Comments to the California Energy Commission
Re: Biofuels Technical Workshop, Docket # 09-ALT-1
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Thank you again for this opportunity to provide comments on the development of the California Energy Commission's AB 118 investment plan for 2010-2011; I am also grateful for the opportunity to have been invited to participate in the algae fuels panel section of the related CEC technical workshop on Tuesday, September 15, 2009. CEC staff developed the following questions for consideration by that panel:

1. What needs to happen in the market, technology or policy arenas before algae-based biofuels can be commercially produced in California?
2. Is more basic research needed before commercial production can begin?
3. What production technologies are best suited to California's constraints and environmental concerns?
4. What are the environmental and sustainability issues associated with commercial-scale production in California? Is water use a limiting factor?
5. How can AB 118 investment monies be used to accelerate demonstration and commercial production facilities?

It is my hope that our dialogue during the workshop helped to provide answers for the staff, or at least move in the direction of these answers. These supplemental comments are intended to provide a more robust context in which to frame the questions, and to support the subsequent recommendations for potential funding allocations.

As was discussed during the workshop on Tuesday, just the night before, on behalf of UCSD, the San Diego Center for Algae Biotechnology (SD-CAB) and our consortium partners, I submitted to the Department of Energy a proposal in response to DOE's call for consortia in the field of algae biofuels research. CEC staff is familiar with this DOE FOA, so I won't characterize it again here. However, given the related questions CEC posed during its workshop, it seems appropriate to provide a relatively brief overview of both what our proposal entails, and the related work already ongoing in our labs, as there

is clearly relevance to the questions CEC is asking, as it considers its funding decisions for the 2010-2011 cycle under AB 118.

Overview of the Consortium for Algal Biofuels Commercialization (CAB-Comm):

The Consortium for Algal Biofuels Commercialization (CAB-Comm) is a partnership led by the University of San Diego with Dr. Stephen Mayfield (UCSD) as the PI. This consortium was assembled in response to the DOE call for proposals on Algal Biofuels Consortia, and brings together some of the nation's leading American bioenergy companies and preeminent U.S. universities performing algal biofuel research. Its aim is to move algal biofuels from a promising renewable energy source to a proven technology with strong scientific underpinnings and reliable, profitable and environmentally-friendly production facilities.

The Consortium includes a major oil company (Chevron), a major power utility company (Sempra Energy), large industrial organizations with interests in bioenergy (WR Grace, Praxair, and General Atomics), several leading algal bioenergy commercialization start-ups (Sapphire Energy, Algenol, and Biolight), and one of the leading research tool technology development companies (Life Technologies). The consortium also includes several of the country's most outstanding biologists, engineers, energy analysts and scientists (including 4 members of the National Academy of Sciences: Steven Briggs, Paul Falkowski, Steve Kay, and James Van Etten). The DOE Lawrence Berkeley National Laboratory and twelve prominent research universities and institutions are partners in the Consortium: University of California campuses at San Diego and Davis and the Scripps Institution of Oceanography; University of Maryland's Center of Marine Biotechnology and Baltimore County campus; University of Nebraska at Lincoln; Colorado School of Mines; Johns Hopkins, Princeton, Rutgers, and Cornell Universities; and Brooklyn College. This outstanding consortium of diverse stakeholders will help to accelerate the algal biofuels industry by identifying and overcoming barriers to commercialization, while acting to recruit, employ, and train the frontline scientific workforce that will support nascent industry and drive future economic growth and innovation in California.

CAB-Comm's objectives are designed to address many of the significant challenges and opportunities of the algal biofuel industry. The core philosophy of the projects is hypothesis-guided research informed by real world industrial activities. Projects range from discovery of promising new algal strains, enhancement of these and existing oleaginous algal strains for better oil quantities and quality through breeding, management of feeding and waste, effects of physical stresses, mutagenesis and genetic engineering of key lipid biosynthetic pathways, development of efficient and economic methods for algal harvesting and oil extraction, and crop protection, to the final refining and distribution of algal biofuels and co-products (Figure 1). Economists and analysts will work with scientists and engineers to evaluate efficiencies, economic viability, and environmental advantages/disadvantages of the processes and procedures. Go/No-Go decision points will be reached leading to completion or redirection of specific activities.

Why are we assembling an Algal Biofuels Consortium?

Development of dependable, economic and environmentally sound sources of renewable biofuels is a major goal for the United States and the world. The uncertainty and fluctuating costs of foreign oil are the cause of significant economic and security concerns. Likewise, exacerbation of global warming by greenhouse gases generated by use of fossil fuels is a global challenge that calls for new technologies and new sources of transportation fuels that are less polluting. Ethanol from corn starch and sugar cane, and soon from lignocellulose, has been an important first step in the right direction. However, a growing number of analyses have pointed to the significant potential and advantages of lipid-rich algae as a renewable source for a variety of high quality oils that can serve as feedstocks for transportation and other fuels.

The often cited advantages of algae as a source of transportation biofuels and other valuable chemicals and molecules include the fact that the primary energy resource needed (sunlight) is "free" and the other resources for photosynthesis (CO_2, simple mineral nutrients, water, and land) are reasonably low in cost. Indeed, excess CO_2 from power plants, various manufacturing facilities, ethanol refineries, etc. consumed by nearby algal production facilities is viewed as a potential "sink" for a small portion of carbon emissions. The water employed does not need to be pure and, for many algae, the water can even be brackish or marine. Likewise, partially treated, nutrient-rich effluent from various animal and human wastewater sources can be recaptured for algal growth. Inexpensive, non-arable land can be used for siting algal production operations, thus maintaining highly valuable agricultural lands for food production. Because only one alga, *Chlamydomonas reinhardtii*, has been studied to any extent from genetic, biochemical and molecular perspectives, and because a truly vast array of highly diverse eukaryotic and prokaryotic microalgae exist, there resides in Nature an untapped wealth of genetic potential for producing valuable oils and co-products from algae we wish to "domesticate" and modify to our advantage – much as the earliest farmers found plants producing a few small, barely edible, seeds and, over time, converted them into domesticated plants that have, since the advent of modern plant breeding and plant genetic engineering, resulted in astonishingly productive crops. For these and other reasons, there is growing commercial and environmental interest in exploring the true potential of algal-derived oils.

Despite these significant advantages**,** considerable scientific and technical barriers exist to achieving the outstanding economic and ecological promise of algal oils. The Consortium for Algal Biofuels Commercialization (CAB-Comm) has been formed by teams of senior scientists and engineers from some of the nation's leading academic institutions and research centers, DOE Lawrence Berkeley National Laboratory, and bioenergy companies to overcome many of the most significant challenges, and exploit the greatest opportunities, in making algal biofuels a commercial reality and success.

From our perspectives, and those expressed by experts at the recently held National Algal Biofuels Technology Roadmap Workshop, the most significant challenges faced by the

emerging algal biofuels industry include the following; all of these challenges are addressed in the research and development plans of CAB-Comm and its partner companies as outlined in this proposal:

- Identification and optimal culturing of those algal species that have the most desirable initial characteristics for biofuel production
- Definition of the metabolic pathways in algae that give rise to the kinds of lipids (oil) that are desirable for production of various types of transportation fuels
- Elucidation and manipulation of the regulatory systems in algal cells that control lipid synthesis using state-of-the-art genomics, proteomics, transcriptomics and metabolomics technologies
- Favorable modification of lipid biosynthetic and regulatory pathways to produce larger quantities of oils and higher value oils through classical genetic manipulations and through advanced genetic engineering techniques
- Design and engineering of large-scale facilities that allow optimal algal growth and oil production in an economically viable manner
- Protection of production-scale algal cultures from the potentially devastating effects of microbial, viral, zooplankton, and phytoplankton contaminations
- Efficient harvesting of microscopic algal cells and extraction of oils in an economic fashion
- Production of valuable co-products to increase overall profitability of manufacturing operations
- Refining and formulating the various types of algal oils that are valuable as transportation fuels
- Integrating the flow of new algal biofuels into existing systems for distribution and utilization of transportation fuels
- Ensuring that the combinations of methods for developing, producing and commercializing algal biofuels are the most efficient and commercially profitable possible
- Detailed Life Cycle Analysis (LCA) analysis of algal biofuels scale-up with consideration of land use change, greenhouse gases, fresh water use and other key parameters related to sustainability and environmental policy.

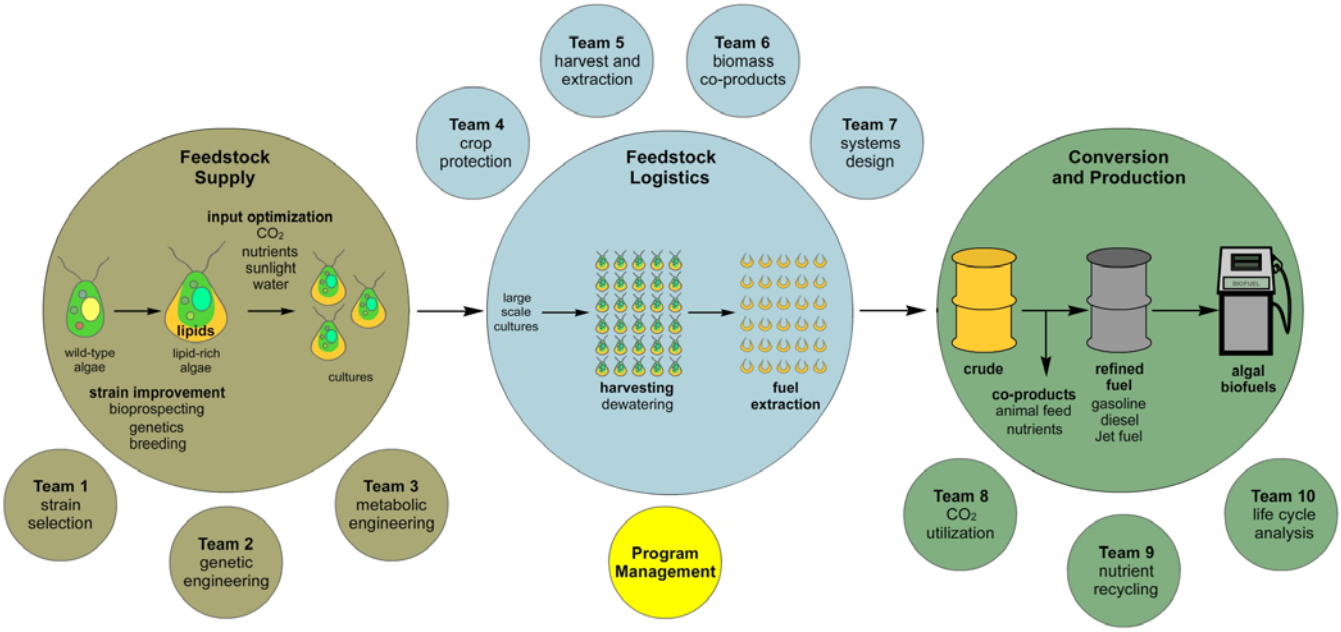

Figure 1. Algal Biofuels Production Chain and Research Team Position

CAB-Comm is structured into four groups of teams organized to take on responsibilities for targeted, specialized research and development tasks (Figure 1). Each task will be the prime responsibility of one team of scientists/engineers/analysts, but each will draw extensively on appropriate expertise from other teams in their own and other groups. Many of the facilities needed already exist or will be operational soon with expanded capacities for cutting-edge research and engineering. A management plan has been designed to foster strong interactions among individuals, teams and groups. An early priority will be the first annual CAB-Comm Research and Development Conference, during which plenary sessions will introduce all members to all aspects of the Consortium's science and engineering agendas; equally important, the conference will include workshops for face-to-face meetings of teams and groups to evaluate diverse approaches and refine specific directions and approaches to reach each milestone identified by the Consortium. It is expected that the definition of clear objectives and pathways to those objectives, along with personal and professional bonds formed in these intense meetings will promote communication and facilitate collaborative interactions among individual members, teams, and groups even over long distances. To promote continued and frequent interactions, a high priority of CAB-Comm will be establishment of high-speed connections for video conferencing and for exchange of copious amounts of data that are inherent to modern "-omics" research and engineering projects.

The CAB-Comm management plan prescribes efficient, industry-style oversight that allows agile, yet measured responses to daily or long-term challenges facing individuals, teams, groups and the Consortium as a whole. Assessments afforded by regularly scheduled evaluations of projects for progress and for go/no go decisions and extensive, ongoing Life Cycle Analyses are intended to keep the Consortium headed directly toward

the ultimate goal of catalyzing the profitable introduction of algal biofuels into the national and global marketplace.

Participant Organizations in CAB-Comm

CAB-Comm is made up of major oil companies, industrial suppliers, and many of the premier start-up companies in the algal biofuel industry along with several eminent scientists, engineers and economic analysts in academic and public research institutions and DOE National Laboratories. Indeed, over 40 individuals with stellar reputations in their fields of study and practice have been drawn from twelve of the country's most preeminent universities and research organizations (including **University of California San Diego (UCSD**, the lead institution), **Scripps Institution of Oceanography (SIO), Johns Hopkins University (JHU), University of California Davis (UCD), University of Nebraska Lincoln (UNL), Rutgers University, Princeton University, Colorado School of Mines (CSM), Cornell University, University of Maryland Baltimore County (UMBC)** and **University of Maryland's Center of Marine Biotechnology (COMB)**. In addition, several researchers and engineers from **Lawrence Berkeley National Laboratory (LBNL)** who are experts in biofuels, algal biotechnology, and transportation fuels are members of various CAB-Comm teams.

CAB-Comm Research and Development Groups

The challenges we face include the identification of algal strains from Nature with the best initial growth and oil content characteristics, and modification of these strains by classical genetic manipulations and genetic engineering techniques to yield superior algal strains with greatly improved production traits. The latter will make extensive use of powerful "-omics" technologies (genomics, proteomics, metabolomics, transcriptomics, etc.). These technologies will allow us to discover and map the lipid biosynthetic pathways in target algal species and design approaches to modify these pathways. This approach will lead to synthesis in algae of more desirable types of oil feedstocks and much larger quantities of these oils—and and in a manner that can be precisely controlled under commercial production conditions. These challenges will be addressed by three teams in our Feedstock Supply Group.

Another set of three teams in the Feedstock Logistics Group will address challenges associated with fighting contamination of algal production batches by various microbes, zooplankton and phytoplankton, and with developing efficient and economic algal cell harvesting and oil extraction from the concentrated cell masses. This group also will focus on increasing the economic viability of algal biofuel manufacture by engineering cells to produce valuable co-products or tailoring algae "residues" for animal feed or methane production.

A third set of three teams, the Conversion and Production Group, will work closely with the companies that are an integral part of the Consortium (ISPs) to tackle the complex design and engineering hurdles that face the algal biofuels industry. Their aim will be to develop specialized extraction, refining and final formulations of a variety of

commercial-grade algal biofuels and specialty chemicals in preparation for delivery through existing fuel distribution systems. Engineering methods for nutrient recycling and advanced super-critical CO_2 extractions that offer significant opportunities for containing production costs also will be a target for this Group. As development of new algal biofuels proceeds toward the marketplace, our ISPs will naturally become increasingly involved in projects that address extraction, refining, and final production and distribution. However, these ISPs also will be involved in the complete span of Consortium projects including algal strain evaluation, "omics" research aimed at elucidating and modifying lipid pathways and engineering improved commercial-scale algal growth facilities.

Guiding the Consortium's operation and rationale, industrial-style decision-making processes will rest with a Management and Assessment Group. The Management team for the consortium will be small and agile to allow rapid decision-making and the implementation of modified or new paths toward the Consortium's goal of catalyzing profitable commercialization of algal biofuels in the shortest possible time. To guide rational decision-making and provide solid information regarding progress toward Consortium goals, a Life Cycle Analysis (LCA) team has been assembled and already has supplied important data that has informed decision-making for the Consortium's Management team in selecting the most critical areas of research and development to emphasize.

The first generation Life Cycle Analysis of algal biofuels.

An LCA is a holistic framework for assessing the resource inputs and waste and air emission outputs associated with a product or system from "cradle to grave" or from "pond to wheels" in the case of algae-derived fuels. The overall process inputs are influenced by the algal species' requirements, yields, and the process design. Calculation of the life cycle impacts requires understanding of the process design as well as life cycle inventory datasets for resource inputs to the production system. For the proposed project, the team will build upon an existing Excel-based algae life cycle process model developed by Life Cycle Associates. The model takes into account the balance of carbon, nutrients, and water for the algae system, solids processing, and conversion to transport fuel. The model also takes into account material recycling from process units as well as power and thermal requirements. In addition to examining the inputs and emissions from an algae system, the analysis will also need to consider the potential co-products such as animal feed, glycerin, and others.

Conclusion and Recommendations:

1. What needs to happen in the market, technology or policy arenas before algae-based biofuels can be commercially produced in California?

We feel that the pathway we've laid out in this proposal to DOE captures many of the fundamental scientific and technology challenges that must be addressed in order to enable robust levels of algae fuels commercialization in the state of California. We also

believe that given the experience of our industry partners, we'll be able to identify and address the market issues, and as well as policy needs or obstacles, that can inform subsequent funding decisions, and possible regulatory and legislative actions.

2. Is more basic research needed before commercial production can begin?

Without question, and it is here that we feel we have a tremendous advantage as a state, as California has already emerged as the national, if not global, leader in this field. With appropriate and strategic investment of state and federal resources, we can expedite the reality of sustainable and environmentally beneficial alternative transportation fuels, and the accompanying economic development and innovation impacts, for the state's future.

3. What production technologies are best suited to California's constraints and environmental concerns?

A significant advantage of algae is the flexibility in growth characteristics, making many geographic environments suitable for algae biofuels production. We need to examine a variety of production technologies to identify those best suited to California, and the research we have outlined will further inform this question, as will the ability of our industry partners to make strategic determinations regarding infrastructure, scale, and potential regulatory issues.

4.What are the environmental and sustainability issues associated with commercial-scale production in California? Is water use a limiting factor?

Water use is clearly a factor for any commercial-scale production of alternative fuels in the state of California, and given our current state-wide water challenges, its availability is potentially limiting. However, for the reasons outlined previously, and with which staff are very familiar, algae is the only feedstock with the potential to contribute a meaningful percentage of the transportation fuels now consumed, and which can be produced at scale in this state (or anywhere else in the southwest) by potentially using saline, brackish, or waste water as the main water source. Certainly some fresh water will be required, and these water issues must be carefully examined, but algae offer a unique alternative to higher plants, which must consume fresh water in order to grow.

Sustainability issues are critical, and our consortium intends to robustly analyze these, so as to better inform future decision-making by the CEC and other state and federal decisionmakers. Here again however, to the extent that any replacement fuel or energy source will raise sustainability questions, the nature of algae renders it far more viable than other potential alternative fuel sources.

5. How can AB 118 investment monies be used to accelerate demonstration and commercial production facilities?

We respectfully recommend that the Commission consider providing $25 million in its 2010-2011 investment plan, for competitive award to a consortium of California

academic, industry, and national laboratory partners that can provide the answers needed to expedite demonstration and commercialization of algae based transportation fuels at pilot scale. The timing of this opportunity is tremendous, as we are at a veritable "tipping point" now, in which such a strategic application of state resources can truly accelerate the scientific and technical understanding of algae and related production infrastructure to a point where it can not only confirm its viability as a sustainable transportation fuel feedstock, but start to contribute in a meaningful way to the volume of such fuels consumed annually in California and nationwide.

As we have seen so many times before, when California leads, the rest of the country follows. Algae-based transportation fuels can be a reality, from Sacramento to San Diego, and the environmental and economic rewards reaped will be tremendous. Thank you again for this opportunity to comment, and please don't hesitate to contact us if we may be a resource to you in any way.

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