maximum $5 million per acre – but you get 10 times the amount of oil and biomass as return on investment." Cohen says. "Ponds cost a couple of million dollars, but they produce only 8000 gallons [of oil] per acre per year." Depending on the price of oil in the coming years, it could take anywhere from five to 30 years before production costs are recouped. On the engineering side, the design and operation of the algae systems is a major issue. Costs involving separation of the algae from the water, management of the algae, separation of the oil from the algae, and finally recycling the algae and the by-products, can be very significant.

Gieskes' company Organic Fuels, partnering with UT Austin, uses an electromechanical fuse – or a high voltage charge – to break through the cell membrane of algae. "We use ponds and photo bioreactors to grow the algae but the problem with extracting anything from algae is that it's a microscopic little balloon on a micrometer scale and these algae are quite strong," Gieskes says.

Another major hurdle is the growing of algae in uniquely Texan weather. For a big state spanning diverse climatic conditions, this poses more questions than it answers. "The problem with algae production in Texas is that six months a year it's cold," Henson says. "There are other places in the world outside the U.S., with whom Texas cannot compete."

If you have a facility that can produce algae 250 to 300 days a year compared to maybe 100 days in Texas, more people will put their money elsewhere. For instance, Mexico, South America, the Pacific coast, the Middle East, desert Africa, and northwestern Australia all have ample land and warm temperatures year round where hurricanes are infrequent and food production will not be disturbed.

In spite of being a renewable source of energy, algae oil also may negatively impact the environment, depending on how it's grown. Algae use many nutrients, like phosphorus and nitrogen, and traditionally these come from fertilizers. Fertilizers, in turn, are produced from natural gas, which is another fossil fuel. "If you're doing it like that, you're essentially displacing the fossil fuel use down the line," engineering student Wogan says. "You just get it from a different place. But if you use wastewater you're

kind of reclaiming the nutrients from there and you're not using fossil fuels for that. If you do it right you can be carbon neutral."

Since algae oil yields exceed those of any other feedstock, algae hold great promise for making biodiesel competitive with petroleum diesel in the long term. But how, is another loaded question. But as to how, the big challenge is cost-effective oil extraction. A nudge in the right direction can be given with the right support from state government entities.

Politics of change

Texas as an oil state has many subsidies in place for the fossil fuel industry, but not for biodiesel companies. "The issue is not who gets the subsidy or how much it is, but does it make good public policy to guarantee a cheap reliable and environmentally sustainable fuel source," says Texas A&M's Avant.

Certain groups have been lobbying the Texas government to pay closer attention to algae biofuels and biodiesel in general. "The National Algae Association has been trying for two years to get [the state's] attention but it is against it because they think biodiesel will affect food channels," Cohen from the NAA, says. "But algae does not do that. Texas has companies that use algae to produce oil and biomass without state assistance – and they are not making major quantities because of [state help]."

Thomas Gieskes of Houston's Organic Fuels believes there is a great need for financial assistance to get the first projects of biodiesel start-ups off the ground – with assistance in the form of loan guarantees or grants. "That first project is going to be extremely difficult to finance and there's large amounts of capital involved," he says. "And that is where the government can play a role."

Major oil companies such as Shell, Exxon Mobile and Conoco Phillips also are heavily investing in biofuel opportunities in Texas and elsewhere. But the state government still seems wary of the potential of algae biodiesel. "Big Oil gets it but not the government," Cohen says. "Algae biofuels are going to enhance the oil industry not harm it."

Once production reaches commercial levels, algae biodiesel will get blended with other kinds of diesel to be sold at gas pumps. However, consumers would not even know that they're buying biodiesel. "The guy who makes the decision is not actually the consumer, it's the blender," Geiskes says. All the big refineries are blenders but especially in the U.S. a large part of these people are independents and are called jobbers." For these middlemen, a penny or a penny and half is big money because they have to buy the diesel from the refiners and compete with them in the same markets again.

Jake Stewart, interim director of the Austin Climate Protection Program at Austin Energy, says that many people don't realize that the the fossil fuel industry in Texas is very highly subsidized. "If you took away the subsidies and the peripheral subsidies of the fossil fuel industry, biofuels would compete with those oil companies and that would

undercut the costs of buying gas at the pump." Consumers pay around $2 to $4 per gallon of gas at the pump. Then reason it is so low is because of the massive subsidies that are given to the companies selling the gas. "People kind of get hung up on 'Oh what if we give biofuels 50 cents a gallon to biofuels'….but you can go either way," Stewart says. "You can either level the playing field by taking away the taxpayers' subsidies and truly creating a free market or you need to level the playing field by giving these new technologies that benefit the society, at least some ground to stand on in a tilted market."

The recently concluded Texas Legislative session was witness to a number of energy bills directed toward bolstering efforts in developing alternative energy sources and putting a cap on carbon emissions. With a few exceptions, most of these bills were passed into law. "Part of that is due to concern for competition or reduced demand from 'traditional' oil and gas interests," state Sen. Watson says. "Some of it was just due to the challenges of passing any legislation within the time constraints of a 140-day legislative session, and how most bills die because legislators simply run out of time."

For example, Senate Bill 1016, which contains the bulk of Senate Bill 1666, included the creation of Bioenergy Policy and Research Councils in Texas composed of people with experience ranging from feedstock development to bioenergy production and distribution. The councils will encourage the development of biofuels in the state. There were other key bills passed relating to biodiesel, including House Bill 432, which established an "aggressive state fleet alternative fuels program with biodiesel being specifically identified as a method of compliance."

Sen. Watson also worked on the failed Senate Bill 541, calling for the creation of 3,000 megawatt non-wind renewable energy production, aimed at developing solar and biomass energy production in Texas. “This bill faced strong opposition at the very end of the session from a few industry groups who made false claims about how the price of electricity might increase from this bill,” Watson says.

“The state government isn’t trying to help,” UT engineering professor, Webber agrees. “There’s no additional help from the state beyond the federal funds.” He says that as a state, Texas has mandates for renewable power and other incentives. But for biofuels, the state hasn’t been pushing it the way they have for electricity. “That doesn’t mean [algae production] won’t happen,” he says. “Maybe it’ll happen because the state is not involved. Maybe we’ll be better at it because there’s no government intervention.”

According to Watson, usually when the state gives attention to something such as an R&D process, it becomes easier for start-ups to get permits for facilities, dedicate some state land for it, and do mandates. Policy change on the government’s part can drive financial incentives to develop new biofuel industries through tax incentives, grant programs and subsidies. With the right policies in place, algae energy can make economic sense for businesses and consumers, and businesses will respond only when there is an economic reason to take action. “The [fossil fuel] oil industry is very powerful and it’s hard to convince politicians that they should come up with a new industry that

might bankrupt the old one," Webber says. "It's not a very appealing 'sell' for a politician."

"The big story in Texas is really, wind," engineering student Wogan says. "We're lagging on solar especially since the legislation died in the last session. I think biofuels are lagging behind even solar." Texas is the leading state in wind energy and the state government has created policies and incentive programs in the last few years to encourage more companies to harness this particular renewable energy source. Although wind is for power and algae is for fuel, and they are not direct competitors, a certain change in the state's focus needs to occur for algae to get government support.

"Texas is built on oil and cattle. Biofuels are going to be politically unpopular," says Earthrise's Henson. "So is vegetarianism."

Risky business

With the current state of the economy, an all-round check has been put by investors on financing emerging technology companies, including the ones producing renewable fuels. Lack of state support is not helping the situation much either. "The unavailability of capital or favorable financing always spells trouble for an emerging industry in dire need of major new investment and capitalization of new technology projects," says Mike Nasi,

an Austin lawyer who has contributed to climate change legislation.

Meanwhile, Thomas Gieskes' Houston company Organic Fuels has applied for a patent for a closed pond system to grow algae. Most of the company's investment is in these cultivation systems – in the piping apparatus and pumping methods for CO_2. Gieskes thinks they can build these systems for around $100,000 an acre. "We might get about 1000 gallons of production per acre but to do a 100 million gallons a year, you need about 10,000 acres at a $100,000 an acre," he says. "This gets to be some serious money [about $1 billion]."

The actual processing equipment would cost around $30 million out of a billion-dollar project – still a major capital investment. Despite these financial odds, Gieskes' company will have to derive a production cost competitive with petroleum-based diesel. Algae biodiesel would have to be in the $50 to $60 [a barrel] bracket to be appealing to consumers.

With such an enormous financial burden for Texas' emerging fuel companies to undertake on their own, "We need to provide algae oil producers subsidies similar to what we're seeing with other biodiesel and alcohol production," Henson says. "If algae production is done in such a way that it does not take food out of people's mouths, then double the incentives. Make it a $1.50 a gallon subsidy. That will stimulate technology and investment."

If the government gave subsidies to algae startups, the funds will have to come from somewhere – most likely from slightly higher taxes for consumers. Gieskes of Organic Fuels says that if the state government gives a tax credit to these startups, it means less money collected in revenue from excise taxes. But on the other hand, a lot more money ends up staying in the country as a direct result of producing homegrown biodiesel as opposed to spending billions importing it from abroad. This makes transport fuels cheaper in the long term for the whole economy and those benefits would be passed on to the consumers, too, even if they had to pay a little more tax initially.

The federal stimulus fund is sending forth considerable money to all states to be invested in the research and development of renewable energy. Out of the $2.5 billion to be invested nationally in renewable energy, $800 million is earmarked for projects related to biomass. Much of this will go to universities doing crucial research in algae biofuels. "UT's a part of a DOE grant for $12 million to produce algae biofuels for the Air Force," says engineering student Wogan. "So there's money and support in that sense."

In spite of DOE and Air Force grants to local entities, state Sen. Watson credits the state government's lack of financial support to industry pressure. "Industry can be reluctant to move away from a 'business-as-usual' approach unless there is a compelling - often economic - reason for them to do so," he says. "For biofuel production to really take off, I believe that the oil, gas and petrochemical industry will have to be willing to embrace it and be part of the solution, rather than just fight it."

However, engineering professor Webber feels that the big oil companies are looking at it from an R&D perspective right now because they're curious about algae biofuels and it's a potential revenue stream for them. "They've got some good engineers," he says. "But they can't do it on scale because in the market the prices aren't right."

The 'other' energy

So although Texas may have the potential to catapult the emerging algae biofuel industry in the country, the survival of this green gold is interlinked with the progress of other renewables competing for similar public and private resources.

The recent criticism that the corn ethanol industry has received may be making it harder for algae start-ups to attract funding. Many people believe that ethanol – although a great source of transportation fuel – is doing more harm than good. It competes with food sources and may be actually harming the environment. "The ethanol bubble has already burst – I don't know any people who are financing ethanol companies right now," NAA's Cohen says. "Ethanol was a badly devised plan; you're never going to be able to grow enough terrestrial [corn] crops to service U.S. energy needs."

On the other hand, it might actually be good for the algae biofuel industry to go the way of ethanol. The U.S. ethanol industry has a current capacity to make 11 billion gallons of ethanol a year. It is still a big industry even if it is down right now. "If [algae biofuels]

got to that size, it would be great," *Business Week's* Carey says. "Otherwise out of around a 100 algae companies right now, only a fraction will make it."

Wind and solar energy are not direct competitors to algae energy in Texas. The only competition may be at the level of government subsidies. Wind and solar right now provide energy to the grid while biofuels supplement traditional petroleum. "The wind does not blow all the time. The two could enhance each other," energy company consultant Byrne says. "We could use the oil from the algae, and use methane from farms to burn and make power. They are complementary even if they are mutually exclusive."

"Algae energy, as far you're concerned with lighting up cities and people's houses, cannot compare to sources like wind which is far more efficient," Earthrise's Henson says. However, aircrafts need liquid concentrated fuel. Nothing beats petroleum-based fuels or the equivalent and this allows algae biodiesel to become a jet fuel. Many American aircraft manufacturers are now offering biodiesel engines. "Forty or 50 years from now you'll probably still be able to buy fuel and it'll probably come from algae," Henson says.

Envisioning a future

Texas still is emerging as prime ground for the cultivation of algae and investment in algae biodiesel plants – something that will benefit the state's economy as well fuel

industry. “If we can make it happen from the ground up here then it’s good for the state,” Wogan says. “We really have an opportunity here to do it. We have a lot of smart people working on it.”

The goal of the U.S. is to have 60 to 65 percent of its liquid fuels to be from homegrown renewables and algae have the potential to be a third of that. In 10 years, there maybe in excess of 100,000 acres of algae production worldwide. The United States could easily account for 25 to 50 percent of that. “If we can develop a credible pathway to creating a system that takes the cost of producing algae oil from about $20 a gallon down to around $2, then algae can be pretty exciting,” Texas A&M’s Avant says.

Many start-ups are currently getting venture capital money from many people but there is just a small handful that is serious about it and may actually have a shot. Most likely, the people collaborating with a national lab or a big oil company like Exxon Mobile or Shell will survive in the long run, according to Wogan. Exxon has recently made a $300 million foray into algae and biofuels. The production of algal biodiesel is going to be interlinked with one of these major oil refineries – most of which are in Texas. Biodiesel production will be compatible with their systems and the small start-ups won’t have to spend millions in designing a new system for themselves. These will be the integrated biorefineries of the future.

“I keep hearing people saying over and over that what we’re talking about here is eventually making biorefineries,” Carey says. “Who has the current expertise and the

pockets to do that kind of stuff? - it's the current oil refining industry." He believes the winners in the end are the ones connected to those traditional industries that know how to scale things up.

Algae production will eventually combine with several other processes, creating integrated biorefineries that are extremely efficient and produce large quantities of fuel. "If you generate 9 billion gallons of biodiesel every year, you're also going to generate 9 billion gallons or more of by-products – triglycerides and mass and fibery chinks of algae that you have to find a home for," UT engineering professor Webber says. "So you want to integrate it so that you can use every little piece of the string and you have no waste."

It will be natural for the oil industry to actively promote algae biofuels, especially in Texas. Webber says that Big Oil is very cash-rich in spite of the constraints on the economy and this puts them in the driver's seat. If this goes well, then the start-ups will develop some technologies and the big companies will buy them. He says a small start-up doesn't have much ability to move billions of gallons of fuel through the distribution system, but a Conoco Phillips or a Shell or an Exxon Mobile does. "If you're a start-up that's created a technology or a patented process or intellectual property or a catalyst, it'll be hard for you to turn it into large-scale production," Webber says. "But the big companies can."

If algae biofuels reach commercial levels, the impact on Texas will be unparalleled. "The vision I imagine is that we have hundreds of thousands of oil and gas wells around the

state and we have pump jacks all over the state pumping oil," Webber says. "And we could have small ponds all over the state, too. Those ponds generate algae that make oil that we pump into those same pipelines to the refineries." But commercialization depends on the price of oil. As oil reserves decrease in the next few decades, the price of oil may be $150 a barrel in the near future and if it remains that way for a couple of years, then a viable large-scale biofuels industry in Texas is on the horizon. If oil prices move up and down, then algae could take a few more decades.

The future of algae biofuels in the state will follow a fairly long and strenuous development path. Experts project the industry needs anywhere from two to 10 years to become large scale. Many believe algae biofuels will replace total crude oil consumption in 50 or 60 years. "But the energy industry is a slow-moving beast," Webber says. "If the government is serious and people spend a lot of money, you can expedite it." He says that ethanol did 9 billion gallons of production last year but it took around 30 years and several government subsidies and support. The same realistic expectations should be put on algae, he says.

"If Texas would lead the nation in the development of alternative, clean fuels, we could export and provide the energy solutions and technologies needed for the future to the rest of the globe, and we would be the leader of the clean energy economy rather than a victim or a byproduct of it," state Sen. Watson says. Already, several teams are putting forth a strong effort in Texas by establishing pilot and demonstration facilities. "By 2010

or 2012 [because of depleting supplies] the price of oil is going to be so high that we're going to look for anything that works," Earthrise's Henson says.

Texas is leading right now in algae oil research and production and companies are putting their best foot forward. The state has vested interests in this and could become a leader or launch pad in the algal biofuel story. "I think if there's one place for this to happen then it's going to be here," Wogan says. "One way or other, it's going to come through Texas."

Whatever the next few years bring, it is undeniable that as the algae story unfolds, the state of Texas will be standing on the brink of an energy revolution.

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Vita

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This report was typed by Ashwini Salpekar.