California Initiative for Large Molecule Sustainable Fuels Roadmap Meeting - Executive Summary

Roadmap Meeting held on October 18, 2012

ABSTRACT

California has always led the nation in innovation and technology advances, and this remains true today in its efforts to develop environmentally and economically sustainable biofuels. To help California and the nation reach legislated requirements in advanced "drop-in" low-carbon fuels, research must focus on all parts of the biofuels production process, including improving system engineering, genetics and crop protection of biomass organisms, and finding cost-efficient processes to recover and recycle resources like nutrients and CO_2. Biofuel feedstocks, including algae, Jatropha, and cellulosic biomass, are being researched and tested for production productivity and process feasibility with varying degrees of success; these science-based results should be reflected in subsequent policy decision-making. Commercial facilities and increasing scale are decreasing production costs, even as industry confronts new challenges, which emerge at larger scales of production. Collaboration among academic research institutions, industry, and government must increase dramatically in order to continue the advancements in biofuel production that will enable California to meet its low-carbon fuel goals. Regulatory uncertainty in California has caused companies to look elsewhere to initiate commercial-scale development, but thoughtful policy measures including pre-permitting, criteria-based exemptions, and pragmatic streamlining of the California Environmental Quality Act (CEQA) process can help to incentivize industry activity in California. In order to meet the goals of Assembly Bill 32 (AB32), more capital investment and commitment is needed to develop and then scale alternative fuels that can leverage available and underutilized resources, such as arid land and brackish water near the Salton Sea, or waste water resources, which are presently discharged into our oceans or pumped underground. Throughout the development process, a transparent, standardized Life Cycle Analysis (LCA) system is essential to ensure that any alternative transportation fuels produced for use in California are truly sustainable and efficient, both environmentally and economically.

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Introduction

California Initiative for Large Molecule Sustainable Fuels

Dave Effross, California Energy Commission

In 2011, the California Initiative for Large Molecule Sustainable Fuels (CILMSF) was set up to help promote biofuels – the advanced fuels industry in California. There are various regulatory and legal structures whereby research funding is used to help promote reductions in greenhouse gases (GHG), low-carbon fuel standards (LCFS), etc., which are all very important goals.

Additionally, the CEC wants to promote a nascent industry in California. Already a national and world leader, the CEC wants to continue to make California the preeminent locus for alternative fuels research, development, and demonstration in the world. Along with the fuels, there are value-added co-products, and co-benefits that can help make these things economical and bring them to market. Green chemistry processes, pharmaceuticals, nutraceuticals, bioplastics, etc., all need to be taken into account, as they can all be part of the processes that go into creating economic alternative fuels.

When the CEC set up this program, it aimed to ensure that on paper, at the outset, it was technology neutral. The program would not pick winners ahead of time. All of the potential bioenergy fuel crops, not just algae, but also other fuel crops, such as Jatropha, are on the table, as far as the California Energy Commission is concerned.

Goals of the CILMSF Roadmap Meeting

Stephen Mayfield, UC San Diego

Meeting Objective

A milestone of the California Initiative for Large Molecule Sustainable Fuels was to hold a meeting of experts from industry, academia, and California politics, and produce a roadmap report, which defines the challenges and the opportunities for the bioenergy industry in this country, and specifically, the unique opportunities and challenges that exist in the State of California. Beyond solving scientific, economic and logistical hurdles, the goal is ultimately to keep California as the leader in this field.

Report Structure

Sections 1 and 2 address the technical challenges that algae and plant research groups are currently working on in the research and development, as well as commercialization, of different biomass feedstocks and their conversion to fuels. Section 3 addresses government policies and regulations, with proposed solutions from industry and government representatives. Section 4 addresses water and land resource issues and opportunities, as well as the economic resources needed for this green sector.

Within each section, a group of experts was invited to present on key topics. Their presentations are summarized below, followed by a concluding statement from CILMSF Project Director, Dr. Stephen Mayfield.

1. Research and Development - Algae

Bioengineering, Genetics, and Crop Protection of Cyanobacteria

Susan Golden, UC San Diego

The Golden labs are focusing on engineering Cyanobacterial polyunsaturated fatty acids (PUFA) synthesis, and identifying and analyzing novel branched hydrocarbon pathways among diverse Cyanobacteria. They are also developing better regulated promoters, allowing for more strategic control of specific genes and avoiding expression changes in off-target genes.

Another project involves engineering for secretion of fatty acids and engineering to change the desaturation levels, making designer profiles of fatty acids with respect to desaturation. Additionally, the labs are getting mutants in Cyanobacteria that are altered in their storage of carbon, in the form of carbohydrate, and trying to get mutants in which they can divert that carbon from carbohydrate to increased lipid production, as well as combining mutants affected in glycogen storage with mutants that secrete fatty acids to improve that diversion of carbon to products in which we are interested.

This group at UCSD has also looked at other challenges like improving genetics for the organisms, and figuring out how to protect organisms out in a pond from predators. For crop protection, the labs have been identifying amoebal grazers that eat Cyanobacteria and have been taking their mutant collections and screening to find mutants that are resistant to amoeba. They are also able to isolate a strain that grows well in a range of salinities and in open ponds, and can easily be genetically manipulated. They are trying to develop that as a new model Cyanobacterium that is a real production strain and will really grow well in a one-acre pond.

Cost-effective Systems for Algae Biomass Commercialization

Alex Aravanis, Sapphire Energy

A leader in the race to commercially produce algal biofuels is Sapphire Energy. They have been making progress in the development of an industrial process to produce algae oil economically and at scale that is competitively priced. To date, it has decreased the cost of production per barrel by an order of magnitude. Although the fuel is not yet competitive with traditional fuels, Sapphire Energy is well along that trajectory to economic viability in the next couple of years.

One major innovation bringing algae biofeuls toward commercialization has been moving to designs like the half-acre pilot pond, a soil-lined pond that is approaching a design closer to a rice paddy. If you can grow productively and stably in that system, you can deploy such a system very rapidly and at very low cost. In addition, Sapphire Energy is using natural resources that are not utilized for food production, including brackish water and non-arable land. There have also been breakthroughs in harvesting techniques, such as how to remove the algae very efficiently from the system, and in the extraction process, such as how to efficiently, economically, and scale-ably remove the oil.

Without focusing on working on a commercial scale, there are a number of problems that would not appear until a company tries to scale up production and operate these processes both at scale and for very long periods of time. The lessons learned from commercial groups such as Sapphire Energy then feed back to the biological algae research at UCSD and other academic partners.

All of the work of improving the unit processes at the Sapphire Energy pilot facility and to ultimately make this a full commercial facility was made possible by a joint reward of $100 million from the USDA/DOE. Hundreds of millions of dollars in capital investment from both the private and pubic sectors is required to create full-scale commercial facilities capable of producing thousands to tens of thousands of barrels a day. A nominal date by which to operate a scale facility may be in 2018.

Resource Recovery and Recycling

David Hazlebeck, General Atomics

General Atomics, with funding from the Defense Advanced Research Projects Agency, started a project to develop a large commercial demonstration site with the goal of producing algae fuel at around $1 per gallon. There are many advances from the General Atomics Biofuels project, especially in the area of crop protection. Despite other researchers' views, General Atomics was able to demonstrate a technology with a high efficiency of CO_2 recovery to supply the system. The project was able to demonstrate technology that can recover 70 to 80% of the CO_2 in a 4.5% flue gas mix from an adjacent power plant in Lihue, Kauai.

The companies pushing forward in algal fuels seem to be a bit ahead of the basic science, but there are still many, many issues that need to be addressed at the basic science level (e.g. some bacterial presence is good for algal growth from empirical evidence, but not yet understood at the microbial level.)

Waste to Energy Using Algae

Tryg Lundquist, Cal Poly San Luis Obispo

Algae, wastewater, and energy intersect in three ways: in producing biofuel feedstock, wastewater can be imported to an algae farm to provide nutrients and water. Algae biofuel production itself creates wastewaters, which, to improve economics and sustainability, must be recycled into more algae production. Finally, wastewater treatment facilities that use algae can have much lower cost and electricity use compared to those using conventional treatment technologies.

The interdisciplinary Algae Technologies Group at Cal Poly State University, San Luis Obispo, conducts research at lab, pilot, and full-scale to improve the performance of algae biofuel and wastewater treatment processes. Algae production for human and animal consumption is an additional activity. Cal Poly is currently engaged in Department of Energy and California Energy Commission projects to demonstrate water and nutrient recycling at its pilot facility, which has nine 30-m^2 raceway ponds and algae settling units.

Need for Cross-sector Collaboration

Greg Mitchell, Scripps Institution of Oceanography

Originally launched in 2009 as the San Diego Center for Algae Biotechnology (SD-CAB), the California Center for Algae Biotechnology (Cal-CAB) has recently expanded to capture top researchers and industry leaders from across California to collaborate on algae biotechnology projects. Cal-CAB currently has a very diverse support group of federal funding, state funding, and a number of industrial and private sector collaborations, but California still needs to create "clusters of excellence" – large centers where academia, government, and industry work together. There can be some proprietary work, but there needs to be transparency as far as sustainability and releasing life cycle analyses (LCA) to inform the public on these matters. In comparison, the terrestrial crops have extensive agriculture research facilities that link industry and university. Algae research needs these as well. Universities are not industry, but industry needs universities' primary product: educated, well-trained humans. It will require several years and additional funding, but these centers should include the correct academic programs and infrastructure to inform public and policy decisions.

One challenge is the integration of engineering principles with biological principles. It is critical to find people who can set a vision and get both sides to buy in - someone with both backgrounds who can establish and maintain continuous collaboration. It is also important to have top minds from the different disciplines, and then a third, interdisciplinary person who can assist in cross-fertilizing the ideas.

Another concern is the use of GMOs, but there is a lot of biotechnology that can be deployed without requiring GMO regulations, such as breeding technologies, large DNA recombination, proto-plasting, mutagenesis, and directed evolution that does not involve recombination with a trans gene.

2. Biomass to Large Molecule Sustainable Fuels

Jatropha: a Source for Biofuel

Brian Brokowski, SG Biofuels

A recent study by University of Illinois estimates that worldwide, there are 2.5 billion acres of underutilized land that could be used for growing energy products, without displacing food crops. SG Biofuels sees an opportunity for energy crops to be part of the portfolio, especially in some key regional areas of the world. In India and Brazil, researchers speak of Jatropha the way researchers in San Diego talk about algae. Jatropha is non-edible, grows on non-arable land and has seeds with large quantities of high quality oil. This oil is useful as drop-in biofuel. Jatropha needs water, and SG Biofuels is seeking rain-fed water as a major source. SG Biofuels began to produce high-performing, profitable strains of Jatropha, and the 25000A site in Guatemala is expected to generate high quality oil at $99 per barrel. Current efforts focus on the process of identifying specific DNA markers associated with certain key traits (higher oil, more fruit clusters, soil adaptations) and any of the other plant characteristics that drive yield and reduce input costs.

The aviation industry is very interested in bio-jet fuel. Lufthansa had several hundred test flights this past year and are looking for these types of alternatives.

Cellulosic Biomass Gasification

Richard Herz, UC San Diego

Cellulosic biomass gasification is a combustion process that creates producer gas, which can be burned in engines directly for electricity, can be used in the synthesis of alcohols, or used to produce diesel and other liquid fuels. The cleaned up gas, called syngas, is composed primarily of CO and hydrogen. A critical step remains for the clean-up of the produced gas (process of reforming). It is necessary to remove high-molecular-weight hydrocarbons, the tars, and other impurities. The goal for commercial facilities is to minimize input, waste, and energy consumption for a given output. The biomass crude decomposition of CO and hydrogen can be used in wide variety of feedstocks, and syngas is a drop-in fuel.

Dr. Richard Herz, a researcher at UC San Diego, is working with a pilot plant facility located in Woodland, CA that is a dual-bed gasifier aimed at converting biomass to synthetic gas.

Dr. Herz is also involved in another project, which is solar thermo-chemical hydrogen production through solar-driven hydrolysis. This involves a field of mirrors that focus solar energy on a tower. The collected thermal solar energy is then carried through a number of chemical reactions. Essentially the material feed is water as input, and hydrogen and oxygen as outputs.

Bio-Butanol Production and Electro-Bioreactor Experimentation

James Liao, UC Los Angeles

Five to six years ago, James Liao's lab wanted to produce fuel that was slightly more advanced than ethanol. They focused on amino acid biosynthesis pathways and shunting the pathways to produce alcohols such as bio-butanol.

Their current focus is trying to bypass lignin-cellulose altogether. They are using genetically-engineered Cyanobacteria to produce iso- and other branched butanols. These alcohols easily diffuse through membranes for direct collection.

The Liao lab engineered *Rastonia eutropha* to produce alternative electro-fuels (isobutanol, 2 methyl 1butanol) by putting electricity from the grid or solar panel into an electro-bioreactor. This prototype electro-bioreactor can not only produce fuel, but can also be used as a storage form of electricity (converting electrical energy to chemical energy). At a large scale, the processes under consideration generate tremendous amounts of biomass (protein) as byproduct, but not all of the proteins are edible.

3. Government Policies and Regulations

Creating a Favorable Regulatory Environment in California

Tim Zenk, Sapphire Energy

Sapphire Energy chose to build its pilot site and first commercial facility in New Mexico because the regulatory environment in the State of California is not conducive to establishing commercial entities. New Mexico has an expedited regulatory process and a governor and elected officials that are interested in our business. The law that establishes our ability to develop clean energy systems favors alcohols and other low-carbon tailpipe emissions, and the California Air Resource Board abandoned use of LCAs in their assessment of alternative fuel projects. It is really the totality of issues to build, permit, and then to sell fuels into the market that really restricts the ability for new entrepreneurs/small companies to locate a facility in California.

One possible solution is pre-permitting, creating a favorable economic zone, and working with a group to file the permits so that a company could come in and simply occupy a footprint. For large projects that need a lot of resources, California needs someone to streamline and coordinate the process. There is a very cooperative executive structure in New Mexico, and an executive policy team that comes together and works out these permitting issues ahead of time. There is a lack of coordination in the State of California that results in an inability for a company with the size and goals like Sapphire Energy to see its way through a timely process.

There are some overarching issues in the California Environmental Quality Act (CEQA) that are insurmountable for small companies. California has all the potential and all the resources. If the state hopes to achieve the GHG objectives, we have to build some energy projects in California. It's not possible to meet the GHG goals by electrification alone.

Focus and Challenges of the California Energy Commission

Tim Olson, California Energy Commission

There are three functions that the CEC conducts: 1) it provides incentives for alternative/renewable fuels vehicle infrastructure development and takes a poly-fuel approach. 2) It funds research and development to accelerate technology advancement. 3) It evaluates deployment progress, economics, and policies; forecast fuel demand and prices; and assess supply scenarios.

The challenges for California to focus on are: 1) Do existing policies/programs provide sustainable guidance and support? 2) Does government, industry, and private investment have a good understanding of how and when advanced biofuel projects will achieve commercial-scale production? 3) How can government funds/programs be configured to make a difference?

There is an effort to stimulate in-state biofuel development, and at blending levels of E10-E15, California would need 15 to 25 bio-refineries producing 50 million gallons annually. The CEC is funneling $91 million into pre-development projects, which suggests a range of $3 to 4 billion capital investment that is needed.

One other point to consider: the CEC research and development funds are facing continual reauthorization challenges regarding funding sources. Some of this funding was based on an electricity and natural gas surtax, which was recently not reauthorized. The Public Utility Commission (PUC) stepped in and offered a short-term source of funds, but biofuels are not high on the PUC agenda. Their main concern is with rate payer benefits.

California Biofuel Projects Investments

Bill Kinney, California Energy Commission

Some of California's key policy objectives are to reduce GHG emissions, reduce petroleum use and replace it with alternative and renewable fuel, and increase in-state biofuel production. Biofuel investment in California is about $20 million a year. The CEC is looking for projects with a clear path to competitive commercialization and deployment of production facilities through technology transformation, market penetration, project readiness and implementation plans, budget efficiency, sustainability, and consideration of global and local economic impact. LCAs of biofuel production are also reviewed when funding requests are received. 40% of the funding is for demonstration scale projects, and 30 to 40% is for small-scale commercial projects. The CEC believes California needs a mix of small, locally-based, competitive businesses as well as larger companies.

California has a byzantine structure as far as CEQA approval, because typically it tends to be a local agency. This creates a patchwork of inconsistency across different jurisdictions. The governor is supportive of streamlining the CEQA process, and the CEC is working to have the Low-Carbon Fuel Standard (LCFS) credits in place to further subsidize their alternative fuel companies/projects production.

Government's Role in Developing a California Biofuel Industry

Brian Bilbray, U.S. House of Representatives

Next generation green fuels can really be a teaching moment for California. There has always been an adversarial approach between the business and environmental movements, but there is a chance for both sides to work together. California needs next generation government; it needs to move away from the concept of the government as only a body to mandate and subsidize.

Assembly Bill 32 (AB32) exemption from CEQA exists. Fast track exemptions and waivers need to happen with green fuels. The government has to be aware of its own assets and act as participants in finding solutions. The federal government has massive lands available, and it need to make public lands open to federal green fuel reserves. The Imperial Valley has huge areas of federal land open to recreational vehicles but not to energy.

The Clean Water, Clean Air and Endangered Species Acts can be pre-permitted. Homestead waivers for farmers should be available and the government can provide or lease public lands for those who are willing to come forward and offer solutions. The government has to be a working partner, rather than a governance body that dictates, stops, and regulates.

4. Resource Requirements

Diverse Portfolio of Fuel and Technologies for the Transportation Sector

Anthony Eggert, UC Davis

With respect to permitting, the Energy Commission in 2010 was successful in permitting 4000MW of solar power – some on federal lands – and this was only possible because of a partnership between the state, the federal government, the local government, and the companies.

The latest estimates are that California will be spending $70 to 100 billion in liquid transportation fuels (LTF), and it is on the order of several billion dollars of investment that will be needed to hit the mark of 3 billion gallons of low-carbon fuels expected by 2020 under AB32.

With regard to climate change, the transportation sector represents 40% of the carbon footprint. With the recent adoption of state GHG and now federal mpg levels, the efficiency of conversion for passenger vehicles would be a doubling of fueling economy by 2025. Research supports that a portfolio of fuels and technologies in the market place is needed, with both an increase in the need for electrification and alternative fuels for all transportation modes.

The challenge for the transportation fuels sector includes addressing environmental performance of the different LTF options, finding a credible path for cost-effective, low-carbon alternatives, and identifying barriers to increasing the science and technology. There is a wide diversity of potential pathways and alternative fuel options, and LCA provides a tool to bring the science together with the policy.

Biofuel Production at the Salton Sea

Barry Toyonaga, Kent Biofuels

There are 900 acres at the North end of the Salton Sea. It's an ideal spot to be growing biomass using brackish water because there is so much water in that agricultural area. The unemployment rate is massive there, and Kent Biofuels wishes it could use that land more productively to clean the water, grow biomass, and create local employment.

Using technology developed to clean water and recycle nutrients during fish production, Kent Biofuels wants to use the 900 acres of land to treat waste. It can run landfill leachate through its algae process and end up with an effluent that is surface-discharge quality by Environmental Protection Agency (EPA) standards.

Standardized Life Cycle Analysis System for Biofuels

Sonia Yeh, UC Davis

Because of our reliance on fossil fuels, we have very limited experience and knowledge of how sustainable, cost-effective, and impactful alternative fuels are. We need to have a better understanding of how robust LCA conclusions/understanding/assumptions are across different system boundaries and timescale considerations.

Based on current scientific publications, there is a lot of negative discussion that biofuels will add to the depletion of water resources, increase the Gulf of Mexico Dead Zone, and have indirect land use changes, but displacement of fossil fuels entirely with renewable energy at the transformative system scale may have an overall very positive global impact. It's important to be looking at these large-scale impacts in a systematic and consistent manner.

In order to design the entire sustainability standard system, it is necessary to establish the principle criteria, the validation and certification system, a chain of custody from production/extraction to consumer delivery, and a benchmark system so standards are consistent and comparable.

Need for Transparency with Life Cycle Analyses

Jamie Rhodes

Using the LCA approach allows a number of opportunities for improving the environmental performance of the systems already in place or for ones we wish to develop. The challenges with using LCA are that there are a wide set of LCA methodologies to choose from, and there are many assumptions that are part of an LCA. The LCA system should be transparent, and it is important to be able to critically evaluate these LCA assumptions in an open discussion. Most of the information we need to understand, the implications of these different systems, especially new technologies, are held in the private sector, and all the incentives exist to keep these processes proprietary. A number of different organizations are increasing their desire to make the information more accessible and more open to public criticism, to see if this is really advancing the objectives and allowing existing incentive programs to be supportive, or if this new technology warrants building new initiatives, such as setting up pre-permitted industrial parks and streamlining the permitting process.

Using Waste Water for Algae Biomass Production

Jonathan Trent, UC Santa Cruz

Algae has emerged as a potentially important contributor to solving some of the very significant global problems associated with fossil fuels, and the key is growing algae at super-large scale. A recent paper by Tryg Lundquist and John Benemann concluded that waste water would be necessary to grow algae at a large scale, so it is necessary to focus on waste treatment locations. It is also important to consider how much energy can be used from the cultivated algal biomass. In California, 20% of the energy goes to moving water for agriculture. It would require huge amounts of land space to treat the supply of wastewater, so the Offshore Membrane Enclosures for Growing Algae (OMEGA) project is looking at putting photo bioreactors out at sea where nutrient-rich waste water is already being pumped. Researchers studied the trace elements that are in the wastewater and found that algae are very effective at eliminating some of the pharmaceutical compounds and personal care products.

However, the LCA and techno-economic analysis based on fuel production indicated that OMEGA isn't economically feasible. Researchers have been exploring other options that utilize the OMEGA infrastructure as a place for solar panels, wind energy, and wave energy to establish an integrated aquaculture system.

The limiting resource to advancing the field right now is commitment. We are contributing a paltry sum of investment. We are trying to replace a $5 trillion fossil fuel industry. If we were serious about replacing fossil fuels, whether it is for environmental, social, or national security implications, we would be mobilizing. As James Hansen says, if we were really serious, we should have austerity measures in place. The major resource we are missing is a really serious, national commitment.

Conclusion

Stephen Mayfield, UC San Diego

This Initiative was launched by the CEC in 2011, and I am pleased to report that its output has exceeded my original expectations of what I initially thought might be possible. In the short time that CILMSF has been operational, the Institute's researchers and students have generated over 30 published articles and patents, with a number of others currently under review or awaiting publication. The topics of these papers range from metabolic engineering of algae for altered fatty acid (fuel) accumulation, to crop protection and co-product production – all important foci critical to helping advanced alternative transportation fuels become economically viable. These publications demonstrate the rapid progress being made toward environmentally and economically sustainable drop-in fuels produced from algae, and represent research accomplishments of which the CEC can be proud. The spin-off technologies from these discoveries can also help to create additional high-paying jobs in California in a sustainable and environmentally friendly manner, further demonstrating how public funds can be leveraged to support this important work. This research productivity also demonstrates the potential of algae as a viable commercial-scale alternative fuel feedstock, and highlights the need for sustained efforts to help bring it from the research and development phase into the commercial phase here in California, in economically impacted places that are ripe for this kind of large-scale agricultural development, such as the Imperial Valley and San Joaquin Valley.

My optimistic perspective on algal biotechnology and the potential of algae to provide low-carbon alternative transportation fuels for California may be unsurprising, but this is hardly some thinly veiled parochial effort to sustain some individually biased viewpoint. This perspective is grounded in peer-reviewed scientific achievements, enabled by the research, which the State of California has helped to generate. It may well be that at some point new feedstocks, in addition to algae, emerge with equal or even greater promise to create the volumes of drop-in, low-carbon fuel that will be required for California to meet its legally mandated targets. However, until such time as new research identifies such feedstocks, I would respectfully continue to argue that it is critical for the State in the near term to look carefully at how it intends to allocate its precious research resources to achieving the volumes of alternative transportation fuels and related greenhouse gas emissions that the State is mandated to deliver.

To this end, I am increasingly concerned that the State has not yet focused in such a manner, and is instead continuing to provide support and generate expectation for non-scalable alternative fuels – i.e. the funding of multiple small awards for first-generation technologies that may indeed be able to produce low-carbon fuels, but which lack any meaningful commercial-scale potential. This is not to be critical of these awards or technologies; my colleagues and I at SD-CAB have long championed the concept of a "silver buckshot," meaning many small solutions that ultimately add up to a significant contribution. However, California is at a point where it is critical to consider allocation of future research and development resources in a more focused manner, and to projects that have the potential to reach – and relatively soon – a scale of production that can have a meaningful impact on California's mandated alternative fuel production targets and GHG reductions. In the absence of such a focused effort, California risks fostering various "one off" type projects in which there may be some marginal benefit, but not realistic and viable commercial-scale potential, whether because of insurmountable technological, resource, or fundamental capital limitations. Such projects will require continued (and considerable) public support in order to operate, and even then will never achieve the scale required to meet these goals. Under the LCFS, California is required to produce about 4 billion gallons of low-carbon fuel, with at least 50% GHG reduction by 2020; that is only seven years away, and will require production of 11 million gallons of low-carbon fuels per day. California leads the world as a direct result of the innovations and inventions made here, and biofuel deployment at the scale required under the LCFS will only be achieved after these innovations and inventions have reduced the price of low-carbon fuels to a level that competes with current fossil fuel costs.

It is perhaps a difficult conversation to initiate, but developing a roadmap that looks forward in a critical and analytical manner requires it; continuing to subsidize currently non-competitive low-carbon fuels will neither promote the required innovation to make low-carbon fuels cost competitive, nor will they provide even a fraction of a percent of the low-carbon fuels which California is mandated to deliver in just seven years. If cost-competitive low-carbon fuels can be realized, the commercial sector will rapidly invest the tens of billions of dollars required to generate production of the 10 million gallons per day we need. Without such cost-competitive fuels, few if any significant commercial investments will be made, and California will be forced to either revisit or reconsider the LCFS, or will be required to invest billions of dollars in public funds to make low-carbon fuels that are not economically competitive, and will therefore require addition subsidies in order to be sold. This approach is neither environmentally nor economically sustainable. Supporting job growth and reducing greenhouse gas emissions by making low-carbon fuels economically viable is the ONLY sensible route to meeting California's LCFS targets. Any investment strategy that does not focus on this hard reality will neither meet the mandated targets, nor provide a sound return on the taxpayers' investment.

My perspective as director of the California Initiative for Large Molecule Sustainable Fuels – and one that is shared by the vast majority of my industry and academic colleagues – is that California has before it a unique opportunity to catalyze an industry by encouraging the development and deployment of algae biotechnology within its borders. We have already seen the research side of this equation result in a meaningful economic impact in the San Diego region alone (see attached 2011 letter from SANDAG). If successfully deployed at commercial scale, these technologies will also generate a significant number of well-paying jobs for the regional and state economy, in addition to helping to meet GHG reduction targets, and mitigating other environmental challenges. Algae are a proven feedstock for drop-in alternative transportation fuels, and large-scale commercial production of algae is underway in Texas, New Mexico, and elsewhere. We have already seen a major refiner (Tesoro) enter into a deal with one of the leading producers of algae (Sapphire Energy) to purchase green crude for refining and distribution into Tesoro's existing commercial supply infrastructure.

Once these production enterprises take root and become more robust, the likelihood of similar economic engines emerging within California becomes far less likely. If California can create an environment in which industry is incentivized to consider in-state production, in places like the Imperial Valley, the long-term economic and environmental benefits could be significant. However, time is a factor, and the window is narrowing; the market will demand commercial-scale production of algae-based alternative transportation fuels, and the question is just where it will occur, and who will reap the economic benefits. It is my continued privilege to work hand in glove with the CEC in the context of this initiative to help California continue its leadership on this front, and I hope this roadmap helps to chart a mutual path forward to continued successes.