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Algal Biofuels Research, Development, and Commercialization Priorities: A Commercial Economics Perspective

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Algal biofuels have enormous potential and offer a breakthrough solution to both energy security and global warming concerns. With significant amounts of venture capital, private equity funds, and human talent having been allocated to numerous algae start-ups/developments, the race is now on to develop the first commercial-scale algal biofuels production system that can generate substantial investor returns and create a new transportation fuel infrastructure model. Technical maturity and commercial viability of algal biofuels is a much debated topic, with estimates ranging from three years to (multiple) decades. However, most people involved in this emerging technology area agree that algal biofuel commercial economics are extremely challenging, highly variable, and subject to dynamic, speculative, and volatile commodity markets. Therefore, understanding and addressing algal biofuel economic drivers is equally as important as maturing growth, harvesting, and conversion technologies.

On June 3, 2009, the U.S. Department of Energy (DOE) released a Request for Information (RFI) that solicits comments to a draft version of DOE's "National Algal Biofuels Technology Roadmap," which provides a framework for qualifying and prioritizing algae technology development objectives. The release of DOE's draft roadmap and renewed government interest in further developing commercial algal biofuels technology has motivated Diversified Energy to share results from a comprehensive body of work associated with algal biofuels economics, with the intent of advancing algae commercial feasibility conversations and focusing development resources on critical commercialization parameters. Over a two-year period, an exhaustive technical, engineering, cost, and economic model was constructed, reviewed, and matured to provide a realistic baseline assessment of algal biofuel economics and the cost drivers associated with commercial-scale algae production. Results from this algal biofuels modeling and analysis effort indicate a clear set of economic-driven research and development priorities, which can be summarized as follows:

1) ***Re-focus research and development (R&D) activities towards minimizing operations and maintenance (O&M) costs for algae production systems***
2) ***Emphasize co-product capture and marketability to maximize revenue generation***
3) ***Aggressively develop technologies and processes that significantly improve total algae yields, without dramatically increasing costs***
4) ***Reduce total capital costs, through advanced technology, of algae production and harvesting***

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While this summary set of priorities may not be revolutionary to people in the algal biofuels business, details supporting these recommended priorities are quite enlightening and provide an in-depth framework for prioritizing research, development, and commercialization initiatives. A comprehensive discussion of the model results is provided below, following a brief description of the model used to perform the commercial economic analysis.

The economic model created for this analysis includes more than 50 independent variables supported by detailed engineering specifications, commodity market data, and vendor quotes for equipment costs. The model is based on a generic baseline algae growth system and is not specific to any particular technology. It is recognized that these analysis results could vary depending on the growth architecture selected and assumptions for algae productivity. However, the general trends and economic/commercialization drivers presented here will apply to virtually any algae production system and the overall research, development, and commercialization priorities are applicable to the broader algal biofuels community. Finally, details of this analysis have been consolidated and simplified into graphical form in order to convey key points and provide support for the suggested R&D and commercialization priorities. The accompanying graphic (**Figure 1**) illustrates a summary of the model results, which are used to justify the following set of algal biofuels development recommendations.

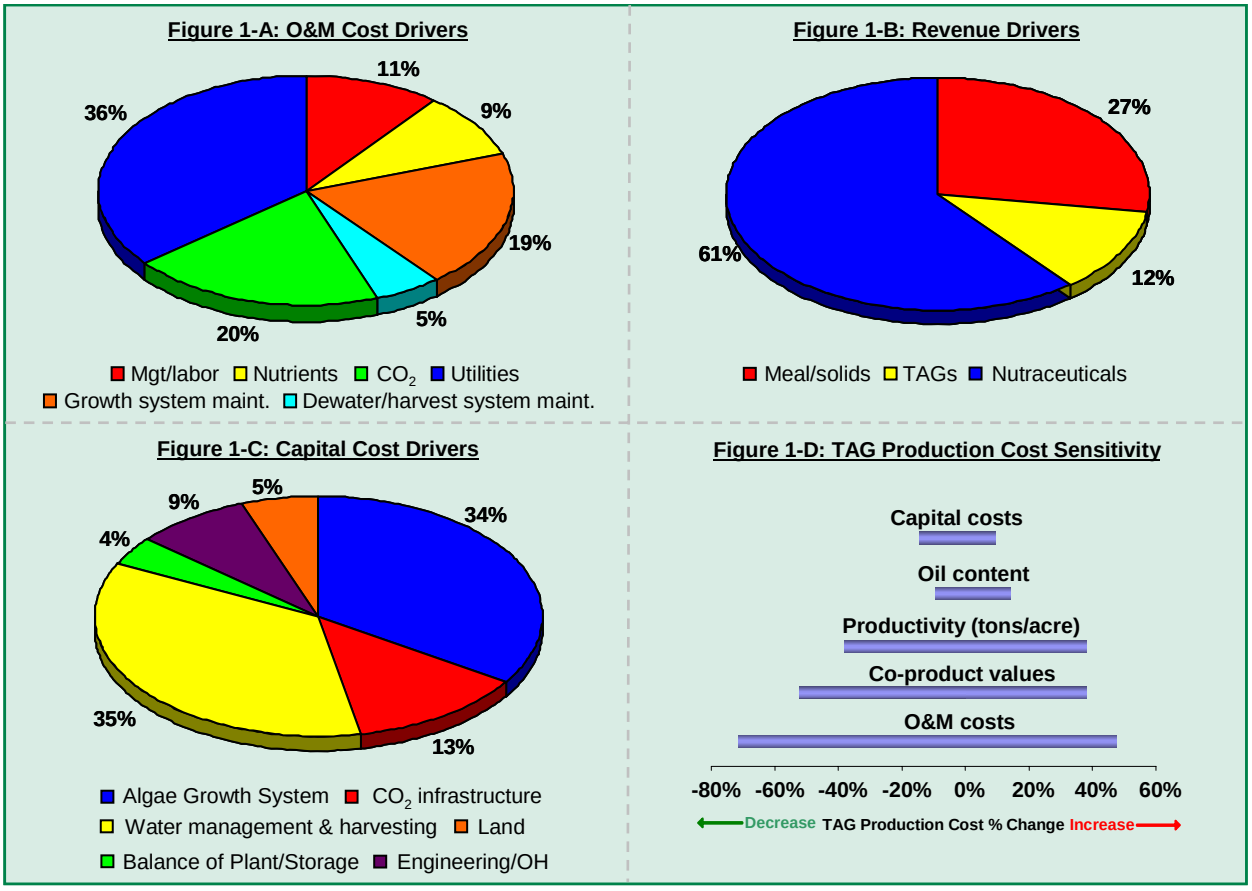

Figure 1: Algal Biofuels Economic Drivers Should Shape Research, Development, and Commercialization Priorities

<u>Priority #1:</u> Re-focus research and development (R&D) activities towards minimizing operations and maintenance (O&M) costs for algae production systems

O&M costs include all expenses required to operate the algal biofuels system on an annual basis. **Figure 1-A** shows a consolidated set of O&M cost drivers and clearly indicates that utilities (electricity, water, etc.), CO_2, maintenance of the algae growth system, labor, and nutrients have the greatest influence on operations costs. Given that most algal biofuels O&M discussions center around CO_2 access and nutrient availability, it was surprising that utility costs accounted for more than $1/3^{rd}$ of total O&M expenses. However, when considering the amount of energy required to transport, handle, and process extremely large volumes of water and biomass material, along with considerable evaporative water losses, it becomes apparent why utilities are a significant cost driver. The cost of CO_2 for this analysis assumes that CO_2 must be purchased for the algal biofuels commercial system, which may or may not be the case depending on project location strategies. Therefore, the following research, development, and commercialization priorities suggested include:

- *Algal biofuels growth, harvesting (includes oil extraction), system architectures, and processes should be developed and matured in a way that minimizes the amount of energy (electricity, etc.) and water required for nominal operations*
- *Technologies should be developed and policies implemented that reduce/eliminate the cost of CO_2 for algal biofuel systems*
- *Algal biofuel technologies should be designed in such a way that maximizes lifetime/longevity and minimizes annual maintenance requirements*

<u>Priority #2:</u> Emphasize co-product capture and marketability to maximize revenue generation

One of the most enlightening discoveries from the modeling and analysis conducted was the realization that triacylglycerols (TAGs) for biofuel production represent a relatively small portion of algae-related revenue opportunities (see **Figure 1-B**). The model assumed an algae strain with an oil/TAG content of 20% and a nutraceutical content of 2%. Granted, claims have been made that several algae strains and production techniques (stressing, etc.) may result in 50% or better oil yields. However, the fact still remains that 50% - 80% of the material produced in an algal biofuels system will be something other than oils used for biofuel conversion. For this analysis, these other materials were categorized as either meals/solids or nutraceuticals. While nutraceutical content in the baseline algae strain is very small, current market values for these products are extremely high and, as illustrated, can have a dramatic impact on overall project economics, although the risk of market saturation and depreciating product values exists when considering large-scale algal biofuels production. It is also worth noting that not all algae strains contain nutraceuticals and may not have the revenue opportunities presented here. Nevertheless, realization of these algae revenue drivers resulted in the following research, development, and commercialization priorities:

- *Harvesting and oil extraction technologies need to focus on highly efficient separation and capture of all valuable algae materials, while minimizing energy and capital costs*

– *Co-product markets must be rigorously analyzed on a regional, national, and international basis to assess the feasibility of realizing revenue opportunities for meals/solids and nutraceuticals*

***Priority #3:* Aggressively develop technologies and processes that significantly improve total algae yields, without dramatically increasing costs**

This research, development, and commercialization priority is straight forward and requires no detailed explanation. If the same unit area can produce 2 – 3 times the algae, assuming that productivity and capital/O&M correlations are less than linear, then total project economics improve. Algae yield is a major project economics sensitivity variable and technologies that efficiently increase algae production yields should be aggressively developed and matured.

***Priority #4:* Reduce total capital costs, through advanced technology, of algae production and harvesting**

Capital costs for an algal biofuels production system are a major commercial viability concern. Estimates for algae system capital costs vary wildly, with ranges of $10k per acre to $100k's per acre installed. The goal of this analysis was to quantify total capital cost drivers for a baseline algae production system in order to focus technology development priorities in areas that would have the greatest impact. **Figure 1-C** illustrates the capital cost drivers for the baseline system and it is very clear that the algae growth system, water management/harvesting/extraction, and CO_2 delivery infrastructure have the greatest capital cost impact. As a result of this capital cost analysis, the following research, development, and commercialization priorities are suggested:

– *Focus R&D resources on algae growth system architectures that require minimal capital cost expenditures*
– *Develop water management, dewatering, harvesting/extraction processes and technologies that require minimum infrastructure*
– *Mature low-cost CO_2 delivery systems or implement policy to provide incentives, grants, loan guarantees, etc. that will reduce or eliminate CO_2 infrastructure costs*

The analysis model also includes a commercial project economics component that allows for commercial viability assessments based on capital, O&M, and revenue variables. Using a Net Present Value (NPV) discounted cash flow approach (including debt/equity ratios and rates, taxes, terminal value, depreciation, etc.), analysis was performed to determine the sensitivity of algal oil (TAGs) production costs as a function of changes to five critical commercial system parameters. A summary of this sensitivity analysis is provided in **Figure 1-D**, which clearly illustrates the relative impacts of O&M costs, co-product values, productivity, oil content, and capital costs on TAG production costs. Results from this sensitivity analysis are consistent with the research, development, and commercialization priorities presented here and reinforce the need to focus on algal biofuels economic drivers in order to realize commercialization objectives.

About Diversified Energy Corporation: Headquartered in Gilbert, Arizona (a suburb of Phoenix), Diversified Energy Corporation (www.diversified-energy.com) is a privately held alternative and renewable energy company focused on maturing innovative technologies,

developing commercial energy projects, and providing engineering and economic consulting services to technology/project developers, investors, government agencies, and policy makers. Principal areas of expertise include biofuels, gasification, and algal biomass commercialization.

About the author: Phillip Brown is Diversified Energy's President and Chief Operating Officer. Since starting at Diversified Energy, Mr. Brown has led multiple economic and commercial feasibility studies for a variety of renewable energy technologies including algae production, advanced biofuel conversion, biofuel feedstock market trends and analysis, and next-generation biomass gasification systems. Mr. Brown also manages three technology development projects funded by the Department of Energy, Department of Defense, and the state of California.