ALGAE BIOMASS ORGANIZATION

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SUBMITTED ELECTRONICALLY

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RE: Algae Biomass Organization Comments on Opportunities and Challenges to Adopt Carbon Use/Reuse Technologies for the Power Generation Sector

I. Introduction

The Algae Biomass Organization (ABO) appreciates the opportunity to comment on opportunities and challenges to the adoption of carbon use/reuse technologies for the power sector. ABO is the trade association for the algae industry, representing the leading developers of renewable, sustainable products from algae. Our membership (http://algaebiomass.org/member-companies/) includes pioneering technology companies, research institutions, leading academics, utilities, end users, and a range of other industry partners throughout the algae supply chain. ABO members are developing a wide range of technology platforms using algae and other microorganisms to convert CO_2 captured from power generation and other industrial sources into renewable fuels, chemicals, fertilizer, plastics, food and feed ingredients and other products.

By creating a market for captured carbon, biological carbon use/reuse can mitigate, offset, or even negate the cost of carbon capture. Through public and private sector investment, a variety of biological carbon capture and use (CCU) technologies have been demonstrated as technically feasible at pilot and demonstration scale. Ongoing research and development continues to improve the effectiveness, efficiency and cost of these and other promising biological carbon use technologies.

Rapid and widespread deployment of biological and other CCU technologies will be essential to CO2 mitigation from the power sector today, and to achieving the more ambitious and vital goal of halting and reversing increases in atmospheric greenhouse gas concentrations in the decades to come.

II. Algae/Microbial Carbon Utilization

a. The Algae/Microbial Platform

The use of algae and other microorganisms to convert CO_2 to valuable products is among the most promising options for reducing CO_2 emissions from existing and future CO_2-producing power plants. Algae are among nature's most prolific and efficient photosynthetic organisms. Algae's exceptional ability to convert sunlight and CO_2 into oxygen transformed Earth's early atmosphere into the oxygen-rich one we enjoy now, and the lipids and carbohydrates produced by these early algae are the original source of the crude oil that drives our economy.

Chemoautotrophic microorganisms perform the same function in the absence of sunlight by mediating chemical reactions.

Both classes of microorganisms thrive on concentrated sources of CO_2. To provide the optimal environment for growth, developers of these technologies must purchase commercial CO_2 – at great expense – as a feedstock. ABO members would welcome the opportunity to participate in reducing emissions of CO_2 from the power sector by partnering with utilities to utilize captured carbon as a feedstock, transforming CO_2 from an expensive waste disposal issue into a resource that will benefit industry, the environment and ratepayers.

b. Technology Demonstration

Algae biomass research, development and deployment is underway throughout the U.S. A 2013 survey of ABO members identified 148 facilities conducting or supporting algae R&D and commercial deployment http://algaebiomass.org/resource-center/abo-resources/algae-map/. Research continues to evolve rapidly, and algae- and other microbial-based carbon utilization is now being demonstrated at scale, including at DOE-funded integrated biorefinery (IBR) projects in Florida and New Mexico, and pilot projects in Iowa, Hawaii, Kentucky, and elsewhere.[1,2] ABO's Algae Project Book (http://algaebiomass.org/wp-content/gallery/2012-algae-biomass-summit/2015/07/ABO_project_book_July2015.pdf) highlights these and other leading projects.

In addition to the projects highlighted here, LanzaTech is deploying their microbial carbon recycling technology at commercial scale with industrial carbon emitters around the world, including the world's largest steel company, ArcelorMittal. The ArcelorMittal project is expected to come online in 2017, and will produce a biofuel with 80 percent lower GHG emissions than the fuel it replaces.[3]

Accelergy Corporation, a leading coal-to-liquids (CTL) technology developer, is currently validating its TerraSync technology for algae-based conversion of CO_2 from CTL fuel production into bio-fertilizer. Algae absorb CO_2 from CTL flue gas and then continue to capture CO_2 and nitrogen from the atmosphere once applied to soil as a fertilizer, greatly enhancing GHG mitigation.[4] Accelergy has signed a deal to deploy the technology at a CTL plant in Mongolia.[5]

MicroBio Engineering, Inc. is working with Orlando Utilities Commission, Arizona State University, Scripps Institution of Oceanography, and others to integrate microalgal systems to beneficially utilize and mitigate CO2 emissions from coal-fired power plant flue gas.[6] Arizona State is also working with Salt River Project in Arizona to identify algae strains for power plant CO2 mitigation.[7]

Algae technology developers Cellana and Renewable Algal Energy have signed offtake agreements with Neste Oil, a leading oil refiner, for algal oil produced at planned commercial algae production facilities,[8] and Mississippi-based Algix, LLC, recently opened its first commercial facility for production of algae-based bioplastics.[9]

Algae biomass developers are also increasingly targeting algae-derived ingredients for human and animal nutrition, personal care, cosmetics and other high value markets that offer near-term opportunity for profitability.[10]

c. Sustainability and Scalability

i. Sustainability

As has been observed by DOE, algae-based CO_2 conversion offers a diverse set of economic and environmental benefits.[11] Algae offer high potential yield per acre, the ability to grow on land not suited for

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[1] http://energy.gov/eere/bioenergy/related-links-0

[2] http://energy.gov/eere/bioenergy/algal-integrated-biorefineries

[3] http://www.lanzatech.com/arcelormittal-lanzatech-primetals-technologies-announce-partnership-construct-breakthrough-e87m-biofuel-production-facility/

[4] http://www.accelergy.com/technology_cbtl.html

[5] http://www.algaeindustrymagazine.com/accelergy-partners-with-yankuang-for-algae-farm-at-coal-to-liquids-plant-in-china/

[6] http://www.netl.doe.gov/research/coal/project-information/proj?k=FE0026490

[7] http://www.srpnet.com/newsroom/releases/032116.aspx

[8] http://www.nesteoil.com/default.asp?path=1,41,540,17988,7906,24191

[9] http://msbusiness.com/blog/2014/11/14/bioplastics-maker-opens-business-east-mississippi/

[10] http://www.biofuelsdigest.com/bdigest/2014/10/01/state-of-the-algae-industry-10-top-level-commercial-leaders-look-at-the-path-to-scale/

[11] http://energy.gov/sites/prod/files/2014/09/f18/algal_biofuels_factsheet.pdf

agriculture and in brackish or wastewater, absorption of CO_2, and relative ease of conversion into fuels and products.

Algae's potential for GHG reductions is among its most desirable characteristics. Environmental Protection Agency (EPA) analyses of algae-based fuel pathways under the federal Renewable Fuel Standard (RFS) program found GHG reductions of 69-85 percent on a full lifecycle basis versus petroleum-based alternatives.[12,13] Algae-based renewable diesel is also approved by EPA under the RFS as a qualified advanced biofuel with lifecycle GHG emissions reductions of greater than 50 percent verses petroleum-based diesel.[14]

In addition to substituting for petroleum in fuels and chemicals markets, algae oils offer a sustainable alternative to palm oil in a wide range of markets such as laundry surfactants and food ingredients.[15] Widespread deployment of algae carbon capture could therefore have the added benefit of reducing CO_2 emissions from deforestation for palm oil production.

This is just one example of the profound indirect climate benefits that can result from beneficial reuse of captured carbon. A seminal study released this year by the International Institute for Applied Systems Analysis[16] found, for example, that substitution of algae-based feed for traditional grain and pasture-based feed, in combination with a modest amount of carbon capture and geologic storage, could help bring atmospheric carbon concentrations down to preindustrial levels by the end of the century, demonstrating that applications of biological carbon utilization can have global-scale beneficial impacts.

An analysis of substitution of algae-based fertilizer produced through carbon capture and use for conventional nitrogen fertilizer indicates that the application of algae-based carbon use/reuse for this purpose can result in avoided emissions of 46 to 116 tons of CO2 equivalent for every ton of CO2 utilized in the algae production process [see **Appendix A**]. Under regulatory regimes that reward such indirect effects, power plants could offset 100 percent or more of their CO2 emissions through capture and use of only a small fraction of total CO2 emissions, making investments in biological CCU especially valuable.

ii. Scalability

Algae production has the potential to scale to very significant levels of commercial production. The DOE has said the production of algae-based fuel represents a significant opportunity to impact the U.S. energy supply for transportation fuels.[17] A comprehensive 2013 analysis by Pacific Northwest National Labs (PNNL)[18] found the nation's land and water resources could support 25 billion gallons of algae-based fuel a year in the United States. And a forthcoming analysis by DOE[19] is expected to find substantial opportunity from co-location of algae production with fossil power generation.

Algae have been demonstrated to produce over 8,000 gallons of biofuel per acre – more than ten times the yield from palm oil – and over 100 gallons of biofuel per ton of CO_2.[20] A 10,000 acre commercial algae production unit would therefore absorb nearly 1 million tons of CO_2 annually – nearly 1/4 of the CO_2 emitted by a typical 600MW coal power plant[21] and more than half the CO_2 from a similar size natural gas unit – all while producing over 80 million gallons of renewable fuel to substitute for fossil petroleum.

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[12] https://www.epa.gov/sites/production/files/2015-08/documents/algenol-determination-ltr-2014-12-4.pdf

[13] http://www.jouleunlimited.com/epa/OAR-16-000-5822_Joule_Petition_Response.pdf

[14] http://www.epa.gov/otaq/fuels/renewablefuels/new-pathways/approved-pathways.htm

[15] http://www.theguardian.com/environment/2014/apr/02/ecover-algae-laundry-liquid-palm-oil

[16] http://cbmjournal.springeropen.com/articles/10.1186/s13021-015-0040-7

[17] U.S. DOE 2010. National Algal Biofuels Technology Roadmap. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Biomass Program.

[18] http://pubs.acs.org/doi/abs/10.1021/es304135b

[19] http://www.biofuelsdigest.com/bdigest/2016/04/03/son-of-billion-ton-the-digests-2016-multi-slide-guide-to-the-usda-billion-ton-report/8/

[20] www.algenol.com

[21] http://www.ucsusa.org/clean_energy/coalvswind/c02c.html#.VFz-JfnF-aI

Some critics have suggested that algae and other CCU platforms could not be deployed at sufficient scale to significantly mitigate CO_2 emissions from the power sector. But DNV, the respected Norwegian classification and risk management society, found in a recent analysis that conversion of CO_2 into fuel, utilization of CO_2 as a feedstock for chemicals, and non-conversion use of CO_2 together have the potential to reduce CO_2 emissions by at least 3.7 gigatons per year (Gt/y) – approximately 10 percent of total current annual global CO_2 emissions – both directly and by reducing use of fossil fuels, and that much greater reductions are possible through wider adoption of these technologies.[22]

Other CCU critics have argued that CO_2 conversion requires high levels of process energy. These critics should be reminded that photosynthesis has been efficiently converting CO_2 to valuable products for millennia using only sunlight. Other biological conversion pathways, such as are found in chemoautotrophs, also do not require energy inputs, since they create their own chemical reactions within the cell.

d. Cost

Perhaps the greatest concern about carbon regulation is the cost of compliance. Absent technologies that can reuse waste carbon, compliance is a sunk cost. Cost has been the leading obstacle to deployment of CCS technologies, for example.[23]

Algae-based CCU is clearly cost advantaged over CCS. For example, Accelergy, estimates the cost of its algae bio-fertilizer CCU platform at \$4 to \$12 per ton of CO_2 captured [see **Appendix A**]. This represents a cost reduction of up to 95 percent versus CCS.

Many of today's algae producers must buy CO_2 from commercial sources. Carbon dioxide procurement is one of the leading operational costs of algae biomass projects. Given these costs, algae project developers are hungry for new sources of CO_2. At over 100 gallons of biofuel produced per ton of CO_2, the value of biofuel produced from algae-based CCU is likely to exceed \$200 per ton of CO_2, for example.[24] Algae project developers are therefore well positioned to mitigate, offset, or even negate the cost of carbon capture, providing a CO_2 reduction mechanism that minimizes the cost to ratepayers. For example, Algenol Biofuels estimated in its November presentation to NRECA that its CCU to biofuels platform could offer up to \$25 per ton in revenue to power generating partners, offering CO_2 solution that benefits ratepayers [see **Appendix B**].

Algae-based CCU also does not require the added expense and parasitic load of CO_2 compression and underground injection associated with CCS. Furthermore, with CCS, the entire cost of capture, purification, compression and underground injection is borne by the ratepayer. CCU offers a market-based alternative for CO_2 that minimizes cost to the ratepayer by turning CO_2 from a waste into a commercial resource.

III. Accounting and Verification of Emissions Reductions

CCU produces real, quantifiable and permanent reductions in CO_2 emissions. Many CCU applications, such as algae conversion to chemical intermediates and plastics, directly sequester CO_2 in enduring products.[25] Other applications, such as production of algae-based soil amendments and bio-fertilizer, can produce ongoing reductions in atmospheric CO_2 well beyond the life of individual organisms.[26,27]

Even when subsequently combusted as a transportation fuel, CO_2 utilization produces ton-for-ton emissions reductions by displacing additional fossil fuel combustion. Every barrel of algae biofuel produced through carbon capture replaces a barrel of petroleum that would otherwise have been extracted and combusted. Through this substitution, CO_2 remains permanently stored underground as petroleum. In this way,

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[22] http://www.dnv.com/binaries/dnv-position_paper_co2_utilization_tcm4-445820.pdf
[23] http://www.cbo.gov/sites/default/files/cbofiles/attachments/43357-06-28CarbonCapture.pdf
[24] www.algenol.com
[25] e.g. www.algix.com
[26] http://www.accelergy.com/technology_cbtl.html
[27] e.g. http://www.slideshare.net/asku92/production-of-biofertilizeranabaena-and-nostoc-using-co2

carbon capture and conversion to biofuel achieves CO_2 emissions reductions comparable to CCS and is a preferred option to reuse for EOR, which by definition increases fossil carbon extraction and subsequent combustion.

A peer reviewed analysis by scientists at the Georgia Institute of Technology provides the first direct comparison of CO_2 reductions achieved using algae-based CCU versus application of CCS for the same power generation facility.[28] The study is attached as **Appendix C**. The analysis found that algae-based CCU results in a greatly advantaged carbon footprint relative to business as usual, and emissions similar to CCS, even when subsequent biofuel combustion is included. For biofuels produced with lifecycle emissions reductions greater than 75 percent relative to petroleum, CCU is advantaged with respect to CCS.

For the wide spectrum of products other than biofuels produced through CCU, the diversity of product lifespans, alternative substitution scenarios, and end-of-life options further complicates accounting for lifecycle reductions in CO_2 emissions. Significant work has been done in this area to establish accounting standards,[29,30] but DOE support to establish carbon accounting protocols for CCU would be beneficial.

IV. Response to Specific Questions

Q1. Depending on the utilization technology proposed, what is the appropriate size/scale (lab, bench small slipstream, small pilot or large pilot) for assessing this approach? How long until your technology will reach the next scale? How long do you anticipate it will take to commercialize your technology: <5, 5-10, 10-20, >20 years?

As identified in the Algae Industry Project Book and above, there are algae and other microbial CCU technologies at all stages of technological development from lab to commercial demonstration. The most important role DOE can play in accelerating deployment of these technologies is to support demonstrations of unit operations of a variety of biological CCU systems at commercially relevant scales at fossil power plants or other relevant industrial facilities. Demonstration of integrated systems will provide the greatest opportunity for relevant learnings to improve efficiency and drive down capital and operational costs. Sustained funding of this nature could achieve commercial deployment of multiple technologies within 5 years.

Q2. What are the markets for your technology's products, both existing and emerging? What is the volume of the proposed market? What is an approximate value of the proposed market? How these products are currently produced?

Bloomberg New Energy Finance recently conducted a comprehensive review of markets for algae-derived products. The analysis is attached as **Appendix D**.

Q3. What metrics do you use to measure the improvement of your technology relative to current production methods (metrics such as profitability, environmental impacts, climate impacts, sustainability, existing technologies and processes)? DOE is seeking only the types of metrics and testing required to compare technologies and is not seeking business sensitive, proprietary, or confidential performance information.

Performance metrics will vary by application and technology platform.

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[28] http://onlinelibrary.wiley.com/doi/10.1002/bbb.1505/references
[29] https://www.bio.org/sites/default/files/Position_Carbon_Footprint_PCF.pdf
[30] http://onlinelibrary.wiley.com/doi/10.1111/j.1530-9290.2012.00468.x/abstract

Q4. When your technology is at full scale, how much anthropogenic CO_2 can it use at each operation or facility?

Potential for CO2 mitigation will vary by application and technology platform, but as referenced in previous sections, the potential cumulative impact of CCU technologies to mitigate climate change is substantial, especially when indirect GHG impacts are appropriately accounted for.

Q5. What are the main technical barriers for the technology and how will these barriers be addressed if R&D funding is provided?

The main technical barrier to deployment of biological CCU technology is gaining operational experience at modular and multi-modular scale to ensure operational integrity and sustainability when operated in conjunction with a power plant and/or on a CO2 distribution pipeline network. Federal funding for commercially relevant demonstration of integrated systems will allow technology developers to gain operational experience in a real time setting to maximize relevant learnings to improve efficiency and reduce capital and operations costs.

Q6. Has your technology been tested on synthetic or real flue gas? If so, what were the impacts of contaminants on your technology? Would access to a government-funded facility (e.g., power plant) be useful to assessing your technology or do you have a facility in mind?

U.S. projects tested on synthetic or real flue gas are identified in previous sections. We refer the Department to these groups to report on the impacts of contaminants, but believe impacts, if any, can and will be readily mitigated. Access to government-funded facilities would certainly be useful in assessing biological CCU technologies. The participation of utilities and other industrial emitters of CO2 will be vital to accelerating the deployment of CCU solutions.

Q7. Why is it appropriate to use government resources for validation and is government cost share necessary for validation of the technology?

The federal government has committed through the Paris accord to substantial reductions in GHG emissions. Investment in technologies with the potential to deliver promised reductions is essential to meeting this obligation. CCU technologies offer the best option for reducing GHG emissions from fossil power generation in the near term, and hold the potential to substantially contribute to the more ambitious and vital goal of reducing atmospheric GHG concentrations in the longer term. In the absence of a clear price on carbon and/or clarity on the legal fate of the Clean Power Plan, utilities and other industrial emitters may be unable to justify substantial investments in CO2 mitigation technologies. These technologies must be ready and available for deployment when this situation changes. Government cost share is essential to achieving this outcome.

*Q8. For plant and algal biomass projects **ONLY**, are bioreactors or ponds preferred? Why?*

DOE should seek to foster a broad set of technology platforms to ensure suitability to multiple geographies, CO2 sources and other operating conditions, including bioreactors, open pond systems, and hybrid systems.

Q9. What technical and financial barriers do you anticipate encountering and how are you planning to overcome these barriers?

ABO refers the Department to the specific project and groups undertaking CCU development to address this question.

Q10. What is the total market *<u>volume</u>* *(both domestic and global if known) of the products you plan to produce with your technology and how much* CO_2 *would these products consume? Consider both existing and emerging product markets.*

See Appendix D

Q11. What is the total market *<u>value</u>* *(both domestic and global if known) of the products your technology produces?*

See Appendix D

Q12. Does your technology result in the carbon in the CO_2 *being sequestered? Sequestering implies the carbon in the product, if left undisturbed, will remain isolated from the atmosphere for a long period of time. This is not the case for products that are consumed, such as fuels, and for most organic chemicals, which degrade rapidly.*

As noted earlier, climate benefits of CCU technologies can result from a variety of direct and indirect impacts. Captured carbon may be sequestration in enduring products, such as plastics, or, as in the case of algae-based fertilizers, in soils; captured carbon may substitute for fossil carbon which would otherwise be extracted and combusted as fuel, thereby sequestering fossil carbon through substitution; and/or the application of CCU technologies may result in indirect GHG benefits such as avoided deforestation or other land use change benefits or substitution for GHG-intensive products or processes. Each of these components should be considered when evaluating the benefits of carbon mitigation technologies.

Q13. Have you considered the greenhouse gas emissions, as well as other environmental impacts (waste, water use, etc.), of your products and technology on a life-cycle basis? If so, how, and did this include a quantitative life cycle analysis (LCA)? Have you considered these same impacts for the existing products and processes you propose to displace?

As noted earlier, Appendix C provides a good example of an LCA assessment of CCU technology relative to alternative approaches, such as CCS or EOR. For the wide spectrum of products other than biofuels produced through CCU, the diversity of product lifespans, alternative substitution scenarios, and end-of-life options complicates accounting for lifecycle reductions in CO_2 emissions. DOE support to establish carbon accounting protocols for CCU would be beneficial.

Q14. If your technology requires significant renewable or nuclear energy sources to achieve greenhouse gas emission reduction benefits when fed by fossil fuel-derived CO_2*, then what is the relative advantages of using this energy to power your technology as compared to putting low-carbon power directly on the grid to reduce fossil fuel use elsewhere?*

Algae and other biological approaches to carbon capture and use are not anticipated to require large energy inputs. Even at higher latitudes, for example, waste heat from the power plant or other industrial source can be used to maintain temperatures of the biological system. Sunlight or chemical reactions provide the principal energy source in these systems. Even in systems with artificial light, highly efficient LED lighting with spectral and temporal control can be used to greatly reduce energy inputs.

Q15. Have you considered how you will address any significant inefficiencies (thermodynamic or otherwise) with respect to the energy required by your technology and by any needed CO_2 recovery and purification from flue gas?

Algae and other microbial CCU systems have the benefit of being well suited to utilizing raw stack gas from coal or natural gas combustion. DOE funding of demonstration and ongoing pilot and R&D projects will substantially aid in optimizing the integration of biological CCU systems with fossil power generation.

Q16. Are there other special circumstances that you feel justify the development of your technology?

Algae and other microbial CCU systems harness earth's original carbon mitigation strategies – photosynthesis and chemosynthesis – to address the urgent modern challenge of climate change. Geologic history proves that these systems have effectively addressed the GHG challenges of the past. We applaud DOE's recognition of the vital role these technologies can play today, and urge the Department to invest aggressively to speed their commercial deployment.