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Green Diesel: Finding a Place for Algae Oil (symposium editor)

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GREEN DIESEL: FINDING A PLACE FOR ALGAE OIL

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INTRODUCTION

Only a few percent of Americans would probably understand the meaning of the term "algae oil," but those that do include influential venture capitalists, oil company executives, military and airline strategists, biotechnologists, and lot of entrepreneurial scientists and engineers. Many of these people think that motor fuel derived from algae is likely to be the most competitive future form of advanced biofuel despite the fact that algae oil technology is barely at the prototype stage.[1]

The objective of this essay is to speculate on the kinds of places in which an algae oil production facility might expect to find sites that meet the applicable criteria for profitability and also comply with the applicable legal requirements. In her excellent review of the prospects for algae oil, Teresa Mata opines that site selection is the key step that will ultimately determine the economic viability of an algae oil project.[2]

For purposes of this essay, I assume that by the end of the 2010s (1) there may be a high level of demand for algae oil, (2) the technology to produce algae oil profitably will be perfected, and (3) the general consensus in the technical literature about the kind of external conditions that are necessary to site a profitable algae oil processing facility will remain the same as it is today. I fully recognize, of course, that these are rash assumptions, but the importance to the nation of creating locally produced "green diesel" justifies some speculative thinking about the land use and environmental issues that may be involved.

This initial overview identifies numerous obstacles that algae oil producers will face unless laws designed specifically to deal with algae oil are adopted. Few, if any, of our major environmental or land use laws were

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1. The technological breakthroughs needed to make algae oil production profitable are reviewed concisely in Paul Chen et al., *Review of the Biological and Engineering Aspects of Algae to Fuels Approach*, 2 INT'L J. AGRIC. & BIOL ENG. 1 (2009).

2. Teresa M. Mata et al., *Microalgae for Biodiesel Production and Other Applications: A Review*, 14 RENEWABLE AND SUSTAINABLE ENERGY REVS. 217, 222 (2010).

drafted with the idea that someone would be making motor fuel out of algae. "In contrast to the development of cellulosic biofuels which benefit from a direct agricultural and process engineering lineage, there is no parallel agricultural enterprise equivalent for cultivating algae at a similar scale."[3] To a great extent, the law of algae oil begins with a blank slate.

I. NATIONAL ENERGY POLICY

In December, 2007, a Republican President and a Democratic Congress reached agreement on a law that orders refiners to produce large volumes of "advanced biofuels" in steadily increasing amounts through 2020. Because development of such fuels was barely beyond the laboratory stage at that time, the Energy Independence and Security Act of 2007 (EISA)[4] ranks as the most dramatic example of a technology-forcing statute since the environmental laws of the early 1970s.

A. Why Biofuels?

Biofuels have a long history,[5] but it was the oil shocks of the 1970s that provided a new impetus to search for home-grown replacements for some of America's oil imports,[6] and interest ramped up again after the attacks on the World Trade Center on September 11, 2001, which highlighted our relations with the Mideast and our dependence on imported oil. It appeared that a complex mix of motives lay behind the government's urgency to increase biofuel production: (1) the desire to reduce imports of motor fuel, (2) hopes for rural redevelopment, (3) fear of upward pressure on petroleum prices from rapid Asian growth, (4) concern that worldwide oil production might soon peak, (5) worry that major regional or global conflict could cut off access to foreign oil, and (6) hope that biofuels might one day improve overall energy efficiency.

The dominant biofuel at the time was ethanol, but ethanol was being made from corn, and in 2007, the increased production of ethanol appeared to be the cause of a sharp rise in the price of corn. The sharp rise in price

3. U.S. DEP'T OF ENERGY, OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY, NATIONAL ALGAL BIOFUELS TECHNOLOGY ROADMAP 5 (2010), *available at* http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf [hereinafter ROADMAP].

4. Energy Independence and Security Act of 2007, Pub. L. No. 110-140, 121 Stat. 1492 (2007) (to be codified as amended in scattered sections of 2, 15, 16, 26, 42, and 49 U.S.C.) [hereinafter EISA].

5. Kevin Hammond, *Biofuel Vehicle History*, BIOFUELSWATCH (June 17, 2010), http://www.biofuelswatch.com/biofuel-vehicle-history/.

6. Bruce A. McCarl & Fred O. Boadu, *Bioenergy and U.S. Renewable Fuels Standards: Law, Economic, Policy/Climate Change and Implementation Concerns*, 14 DRAKE J. AGRIC. L. 43, 44–48 (2009).

angered people buying corn for other purposes and prompted them to ask Congress to put a cap on the production of corn-based ethanol.[7] Arnold Reitze echoed the views of many observers when he wrote that "the renewable fuels program is primarily designed to put money in the pockets of corn farmers and corn-based ethanol producers at a high cost to consumers."[8] This has led to a search for biofuel products that could be grown on lands that would not replace existing agriculture,[9] but would still be capable of high productivity.[10]

The push for more biofuel also coincided with a growing concern about climate change. Although claims were sometimes made that all biofuels could reduce greenhouse gas (GHG) emissions, some scientists argued that because farmers worldwide were responding to higher prices by converting forest and grassland to new cropland, "corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years."[11] On balance, the science seems to suggest that GHG impact is so crop-specific and site-specific that the aggregate impact of biofuels on GHGs is very difficult to predict.[12]

In December 2007, when Congress passed and President Bush signed the EISA, they were aware of the debates about the impacts of corn-based ethanol on corn prices, climate, and land use. The statute required the production of corn-based ethanol to reach a peak in 2015.[13] After that, all growth in biofuel production was to come from "advanced biofuels."[14] Refiners of motor fuel are required to increase production of advanced

7. Arnold W. Reitze, Jr., *Biofuels: Snake Oil for the Twenty-First Century*, 87 OR. L. REV. 1183, 1203, 1208 (2008).

8. *Id.* at 1203. In Europe the most common biofuel is biodiesel made from locally grown rapeseed and sunflower oil, or increasingly made from palm oil produced in Malaysia and Indonesia, where large tracts of tropical forest are being cleared in order to plant oil palms, the fruit of which can be refined to produce biodiesel. Diesel automobiles are outselling gasoline models throughout Europe, but biodiesel has come under criticism in Europe for reasons similar to the objections to ethanol in the U.S. James Murray, *EU Sets Out Sustainable Biofuel Criteria*, BUSINESSGREEN.COM (June 14, 2010), http://www.businessgreen.com/business-green/news/2264715/eu-sets-sustainable-biofuel.

9. Richard Hamilton, *Biotechnology for Biofuels Production*, *in* A HIGH GROWTH STRATEGY FOR ETHANOL: THE REPORT OF AN ASPEN INSTITUTE POLICY DIALOGUE 55, 58 (Aspen Inst. ed., 2006).

10. Monique Hoogwijk et al., *Potential of Biomass Energy Out to 2100, for Four IPCC SRES Land-Use Scenarios*, 29 BIOMASS & BIOENERGY 225, 252 (2005).

11. Timothy Searchinger et al., *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change*, 319 SCIENCE 1238, 1238 (2008).

12. For a current analysis, *see* Thomas W. Hertel et al., *Effects of U.S. Maize Ethanol on Global Land Use and Greenhouse Gas Emissions: Estimating Market-mediated Responses*, 60 BIOSCIENCE 223 (2010).

13. EISA § 202(a)(2)(B)(I)&(II).

14. *Id. at* § 202. For an illustration of the requirements, *see* Ron Pate, Sandia Nat'l Lab., The Promise & Challenges for Algae Biofuels, Overview of Approaches and Issues for Sustainable Production Scale-up, at slide 6, Presented at the Symposium on Algae for Food, Fiber, Freshwater and Fuel, AAAS Annual Meeting (Feb. 19, 2010).

biofuels from almost nothing but soybean-based biodiesel today to twenty-one billion gallons by 2022.[15] In the EISA, "advanced biofuels" potentially could include almost any bio-based fuel except ethanol made from the kernels of corn, that is,, cornstarch. But to qualify as "advanced," the fuel must reduce greenhouse gas emissions by at least 50% in comparison to baseline emissions.[16]

B. *Why Algae?*

Technology companies are working on a wide range of potential biofuels that they hope may meet the tests of the EISA, including such fuels as biobutanol and cellulosic ethanol. This essay deals with just one category of advanced biofuel—fuel made from the single-celled organisms called "microalgae," which will be referred to herein simply as algae.[17] "[A]lgae are relatively simple plant-like organisms that capture light energy through photosynthesis and use it to convert inorganic substances (water, carbon dioxide, nutrients) into organic matter and store the trapped energy as some form of carbohydrates."[18] Although most algae grow by using a photosynthetic process to convert the energy from sunlight into living material, some algae are photoheterotrophic—able to grow using both sunlight and organic compounds, such as carbon, as an energy source.[19]

The EISA listed algae as a potential source of advanced biofuel[20] and required the Department of Energy (DOE) to report on the progress of algae fuel research.[21] Of the tens of thousands of species of microalgae,[22] the

15. EISA § 202(a).

16. "The term 'advanced biofuel' means renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions, as determined by the Administrator, after notice and opportunity for comment, that are at least 50 percent less than baseline lifecycle green house gas emissions." *Id.* § 201(1)(B)(i).

17. There is also interest in the possibility of getting fuel from macroalgae, such as kelp, but this research is at a very early stage, and there seems to be a greater likelihood that if macroalgae is cultivated it will be for non-fuel uses. ROADMAP *supra* note 3, at 22, 30.

18. CHRISTINE RÖSCH ET AL., INST. FOR TECH. ASSESSMENT AND SYS. ANALYSIS, MICROALGAE – OPPORTUNITIES AND CHALLENGES OF AN INNOVATIVE ENERGY SOURCE 1, Presented at the 17th European Biomass Conference and Exhibition, Hamburg, Ger., June 29–July 3, 2009.

19. Mata et al., *supra* note 2, at 223. Some algae can be grown without sunlight—heterotrophically—but this process requires the same feedstocks as cellulosic ethanol and does not appear as promising at present. Randor Radakovits, *Genetic Engineering of Algae for Enhanced Biofuel Production*, 9 EUKARYOTIC CELL 486, 494–95 (2010). Because the EPA's current projection of cellulosic biofuel for 2011 is only 17.1 million gallons, and because heterotrophic algae fuels raise many of the same land use issues that plague traditional ethanol, this essay will not explore heterotrophic algae oil production. Regulation of Fuels and Fuel Additives: 2011 Renewable Fuel Standards, Proposed Rule, 75 Fed. Reg. 42238, 42242 (proposed July 20, 2010) (to be codified at 40 C.F.R. pt. 80); *See also* ROADMAP, *supra* note 3, at 74, 102.

20. EISA § 201(1)(B)(ii)(VII).

21. *Id.* § 228.

ones being studied for fuel production are single-celled organisms living in liquid environments.[23] Because algae can live in salt or brackish water wetlands,[24] as well as in fresh water wetlands, they are less likely to compete with traditional crops than plants used for cellulosic biofuels.[25] Different species of algae can produce different feedstocks for energy generation, but the focus of this essay is on the production of lipids that can be used for the production of diesel and jet fuel.[26] Colloquially, when biodiesel is made from algae it is often called "green diesel."[27]

In choosing among the many species of algae for a fuel source, scientists seek at least three qualities: (1) high lipid content, (2) fast growth rates, and (3) simple structure amenable to genetic manipulation.[28] Lipids from microalgae are chemically similar to common vegetable oils that are often used to produce biodiesel.[29] Many species of algae have high lipid content, amounting up to half of their weight.[30] Algae typically have high growth rates, and commonly double their biomass within twenty-four hours.[31] Both of these factors contribute to the ability of algae to produce marketable quantities of oil in a remarkably small land area relative to other biofuel crops. In one comparative modeling analysis, scientists estimated that algae oil production can reach twenty-six tons per hectare per year,—

22. Qiang Hu et al., *Microalgal Triacylglycerols as Feedstocks for Biofuel Production: Perspectives and Advances*, 54 PLANT J. 621 (2008), *available at* http://onlinelibrary.wiley.com/doi/10.1111/j.1365-313X.2008.03492.x/pdf.

23. Mata et al., *supra* note 2, at 219.

24. Donghui Song et al., *Exploitation of Oil-bearing Microalgae for Biodiesel*, 24 CHINESE J. OF BIOTECHNOLOGY 341, 344 (2008) (The "Chinese mainland coastline stretches for some 18,000 km with a large swamp wetland and marshes, suitable for large-scale cyclic cultivation of oil-bearing microalgae.").

25. Vishwanath Patil et al., *Towards Sustainable Production of Biofuels from Microalgae*, 9 INT'L J. MOLECULAR SCI. 1188, 1189 (2008). Shallow offshore waters are, however, increasingly used for aquaculture. *Offshore Aquaculture*, U.S. DEP'T OF COMMERCE, NAT'L OCEANIC & ATMOSPHERIC ADMIN., NOAA AQUACULTURE PROGRAM, http://aquaculture.noaa.gov/us/offshore.html (last updated Oct. 22, 2007).

26. Matthew N. Campbell, *Biodiesel: Algae as Renewable Source for Liquid Fuel*, 1 GUELPH ENGINEERING J. 2 (2008).

27. *Green Diesel*, WIKIPEDIA, http://en.wikipedia.org/wiki/Green_diesel (last visited Sept. 6, 2010). *See also* ROADMAP, *supra* note 3, at 56.

28. RÖSCH ET AL., *supra* note 18, at 1.

29. Sheng-Yi Chiu et al., *Lipid Accumulation and CO_2 Utilization of Nannochloropsis Oculata, in Response to CO_2 Aeration*, 100 BIORESOURCE TECH. 833, 833 (2009).

30. Al Darzins, Nat'l Renewable Energy Lab., Development of Advanced, High-Energy Density Biofuels Based on Algal Feedstocks at slides 6–7, Presented at the Symposium on Algae for Food, Fiber, Freshwater and Fuel, AAAS Annual Meeting (Feb. 19, 2010).

31. Yusuf Chisti, *Biodiesel from Microalgae Beats Bioethanol*, 26 TRENDS IN BIOTECHNOLOGY 126 (2008).

fifty-five times the oil production of soybeans, twenty times that of rapeseed, and six times that of oil palms.[32]

The DOE began research into the possibility of using algae as a source of oils after the oil shocks of the 1970s. But as oil prices began to fall in the mid-80s, the interest in the topic waned, and the DOE eventually cancelled the program in 1996.[33] At that time it seemed highly unlikely that algae oil could ever compete with petroleum oil, which was then selling for about $20 a barrel.[34] However, private research and development of other algae byproducts continued; enclosed photobioreactors (PBRs) are now using algae to produce high-value biological derivatives used in cosmetics, food additives and natural dyes.[35] Certain species of algae are also grown in open ponds for use as food for the aquaculture industry.[36]

By the time that the EISA reopened the DOE's interest in algae fuels, four major changes had happened: (1) worries about future oil price and availability had increased;[37] (2) biotechnology was becoming widely accepted in agriculture;[38] (3) concern about carbon dioxide had increased;[39] and (4) venture capital groups were already pouring lots of money into startup companies that were studying every part of the process of making "green diesel."[40]

When Congress then set specific targets for advanced biofuels in the EISA, many people had a vision of a high future market price for algae oil. Oil companies soon began multimillion dollar joint ventures in the hope of

32. Laurent Lardon et al., *Life-Cycle Assessment of Biodiesel Production from Microalgae*, 43 ENVTL. SCI. TECH. 6475, 6479 (2009).

33. *See generally* JOHN SHEEHAN ET AL., NAT'L RENEWABLE ENERGY LAB., A LOOK BACK AT THE U.S. DEPARTMENT OF ENERGY'S AQUATIC SPECIES PROGRAM: BIODIESEL FROM ALGAE (1998).

34. *Spot Oil Price: West Texas Intermediate*, DOW JONES & COMPANY (Sept. 1, 2010) http://research.stlouisfed.org/fred2/data/OILPRICE.txt.

35. Julian N. Rosenberg et al., *A Green Light for Engineered Algae: Redirecting Metabolism to Fuel a Biotechnology Revolution*, 19 CURRENT OPINION IN BIOTECHNOLOGY 430, 431 (2008).

36. Mata et al., *supra* note 2, at 229–30.

37. Steve Geli, *Crude oil prices hit a new record of $99 a barrel in 2007, on its way to even higher prices in 2008*, MARKETWATCH (Dec. 17, 2007, 2:05 PM), http://www.marketwatch.com/story/after-2007-records-oil-expected-to-turn-back-toward-100.

38. COMM. ON THE IMPACT OF BIOTECHNOLOGY ON FARM-LEVEL ECON. AND SUSTAINABILITY, NAT'L RESEARCH COUNCIL, IMPACT OF GENETICALLY ENGINEERED CROPS ON FARM SUSTAINABILITY IN THE UNITED STATES 9 (2010), *available at* http://www.nap.edu/openbook.php?record_id=12804&page=R1 [hereinafter SUSTAINABILITY]. "Clearly, the future agenda for genetic-engineering technology is extensive and of great importance for improvements in agricultural productivity and sustainability in a rapidly-changing world." *Id.* at 213.

39. Advocates for algae oil said every gallon of algae fuel produced would recycle twelve to fifteen kilograms of carbon dioxide. Daniel M. Kammen, Univ. of Cal., Berkeley, Algae and Waste for Biofuels: Energy Without Conflicts?, at slide 6, Presented at the Symposium on Algae for Food, Fiber, Freshwater and Fuel, AAAS Annual Meeting (Feb. 19, 2010).

40. Amanda Leigh Haag, *Algae Bloom Again*, 447 NATURE 520, 520–21 (2007).

finding new domestic sources of fuel for their plants and refineries.[41] Shell,[42] Chevron,[43] and Exxon-Mobil[44] are among the investors.[45] Other contributors include Bill Gates,[46] Dow Chemical, BP, the U.S. Navy,[47] and the Carbon Trust, an independent company backed by the British government.[48] Investors were encouraged by the fact that scientists and engineers were making progress in finding strains of algae that would reliably produce high yields, keep contamination at bay, and allow for efficient harvesting of oil from the cells.[49]

C. Potential Additional Stimuli to Algae Oil Development

Investors in algae research and development have long-term expectations. Few people are predicting that algae will be a significant source of motor fuel in the next few years. A 2009 Accenture study opines that commercialization of fuel from algae is not expected for another ten

41. Although algae-based biodiesel is receiving the most interest, there are ways of converting lipids from algae into other hydrocarbons as well. Darzins, *supra* note 30, at slide 5.

42. Lewis Page, *Shell in Hawaiian Algae Biofuel Pilot: Sees Big Future in Green Scum*, THE REGISTER (Dec. 12, 2007, 12:56 GMT), http://www.theregister.co.uk/2007/12/12/shell_algae_biofuel_green_scum_plan.

43. *Chevron Partners with Solazyme on Developing Biofuel from Algae*, S.F. BUSINESS TIMES (Jan. 22, 2008), *available at* http://www.bizjournals.com/eastbay/stories/2008/01/21/daily22.html. Chevron also made a grant to the National Renewable Energy Laboratory to jumpstart the DOE's algae research program. Amanda Leigh Mascarelli, *Gold Rush for Algae*, 461 NATURE 460, 460 (2009).

44. Exxon-Mobil is partnering with Craig Venter's firm, Synthetic Genomics, in building a facility in La Jolla, CA, that will test algae growing systems in greenhouse conditions. *ExxonMobil and Synthetic Genomics Inc. Advance Algae Biofuels Program with New Greenhouse*, SYNTHETIC GENOMICS (July 14, 2010), http://www.syntheticgenomics.com/media/press/071410.html. Synthetic Genomics maintains that it has engineered algal cells that can directly secrete hydrocarbons in pure form.

> The ideal species will be able to stand up to intense illumination (more light means faster photosynthesis) and heat (for the high levels of sunlight will also warm things up). It will also need to be resistant to viruses, which will otherwise be a big threat to such a concentrated population of identical organisms.

Biofuels from Algae: Craig's Twist, ECONOMIST.COM (July 15, 2009), http://www.economist.com/research/articlesbysubject/displaystory.cfm?subjectid=8780295&story_id=14029874 [hereinafter *Craig's Twist*].

45. "It is worth noting that the petroleum industry began by developing a replacement for whale oil, and now it is apparent that it is beginning to return to biological feedstocks to keep the pipelines full." ROADMAP, *supra* note 3, at 56.

46. E. Shailaja Nair, Algae—Biofuel of the Future or Pipedream?, http://www.platts.com/Magazines/Insight/2008/oct/20081d0iz07Kh16dW552K9_1.xml.

47. Mascarelli, *supra* note 43, at 460–61.

48. *Algae Biofuels Challenge*, CARBON TRUST, http://www.carbontrust.co.uk/emerging-technologies/current-focus-areas/algae-biofuels-challenge/Pages/algae-biofuels-challenge.aspx (last visited Sept. 8, 2010).

49. Mascarelli, *supra* note 43, at 460.

years.[50] However, investors are also aware that any number of things could happen within a shorter time frame that would speed up the timetable.

For example, the remarkable volatility of oil prices in the first decade of the twenty-first century is fresh in everyone's mind.[51] The price of diesel fuel and gasoline goes up and down with the price of crude oil. Because crude oil's price per barrel has ranged from near $14 a barrel to around $140 per barrel, oil companies investing in algae see their investments as a hedge against future price increases.

The military's interest in alternate fuels is stimulated not only by price but by availability.[52] Both the Air Force and Navy have never been comfortable relying on fossil fuels that come from countries whose relations with the United States have at times been strained. They see the development of biofuels as one way to counter a serious security threat in case of major international conflicts.[53]

Research and development breakthroughs could focus attention on a narrower range of potentially low-cost options. As Accenture pointed out in its 2009 report, if one or more low-cost options prove to be viable, the industry will be likely to consolidate more rapidly and reach quicker agreement on common standards and methods.[54]

II. CHARACTERISTICS OF A MODEL ALGAE OIL PRODUCTION PROCESS

Because the research and development of algae is still in a fairly early stage, one can only hypothesize what the makeup of an ideal high-volume algae oil production facility will be. But based on an overall review of the current literature, we may expect that it will include the following elements

50. MELISSA STARK ET AL., ACCENTURE, BETTING ON SCIENCE: DISRUPTIVE TECHNOLOGIES IN TRANSPORT FUELS: STUDY OVERVIEW 17 (2009), http://www.accenture.com/NR/rdonlyres/56E63FA4-2EDD-485D-9B44-72685A310CE7/0/Accenture_Betting_on_Science_Study_Overview.pdf. In Britain, the Carbon Trust's project is also assuming commercialization by 2020. Alok Jha, *UK announces world's largest algal biofuel project*, GUARDIAN.CO.UK (Oct. 23, 2008, 00:01 BST), http://www.guardian.co.uk/environment/2008/oct/23/biofuels-energy.

51. *Why Oil Prices Are Bound to Rise*, WHAT MATTERS (May 16, 2009, 9:47 PM), http://economatters.wordpress.com/2009/05/16/why-oil-prices-are-bound-to-rise/.

52. Ronald E. Minsk et al., *Plugging Cars into the Grid: Why the Government Should Make a Choice*, 30 ENERGY L.J. 317, 346 (2009) ("[T]he strategic vulnerability of supply lines for fuel in the field has become one of the greatest threats to U.S. troops.").

53. CHRISTOPHER STEINER, $20 PER GALLON: HOW THE INEVITABLE RISE IN THE PRICE OF GASOLINE WILL CHANGE OUR LIVES FOR THE BETTER 218–23 (2009). *See also* ENERGY SEC. LEADERSHIP COUNCIL, A NATIONAL STRATEGY FOR ENERGY SECURITY: RECOMMENDATIONS TO THE NATION ON REDUCING U.S. OIL DEPENDENCE 104 (2008), *available at* http://www.secureenergy.org/sites/default/files/936_A_National_Strategy_for_Energy_Security.pdf.

54. STARK ET AL., *supra* note 50, at 22. For an enthusiastic endorsement of the future of algae research and development, *see* MARK R. EDWARDS, GREEN ALGAE STRATEGY: END OIL IMPORTS AND ENGINEER SUSTAINABLE FOOD AND FUEL (2008).

to be discussed in this essay: (1) genetically modified, patented varieties of algae designed specifically for rapid growth and high lipid content; (2) open ponds in which the algae will be grown and harvested; (3) a regional location that offers optimal sunlight, surplus water supply, and relatively low evaporation; (4) proximity to a source of waste carbon dioxide from a power plant or other industrial facility; (5) availability of nitrogen-rich wastewater, most likely from sewage treatment; (6) pipeline connections to oil refineries; and (7) life-cycle reduction in greenhouse gases in comparison to those emitted by petroleum oil.

Developers of large-scale algae oil facilities will need to be prepared to address many legal and policy issues.[55] Because it is unlikely that any such facility will be built within the next few years, analyses of existing statutes and regulations in detail is probably premature. It may be worthwhile, however, to speculate on the various laws and policies that may affect the location and construction of such a facility in the relatively near future.

A. Genetic Modification of Algae Species

Algae are attractive to biotechnologists because they are so easy to work with.[56] In addition to the more traditional approaches to genetic modification, microalgae are amenable to a number of biotechnological techniques, such as nuclear transformation and chloroplastic transformation.[57] Promising algal strains have been developed in the laboratory with "recombinant protein expression, engineered photosynthesis, and enhanced metabolism. . . ."[58]

Once controversial in the U.S., biotechnology has become commonplace for major crops such as corn, soybeans and cotton; over 80% of American farmers are now planting genetically modified versions of major crops.[59] The National Academy of Sciences has concluded that worries about the mixing of modified genes with native plants have been mitigated by the fact that for the three most commonly planted genetically engineered

55. *See* Rachel G. Lattimore, Bloomin' Government! Environmental Laws and Regulations That May Impact Algae Production (Feb. 20, 2008), *available at* http://www.nrel.gov/biomass/pdfs/lattimore.pdf. This presentation provided valuable insights and stimulated my interest in the subject.

56. It should be noted, however, that the biotechnologists' interest in algae is much more recent than their interest in bacteria, fungi and higher plants, so baseline data on algae are not as rich as for these other types of organisms. ROADMAP, *supra* note 3, at 16.

57. Rosenberg et al., *supra* note 35, at 430.

58. RÖSCH ET AL., *supra* note 18, at 3; ROADMAP, *supra* note 3, at 16–21.

59. SUSTAINABILITY, *supra* note 38, at 1.

crops, "gene flow to wild or weedy relatives has not been a concern to date because compatible relatives of corn and soybean do not exist in the United States and are only local for cotton."[60]

American farmers have become comfortable with genetic modification of familiar crops if the modifications provide economic advantages for the grower. Algae, however, is not a familiar crop to most farmers. If farmers think about algae at all it is probably in the context of pollutants to their fishpond. Many other Americans are likely to associate algae with red tides that kill fish and marine mammals.[61] Consequently, biotechnology regulators cannot count on the same degree of popular support for innovations in genetically modified algae. Moreover, because modified microalgae could be transported over long distances by air and also survive a variety of harsh conditions in a dormant stage, the risk of windblown algae mixing with some of the tens of thousands of other algae species ought to receive careful consideration.[62]

Although there may be resistance to the outdoor culture of genetically modified algae, if a new strain has highly desirable qualities, the pressure will be great to use it on a large scale. In Europe, however, advances in genetic engineering of algae are "viewed with caution because transgenic algae potentially pose a considerable threat to the ecosystem and thus will most likely be banned from outdoor cultivation systems."[63] Further, it has also been warned that

> [l]arge-scale cultivation of genetically modified strains of algae compounds the risk of escape and contamination of the surrounding environment and of crossing with native strains. . . . Thus, cultivation of genetically modified algae can have unintended consequences to public health and the environment and could constrict public confidence in microalgae cultivation systems. These concerns have to be integrated in the design of large-scale production systems working with modified microalgae.64

For products that do not have enthusiastic support from the agricultural lobby, it is not easy to predict what the future of biotechnological regulation may hold. Current regulation of biotechnology in the U.S. can bring into play the Environmental Protection Agency, the Department of Agriculture, and the Food and Drug Administration. In some instances, registration under the Toxic Substances Control Act may be needed. If federal funds are used, compliance with National Institutes of Health guidelines is re-

60. *Id.* at 8.

61. Amanda Lu, *Nature's Lean and Green Machine*, HARV. SCIENCE REV., Spring 2010, at 13, 15.

62. RÖSCH ET AL., *supra* note 18 at 4.

63. Mata et al., *supra* note 2, at 221.

64. RÖSCH ET AL., *supra* note 18, at 4.

quired.[65] The potential invasiveness of genetically modified algae will be a major concern.[66] Concern about invasive species is a major issue for both ecologists and agricultural scientists because of a long history of experience with economic damage to biodiversity and crops resulting from invasive species of plants and animals. Some scientists argue that the use of any kind of nonnative organisms causes alarming risks of creating harmful invasive species,[67] but other scientists suggest that climate change will inevitably bring nonnative organisms into play.[68] To counteract the fears that normally arise when such a radically new technology is being introduced, it will be important for the industry to educate the public on the overall advantages of algae oil to the economy, national security, and the environment.

B. An Open Pond System

Much of the existing research into algae oil production has taken place in enclosed PBRs.[69] Indoor culture of algae in PBRs offers scientists many advantages. In a PBR, for example, light and temperature can be carefully controlled and invasion by competing species can be minimized. Comparative studies of different strains and different growing conditions can be conducted without having to account for the exogenous variables of outdoor conditions.[70]

Despite their advantages, PBRs probably will not have a significant impact in the near future on any product or process that can be operated in large outdoor ponds.[71] PBRs cost about ten times as much as open ponds, so many operators grow the algae in a PBR and then inoculate open ponds with the desired species.[72] The most common type of pond is what is

65. Lattimore, *supra* note 55, at slides 3–5.

66. ROADMAP, *supra* note 3, at 22.

67. Jacob N. Barney & Joseph M. DiTomaso, *Nonnative Species and Bioenergy: Are We Cultivating the Next Invader?*, 58 BIOSCIENCE 64, 64–68 (2008).

68. Carl Hershner & Kirk J. Havens, *Managing Invasive Aquatic Plants in a Changing System: Strategic Consideration of Ecosystem Services*, 22 CONSERVATION BIOLOGY 544, 546 (2008).

69. A bioreactor is any device or system that supports a biologically active environment, and a photobioreactor is a bioreactor that incorporates some type of light source to provide photonic energy into the environment. *Bioreactor*, WIKIPEDIA, http://en.wikipedia.org/wiki/Bioreactor (last modified June 10, 2010); *Photobioreactor*, WIKIPEDIA, http://en.wikipedia.org/wiki/Photobioreactor (last modified Sept. 13, 2010).

70. ROADMAP, *supra* note 3, at 29–30.

71. Mata et al., *supra* note 2, at 226. However, a PBR could serve as a breeder/feeder system for a pond facility. Peer M. Schenk et al., *Second Generation Biofuels: High-Efficiency Microalgae for Biodiesel Production*, 1 BIOENERG. RES. 20, 33 (2008).

72. *See* Palligarnai T. Vasudevan & Michael Briggs, *Biodiesel Production—Current State of the Art and Challenges*, 35 J. INDUS. MICROBIOLOGY TECH. 421, 427–28 (2008); Hu et al., *supra* note 22, at 635.

known as a "raceway," in which an area is divided into a rectangular grid, with each rectangle containing a channel in the shape of an oval and connected to the other rectangles to create a circuit, through which paddle wheels create a continuous flow.[73] The building and operation of open ponds can be relatively economical and hence offers many advantages as long as the species for cultivation can be maintained.[74] Existing suppliers of algae to the aquaculture industry often suppress competing algae by maintaining extreme conditions of salinity or alkalinity that can be tolerated only by the target species.[75] Algae that live in such areas as thermal springs and industrial wastewaters are targets for research because they may be best adapted to withstand competition.[76] When the pond eventually becomes contaminated with competing species the pond can be drained and sterilized before being reinoculated.[77]

Ponds can be constructed on land that is not suitable for high-value agriculture, thus avoiding competition with other crops.[78] Sites will need to be relatively flat and have soil that is not too permeable or porous.[79] Because algae grow only in water, it seems likely that existing wetlands will be a logical site for algae cultivation. Existing U.S. laws, however, never contemplated growing algae in wetlands as a business venture; thus under federal or state wetland laws, it is not clear to what extent permits would be required to use existing wetlands for the culture of algae.[80] At the 2008 meeting of the Conference of the Parties to the Convention on Wetlands, many participants expressed concern about the potential impact of biofuels on wetlands.[81]

73. Schenk et al., *supra* note 71, at 29.

74. The DOE cites maintaining stability in open ponds as a serious issue because there is still little understanding of the potential of invasion of the ponds by competitors, predators or pathogens. ROADMAP, *supra* note 3, at 31–32.

75. RÖSCH ET AL., *supra* note 18, at 2. Algae can be used in producing feed for animals grown by aquaculture. *NOAA-USDA Alternative Feeds Initiative*, U.S. DEP'T OF COMMERCE, NAT'L OCEANIC & ATMOSPHERIC ADMIN., NOAA AQUACULTURE PROGRAM http://aquaculture.noaa.gov/news/feeds.html (last modified Aug. 19, 2010).

76. Mata et al., *supra* note 2, at 222.

77. *See generally* Mark E. Huntley & Donald G. Redalje, *CO_2 Mitigation and Renewable Oil from Photosynthetic Microbes: A New Appraisal*, 12 MITIGATION & ADAPTATION STRATEGIES FOR GLOBAL CHANGE 573, 582 (2007).

78. Pate, *supra* note 14, at slide 13.

79. ROADMAP, *supra* note 3, at 81.

80. Fred Bosselman, *Swamp Swaps: The "Second Nature" of Wetlands*, 39 ENVT'L. L. 577, 607–08 (2009).

81. The conference resolved that decisions on land use change must integrate adequate knowledge of the range of benefits, and their values, that wetlands provide for people and biodiversity. Decision-making should, wherever possible, give priority to safeguarding naturally-functioning wetlands and the benefits they provide, especially through ensuring the sustainability of ecosystem services, while recognizing that human-made wetland systems can also make a significant contribution to water and food

To the extent that federal grants or permits are involved, compliance with the National Environmental Policy Act will be required. Scoping the potential issues will be challenging because there has been so little experience with this technology. If some national standard-setting body has issued criteria for this industry, it would make compliance easier.[82]

The Plant Protection Act[83] gives the U.S. Department of Agriculture (USDA) authority to regulate any kind of "plant pest," which would cover algae only if it posed a risk for beneficial or rare organisms or local biodiversity. Endangered Species Act issues may prove to be a problem in a few cases, such as those involving vernal pools, where many rare animals and plants are found.[84] Insofar as biodiversity is concerned, a large expanse of ponds devoted to one or a small number of algae species is the antithesis of biodiversity, but so is a cornfield. However if the pond replaces highly biodiverse wetlands, the mitigation requirements maybe so extensive as to make the project unprofitable.[85] The DOE's research program will study the impact of biofuels industry growth on biodiversity and sensitive ecosystems.[86]

State and local zoning regulations have traditionally classified land uses into certain major categories, including agricultural and industrial. In most states agricultural uses have received broad exemptions from most land use regulations while industrial uses are more heavily regulated. The open ponds in which algae are grown might fit into the same agricultural category as a fish farm or a rice field, but an algae processing facility is more similar to an oil refinery, and its industrial use would be a more heavily regulated.[87]

Where land use regulations are not controlling, the common law of nuisance may apply. What will 1000 acres of algae smell like? What will the effluent from the processing plant contain? What impact will it have on

security objectives. 10th Meeting of the Conference of the Parties to the Convention on Wetlands (Ramsar, Iran 1971), Changwon, Rep. of Korea, , Resolution X.25—Wetlands and "Biofuels,"(Oct 28–Nov. 4, 2008), http://www.ramsar.org/pdf/res/key_res_x_25_e.pdf.

82. ROADMAP, *supra* note 3, at 32.

83. 7 U.S.C. § 7701 (2006).

84. *Central Valley Vernal Pools*, CAL. ACAD. OF SCI., http://www.calacademy.org/exhibits/california_hotspot/habitat_vernal_pools.htm (last visited Sept. 16, 2010).

85. Palmer Hough & Morgan Robertson, *Mitigation Under Section 404 of the Clean Water Act: Where It Comes From, What It Means*, 17 WETLANDS ECOLOGY & MGMT. 15, 24 (2009).

86. Pate, *supra* note 14, at slide 31.

87. *See, e.g.*, Peggy Kirk Hall, *Understanding the Agricultural Exemption from Ohio Zoning Law: Summary of Relevant Court Cases and Attorney General Opinions*, http://aede.osu.edu/programs/AgLaw/docs/Ag%20Exemption%20Opinions.pdf (last visited Sept. 16, 2010).

downstream waters? What will happen if heavy rains caused the ponds to flood? If coastal wetlands are being used, what happens if high tides or heavy storms spread the algae over neighboring land? Developers will need to be aware of these and other issues that neighbors may raise.[88]

C. *A Climate Offering Sunlight, Water, and Low Evaporation*

Finding a site that has ideal characteristics for open pond fuel production will be a challenge. The key variables—sunlight, water, and low evaporation—are not likely to be maximized in the same locations. For example, areas like the Mojave Desert have plenty of sunlight but evaporation rates are high.[89] High sunlight levels often bring high temperatures, which ordinarily encourage algae growth,[90] but temperatures reaching extreme heat can be detrimental to the growth of algae; many species of algae can be killed by temperatures only 2-4°C higher than their optimum range.[91] Desert areas also tend to have heavy demands on scarce water resources. Balancing the need for adequate sunlight and the need for adequate water supplies may mean that the cost of obtaining water rights will be a serious issue.

Regional elements of the burgeoning algae oil industry are beginning to compete for the title of best climate. Sapphire Energy, a year-and-half-old startup in San Diego, envisions that "dozens of locations in the American Southwest near the coast will be converted into algae farms. Under warm, sunny skies, with a little help from nutrients, the algae will proliferate, be harvested, and its energy-containing compounds transformed into what the company calls 'green crude.'"[92] On the other hand, scientists at the University of Virginia suggest that the rate of evaporation in California might make water use for algae ponds unacceptable, while in Virginia the fact that the net evaporation rate is less than zero would compensate for the lower rate of sunlight.[93] From New Mexico, however, a recent article suggests that semiarid Southwestern inland sites would be ideal for algae oil production because the region's plentiful sunlight could be combined with

88. *See, e.g.*, Parr Richey Obremskey Frandsen & Patterson, *When Does an Indiana Farming Business Constitute a Nuisance?*, IND. BUSINESS LAWYER BLOG (Oct. 23, 2009), http://www.indianabusinesslawyerblog.com/2009/10/when_does_an_indiana_farming_b_1.html.

89. Pate, *supra* note 14, at slides 10–12.

90. Hu et al., *supra* note 22, at 634.

91. Mata et al., *supra* note 2, at 223.

92. Bradley J. Fikes, *Sapphire Energy Says Algae Can Relieve Dependence on Foreign Oil*, N. COUNTY TIMES (Escondido, CA), Nov. 13, 2008.

93. Andres F. Clarens et al., *Environmental Life Cycle Comparison of Algae to Other Bioenergy Feedstocks*, 44 ENVTL. SCI. & TECH. 1813, 1816 (2010).

substantial saline groundwater resources found in several huge aquifers.[94] Sandia National Laboratories and the Pacific Northwest National Laboratory have been working on mapping key climate factors for siting algae oil facilities.[95] The DOE has also awarded a grant to the National Alliance for Advanced Biofuels and Bioproducts to set up multiple test sites in diverse environmental regions.[96]

Water requirements for a large-scale open pond system are substantial, even if the ponds are kept at an optimally shallow depth.[97] One study concluded that it would take 530,000 gallons to fill a one hectare series of ponds at a depth of 20 cm.[98] Even if saline or brackish water is used initially, the water that will be lost to evaporation will be fresh water, and will need to be replaced by fresh water unless expensive desalination is used.[99] The rate of evaporative water loss will vary greatly from region to region and will be an important factor to consider in locating a plant.[100] Some of the water can be recycled, but the treatment and pumping of the recycled water adds significant costs.[101] A 2006 Sandia study suggested that biofuels grown with "nontraditional" water, such as treated wastewater,[102] might be superior to other forms of energy in terms of impact on water use.[103]

Another climate related factor that will come into consideration in site selection is the likelihood of severe weather events. Offshore sites will need to cope with storms and tides and the corrosive effect of salt water on equipment.[104] Inland sites may be affected by flooding, dust storms, tornadoes, and hurricanes.[105]

94. Bobban Subhadra & Mark Edwards, *An Integrated Renewable Energy Park Approach for Algal Biofuel Production in United States*, 38 ENERGY POLICY 4897, 4898 (2010).

95. ROADMAP, *supra* note 3, at 76–77.

96. Press Release, U.S. Dep't of Energy (Jan. 13, 2010), *available at* http://www.energy.gov/news/8519.htm.

97. Lardon et al., *supra* note 32, at 6476.

98. J.C. WEISSMAN ET AL., DESIGN AND OPERATION OF AN OUTDOOR MICORALGAE TEST FACILITY 9–10 (1989), http://www.nrel.gov/docs/legosti/old/3569.pdf.

99. ROADMAP, *supra* note 3, at 34.

100. Pate, *supra* note 14, at slides 24–25.

101. ROADMAP, *supra* note 3, at 34.

102. *See infra* Section II, E.

103. "On the other hand, biofuel feedstock produced from . . . feedstocks grown with nontraditional water, will have minimal freshwater use intensity associated with production." U.S. DEP'T OF ENERGY, ENERGY DEMANDS ON WATER RESOURCES: REPORT TO CONGRESS ON THE INTERDEPENDENCY OF ENERGY AND WATER 44 (2006), *available at* http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf.

104. ROADMAP, *supra* note 3, at 103.

105. *Id.* at 77.

D. A Convenient Nearby Source of Cheap CO_2

Under natural growing conditions, algae grow by using photosynthesis, a process that uses carbon dioxide (CO_2) from the air as a nutrient. But although the amount of carbon dioxide in the air is growing, it is a small percentage, and far too small to support mass production of algae for oil. Therefore, scientists assume that supplemental carbon dioxide would be needed, which would be likely to make the process prohibitively expensive if the carbon dioxide had to be purchased on the open market.[106] This has led to extensive exploration of the possibility that algae production facilities might be fed with the exhaust gases from coal or gas fired power plants, cement plants, breweries, fertilizer plants, or steel mills.[107] If ponds are located in the vicinity of a coal-fired power plant or other industrial facility that can provide flue gas that is high in CO_2, the growth rate of the algae might be increased substantially.[108]

The opportunity to grow algae using waste $CO_2$from power plants or industrial facilities has already led to a number of prototype projects.[109] For example,

> Inventure Chemical and Seambiotic have announced that they have formed a joint venture to construct a pilot commercial biofuel plant with algae created from CO_2 emissions as a feedstock. The plant will use algae strains that Seambiotic has developed coupled with conversion processes developed by Inventure to create ethanol, biodiesel and other chemicals.[110]

If the need for proximity to sources of CO_2 proves to be essential, then it seems likely that an industrial area will have the only sites available. However, the likelihood of finding adequate space for large-scale open ponds in most existing industrial areas may be slim.

> Capturing any significant fraction of the CO2 from large fossil fuel (e.g. coal) power plants will require tens of thousands of acres of algae ponds in close proximity to these plants, as flue gas transport for any distance is impractical. Suitable land and water resources are not available adjacent

106. *Id.* at 86–89.

107. Clarens et al., *supra* note 93, at 1816; *e.g.*, *see* Sally Xiaolei Sun and Raymond Hobbs, Power Plant Emissions to Biofuels, presentation at NREL-AFOSR Workshop on Algal oil for Jet Fuel Production (February 19-21, 2008) (reporting on a contract for the use of algae biofuels by Arizona Public Service at a coal-fired power plant).

108. Clarens et al., *supra* note 93, at 1816–17. This will require the use of natural or genetically modified algae species that can tolerate exposure to high levels of carbon dioxide. Mata et al., *supra* note 2, at 228.

109. Jim Lane, *Updates on Power Plant-algae Biofuels Pilot Projects in Georgia and Missouri*, BIOFUELS DIGEST (Aug. 27, 2009), http://www.biofuelsdigest.com/blog2/2009/08/27/updates-on-power-plant-algae-biofuels-pilot-projects-in-georgia-and-missouri/.

110. *Algae Cultivation Near Power Plant*, OILGAE, http://www.oilgae.com/algae/cult/cos/pow/pow.html (last visited Sept. 2, 2010).

to most large power plants. CO2 capture from flue could allow longer-distance transport, but is very expensive.[111]

A number of competing processes are being tested for creating a separate stream of carbon dioxide from an industrial facility such as a power plant.[112] The DOE is supporting extensive research into methods of separating and capturing carbon dioxide from power plants, but the existing technology is quite expensive.[113]

Power plant operators might find benefits from providing CO_2 as fuel for algae farmers. For example, the waste from the algae farm might provide fuel suitable for combustion with coal in the power plant,[114] but power plant operators and state public utility commissions do not have a reputation for eager innovation at the ratepayers' expense.[115] In addition, a number of technical obstacles will need to be overcome. During the night and on cloudy days the algae slow down their reproduction rate and thus take up less CO_2.[116] A recent analysis concludes that only 20%–30% of CO_2 from a power plant could be captured, and that large power plants would need many tens of thousands of acres of algae production, and large volumes of water, to obtain disposal of 20%–30% of the CO_2 emitted.[117] Further, the impact of other components of flue gas on algae growth needs further testing.[118] Research is also needed to find the optimum level of CO_2 aeration because some studies have found that too much CO_2 may limit algal growth.[119] If algae production could take advantage of a network of CO_2 pipelines aimed at underground sequestration projects, the intermittent nature of their usage might not be so problematic.[120]

"Algae technology is unique in its ability to produce useful, high-volume product from waste CO_2."[121] However, using CO_2 from power plants to produce algae oil that will then be burned as motor fuel is reusing

111. JOHN R. BENEMANN, MICROALGAL BIOFUELS: A BRIEF INTRODUCTION 5, Presentation to the AFOSR-NREL Microalgal Lipid to Biofuels Workshop (Feb. 20, 2008).

112. *What Is Carbon Capture?*, NAT'L ENERGY TECH. LAB., http://www.netl.doe.gov/technologies/carbon_seq/faqs/carbon-capture.html (last visited Sept. 2, 2010).

113. Press Release, U.S. Dep't of Energy, Office of Fossil Energy, Research Projects to Convert Captured CO_2 Emissions to Useful Products (July 6, 2010).

114. Clarens et al., *supra* note 93, at 1817.

115. ROADMAP, *supra* note 3, at 86, 88.

116. RÖSCH ET AL., *supra* note 18, at 5.

117. D.E. Brune et al., *Microalgal Biomass for Greenhouse Gas Reductions: Potential for Replacement of Fossil Fuels and Animal Needs*, 135 J. ENVTL. ENGINEERING 1136 (2009).

118. Clarens et al., *supra* note 93, at 1817. Natural gas-fired power plants, if operated as baseload generators, may offer cleaner flue gas as well as some other advantages over coal-fired plants. ROADMAP, *supra* note 3, at 87.

119. Chiu et al., *supra* note 29, at 835.

120. *See* ROADMAP, *supra* note 3, at 80–81.

121. SHEEHAN ET AL., *supra* note 33, at 10.

the CO_2, not sequestering it.[122] "Although most of the CO_2 will ultimately be deposited in the atmosphere, we can realize a greater energy return for each molecule of carbon."[123] In state or regional programs that require power plants to reduce greenhouse gas emissions, but do not regulate emissions from motor vehicles, it will be interesting to see whether a power plant operator could get partial credit for recycling its carbon dioxide rather than sequestering it.

E. A Nearby Source of Waste Nitrogen

Algae producers must provide the inorganic elements that constitute the algal cell. The supply and cost of nitrogen, phosphorus, and potassium is perhaps the most important issue that affects the affordability of algae oil production.[124] Algae have especially high requirements for nitrogen, up to 10% on a dry-weight basis, several-fold higher than the requirements of higher plants.[125] These needs could be supplied by fertilizer, but the large amounts needed might make the process prohibitively expensive.[126] To make production economically feasible, strategies to reduce the use of fertilizer are needed. A recent modeling exercise by Colorado State University concluded that the need for large quantities of nitrogen-based fertilizer is one of the toughest challenges to profitable algae oil production.[127] Another modeling study concluded that even if flue gas is used as a source of carbon, the total energy consumption of algae ponds was still higher than for crops such as corn, canola, or switch grass because of the cost of chemical fertilizer needed to produce large quantities of algal biomass.[128] The study suggested, however, that adding wastewater from a conventional activated sewage sludge treatment plant with nitrification would substantially reduce the cost of fertilizer.[129]

The nitrogen-rich output of sewage treatment plants has seemed like a win-win option, particularly in view of the increased construction of wastewater treatment wetlands. These wetlands use algae to provide oxy-

122. ROADMAP, *supra* note 3, at 80.

123. Campbell, *supra* note 26, at 6.

124. ROADMAP, *supra* note 3, at 83.

125. RÖSCH ET AL., *supra* note 18, at 5. "Another concept to minimise the demand of nitrogen fertiliser might be to engineer photosynthetic algae in a way that they are capable to fix nitrogen." *Id.*

126. Pate, *supra* note 14, at slide 26. If power plant flue gas is used to supply CO_2 it may be possible to obtain some nitrogen from the nitrogen oxides in the flue gas. ROADMAP, *supra* note 3, at 33.

127. Liaw Batan et al., Net Energy and Greenhouse Gas Emission Evaluation of Biodiesel Derived from Microalgae, Presented at CO_2 Summit: Technology and Opportunity (June 8, 2010).

128. Clarens et al., *supra* note 93, at 1817.

129. *Id.* at 1818.

gen for the bacterial breakdown of organic materials, and to sequester nitrogen and phosphorus into biomass for water clean-up.[130] Many kinds of algae benefit from the high nitrogen content of wastewater from sewage treatment plants, and, by utilizing the nitrogen, certain types of algae can reduce nutrient loading in surface and ground waters.[131] "Ultimately, successful utilization of wastewater effluents in locations with abundant sunlight would make algae cultivation more efficient with respect to both land use and real water use."[132]

Development of prototype projects using both wastewater nitrogen and supplemental carbon dioxide are beginning. For example, in 2009, the National Institute of Water and Atmospheric Research of New Zealand began converting part of the 230 hectares of polishing ponds that are currently used to provide disinfection of Christchurch's wastewater into a series of specially designed High Rate Algal Ponds with CO_2 addition.[133] The algae growing in these systems will be harvested by simple gravity, be converted to biofuel, and the residue used as fertilizer.[134]

> The algae is to be collected from the harvesters and pumped to [Solray Corporation's] specially designed "Super Critical Water Reactor" where pressure and heat will convert it to bio-crude oil. The bio-crude, like fossil crude oil, can then be refined into LPG, petrol, kerosene, diesel, bitumen, and other oil based products.[135]

If nutrients are being added to an open pond system that is connected with jurisdictional water in the U.S., the Clean Water Act may require issuance of a National Pollutant Discharge Elimination System (NPDES) permit.[136] This will require attention to the control of wastewater from the algae oil facility. It will be important to recycle as much of the water as possible. However, evaporation will inevitably cause buildup of salt and other minerals, and the operator will need to dispose of the excess in an approved way. In addition, to the extent the effluent contains excess phos-

130. Thomas E. Dahl, U.S. Dep't of the Interior, Fish and Wildlife Service, Status and Trends of Wetlands in the Conterminous United States 1998 to 2004 60 (2006), *available at* http://www.fws.gov/wetlands/_documents/gSandT/NationalReports/StatusTrendsWetlandsConterminousUS1998to2004.pdf; ROADMAP, *supra* note 3, at 33; Chen et al., *supra* note 1, at 22–23; *see generally* T.C. Lundquist et al., A Realistic Technology and Engineering Assessment Of Algae Biofuel Production, Energy Biosciences Institute, University of California, Berkeley, California (October, 2010).

131. Darzins, *supra* note 30, at slides 13, 15.

132. Clarens et al., *supra* note 93, at 1818.

133. *Wastewater Algae Turned to Fuel*, SCI. ALERT (Nov. 20, 2009), http://www.sciencealert.com.au/news/20092011-20266.html.

134. *Id.*

135. *Id.*

136. Lattimore, *supra* note 55, at slide 18.

phorus or nitrogen, it may produce euthrophication problems downstream.[137]

F. Availability of Oil Refining Infrastructure

Harvesting and processing methods for algae are currently energy intensive and expensive.[138] Many alternative methods are being tested, but there is no current indication that the choice of method would influence site selection.[139] When the fuel or fuel components are produced, however, they will need to be fed into the existing oil pipeline and refinery infrastructure.[140] Here, the proximity of the algae facility to the extensive oil industry network will be important, as will the standards required by the network to join the system. The DOE has awarded a grant to the National Advanced Biofuels Consortium to conduct research and develop infrastructure-compatible biofuels that maximize existing refining and distribution infrastructure.[141] The DOE considers infrastructure for fuel testing and delivery to be a high priority for further research.[142] Al Darzins of the National Renewable Energy Laboratory states simply that "infrastructure does not exist for an algae biofuels industry."[143]

The conversion of lipid extracts derived from algal sources is the typical mode of biofuel production from algae.[144] Most processes for large-scale production of algae oil will need to transport and store these algal lipid intermediates, but standards for such transport and storage mechanisms have not yet been established, and other biofuels have had problems complying with existing pipeline and tanker standards.[145]

Exxon's collaboration with Synthetic Genomics proposes to force feed CO_2 to bioengineered algae to create a mixture of hydrocarbons that can be fed into the stage of the oil refining process just before diesel is produced.[146] Such a combination requires a site conveniently located near both a power plant and an oil refinery, which might severely limit site selec-

137. ROADMAP, *supra* note 3, at 33, 78.

138. Lardon et al., *supra* note 32, at 6476.

139. RÖSCH ET AL., *supra* note 18, at 3–4.

140. Darzins, *supra* note 30, at slide 15.

141. Press Release, U.S. Dep't of Energy, Secretary Chu Announces Nearly $80 Million Investment for Advanced Biofuels Research and Fuel Infrastructure (Jan. 13, 2010), http://www.energy.gov/news/8519.htm.

142. Pate, *supra* note 14, at slide 36.

143. Darzins, *supra* note 30, at slide 41.

144. ROADMAP, *supra* note 3, at 53.

145. *Id.* at 69.

146. *Craig's Twist*, *supra* note 44.

tion.[147] Proposals for algae oil industrial parks suggest that these problems may be reduced by economies of scale.[148]

Finally, profitability may require that the post-processing algal remnants be converted to salable products. Oil refineries currently take pride in turning every part of the petroleum feedstock into a marketable product. The DOE's roadmap concludes that "the greatest challenge in algal fuel conversion is not likely to be how to convert lipids or carbohydrates to fuels most efficiently, but rather how best to use the algal remnants after the lipids or other desirable fuel precursors have been extracted."[149] The most promising current approaches are the anaerobic digestion of algal remnants to produce biogas and the fermentation of polysaccharides and other oligosaccharides into biofuels.[150]

G. Life Cycle Analysis Under EISA

The EISA currently requires that biofuels seeking to qualify under the act meet specific tests relating to the greenhouse gas impact of the entire "life cycle"—from production to use—of the biofuel.[151] The EPA's rule implementing this section (RFS-2) concluded that algae-based biofuel easily met this standard.[152]

The DOE's research priorities include developing models to help study international land use impact of domestic biofuels production.[153] The DOE is also developing methods to analyze the life cycle of biofuels through a wide range of existing and future production pathways.[154] Of particular concern is the relative impact on water quantity from various types of biofuels and competing petroleum fuels.[155]

The EPA's interpretation of the EISA's life cycle analysis requirement aroused strong opposition from the biofuels industry, especially the corn-based ethanol producers. Manning Feraci of the National Biodiesel Board, the national trade association for the industry, testified at a hearing on the rule in 2009 that

147. *Id.*

148. Subhadra & Edwards, *supra* note 94, at 4898.

149. ROADMAP, *supra* note 3, at 48.

150. *Id.* at 57.

151. 42 U.S.C. § 7545(o)(2)(A)(i) (2006). *See also* EISA § 201(i)(H).

152. *Renewable Fuel Standard*, U.S. ENVTL. PROT. AGENCY, http://www.epa.gov/otaq/fuels/renewablefuels/index.htm (last updated July 7, 2010).

153. Pate, *supra* note 14, at slide 30.

154. *Id.*

155. *Id.*

> [w]e recognize that [EISA] requires the EPA to consider significant indirect emissions when calculating a renewable fuel's emission profile. This does not require the EPA to rely on faulty data and to fabricate unrealistic scenarios that punish the U.S. biodiesel industry for wholly unrelated land use decisions in South America. Make no doubt about it, this is what the EPA's proposed rule does. Biodiesel produced from domestically produced vegetable oils are disqualified from the Biomass-based Diesel program, making it all but impossible to meet the volume goals established by statute.[156]

Whether the final rule will withstand industry pressure remains to be seen.

III. FUTURE LEGAL AND POLICY CONSTRAINTS TO LARGE-SCALE OPERATIONS

The idea of a large-scale, outdoor process of producing motor fuel from algae was not on anyone's radar screen when the existing statutes were written. This means that attempts to regulate such a process would need to analogize it to other unrelated activities, leading to semantic quibbles about the interpretation of outdated language. This is not a new problem—the attempt to regulate greenhouse gases under the Clean Air Act poses the same problem, but also illustrates its difficulty.

If the need for algae oil develops slowly, reflecting no great urgency, then the laws can probably be tweaked from time to time in ways that minimize the difficulties of interpretation. But such tweaks still leave multiple regulatory overlays that might create virtual gridlock that would substantially increase the cost of commercial production and slow the progress of research and development.

Of course the idealistic goal of any industry is "one-stop shopping" in which a single governmental agency has the power to decide all of the rules that affect the industry. Although one-stop shopping is unrealistic, some consolidation of regulatory processes may be feasible. Recent agreements between FERC and NOAA about the jurisdiction for offshore windfarm regulation demonstrate that when the pressure for a new technology becomes significant, bureaucratic roadblocks can be alleviated. But consolidation of regulatory procedures is not the only important goal—agreement on the substance of standards is also important. Conversion of algae to biofuel will require a host of new products and processes involving the work of a wide variety of science and engineering disciplines. The industry is currently highly fragmented with many new ventures seeking to obtain patents for many different stages of the biofuel production process. In some

156. *Biofuel Producers Give EPA an Earful on Renewable Fuel Standard*, ENV'T NEWS SERV. (June 9, 2009), http://www.ens-newswire.com/ens/jun2009/2009-06-09-094.html.

of these cases the law governing the patentability of the product or process may be in flux. Consolidation of the industry may eventually alleviate the cost of assembling a successful package of intellectual property rights but in the early stages of development the cost of assembling these rights is likely to be quite expensive.[157]

Startup firms financed by soft money do have an interest in foreseeing the kinds of environmental and economic externalities that the processes they are developing will create. But at the early stage of research and development for a complex process that has not been proven to operate at a profit on a large scale, these issues are not likely to be high on the priority list for private companies. Only a consolidated research program financed by both governmental and private funds would be likely to give such issues the prominence they deserve. The DOE's biofuels roadmap is a promising start, but it is important for the USDA, EPA, NOAA, and state agencies to coordinate their own research agendas as well.

A program to fund coordinated legal research would also be a valuable addition to the package. If any or all of the dramatic changes in the motor fuel market illustrated in section II, C of this essay occur, changes in the law to promote algae biofuel may receive sudden prominence. If the background work for a prototype of an "Algae Oil Act" was underway, development of laws to speed up the process would be easier. There is nothing more likely to interest industry and the regulatory agencies in thinking about these legal issues than the knowledge that some impartial and influential body is evaluating them.

At first blush, it may seem farfetched to worry so much about an industry that has so many scientific and technological hurdles to overcome before it can begin to play a significant economic contribution to our national interest. But if our "addiction to oil" is a serious disease, as many people of many different political persuasions perceive, the modest amount of investment in foresight would be well worthwhile.

157. The DOE is encouraging partnerships between private companies, universities and the national laboratories as a way of helping overcome the fragmentation problem. ROADMAP, *supra* note 3, at 109.