Algae's Potential as a Transportation Biofuel

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Summary

Congress continues to debate the federal role in biofuel research, biofuel tax incentives, and renewable fuel mandates. The debate touches on topics such as fuel imports and security, job creation, and environmental benefits, and is particularly significant for advanced biofuels, such as those produced by algae.

Congress established the Renewable Fuel Standard (RFS2)—a mandate requiring that the national fuel supply contain a minimum amount of fuel produced from renewable biomass. The RFS2 is essentially composed of two biofuel mandates—one for unspecified biofuel, which is being met with corn-starch ethanol, and one for advanced biofuels (or non-corn starch ethanol), which may not be met in coming years. Within the advanced biofuels category, the RFS2 requirements for the cellulosic biofuels subcategory (e.g., ethanol from switchgrass) have not been met for the last few years, which could cause alarm, as this subcategory is slated to ramp up from roughly 3% of the standard in 2012 to roughly 44% of the standard in 2022. Limited cellulosic biofuels production has occurred to date. As a result, as allowed under the RFS2, the Environmental Protection Agency (EPA) has lowered the required cellulosic biofuels volume for 2010, 2011, and 2012 and has proposed to do the same for 2013.

Currently, algae-based biofuel qualifies as an advanced biofuel under the RFS2, but not as a cellulosic biofuel. One possible solution to meet the RFS2 cellulosic biofuels mandate is to add algae as an eligible feedstock type. Because algae is not cellulosic and is not defined as such in the RFS2, it does not qualify for this subcategory. Algae does qualify as a feedstock for the biomass-based diesel subcategory of the RFS2 advanced biofuel mandate. The RFS2 does not mandate rapid growth of biomass-based diesel, as it does for cellulosic biofuels.

Algae can be converted into various types of energy for transportation, including biodiesel, jet fuel, electric power, and ethanol. The potential advantages of algae-based biofuel over other biofuel pathways include higher biomass yields per acre of cultivation, little to no competition for arable land, use of a wide variety of water sources, the opportunity to reuse carbon dioxide from stationary sources, and the potential to produce "drop-in" ready-to-use fuels. Potential drawbacks include the anticipated cost of production, the amount of resources (e.g., water and land) required to produce the biofuel, and the lack of commercial-scale production facilities. Algae-based biofuel research and development are in their infancy, although work has been conducted in this area for decades. At present, published research efforts offer policymakers little guidance on what algae types or conversion methods for which biofuel could be the front-runner for commercial production, and when.

Congressional support for algae-based biofuel has consisted of congressionally directed projects and funding of programs and studies by the Departments of Energy (DOE) and Defense (DOD). Some algae industry advocates contend that Congress should encourage advances in algae-based biofuel production by extending the expiration date for eligible tax credits, appropriating additional federal funds for algae-related programs, and modifying the RFS2 to include algae in the cellulosic biofuels mandate, as was done recently for the cellulosic biofuels production tax credit. In contrast, some argue that Congress should reconsider its investment in biofuels because of the current federal budget crisis and the lack of any measurable progress in cellulosic biofuels production.

Proposed legislation in the 112th Congress would have either expanded the cellulosic biofuels definition for the RFS2 to include algae by amending the Clean Air Act, and/or expanded the definition in the tax code for select tax credits to incorporate algae (e,g., H.R. 1149, S. 1185). The American Taxpayer Relief Act of 2012 (ATRA; P.L. 112-240) did amend both the cellulosic biofuel production tax credit and the cellulosic biofuel depreciation allowance to include algae-based biofuels.

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Introduction

Congress is currently questioning whether existing policies are producing the desired growth for domestic advanced biofuels, including algae-based biofuels (ABB), and for related private-sector investment in ABB research, development, and commercialization. In the Energy Independence and Security Act of 2007 (EISA, P.L. 110-140), Congress expanded the Renewable Fuel Standard (RFS2) by mandating that increasing volumes of renewable biofuels be used in the nation's transportation fuel supply.[1] The RFS2 identified four specific biofuel categories and established time-specific mandates for quantities of fuels, the fastest-growing and largest of which is the cellulosic biofuels category. Algae is not identified as a cellulosic biofuel feedstock type to meet the RFS2.

A minimal amount of cellulosic biofuel was produced in 2012.[2] As a result, the Environmental Protection Agency (EPA) was compelled to lower the cellulosic biofuel mandate for the third successive year and has proposed to do so for a fourth year in 2013. Moreover, a $1.01 per gallon cellulosic biofuel tax credit is set to expire at the end of 2013. There is considerable concern about how the U.S. cellulosic biofuels industry will develop to meet the mandates in the absence of federal support and which, if any, other types of biomass could be used as a primary feedstock to meet the mandate.

Congress held hearings and Members introduced legislation during the 112th Congress that supported the use of multiple biomass feedstocks as energy sources to meet transportation needs.[3] Of particular interest are feedstocks that are sustainable and domestic in origin, could spur job creation, and would have few adverse environmental impacts. Some argue that algae—generally defined as simple photosynthetic organisms that live in water—is one biomass feedstock that could meet these criteria. Algae can be used to produce a variety of biofuels, but most production to date has focused on biodiesel, and it is unclear whether production of other biofuels would be feasible given resource requirements and other concerns.

If successfully commercialized, ABB would have potential advantages and disadvantages compared to other biofuels. Among its advantages, algae has higher biomass yields per acre of cultivation than other feedstocks, leading to larger oil yields. It also may use water that is undesirable for other uses (e.g., wastewater or saline sources). In addition, ABB production could potentially recycle carbon from carbon dioxide-rich flue emissions from stationary sources (e.g., power plants), if ABB facilities are co-located with such facilities.[4] Some ABB drawbacks concern the volume and availability of resource inputs (e.g., water, land, and nutrients), the

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[1] For more information on the RFS, see CRS Report R40155, *Renewable Fuel Standard (RFS): Overview and Issues*, by Randy Schnepf and Brent D. Yacobucci. Congress first established an RFS with the enactment of the Energy Policy Act of 2005 (EPAct, P.L. 109-58). This initial RFS is referred to as RFS1. Two years later, EISA superseded and greatly expanded the biofuels mandate. The expanded RFS is referred to as RFS2.

[2] Approximately 20,000 gallons of cellulosic ethanol was produced and registered with the RFS in 2012 at a demonstration plant owned by Blue Sugars Corporation. Susanne Retka Schill, "Milestones Reached," *Ethanol Producer Magazine*, October 5, 2012.

[3] For more information, see CRS Report R41282, *Agriculture-Based Biofuels: Overview and Emerging Issues*, by Randy Schnepf.

[4] U.S. Department of Energy, *National Algal Biofuels Technology Roadmap*, May 2010, http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf.

immaturity of technology to convert algae into biofuels, the sensitivity of algae to minor changes in its environment, and the cost of running a commercial-scale facility.

Substantial ABB research and development (R&D) has taken place since the 1950s, but for various reasons ABB has yet to gain a foothold in the transportation fuel market. The main reason is that ABB is not currently economical to produce at commercial scale. Also, it is not a major component of energy and agricultural statutes; as a result there is likely more inherent investment risk. The relevance of ABB to the U.S. transportation sector could potentially rise if technological advances are achieved, if oil prices rise, if certain fuels (e.g., cellulosic biofuels) prove incapable of meeting annual RFS2 mandates, or as federal agencies and corporations announce ventures involving ABB for both vehicle and aircraft use.

This report discusses the status of ABB research and development, federal funding, and legislative concerns. While this report focuses on the use of algae as a biomass feedstock for transportation fuel, there are other applications for algae (e.g., nutraceuticals, cosmetics). However, congressional and public interest are currently focused on algae use for transportation.

Algae and the Renewable Fuel Standard

Many ABB discussions involve its limited eligibility for the RFS2—a mandate requiring that the national fuel supply contain a minimum amount of fuel produced from renewable biomass—compared to other biomass feedstocks.[5] Although ABB is eligible to participate in the RFS2, it does not qualify as an eligible feedstock under the cellulosic biofuel subcategory. Algae is not cellulosic and is not defined as cellulosic in the RFS2 regulations.

Assuming algae is converted to a diesel substitute, ABB would qualify for the biomass-based diesel subcategory, but to date it cannot compete cost-effectively with soy biodiesel in this subcategory.[6] In February 2013, EPA clarified that the RFS biomass-based diesel subcategory does include jet fuel.[7] One study reports that the production of algae biodiesel could cost from $9.84 to $20.53 per gallon, compared to $2.60 per gallon for petroleum diesel production.[8] In 2011, the U.S. Navy and the U.S. Department of Agriculture (USDA) announced the $12 million purchase of 450,000 gallons of advanced drop-in biofuel, from a blend of non-food waste and algae, to be mixed with aviation gas or marine diesel fuel.[9]

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[5] Questions also arise about tax credits and grants available for ABB, but these topics are beyond the scope of this report.

[6] 40 CFR 80.1125; for more information, see CRS Report R41631, *The Market for Biomass-Based Diesel Fuel in the Renewable Fuel Standard (RFS)*, by Brent D. Yacobucci.

[7] U.S. Environmental Protection Agency, *Regulation of Fuels and Fuel Additives: Identification of Additional Qualifying Renewable Fuel Pathways under the Renewable Fuel Standard Program*, February 22, 2013.

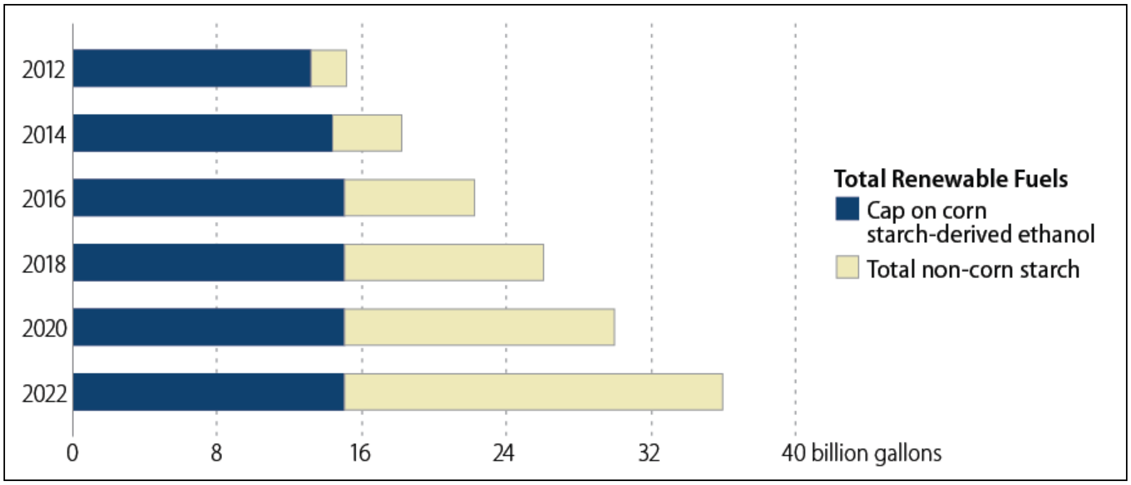
[8] Ryan Davis, Andy Aden, and Philip T. Pienkos, "Techno-Economic Analysis of Autotrophic Microalgae for Fuel Production," *Applied Energy*, vol. 88, no. 10 (October 2011), pp. 3524-3531. Production cost of $9.84 and $20.53 per gallon is with the use of an open pond system and a photobioreactor, respectively, for 2011.

[9] U.S. Department of Agriculture, "Navy Secretary Ray Mabus and USDA Secretary Tom Vilsack Announce Largest Ever Government Purchase of Biofuel," press release, December 5, 2011, available at http://www.usda.gov/wps/portal/usda/usdahome?contentid=2011/12/0500.xml&contentidonly=true.

The RFS2 is composed of two biofuel categories: unspecified biofuel and advanced biofuels (or non-corn starch ethanol; see **Figure 1**).[10] The advanced biofuel portion includes three subcategories: cellulosic and agricultural waste-based biofuels, biomass-based diesel, and "other" (see **Figure 2**). Each advanced biofuel subcategory has a specific volume mandate for each year of the RFS2 (currently 2006-2022) and must meet lifecycle greenhouse gas (GHG) emissions reduction thresholds. The cellulosic biofuels subcategory is ultimately the largest component of the RFS2. Its carve-out is set at 0.5 billion gallons for 2012 (roughly 3% of the RFS2) and ramps up to 16 billion gallons in 2022 (roughly 44% of the RFS2). The biomass-based diesel carve-out of the advanced biofuel category (the portion that algae-based biofuels does qualify for) has a 2013 mandate of 1.28 billion gallons. The biomass-based diesel volume for 2014 to 2022 has not been set and will be determined by the Environmental Protection Agency (EPA) in future rulemaking, but is to be no less than 1 billion gallons.

Even with an RFS2 mandate and tax credits, cellulosic biofuels have yet to meet the required mandate. EPA reports that very few, if any, facilities are consistently producing cellulosic biofuels for commercial sale. As a result, the EPA lowered the 2010, 2011, and 2012 cellulosic biofuel mandates and proposes to lower the 2013 mandate.[11] Congress may consider whether other biomass feedstock types, including algae, should play a larger role in meeting the overall RFS2 mandate. Some suggest that broadening the RFS2 to include algae as a cellulosic biofuel feedstock would boost production opportunities. Others contend that ABB will never be cost-competitive.

Figure 1. RFS2 Biofuel Mandate



Source: EISA (P.L. 110-140), Section 202.

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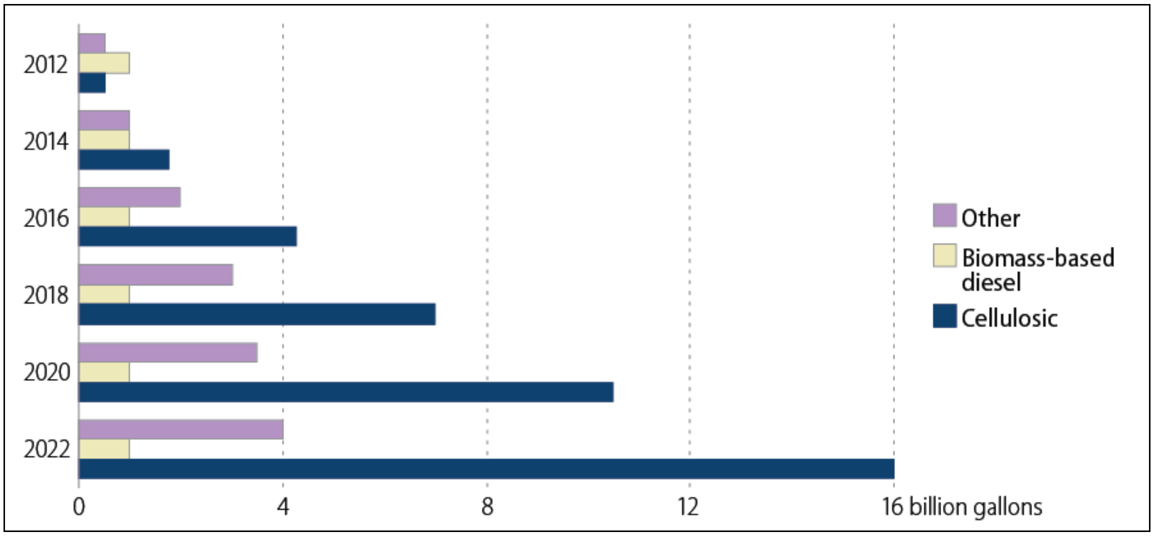
[10] While corn-starch ethanol technically is not a biofuel category of the RFS, most unspecified biofuel used to satisfy this portion of the mandate tends to be corn-starch ethanol.

[11] For more information, see CRS Report R41106, *Meeting the Renewable Fuel Standard (RFS) Mandate for Cellulosic Biofuels: Questions and Answers*, by Kelsi Bracmort.

Figure 2. RFS2 Advanced Biofuel Subcategory Mandates



Source: EISA (P.L. 110-140), Section 202.

a. "Other" includes any advanced biofuel as determined by EPA.

b. The mandate for biomass-based diesel is to be determined by EPA through a future rulemaking, but is to be no less than 1.0 billion gallons.

Technical Background on Algae-Based Biofuel

Algae (like any organic matter) can be converted into multiple forms of energy, including diesel or jet fuel, or used to produce electric power, biogas, and other liquid fuels. The key is to develop a technology to convert this biomass feedstock into a transportation biofuel economically and at commercial scale. While no technology is currently available to make this conversion commercially viable, microalgae, macroalgae, and cyanobacteria are each being considered for ABB production. Microalgae are microscopic photosynthetic organisms. Macroalgae, commonly referred to as seaweed, are fast-growing marine and freshwater plants that can grow to be quite large. Cyanobacteria are not technically algae, but bacteria that live in water and collect energy via photosynthesis. All three require light, nutrients, water, land, and carbon dioxide (CO_2) or sugar to be successfully cultivated. Three primary components of algae—lipids, carbohydrates, and proteins—can be used to make energy. Different algae strains produce these components in different proportions.[12] Depending on the biofuel to be produced, all or only one of these components may be used.

Algae undergoes four major processes in its conversion to biofuel: cultivation, harvest, processing, and biofuel/bioproduct conversion (see **Figure 3**). Algae cultivation may be photoautotrophic (algae requiring light to grow) or heterotrophic (algae grown without light and requiring a carbon source such as sugar to grow).[13] Photoautotrophic cultivation can occur in an

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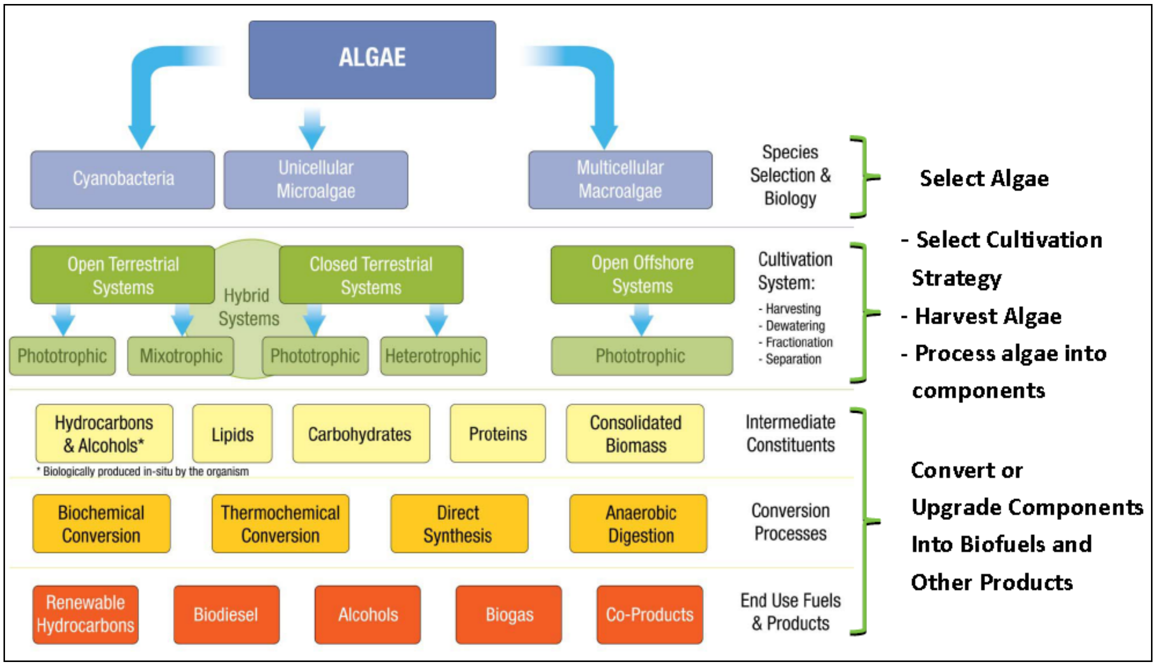
[12] For more information on the chemical composition of algae, see Table 6-1 in Food and Agriculture Organization of the United Nations, *Renewable Biological Systems for Alternative Sustainable Energy Production*, 1997, http://www.fao.org/docrep/w7241e/w7241e00.htm#Contents.

[13] Algae cultivation methods described here are for microalgae and cyanobacteria. Macroalgae requires unique cultivation strategies such as offshore, near-shore, or open pond facilities. This report does not address another cultivation method—mixotrophic cultivation which combines photoautotrophic and heterotrophic cultivation methods.

open pond or in a closed system (e.g., a photobioreactor; see **Figure 4**). Each has advantages and challenges.[14] Open pond cultivation is generally cheaper and simpler to build, but is subject to weather conditions, contamination, and more water consumption. Cultivation conditions may be better controlled in a closed system, but there are scalability concerns, and closed systems historically have been more expensive than open ponds. Heterotrophic cultivation occurs in a fermentation tank and can use inexpensive lignocellulosic sugars for algae growth, which could lead to competition for feedstocks with other biofuel technologies.

After cultivation, a variety of methods can be used to harvest the algae, including flocculation, filtration, and centrifugation.[15] While algae harvest cycles vary based on the strain, in general algae can be harvested numerous times throughout the year, compared to once a year for many conventional crops. The next step is to process the algae, usually by dewatering or drying, which separates the algae into the various components necessary for biofuel conversion. Afterward, certain components of the algae, such as lipids and oils, are extracted for biofuel conversion. The algal biomass is converted into biofuel through a chemical, biochemical, or thermochemical conversion process, or through a combination of these processes (see **Figure 5**).

Figure 3. Algae to Fuel Pathways



Source: U.S. Department of Energy. "The Promise and Challenge of Algae as Renewable Sources of Biofuels." September 8, 2010. http://www1.eere.energy.gov/biomass/pdfs/algae_webinar.pdf.

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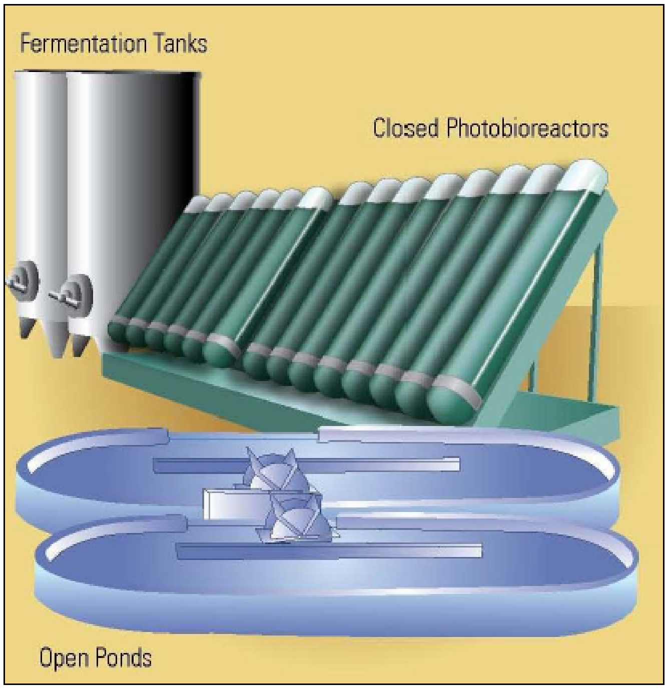
[14] For more information on the technical advantages and limitations of cultivation systems, see Table 2 in Giuliano Dragone, Bruno Fernandes, and Antonio A. Vicente, et al., "Third Generation Biofuels from Microalgae," *Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology*, 2010, pp. 1355-1366, http://www.formatex.info/microbiology2/1355-1366.pdf.

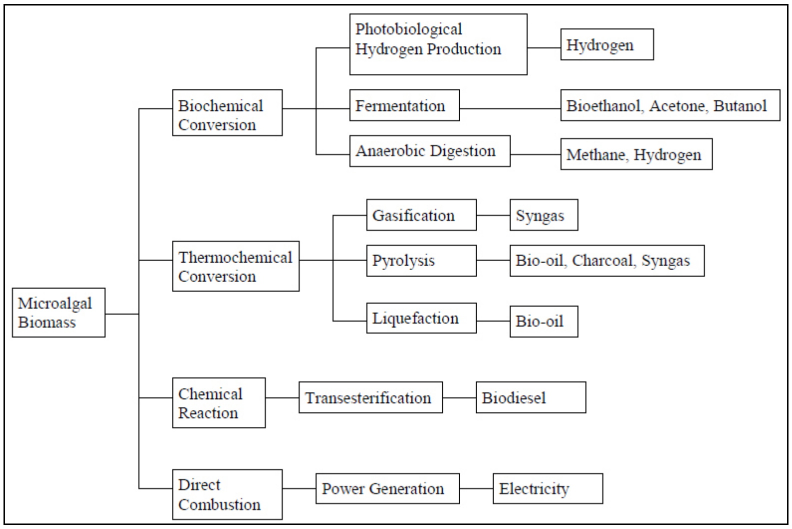
[15] Flocculation is the process by which clumps of solids in water or sewage aggregate through biological or chemical action so they can be separated from water or sewage. Filtration is a treatment process that removes solid matter from water by passing the water through a porous medium, such as sand or a manufactured filter. Centrifugation is the process of separating substances of different densities using centrifugal force.

Figure 4. Algae Cultivation Systems



Source: U.S. Department of Energy. "The Promise and Challenge of Algae as Renewable Sources of Biofuels." September 8, 2010. http://www1.eere.energy.gov/biomass/pdfs/algae_webinar.pdf.

Figure 5. Conversion Processes for Energy Production from Microalgal Biomass



Source: Giuliano Dragone, Bruno Fernandes, and Antonio A. Vicente, et al., "Third Generation Biofuels from Microalgae," *Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology*, 2010, pp. 1355-1366. Adapted by CRS.

Potential Challenges

The primary challenge for ABB is that it has not yet been demonstrated to be affordable at commercial scale.[16] This type of demonstration, preferably from monitoring a large-scale facility, would be critical to gauging the potential impact ABB could have on the national transportation fuel network. Also, as mentioned above, algae cultivation requires significant amounts of CO_2, and there are questions about where this CO_2 would come from. While the CO_2 could come from existing stationary sources, it may be incorrect to assume that all algae processing facilities would be located near existing sources of CO_2 or that enough CO_2 from existing sources would be available to meet demand for commercial levels of ABB production. It is likely that siting and permitting of these facilities would require involvement of local, state, and federal government agencies.

There may be supply and demand concerns for ABB. The use of some feedstocks for biofuels has been controversial, as some report that rising demand for biofuels shifts biomass feedstocks and arable land away from use for other purposes (e.g., food).[17] Some assert that significant quantities of resources (e.g., land, water, and CO_2) exist to support algae-based biodiesel production;[18] however, it is not clear if existing resources can support biodiesel *and* bio-jet fuel, bioethanol, and more from algal feedstock. The National Research Council (NRC) reports that the quantity of water necessary for algae cultivation is a concern of high importance, among others, that has to be addressed for sustainable development of ABB.[19] In general, biofuels derived from open-pond algae production consume more water for feedstock production and fuel processing than petroleum-derived fuels, although the water quality may not be comparable, since some algae is able to use waste- or brackish water. One reported possible technique to drastically curb water use is to site ABB facilities at optimized locations—locations where land with the lowest water use per liter of biofuel produced is available—but algae would still use significantly more water than petroleum.[20] Another technique is to use water unsuitable for other purposes. Algae requires both water and nutrients (e.g., phosphorus) to grow, which may inadvertently put it in competition with other areas of agriculture, depending on water sources and land types selected for algae cultivation should ABB be produced at a large scale. Also, large-scale ABB production may involve the use of genetically modified algae, which some may oppose because of concerns that genetically modified algae may escape into the environment and become invasive, as algae that are non-native to that location.

Potential Benefits

ABB could have some potential benefits relative to other biomass feedstocks used for biofuel production, primarily its ability to produce large oil yields using considerably less land than other

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[16] DOE estimated open pond algae feedstock production and logistics costs for a 12-year timeframe based on certain technical projections ranging from $18.22 per gallon gasoline equivalent (GGE) in 2012 to $3.27/GGE in 2022. U.S. Department of Energy, *Biomass Multi-Year Program Plan*, November 2012.

[17] For more information, see CRS Report R41282, *Agriculture-Based Biofuels: Overview and Emerging Issues*, by Randy Schnepf.

[18] U.S. Department of Energy, *A Look Back at the U.S. Department of Energy's Aquatic Species Program*, NREL/TP-580-24190, July 1998, http://www.nrel.gov/biomass/pdfs/24190.pdf.

[19] National Research Council of the National Academies, *Sustainable Development of Algal Biofuels in the United States*, 2012.

[20] Ibid.

biomass feedstocks (see **Table 1**). The DOE identified nearly 4 million acres of suitable land—mostly in the Southwest and Gulf Coast—for algae cultivation that minimizes water use and could support approximately 5 billion gallons per year of algal oil production.[21] A further advantage is that algae cultivation does not have to compete for land or water traditionally used for food, feed, and fiber production, because algae may be cultivated using non-freshwater (e.g., saline, wastewater) and can be cultivated on non-productive, non-arable land. Certain ABB types also have the potential to be a "drop-in" fuel that could be used without having to modify existing vehicles or build new transportation and distribution networks.[22] Algae cultivation requires CO_2, a greenhouse gas that has been targeted for emission reductions. As a result, algae could potentially reuse CO_2 emitted as a waste product from stationary sources. Last, ABB companies could control their own feedstock, meaning they could grow the algae needed for conversion to biofuel and would not be dependent on external forces that could potentially affect feedstock supply and price, such as drought or an economic incentive to grow a traditional row crop as opposed to switchgrass for cellulosic ethanol.[23]

Table 1. DOE Biofuel Oil Yield Comparisons

Crop	Oil Yield (Gallons/Acre/Year)
Soybeans	48
Camelina	62
Sunflower	102
Jatropha	202
Oil Palm	635
Algae	1,000-6,500[a]

Source: U.S. Department of Energy, *National Algal Biofuels Technology Roadmap*, May 2010, National Algal Biofuels Technology Roadmap.

a. Estimated yields.

Research and Development

U.S. Government

Funding

Since at least the late 1970s, Congress has appropriated funds for ABB, some of which were targeted for general agency programs and some for specific projects. Federal research and

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[21] U.S. Department of Energy Biomass Program, *Pathways for Algal Biofuels*, November 27, 2012.

[22] The "drop-in" characteristic is not unique to algae-based biofuels. For example, biobutanol is also a potential drop-in fuel. Biobutanol, butanol produced from biomass feedstocks, is a liquid alcohol fuel that can be used in gasoline-powered internal combustion engines. Biobutanol may be blended with gasoline, and is also compatible with ethanol blending and can improve the blending of ethanol with gasoline.

[23] The presumption is that in the beginning ABB companies are likely to own the algae farms, which means control of the feedstock. However, in the future there may be market forces that could lead to ownership of algae farms by companies external to the ABB industry, which might affect how algal biomass is utilized.

development funding for ABB has fluctuated over time. The Department of Energy (DOE) and the Department of Defense (DOD) are the two agencies that have spent the most money on ABB.

ABB has been a minor component of the DOE biofuels program relative to other biofuels. DOE has funded algae through its Office of Biomass Program (OBP), the Advanced Research Projects Agency (ARPA-E), Office of Science, the Fossil Energy Program, and the Small Business Innovation Research Program (SBIR). DOE reports it spent approximately $43.0 million on ABB in 2012.[24] Additionally, DOE reports that it proposes to spend approximately $51.5 million on ABB in FY2013.

As of December 2010, DOE cumulatively had invested about $236 million in algae R&D.[25] The DOE OBP spent roughly $183 million on algae R&D from FY2009 to FY2011, of which roughly $146 million was from the American Recovery and Reinvestment Act of 2009 (ARRA; P.L. 111-5) and roughly $37 million was program funding.[26] The ARRA funding was spent on three algae-related integrated biorefinery (IBR) projects cost-shared with industry, two of which are at pilot scale (Algenol, with DOE's cost-share of $25 million and nearly $34 million in non-federal funding to construct an integrated pilot-scale biorefinery with the capacity to produce more than 100,000 gallons of fuel ethanol per year; and Solazyme, with $22 million in DOE cost-share and close to $4 million in non-federal funding to build, operate, and optimize a pilot-scale integrated biorefinery with the capacity to produce 300,000 gallons of purified algal oil per year) and one at demo scale (Sapphire, with $50 million in DOE cost-share and roughly $85 million in non-federal funding to construct an integrated algal biorefinery with the capacity to produce 1,000,000 gallons of jet fuel and diesel per year).[27]

Additionally, $49 million from ARRA was spent on the National Alliance for Advanced Biofuels and Bio-products (NAABB) algae biofuels R&D consortium project, a cost-shared effort with industry, university, and national lab partners. OBP program funds were spent to support three other cost-shared algae R&D consortium projects and a number of additional algae-related projects with industry, universities, national labs, and the National Academy of Sciences. DOE also supported algae R&D through a nearly 20-year Aquatic Species Program (ASP) at a total cost of roughly $25 million from 1978 to 1996. The major focus of the ASP was to produce biodiesel from high lipid-content algae grown in ponds, using waste CO_2 from coal-fired power plants.[28]

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[24] FY2012 and FY2013 spending data provided from various DOE offices to CRS in January 2013 under the coordination of Martha Oliver.

[25] David Schwartz, "*The A.I.M. Interview: Sandia and DOE's Ron Pate*," Algae Industry Magazine, September 18, 2011, http://www.algaeindustrymagazine.com/aim-interview-sandia-and-does-ron-pate/.

[26] As a comparison, DOE was appropriated $215 million to use towards cellulosic biofuels in FY2009. For more information on direct federal spending on R&D for cellulosic biofuels, see CRS Report RL34738, *Cellulosic Biofuels: Analysis of Policy Issues for Congress*, by Kelsi Bracmort et al.

[27] U.S. Department of Energy, *Integrated Biorefinery Project Locations*, 2011, http://www1.eere.energy.gov/biomass/integrated_biorefineries_text_only.html; U.S. Department of Energy, Energy Efficiency and Renewable Energy, Biomass Program News "$564M Biomass Project Descriptions: Pilot and Demonstration Scale FOA," December 4, 2009, http://energy.gov/sites/prod/files/edg/news/documents/564M_Biomass_Projects.pdf.

[28] U.S. Department of Energy, *A Look Back at the U.S. Department of Energy's Aquatic Species Program*, NREL/TP-580-24190, July 1998, http://www.nrel.gov/biomass/pdfs/24190.pdf.

Both the DOD Defense Advanced Research Projects Agency (DARPA) and the Defense Logistics Agency (DLA) have funded algae-related efforts.[29] DLA is interested in algae oil-derived fuel for Navy ship engine testing. DARPA is interested in cost-effective, large-scale production of algae oil to be processed into a JP-8 jet fuel surrogate.[30] In 2009, DARPA stated that algae research was in its early stages.[31] DARPA provided funding for two algal fuel projects, run by Science Applications International Corporation (SAIC) and General Atomics.[32] Reports indicate that in 2009 DARPA awarded SAIC $25 million to develop jet fuel from agricultural and aquacultural feedstock materials.[33] General Atomics received a $43 million contract from DARPA in 2009 to develop a scalable process for cost-effective, large-scale production of algae oil and an algae-derived JP-8 jet fuel surrogate.[34] DOD reports that the $12 million purchase of 450,000 gallons of cooking oil and algal fuel was the only algae-based biofuel expenditure for FY2012.[35]

With regard to specific congressionally directed projects, roughly $11 million was appropriated between FY2008 to FY2010, with the vast majority in 2010, for at least 13 projects.[36] A CRS analysis of conference reports for appropriations bills suggests that one project was funded in FY2008 at a total cost of $0.98 million, three projects in FY2009 at $2.4 million, and nine projects in FY2010 at $7.7 million.

Selected Research Challenges

In 2010, DOE issued an algal biofuels technology roadmap that detailed the challenges and opportunities associated with ABB production. The roadmap acknowledged that "many years of both basic and applied science and engineering will likely be needed to achieve affordable, scalable, and sustainable algal-based fuels."[37] Furthermore, DOE noted that "[c]ost-effective methods of harvesting and dewatering algal biomass and lipid extraction, purification, and conversion to fuel are critical to successful commercialization of the technology."[38] On the other

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[29] A study from the RAND Corporation suggests the defense industry would be better served by focusing on using energy more efficiently in the near-term, and that the use of alternative fuels such as algae offer the armed services no direct military benefit. James T. Bartis and Lawrence Van Bibber, *Alternative Fuels for Military Applications*, RAND Corporation, 2011.

[30] JP-8 is a jet fuel. JP-8 surrogate is a replacement fuel for JP-8 with similar performance characteristics.

[31] U.S. Congress, House Committee on Armed Services, Subcommittee on Terrorism, Unconventional Threats and Capabilities, *Terrorism, Unconventional Threats and Capabilities Subcommittee: FY10 National Defense Authorization Budget Request for DOD Science and Technology Programs*, hearing, 111th Cong., May 20, 2009.

[32] Suzanne Goldenberg, "*Algae to Solve the Pentagon's Jet Fuel Problem*," The Guardian, February 13, 2010, http://www.guardian.co.uk/environment/2010/feb/13/algae-solve-pentagon-fuel-problem.

[33] Socaltech.com, "*SAIC Gets $25M In DARPA Biofuel Contract*," January 27, 2009, http://www.socaltech.com/saic_gets__25m_in_darpa_biofuel_contract/s-0019592.html.

[34] Susanne Retka Schill, "*DARPA Finances General Atomics Algae Project*," Biodiesel Magazine, January 27, 2009, http://biodieselmagazine.com/articles/3184/darpa-finances-general-atomics-algae-project.

[35] E-mail to CRS from Brian Greer, Department of Defense, January 23, 2013. DOD staff is unaware of any specific proposals to purchase algae-based biofuels in FY2013.

[36] Analysis based on information contained in conference reports for appropriation bills. CRS performed a keyword search for 'alga' and 'algae' in conference reports for the relevant divisions of the appropriations bills for each fiscal year. Spending tables for congressionally directed projects (CDPs) list the title of the project and not a summary. Thus it is possible that a CDP may include algae, but not be included here because 'alga' is not listed in the spending table.

[37] U.S. Department of Energy, *National Algal Biofuels Technology Roadmap*, May 2010.

[38] According to DOE and the Algal Biomass Organization in 2011, the United States has a slight edge in ABB research and development fields, but they also report that this edge could be surpassed quickly. China and Australia were reported as countries that might surpass the United States in ABB research and development.

hand, in 2011, industry sources indicated that the following two years could perhaps tell whether ABB production could be commercially viable, as various pilot projects are expected to come online.[39] The Algal Biomass Organization reported that in 2011 algae projects were underway in research labs and pilot plants in 44 U.S. states.[40]

Some research and development challenges must be addressed before large-scale ABB production can take place.[41] The largest challenge appears to be that there is no long-term history of comprehensive published algae research. For example, it has not yet been determined which algae species will be most cost-effective and produce the highest biomass yields. Furthermore, multiple processing techniques exist, using various components of the algae. It may be that no one algal species or processing method is identified as optimal. In addition, scaling up the algae cultivation process from small-scale research to commercial size has proven challenging, both technically and economically, and the current research has not yielded new solutions.

Comprehensive studies of ABB's energy balance, life-cycle emissions, environmental impact, and water demand would also be needed for policymakers to understand the implications of policies that promote ABB commercialization. Certain ABB production steps, such as mixing the water during algae cultivation and dewatering algae to prepare it for biofuel processing, are energy-intensive and therefore costly. Research into processes that reduce the amount of energy needed and lower the cost could make ABB production more economical. Additionally, standards would need to be developed for ABB production to ensure uniformity and assist with potential regulatory compliance measures.

If ABB is to be used nationwide, in addition to solving production problems, additional research would need to be conducted on major points of distribution and utilization, and availability of inputs including water sources and CO_2 sources (see **Table 2**). More analysis would be needed on the best locations to site ABB facilities. Some might consider locating ABB facilities in the Southwest, where there is plenty of sunlight and less agriculture than in other parts of the country, but this region faces water supply concerns. Some might consider locating ABB facilities in the Rice Belt (e.g., Louisiana, Mississippi), where there might be fewer water supply concerns. Consideration of stationary CO_2 sources will also likely have to be taken into account when siting an ABB facility.

It is difficult to predict what ABB type might be most promising, and when it might be commercial. Federally funded research efforts are at a significantly lower level for algae than for other biofuels. While private companies periodically report their financial investment in ABB, for proprietary reasons they rarely report scientific or technological breakthroughs. This limits the ability of policymakers and analysts to assess and predict future ABB developments.

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[39] Personal conversation with Stephen Mayfield, Director, of the San Diego Center for Algae Biotechnology, November 2011.

[40] Jeremy Shere, "Backers Of Algae Biofuel R&D Want Equal Treatment," *Talking Points Memo (TPM)*, October 11, 2011, pp. http://idealab.talkingpointsmemo.com/2011/10/backers-of-algae-biofuel-rd-want-equal-treatment.php.

[41] This section highlights a few of the more important ABB research and development challenges. A list of challenges composed by the DOE is available on p. 6 of the National Algal Biofuels Technology Roadmap, at http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf.

Table 2. Key Resource Requirements for Algae Systems

Algae Production Approach	Key Resource Requirements
Photoautotrophic Microalgae Production	Climate, water, CO_2, other nutrients, required energy inputs, and land
Heterotrophic Microalgae Production	Suitable organic carbon feedstock, water, energy, and other inputs required for siting and operating industrial bioreactor-based algae production, and post-processing to fuels and other co-products
Photoautotrophic Macroalgae Production	Suitable coastal and offshore marine sites

Source: U.S. Department of Energy, National Algal Biofuels Technology Roadmap, May 2010, National Algal Biofuels Technology Roadmap.

Private Research Efforts

In late 2011, there were approximately 65 U.S. ABB companies.[42] The Algal Biomass Organization reported that between 2000 and 2010, the private sector invested more than $2 billion into the algae industry.[43] One source reported a global investment (based on funding announcements) of more than $1 billion in algae-based biofuels in 2009, with more than half of that capital coming from strategic investors.[44]

In 2010, DOE reported that private investment in ABB currently was outpacing government funding.[45] For instance, ExxonMobil expects to spend some $600 million on an Algae Biofuels Research and Development Program over the next decade if R&D milestones are met successfully,[46] which on an annual basis would represent almost double what DOE spent in 2010 ($35 million).[47]

Legislative Issues

Congress has debated whether algae-based biofuel could help diversify the U.S. transportation fuel portfolio. While Congress has created a policy that mandates the use of alternative fuels for

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[42] Personal conversation with Stephen Mayfield, Director, of the San Diego Center for Algae Biotechnology, November 2011.

[43] Algal Biomass Organization, 2010 Finance Summit Conference Report, http://www.algalbiomass.org/wp-content/uploads/2010/07/2010-Finance-Summit-conference-report.pdf

[44] Jim Lane, "Algae: Funding, Parity & Scale (Opportunities and Challenges)," *Biofuels Digest*. February 2010, http://www.ascension-publishing.com/BIZ/WBM0310-BD.pdf. Data comes from the *Biofuels Digest* Advanced Biofuels Project Database, a database that tracks advanced biofuel projects on a quarterly basis. The database appears to track at least roughly 32 algae-based biofuel companies, http://biofuelsdigest.com/bdigest/2011/11/16/free-database-download-207-advanced-biofuels-chems-projects/.

[45] U.S. Department of Energy, *National Algal Biofuels Technology Roadmap*, May 2010 National Algal Biofuels Technology Roadmap.

[46] Exxon Mobil, "ExxonMobil and Synthetic Genomics Inc. Advance Algae Biofuels Program with New Greenhouse," press release, July 14, 2010, http://www.businesswire.com/portal/site/exxonmobil/index.jsp?ndmViewId=news_view&ndmConfigId=1001106&newsId=20100714006070&newsLang=en.

[47] U.S. Department of Energy, *The Promise and Challenge of Algae as Renewable Sources of Biofuels*, September 8, 2010, http://www1.eere.energy.gov/biomass/pdfs/algae_webinar.pdf.

transportation (e.g., RFS2) and set up tax credits that support alternative fuel production, much of the legislation and tax provisions for alternative transportation fuel is constrained to a set of feedstock types (e.g., cellulosic) and fuel types as defined in the statute (e.g., ethanol, biodiesel). Going forward, Congress may choose to reevaluate how it supports alternative fuels by possibly expanding the feedstock and fuel types that qualify for transportation and energy mandates. Indeed, the American Taxpayer Relief Act of 2012 (ATRA; P.L. 112-240) amended both the cellulosic biofuel production tax credit and the cellulosic biofuel depreciation allowance to include algae-based biofuels. Additionally, algae is eligible for one part of the Biomass Crop Assistance Program (BCAP).[48]

Some in Congress have expressed interest in ABB because it could have significantly lower greenhouse gas emissions on a life-cycle basis than conventional fuels.[49] If ABB is to become an alternative to help reduce U.S. dependence on petroleum and reduce greenhouse gas emissions, some stakeholders contend that consistent, comprehensive, long-term (for the duration of multiple congressional sessions) policy support, as well as further research and development, would be required. Options that have been proposed for policies to encourage ABB include modifying the RFS2, creating a federal low-carbon fuel standard, or placing a tax on carbon.

ABB advocates also assert that Congress could encourage the growth of the U.S. algae industry by providing tax parity with other biofuels, appropriating additional federal funds for algae-related programs, and modifying the RFS2 to be feedstock-neutral so that algae-based biofuels can be more broadly included.[50] Tax incentives may accelerate ABB research, development, and demonstration testing, thus possibly shortening the timeline for commercial ABB production. However, some might argue that it is premature to issue tax breaks to an industry that has no commercial production facility. Furthermore, it may be that tax breaks for renewable energy in general will phase out under the emerging policy environment of fiscal discipline and budget restraint. Opponents of such support argue that Congress should not be involved in selecting biomass feedstock types for biofuels before commercial success has been proven, or more broadly, that Congress should not be selecting the technology at any point. Congress did select certain feedstock types for biofuel production under the RFS2. At the time, industry assertions and government data supported the argument that certain levels of cellulosic biofuel production capacity would be achievable within the given time frame.[51]

Given the federal budget situation and that the private sector appears to be spending more on R&D than the federal government, Congress could decide to let industry take the research funding lead and encourage industry growth by expanding the cellulosic biofuel definition to include algae. This could give the ABB industry a long-term goal and guaranteed market as part of the RFS2 (for roughly 10 years). At a later time, perhaps after the ABB pilot projects that have

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[48] Algae is an *eligible crop* for the establishments and annual payment portion of BCAP. Algae is not an *eligible material* for the matching payment portion of BCAP. For more information on BCAP, see CRS Report R41296, *Biomass Crop Assistance Program (BCAP): Status and Issues*, by Randy Schnepf.

[49] At present there are a limited number of studies that compare the greenhouse gas emission profile of ABB to other biofuels and conventional fuels, due to some extent to the nascent nature of the industry. Some contend that significant amounts of CO_2 will be sequestered during algae growth.

[50] Algal Biomass Organization, *How Can Congress Support the U.S. Algae Industry*, http://www.algalbiomass.org/how-can-congress-support-algae/.

[51] For more information, see CRS Report R41106, *Meeting the Renewable Fuel Standard (RFS) Mandate for Cellulosic Biofuels: Questions and Answers*, by Kelsi Bracmort.

come online yield data on the feasibility of ABB production, Congress could have a legislative discussion about what federal funding or other types of support, if any, would be appropriate.

Legislation introduced in the 112th Congress would have incorporated some of these ideas. In general, proposed legislation either would have expanded the cellulosic biofuels definition for the RFS2 to include algae by amending the Clean Air Act (codified as 42 U.S.C. 7401 et seq.), and/or would have expanded the definition in the tax code for select tax incentives to incorporate algae—which Congress did with ATRA. For example, H.R. 1149 (112th Congress) would have amended the Clean Air Act to include algae-based biofuel in the renewable fuel standard program, and allowed algae-based biofuel to qualify for the cellulosic biofuel producer tax credit by expanding the definition of cellulosic biofuel to include algae-based biofuel in the Internal Revenue Code. S. 1185 (112th Congress) would have modified the definition of "cellulosic biofuel" for the cellulosic biofuel producer tax credit and the special depreciation allowance to mean any liquid fuel that is derived solely by or from qualified feedstocks, including any cultivated algae, cyanobacteria, or lemna, but would not have amended the Clean Air Act.

Conclusion

Algae-based biofuel is being considered for U.S. transportation needs. ABB is a potential domestic option that could help to smooth fluctuations in petroleum supply, and it could potentially diversify the biomass feedstock supply needed to meet renewable liquid transportation fuel mandates. The potential benefits of ABB include per-acre yields reported to be significantly larger than those for other biofuel feedstocks (e.g., soybean, jatropha), and the potential for algae to grow in water not traditionally used for other purposes. The potential concerns of ABB include limited information about the costs of large-scale ABB production, the amount of energy required, and life-cycle emissions analysis. The need for large amounts of the greenhouse gas CO_2 to grow algae may be a benefit or a concern: algae cultivation could potentially contribute to emissions neutrality by reusing CO_2 from stationary sources, but there are concerns about whether enough CO_2 from existing sources is available to support commercial levels of ABB production. The use of genetically engineered algae could also be a benefit or concern: genetically engineered algae could lead to higher yields, but also could have unintended consequences such as threatening aquatic ecosystems.

While the DOE has studied algae for at least 20 years, much of that research has focused on using algae to produce biodiesel. Current research efforts examine the use of algae for jet fuel, power, bioproducts, and more.[52] Federal support for ABB has occurred through general agency programs and specific projects.

Currently, there are no commercial-scale ABB plants,[53] although ABB was offered for sale at retail pumps in late 2012 in California for a limited time.[54] ABB pilot facilities projected to come online over the next year may give a better indication of ABB's productivity potential and cost

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[52] Bioproducts are products made from biomass (e.g., plastics, glues).

[53] Philip T. Pienkos and Al Darzins, "The Promise and Challenges of Microalgal-Derived Biofuels," *Biofuels, Bioproducts and Biorefining*, vol. 3 (2009), pp. 431-440.

[54] Solazyme, Inc., "Propel Fuels & Solazyme Deliver World's First Consumer Access to Algae-based Fuel," press release, November 13, 2012, http://solazyme.com/media/2012-11-13.

effectiveness.[55] Even if ABB is demonstrated to work at a commercial level at one or two facilities, it may not produce a significant portion of the U.S. transportation fuel supply in the near term. Multiple commercial-scale facilities that could possibly produce ABB in significant quantities will require financing, a labor force,[56] and distribution and supply infrastructure that may take some time to devise. Because no ABB facilities are operating at commercial scale, it is not yet known what regulatory issues might arise. As with many new technologies, regulatory issues and perception by the general public are likely to be a concern.

ABB currently faces many of the same questions as were posed about biofuel industries that preceded it (e.g., corn-starch ethanol). Indeed, while ABB is less developed than established biofuels industries such as corn-starch ethanol, its development and deployment at commercial scale may be quickened by lessons learned from these industries. For instance, mastering the technology to convert a certain feedstock to a biofuel may not happen in the timeframe predicted, regardless of the amount of financial and technical assistance granted. Additionally, the development of corn-based ethanol showed that long-term contracts for feedstock supply and associated resource requirements are vital to gauging the economic standing of biofuel production. Last, uncertainties about policy support (e.g., inclusion in the RFS2, lowering RFS2 mandates, and expiring tax provisions) and unforeseen competition from other fuels internal and external to the biofuel industry could all have an impact on the bottom line and the aggressiveness put toward ABB production.

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[55] One such project is the Algenol Biofuels facility. Algenol reports that it should demonstrate the commercial viability of its technology in the first quarter of 2013. Algenol Biofuels, http://www.algenol.com/about-algenol/our-path-forward.

[56] ABB production would likely require employees with a scientific and technical background (e.g., phycologists, microbiologists, agricultural engineers).