ENERGIZE MISSOURI

RENEWABLE ENERGY

Missouri Department of Natural Resources

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Preface

This report was prepared for the Missouri Technology Corporation under a subgrant award to MRIGlobal and entitled "Energize Missouri: Algae-Based Renewable Energy Study" signed by Mr. Jason Hall and dated February 28, 2011. Work was initiated in accordance with a work plan submitted and approved on March 11, 2011. The project team includes members from MRIGlobal, Washington University in Saint Louis, and the University of Missouri, Columbia.

The objective of the grant is to produce a study to help define the development and commercialization of algae as a fuel source that would be a valuable adjunct to the state energy plan. The study would emphasize the potential benefits to the state economy that a commercial algae industry could bring, opportunities for Missouri to become a leader in such an industry, and the policy steps and collaborations that the state could initiate to strengthen Missouri's leadership in this area. The study is divided into seven (7) tasks plus a final report. This report is the final report which summarizes our conclusions and recommendations for Missouri to maintain its role in algae biofuels. Greater technical details and full citations for the items discussed here are found in the Task Reports.

This Final Report study was authored by Thomas Grant of MRIGlobal as Principal Investigator and the author wishes to acknowledge the contributions of all the members of the study team:

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Section 1. Introduction

1.1 Background

This report results from a study sponsored by the Missouri Technology Corporation (MTC) entitled "Energize Missouri: Algae-Based Renewable Energy Study." The study produced seven (7) task reports as follows:

A. Assess the potential for algal biofuels to help meet the energy needs of Missouri and the United States.

B. Identify and document Missouri's algal biofuels research, resource, and industrial assets.

C. Compare Missouri's algal biofuels research, resource, and industrial assets to those of other states and countries to examine Missouri's competitive advantages, and to identify areas where greater efforts are needed.

D. Identify opportunities for Missouri to be a leader in supplying products and services to implement commercially viable production systems for algal biofuels.

E. Identify technical, regulatory, and fiscal challenges that prevent or hinder broad implementation of algal biofuels production systems.

F. Recommend strategic policy initiatives that Missouri could pursue to advance the large-scale implementation of algal biofuels systems.

G. Identify and recommend opportunities for Missouri to collaborate with other states and countries that have algal research, commercialization, and production expertise.

This Final Report is based on the results and findings of the completed Task Reports, and it presents the recommendations and conclusions of the study team.

1.2 Biofuels

Petroleum-based fuels account for 38 percent of the overall U.S. Energy consumption, and there are significant concerns about our continued reliance on these fuels. Currently greater than 50 percent of our petroleum is imported, some from regions of political instability. This importation of large quantities of oil has an effect on our economy, and is generally considered to be unsustainable. Recent events have resulted in large price swings, with a projection of a continued rise in the price of oil. Environmental concerns about the use of fossil fuels have also put the spotlight on oil. In light of economic, supply security, and environmental stressors that come with our reliance on petroleum—especially imported—there is an incentive to find an alternative "drop-in" transportation fuel that is compatible with current vehicle engines and can be blended with existing fuels.

Over a little more than a decade, biomass-based fuels have made great strides in trying to address the problems of petroleum fuels. Encouraged by various government incentives, corn based ethanol in the last 15 years has gone from near zero to over 13 billion gallons a year. Blended with gasoline typically at 10 percent to 15 percent, ethanol is replacing an estimated 8 percent of U.S. gasoline.

Biodiesel is diesel fuel made from the oil or lipids of agriculture products such as vegetable oils, animal fats (tallow) used cooking oils (yellow grease), or oil from algae. Depending on the feedstock, it can be used by itself or blended with petroleum-based diesel requiring no changes in the vehicle engines. Biodiesel from soy and other crops peaked at over 600 million gallons in 2008. Today, biomass is the single largest renewable energy source in the United States. This industry has had a major effect on the economy of the agricultural states involved—especially in the Midwest—creating tens of thousands of jobs and pumping billions of dollars into the local economy. For certain states like Iowa, biofuels is one of the largest industries in the state.

Although successful, the growth of crop biofuels has been contentious for its impact on food and feed prices, combined with the belief that the land use and water requirements would eventually limit the production of these conventional biofuels. The federal government has switched its research emphasis to “advanced biofuels” to include cellulosic-based biomass such as corn stover and switchgrass, waste products, and other non-food crops such as algae. The government continues to encourage biofuels through a variety of tax incentives and mandates. Certain mandates such as the Renewable Fuel Standard require specific goals for advanced biofuels. This has created an R&D industry accompanied by a variety of small and large companies looking for the key that will propel the advanced biofuel market forward.

The tax credits, mandates, and other directives all suggest optimism for an expanding biodiesel market. Indeed, the National Biodiesel Board expects 2011 to be a record year for biodiesel production with average growth of 14 percent per year. The EPA estimated in late 2010 that total biodiesel production capacity in the U.S. was about 2.4 billion gallons per year, although actual production was less than this.

Section 2.
Algae-Based Biofuel

2.1 Algae

Algae, thought of as "pond scum" by the average person, is a large group of diverse simple aquatic organisms that have photosynthetic machinery ultimately derived from Cyanobacteria algae are "simple" in that they do not have the organs and different tissues commonly found in terrestrial plants algae encompass thousands of different strains found worldwide in fresh, salt, and brackish water; each strain has different characteristics and requirements for growth. Typically algae requires a combination of water, light, nutrients, carbon dioxide, and the correct temperature range for the species to grow and reproduce. Algae can be grown in open ponds, covered ponds, closed photobioreactors, or some hybrid system. Each process has advantages and disadvantages along with associated costs.

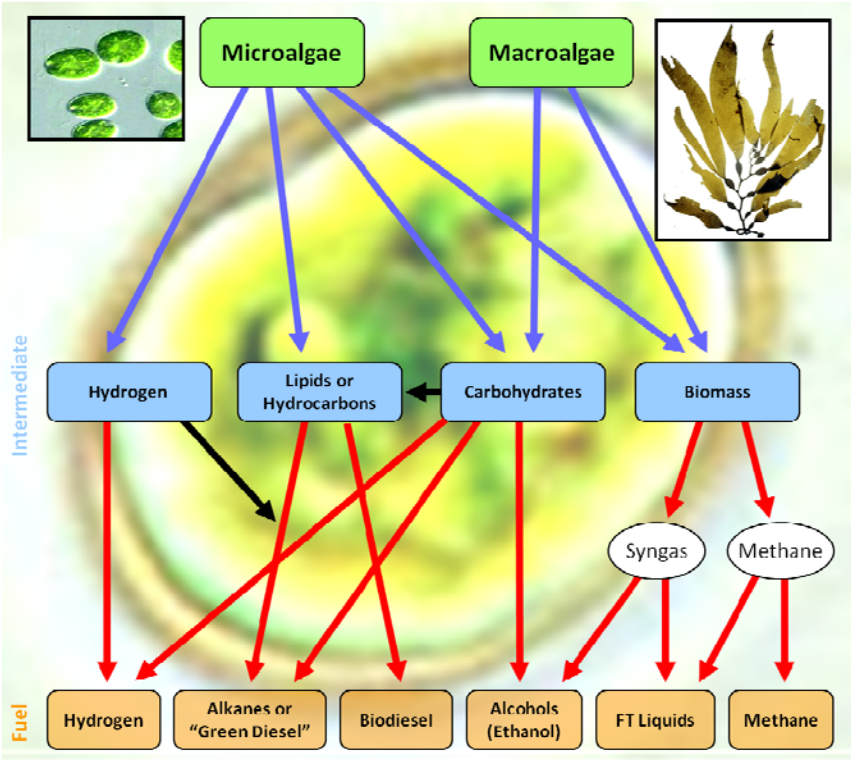


Figure 1. Potential Biofuels Portfolio Using Algae as a Feedstock

Algae are efficient factories capable of taking carbon dioxide and converting it to biomass. The lipid (oil) content of algae biomass, which can be converted into biodiesel, can vary between 5 percent and 50 percent depending on the strain and the growing conditions. The remaining components of the algae are protein, carbohydrates, and smaller amounts of nucleic acids. Figure 1 shows a spectrum of fuels that can be derived from algae, but the biodiesel pathway is the most developed and holds the greatest potential for near term commercialization. In this process, the algal oil can be refined into biodiesel in a manner similar to other vegetable oils in a process called transesterification. Here, a catalyst such as sodium hydroxide is mixed in with an alcohol such as methanol. This creates a biodiesel fuel and a glycerol by-product. The biodiesel is usually blended with petroleum-based diesel to get uniform properties, but can be used by itself.

The main steps in algal biofuels production include: algae strain selection; algae cultivation; harvesting, dewatering, and oil extraction; and conversion of the extracted algal intermediates to biofuels and possibly other co-products. These steps and the key siting, and resource elements are depicted in Figure 2. Each of these steps has an established foundation, but technology innovations are needed to make production viable at the commercial scale. Various types of systems have been proposed to cultivate microalgae, and assessments have been conducted for both photobioreactors and open-pond raceways systems. At this time, there is no clear favorite, but the open-pond raceway configuration is getting the most attention from a demonstration and commercialization perspective. Once grown, the algae must be harvested and dewatered. Approaches to harvesting and dewatering include flocculation and sedimentation, dissolved air flotation, filtration, and centrifugation. Additional drying may be necessary to reduce moisture content suitable for downstream processing. Conventional processes for drying could be energy intensive. Subsequently, the lipids (and other intermediates) must be extracted from the cell. Solvent-based extraction is assisted by microwaves or sonication to rupture the cells. Other novel extraction approaches are being investigated. Next the algal extracts are converted to fuels, and the processes employed necessarily depend on the type(s) of fuels to be produced. In particular, lipids can be converted to biodiesel using chemical transesterification or biochemical, enzymatic conversion. Algal biofuels production is a multi-step process that requires numerous raw materials and energy. This presents the challenge of recovering the investment in capital equipment, supplies, and labor through fuel and byproduct sales.

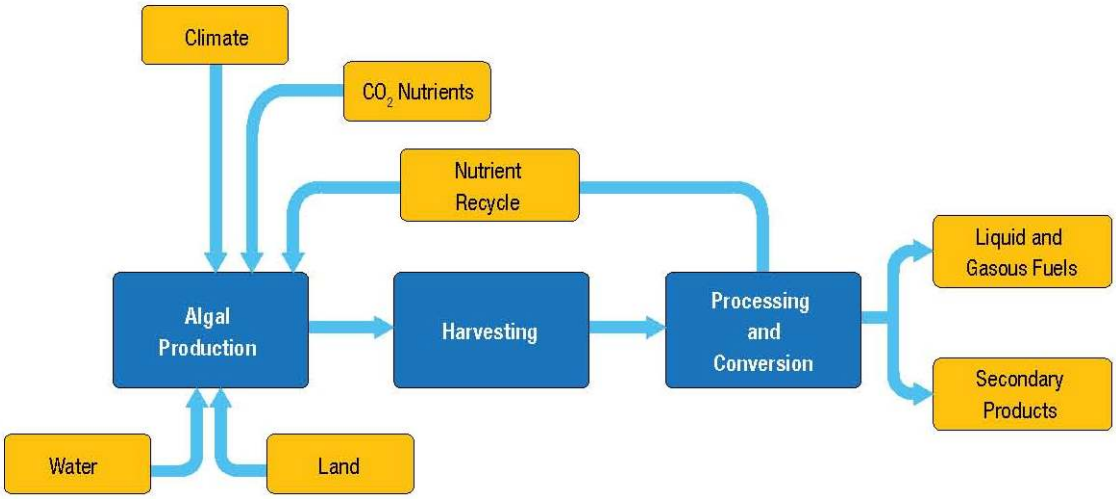


Figure 2. Key Siting and Resource Elements in Algal Biofuel Production (From the DOE National Algal Biofuels Technology Roadmap)

2.2 Advantages of Algae-Based Fuel

Algal feedstocks have been recognized as having unique advantages for the production of advanced biofuels:

- Algae cultivation features high area productivity. Yields of 3,000 gallons of oil per acre could be achievable for algae compared to current yields of fewer than 100 gallons per acre for soy or rapeseed. Land requirements may make algae the only feedstock that has the potential to make significant inroads in the replacement of petroleum.
- Algae production minimizes competition with conventional agriculture. The present focus of government energy policy is for non-food-based biofuels to avoid the food price escalation evident in the corn ethanol enterprise.
- Algae can utilize water from a wide variety of sources, including water of compromised quality, such as waste water or brackish water. It is important that biofuel production does not stress local fresh water supply. In addition, algae can be used to mitigate certain water pollutants.
- Algae can be used to recycle emissions of carbon dioxide from stationary sources such as electric utility power plants. Should carbon emissions be regulated in the future or a carbon tax be imposed, this pathway would have advantages.
- Algae production is compatible with the integrated production of fuels and co-products within biorefineries. As shown above, algae feedstock can be processed in a variety of ways to produce a suite of fuels and chemicals.
- The co-products that can be obtained from the residual algae after the oil has been removed could have a value that significantly affects the economics of the process, and in some cases the value of by-products could exceed the value of the biodiesel. Residual algae biomass can be as much as 50 percent protein, which can be sold as fish food at the lower end and nutraceuticals at the higher end.

Section 3.
The Algae Enterprise

The biofuels industry in general and biodiesel from microalgae in particular, holds significant promise. It is technically feasible, but advances are needed in both the biology and downstream processing to make it commercially viable. Algal biofuel production has not yet been realized on a commercial scale, but relatively large investments are currently being made to address the barriers to commercial viability. Several recent summaries present a relatively optimistic view of the prospects for algal biofuel commercialization both domestically and abroad. One source states that "it is foreseen by the U.S. industry that full commercialization of algae oil will begin to take place in the U.S. in roughly 4 to 5 years. Other projections estimate that it will be at least 10 years for a robust commercial algae biofuel industry to take hold.

An algae industry and market report (Algae 2020 issued by Emerging Markets Online) predicts that the growth of commercial algae production will begin with high value, low volume product markets. These markets are expected to be specialty food additives, healthy oils high in Omega 3, 6 fatty acids, high value animal and fish protein additives, and other nutraceuticals. A few companies have already begun operations in this market, such as Cyanotech, which has 30 acres in Hawaii producing nutritional supplements from algae. As production efficiencies increase and the costs of production go down, products for larger markets, yet lower value will be targeted. The synergism for the algae biofuel industry is clear, and the future of algal biofuel may depend on the value of the byproducts.

There are several companies that have announced plans for demonstration or commercial size algae facilities ranging from 30 to over 200 acres, with a mix of products including biodiesel that could become reality in the next few years depending on the financing. A new industry is slowly being born, and more than 50 companies around the world are developing algal-based processes for biofuel production and other purposes. Table 1 gives a representative sample of U.S. companies involved in the algae enterprise.

Table 1. Representative List of U.S. Companies Active in the Algal Biofuels Industry

Company	Location	Type of activity
Sapphire Energy	San Diego, California	Algal biofuels; 100 acre biorefinery under construction in New Mexico
Synthetic Genomics	San Diego, California	Genomic-driven solutions to develop green crude
General Atomics	San Diego, California	Jet fuel project, pilot scale facility on Kauai
LS9	South San Francisco, California	Fermentation-based technology to produce biofuels from feedstocks such as algae
Solazyme	South San Francisco, California	Manufacturer of algal-derived fuels
Algenol	Bonita Springs, Florida	Focuses on ethanol production from algae
PetroAlgae	Melbourne, Florida	Green diesel, gasoline, and jet fuel from algae
Aquatic Energy	Lake Charles, Louisiana	Biodiesel and byproducts. One acre pilot, planning a 30 acre facility in Louisiana

Table 1. Representative List of Companies Active in the Algal Biofuels Industry (Continued)

Company	Location	Type of activity
BioProcess Algae	Providence, Rhode Island	Designs, manufactures, and operates integrated bioreactor systems for algae production
Cellana (Shell and HR Biopetroleum)	Big Island, Hawaii	6 acre hybrid photobioreactor-pond development and algae, identification on Big Island; planning 217 acres on Maui, but partner Shell has recently withdrawn support
Cyanotech	Big Island, Hawaii	Nutraceuticals, 30 acres in production on Big Island, Hawaii
Martek	Columbia, Maryland (with facilities in Colorado, Kentucky, South Carolina)	Algae fermentation—focused primarily on nutraceuticals including omega-3
Phycal	Cleveland, Ohio	Integrated production system with focus on algal oil. Planning 40 acre facility on Oahu
Phyco Biosciences	Chandler, Arizona	"Super Trough" algae production technology to compete with open pond raceways and photobioreactors
Solix Biosystems	Fort Collins, Colorado	Floating photobioreactors to provide an outdoor growth environment for algae
Virent	Madison, Wisconsin	Plant sugars to biofuels using a variety of feedstocks including algae, investments from Shell and Cargill

The algae enterprise in the U.S. seems to follow regional clusters with groups of companies and/or research institutions in the following geographic areas: St. Louis, San Diego Area, San Francisco Bay Area, and South Florida. Ironically much of the focus on domestic algae production centers on areas outside of the regional R&D clusters. Demonstration or commercial scale algae facilities are planned for the warm climates of Arizona, New Mexico, West Texas, and Hawaii. Most of the planned facilities intend to use salt water on the assumption that fresh water resources are too expensive or not sustainable in these regions. International algae clusters can also be found in: Netherlands, Israel, and South Korea. Israel has been active for many years in the production of nutraceuticals like Astaxanthin from algae.

The algae enterprise may be in its nascent stages, but the interest that both the government and private industry has shown has given it momentum. It is a given that biofuels from algae has a long way to go to a mature market, because prior to achieving commodity level quantities an entire production to refinery to market infrastructure must be created. Infrastructure such as storage bins, silos, collection depots, bulk handling equipment, rail transportation, and oil extraction facilities are needed. This represents an economic opportunity for those entities that are positioned to support the industry as it grows. *Algae 2020*, which has tracked recent announcements in algae biodiesel to develop a rough-sketch scenario of growth in production of algal biofuel, forecasts production increasing from approximately 100,000 gallons in 2010 to over 6 billion gallons in 2025. Including by-product value, this represents a potential $80 billion in annual revenue that would be created in the coming decades.

Section 4.
The Market Challenge

The large-scale market penetration of technological innovations, like algae-based biodiesel fuel, is a high risk venture. Yet, there is almost universal agreement that innovation is critical to economic growth. The commercial success of an innovation is influenced by three interactive forces (1) science and technology (S&T), (2) markets, and (3) policy. The general view of sources consulted for this report is that algae-based renewable energy has a great potential to be a source for biodiesel in the United States, but the S&T is still in its infancy, and significant advances need to be made through research, development, and demonstration (RD&D) activities before it is ready for large-scale diffusion in the liquid fuels market. A variety of market challenges await a new technology as it begins to diffuse into its target market, ranging from human capital challenges involving the installation, operation, and servicing of the innovation; to capital challenges related to funding a start-up company that will manufacture and market the innovation; to technology lock-in challenges that have essentially "institutionalized" the existing technology in the target market. In the case of algae-based biodiesel, two of the biggest market challenges are (1) the price of oil, and (2) the market success of biodiesel fuels.

4.1 The Price of Oil

All markets depend on the price of the alternative. Over the last 20 years, the price of petroleum was remarkably stable through 2004, but has exhibited dramatic fluctuations since that time. In July 2008, it reached a record high on the futures market of $145 per barrel before bottoming out at $30 per barrel less than 6 months later. The price once again rose due to an improved economy driving demand and concern about geopolitical instability in the Middle East. The recent soft economy is somewhat offset by the political instability in Libya. The world price of crude in August 2011, averaged $105 per barrel on the futures market. The Energy Information Administration forecasts that oil prices will continue to be well above historic levels.

Recent price increases and price volatility aside, there are other issues that push the U.S. towards pursuing other energy sources, among them concerns over climate change. While a carbon tax or cap and trade scheme is unlikely in the near future, the EPA is moving forward with attempting to regulate carbon emissions through the Clean Air Act. Furthermore, in the Energy Independence and Security Act of 2007 (EISA) renewable fuel standards have greenhouse gas (GHG) thresholds for what fuels qualify for each category such as advanced biofuels.

4.2 Biofuels Market

Recent trends in domestic consumption of energy from renewable sources are shown in Figure 3. Over the past 6 years domestic consumption of renewable energy has increased by 29 percent and in 2009, accounted for 8 percent of total energy consumption. Biofuels energy consumption was over 300 percent higher in 2009 compared to 2004. Biofuels are an important

segment of the nation's renewable energy portfolio and biofuels consumption has been increasing at a rate much higher than the overall renewable energy portfolio.

While overall biofuels consumption markedly increased over the 2004 to 2009 period, the trends are different for the two key biofuels—ethanol (which is blended into motor gasoline) and biodiesel. Focusing on these two biofuels, which represent virtually all of the biofuels market, ethanol production has steadily increased over the past 6 years and accounts for 98 percent of biofuels production. The historical picture for biodiesel is more complicated. Biodiesel production reached a maximum of 7 percent of overall biofuels production in 2007, and in the past 2 years has decreased in both relative and absolute terms. This trend is consistent with the timing of federal biodiesel tax credits that started in 2005 and expired in 2009, and the timing of a tariff on biodiesel U.S. exports to European Union (EU) countries.

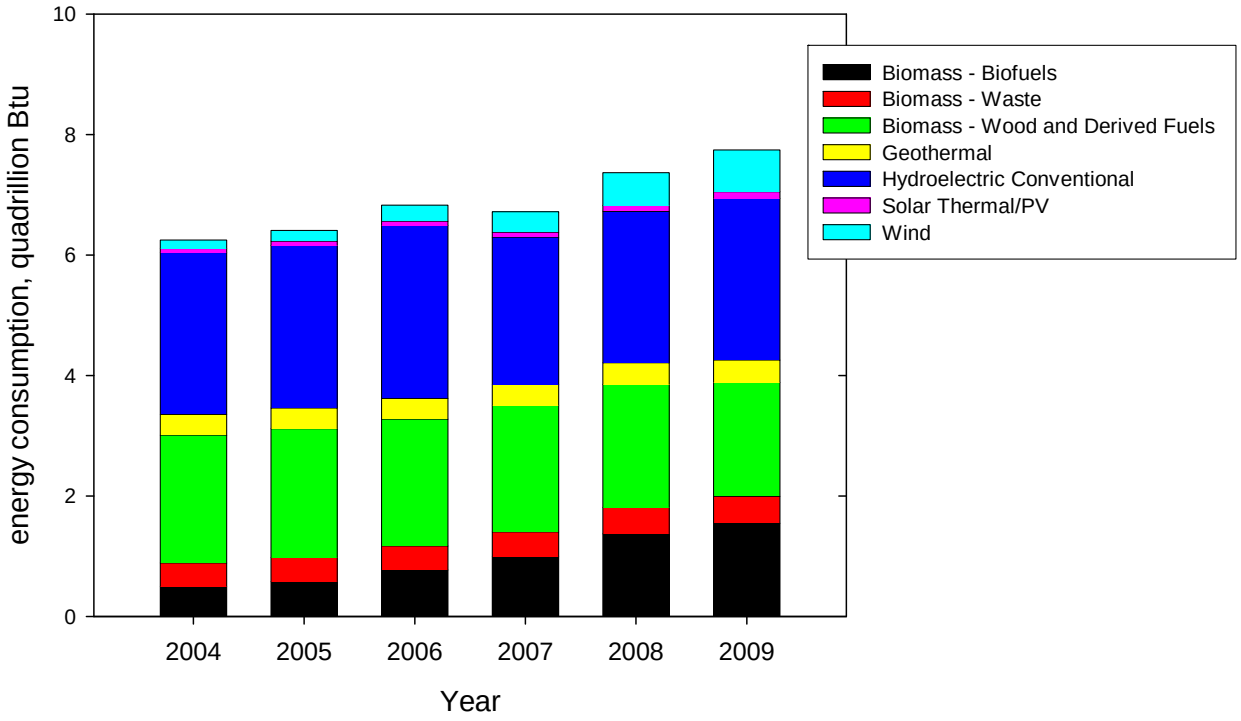


Figure 3. U.S. Annual Energy Consumption From Renewable Energy Sources, 2004 to 2009

Looking father into the future is a more uncertain task. However, the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri-Columbia is a leader in such projections. In 2010 FAPRI published a market outlook through 2020. Key assumptions included the $1/gallon tax credit is extended indefinitely and the RFS2 biomass-based diesel mandate is fixed at 1 billion gallons per year after 2012. Their key conclusions include:

- Biodiesel production will increase to satisfy the RFS2 biomass-based diesel requirements and to help meet the RFS2 advanced biofuels requirements.
- In the out-years there will be modest increases in biodiesel exports, despite the EU tariffs, due to increased biodiesel prices in Europe.

Within the transportation sector 94 percent of the energy demand is provided by petroleum. Alternative transportation fuels such as compressed and liquefied natural gas, electricity, and hydrogen will likely continue to gain market penetration over the next few years, but these technologies affect the motor vehicle gasoline market, and thus the operating space for ethanol, whereas in the U.S. the motor vehicle diesel market, which in 2008 accounted for 24 percent of all vehicle fuels consumed, is largely separate and in the near term will not be strongly influenced by competing vehicle technologies that can use the alternative fuels. From a fuels consumption perspective, the portion of the motor vehicle fleet relying on diesel fuel is unlikely to change in the near term and biodiesel is currently the only viable alternative to petroleum diesel for powering this fleet.

4.3 Federal Tax Policies and Mandates

The biofuels market is also impacted by government mandates, and incentives such as tax credits. Tax credits are used to achieve energy and environmental policy goals by making biofuels economically competitive with petroleum fuels. The American Jobs Creation Act of 2004 provided the first significant federal excise tax credits for biodiesel, which together with agricultural subsidies for soybean crops led to favorable economics for soy-based biodiesel production. The central element of the multi-faceted biodiesel tax credit program was a $1.00 credit per gallon produced and resulted in $840 million of tax expenditures in fiscal year 2009. These credits expired on December 31, 2009, and, along with a tariff on biodiesel exported to Europe, led to production decreases because biodiesel was not competitive with petroleum-based diesel. Biodiesel production from soybean oil decreased while production from other fats and oils remained largely unchanged. Total biodiesel production in 2010 was less than half of that in 2008, so on average current production is well below plant capacity. The Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010, enacted in December 2010, retroactively extended the biodiesel tax credit through December 31, 2011, and is expected to increase domestic biodiesel production.

In addition to tax credits, mandates are important elements of a comprehensive policy to promote the production and use of biofuels. The Energy Independence and Security Act of 2007 (EISA) set requirements for the minimum use of renewable fuels through 2022. EPA enforces the EISA requirements through the Renewable Fuel Standard (RFS) program (RFS2 as amended to satisfy EISA). EISA includes requirements for the minimum consumption of cellulosic biofuels, biomass-based biofuels, advanced biofuels, and total renewable fuels. The biomass-based diesel fuel requirement reaches 1.0 billion gallons in 2012 with requirements in the out-years to be determined annually by EPA rulemaking based on U.S. EIA estimates and an assessment of domestic production capacity, but shall be no less than 1.0 billion gallons per year. The advanced biofuels requirement started at 0.6 billion gallons in 2009 and increases to 21.0 billion gallons in 2022. These credits and mandates will have a direct impact on the algae biodiesel market.

Section 5.
Missouri Assets

Missouri's assets for algal biofuel production are evaluated against the potential roles involved in the enterprise:

1. Serving as a hub for research and development
2. Providing manufacturing and other services supporting the algal biofuel production enterprise
3. Providing the end use refining of the biodiesel product
4. Providing the production space to grow the algae

5.1 Research and Development

A host of Missouri-based institutions are active in addressing research needs in the algal biofuels field. Missouri excels in algae R&D and is one of the two DOE supported algae hubs. Grant funding for algae research led by Missouri institutions exceeds $80M. In fact, Biofuels Digest readers named St. Louis the "King of Algae" in 2009, beating out San Francisco Bay area, Seattle, and San Diego. The list of these institutions and their principal focus areas is given in Table 2. Missouri is also home to the National Biodiesel Board (NBB), a national trade group headquartered in Jefferson City that represents the biodiesel industry. NBB was founded in 1992, by state, soybean commodity groups and has a stated goal of replacing 5 percent of domestic diesel demand with biodiesel by 2015. Given the ongoing importance of agriculture to the state's economy, there is significant research infrastructure in place in the biological, engineering, and economic arenas needed to move the algae biofuels industry forward.

Table 2. Research and Development Activity in Algal-Based Biofuels in the State of Missouri

Institution	Focus	Contact
Danforth Plant Science Center [St. Louis]	National Alliance for Advanced Biofuels and Bioproducts; research and development of genetically optimized algae strains	Dick Sayre, Ph.D.
Lincoln University [Jefferson City]	Field trials of algae cultivation using flue gas from coal-fired power plant	Keesoo Lee, Ph.D.
Missouri University of Science & Technology [Rolla]	Field trials of algae cultivation/harvesting using flue gas from coal-fired power plant	Paul Namm, Ph.D.
MRIGlobal [Kansas City]	Center for Integrated Algal Research—photobioreactor engineering; diversification of output from algal farms; nutrient recycling from WWTPs	Thomas Grant, Ph.D., P.E.
University of Missouri-Columbia [Columbia]	Algal raceway integration with tilapia; Rural Policy Research Institute—Agricultural Economics	Dave Brune, Ph.D. Tom Johnson, Ph.D.

Table 2. Research and Development Activity in Algal-Based Biofuels in the State of Missouri (Continued)

Institution	Focus	Contact
Washington University [St. Louis]	I-CARES—algae research including but not limited to genetic modification and techno-economic lifecycle analysis for algal biodiesel production; Consortium for Clean Coal Utilization—photobioreactors using fossil fuel combustion flue gas Photosynthetic Antennae Research Center (PARC)—basic research into solar energy collection by photosynthetic organisms such as algae	Hamadri Pakrasi, Ph.D. Richard Axelbaum, Ph.D. Robert Blankenship, Ph.D.
National Biodiesel Board [Jefferson City]	Coordinating industry association for R&D, regulatory aspects, and marketing of biodiesel in the U.S.	Tom Verry

5.2 Industrial Assets

There are few equipment companies currently working to support an algae industry that currently does not exist. However, given the historical importance of Missouri's agricultural industry, there is an impressive list of industrial assets which could play a role in a future algal biofuels industry. Missouri produces over $7 Billion worth of agriculture products each year, and 66 percent of its land is used for agriculture. Missouri has a comprehensive infrastructure focused on the planting, fertilizing, harvesting, storing, transporting, and processing of this agriculture produce. This same infrastructure is available to support the production of an algae crop.

Missouri has the requisite engineering firms to support large scale algae biorefineries. Firms of Black & Veatch and Burns & McDonnel in Kansas City and Jacobs Engineering in St. Louis are particularly suited for the design and construction of the biorefineries and associated process systems and water supply/treatment. Another company of note is Monsanto, a St. Louis-based life sciences company, which is currently a partner with Sapphire Energy in their genetic engineering platforms, which could bring them together on Sapphire's efforts to commercialize algae for biofuels.

Biorefineries. Missouri is home to nine biodiesel refineries scattered throughout the state. It has been challenging to document the precise status of some of these biodiesel refineries and this summary reflects our current understanding based on various sources on information. At least six of these refineries are currently in production, but the economic problems encountered by the various refineries in the past 2 years are instructive. The three largest plants are in St. Joseph (owned by AGP, a grain processor), Kansas City (a joint venture between Cargill and a farmers' cooperative), and Mexico (a joint venture between ADM and a farmers' cooperative). In all cases, processing of a commodity crop to a drop-in fuel is the responsibility of a company with substantial expertise in the industrial-scale processing of related feedstocks.

The other three plants in operation are relatively smaller operations located in southeast Missouri and are wholly-owned by a farmers' cooperative. One of the three plants, ME Bioenergy, was idle for 3 years and only recently was restarted under new management. The remaining three plants are under construction. In addition, there are several biodiesel plants in Tennessee along the Mississippi River that could provide an outlet for Missouri's algal oil.

The St. Louis area is also home to two major biofuel industry participants. Bunge North American Headquarters, located in St. Louis, is the second largest soybean processor in the U.S. and the largest canola processor in Canada. Bunge oilseed processing facilities and expertise is a substantial asset that could be utilized to bring algae processing to full commercial scale. Abengoa Bioenergy Corporation is also headquartered in St. Louis. Abengoa is primarily an ethanol production company; however, its expertise in biofuel manufacturing and distribution is an asset for the state.

Another significant asset to the state of Missouri is a fuel distribution terminal located in St. Louis. The Center Point Terminal is owned and operated by Center Oil Company, which distributes gasoline and other refined petroleum products throughout the U.S. by pipeline, ship, barge, and truck. Schaeffer Manufacturing is an oil-lubricant formulator and marketing company also in St. Louis. Schaeffer maintains several soy oil-based fuel additive, hydraulic oils, and lubricant products. These product lines have the potential to utilize alternative sources of vegetable oils such as algae.

5.3 Algal Biofuel Production

Large-scale cultivation of algae in outdoor raceway ponds will require water, sunlight, favorable temperatures, nutrients, and relatively flat land, with a potential boost from a concentrated source of CO_2. Conventional wisdom is that optimum conditions for algae production is in the warmer southern states or Hawaii; however, the key to promoting large-scale cultivation is to find the best combination of all of these requirements at the lowest cost. The figure of merit is not the tons per acre produced, but the cost per ton delivered to the market.

Climate (Sunlight, Temperature). Missouri winters are relatively cold and this makes the outdoor cultivation of algae a challenge during these months. Year-round outdoor algae production may not be viable in the absence of pond heating, such as used by The Lincoln University research team, which was able to cultivate algae in January 2010, by using heat from a power plant's water outfall. This approach emphasizes the potentially important role of industrial symbiosis to the algal biofuels enterprise—in this case a waste heat stream from the power plant being used to maintain adequate pond temperature for algae cultivation.

Sunlight is needed to drive the photosynthetic growth of algae. The concept that more sunlight is always better may be unfounded; however, because light utilization by algae reaches a saturation point beyond which more intense sunlight does not lead to more rapid growth.

Flat Land. Large-scale algae production using open raceway ponds will require large tracts of flat land. Missouri has large tracts of flat land in the Bootheel section; however, as noted later in this report, smaller scale production could be accommodated in many areas of the state.

Water. With the Missouri River bisecting the state and the Mississippi River running along its eastern border, Missouri in general possesses abundant quantities of water. However, while the southern tier and areas near the Missouri River have access to plenty of surface water, northern Missouri relies on less available and poorer quality groundwater. Water requirements

for a modest size algae raceway system are of the same order of magnitude as a center pivot irrigation system, which is possible in many areas of the state. For larger scale development, the Bootheel region again appears to be among the most favorable locations within the state from a water resources perspective.

Carbon Dioxide. Algae growth requires a source of CO_2. While CO_2 is present in air, high CO_2 sources could accelerate growth. Numerous point sources in the State of Missouri have large emissions of CO_2, and if this proves economical co-locating algae growth facilities near such facilities could be potentially advantageous.

Nutrients. Both phosphorus and nitrogen are needed in large amounts for algae cultivation. One promising source is wastewater treatment plants. However, another intriguing possibility is the use of waste from livestock, and in particular from confined animal feeding operations (CAFOs). Currently, waste from CAFOs is a significant operational problem for these farms. Using this material to feed algae could address both energy and environmental needs. Missouri has significant CAFOs in the north central section (hogs), and southwest section (poultry).

Section 6.
A Missouri Strategy

Missouri's 2008 expenditures for petroleum were $17.1 billion. The transportation sector accounted for 80 percent and the industrial sector accounted for 14 percent of Missouri's 2008 total petroleum consumption. Within the transportation sector, petroleum was 99 percent of Missouri's 2008 energy consumption. These trends point to the prominent role of petroleum, including diesel fuel, in Missouri's economy; yet there are no petroleum refineries in Missouri. Furthermore, 2008 crude oil production in Missouri was only 99 thousand barrels, which was only 2 percent of the state's *fuel ethanol* production. The operating space is immense for Missouri to become more self-reliant on transportation fuels by displacing petroleum fuels—with crude oil produced nearly completely out of state and refined entirely out of state—with Missouri-based biofuels and thereby bring economic benefits to the state. Furthermore, the benefits to the Missouri economy through the post-refining distribution and sale of diesel fuel will be present regardless of fuel source. Increased production of biofuels within the state would represent economic growth rather than displacement from one sector to another.

The authors believe that the growth and build-out of an algae industry holds significant opportunities for the state of Missouri. The four main algae business areas identified are; (1) Research and Development, (2) Equipment Manufacturing and Engineering, (3) Bio-Fuel and Bio-Product Companies, and (4) Algae Biomass Production.

Missouri has a unique blend of assets in each of these areas except Algae Biomass Production, but has the required natural resources to build assets in the area. Missouri's strengths in the algae industry currently reside in the research and development, large project engineering firms, and Biodiesel conversion facilities areas. Other significant strengths come from the agricultural and agribusiness assets as well as natural resources available to support the area of algae biomass production. The Missouri Bootheel region is a high value target area for algae production in the state and possesses all the major natural resources and industrial assets for a highly integrated algae production industry. We believe that Missouri should consider strategies that leverage the significant accomplishments to date of the research institutions in the state, and which could utilize the other strengths that the state can bring to the table.

We believe that a Missouri strategy should consider production. Perhaps the most viable strategy is to support the development of an in-state algae cultivation industry for the production of high value-added products. This is consistent with the business models of most companies engaged in the industry. The smaller scale of such operations could open up more regions of the state as candidate areas for cultivation. This approach would provide the capacity to capitalize on continuing innovations in the field that could eventually lead to biofuels being a viable coproduct and, perhaps in the out years, large scale production of algal biofuels.

A national assessment of algae productivity rates across the continental U.S. based on current technology demonstrates up to a twofold difference in productivity depending on location. This spread is relatively narrow and strongly suggests that other factors—especially the availability of resources—will significantly influence the attractiveness of one area compared to

others for algae cultivation. Key resources include suitable land, water of adequate quality and quantity, concentrated streams of carbon dioxide, and nutrients. While a systematic assessment of these resources has not been conducted, a qualitative assessment suggests certain regions of Missouri—including but not limited to the Bootheel—might be very attractive for large-scale algae cultivation.

Innovations to improve production economics will be location-specific, especially when using outdoor ponds for algae cultivation. For example, large-scale production in the southwest U.S. will likely rely on saline or brackish water and the impact on downstream processing needs to be considered. In areas like Missouri, the approaches such as using waste heat from an industrial facility or utility to heat the ponds could significantly extend the growing season and improve production economics.

Economic incentives can always be used, but we see no need for any change in regulations. The general view of sources consulted for this Report is that regulatory challenges are not a significant barrier to the development and expansion of algae-based renewable energy at this time because the technology that will eventually shape the algal biofuels industry is still in its infancy. Thus the development of algae-based renewable energy is not being hampered by a particular set of regulatory challenges that need to be resolved before it can expand on a large-scale in the liquid fuels market.

While full development of the algae-based biofuel industry is by some estimates a decade or more away from emerging, R&D activities related to algae-based biodiesel is already quite extensive nationally and internationally. Missouri universities, firms, and organizations are already major players in this R&D process, but will need to have continued growth if Missouri is to become a global leader in the emerging industry. To be successful Missouri will need a complementary and coordinated complex for research, engineering and manufacturing, algae production, and biodiesel processing, which builds on Missouri's strengths and unique characteristics.

Missouri offers a unique geographical, ecological, economic, and institutional context within which algae-based biofuel will develop and thus needs to develop a unique strategy or niche if the sector is to achieve its full potential. One key opportunity will be to take advantage of its large and diverse agricultural sector. Missouri has over 100,000 farms, second only to Texas. Many of these farms are relatively small offering only part-time employment for the farm families that operate them. In addition, Missouri's geography varies from the fertile plains of the north and the Missouri and Mississippi flood plains to the hilly geography of the Ozark region.

This report presents a case for algae production in the Bootheel as having the best set of characteristics for large scale biodiesel production, but algae-based technologies could emerge at various scales. Often large scale is required to achieve low unit costs of production, but in other cases moderately sized technologies can achieve satisfactory economies. This could be true for production of high value nutraceutical products, which will most likely be the vanguard industry that jumpstarts the lower value biodiesel production. One of Missouri's strength is that it could support both large scale and small scale algae production.

First, smaller scale production facilities offer several potential advantages in the Missouri context. First it is much more likely that small scale production facilities could be sited on underutilized land in Missouri. Given Missouri's vast areas of arable lands in the north and along the Missouri and Mississippi rivers the total area of unutilized or underutilized land would be much larger if smaller parcels are utilized. Similarly, because of the need to site algae growth facilities on relatively level land, smaller facilities would be more appropriate in the hillier lands in the Ozark region.

Second, given the large water needs for algae production the northern half of the state would be less likely to accommodate larger scale production facilities. Smaller scale facilities could more easily be sited near available water supplies.

Third, Missouri is part of two major livestock clusters—large scale hog production in the North, and large scale poultry production in the Southwest. These clusters currently produce large volumes of animal waste, which could be used as sources of nutrient for algae production facilities.

Fourth, Missouri farmers represent a ready supply of entrepreneurs, part-time labor, capital, and management that, with the necessary skill development, technical assistance, financing, and encouragement could provide the foundations for a successful algae production sector. Just as they responded to the opportunity to get involved in the ethanol, soy-based biodiesel, and wind energy industries over the last decade, many will respond to the opportunity to utilize under-utilized land, machinery, and labor to produce algae if given the financial incentives.

Fifth, farm-scale algae production would complement Missouri's small farms and rural communities. Some of the by-products from biodiesel production could be utilized on the same or neighboring farms as animal feeds, fertilizers, and soil amendments.

Finally, distributed algae-based biodiesel would be an important economic development opportunity for rural Missouri. Unlike many other renewable energy sectors, algae production requires significant levels of labor. Distributing the labor across the rural areas of the state could help stem population loss and make these areas more economically resilient. It would further diversify Missouri's and especially rural Missouri's economy.

A distributed production strategy would require a corresponding strategy for marketing, transporting and handling algae as it is prepared for processing. Depending on the ideal scale of the processing activity, this might involve a number of producers for each processor. Again this issue has been addressed by the poultry, hog, ethanol, and oilseed industries through contracting, cooperative ownership, and spot-markets.

To make either strategy of large or smaller scale production work, Missouri will require foundational and on-going research to support the production and processing of algae products. As pointed out elsewhere in this report, Missouri has a rich research infrastructure in place. What is needed is a strategy for coordinating the elements of this public-private-university infrastructure and focusing on a strategy such as that suggested here.

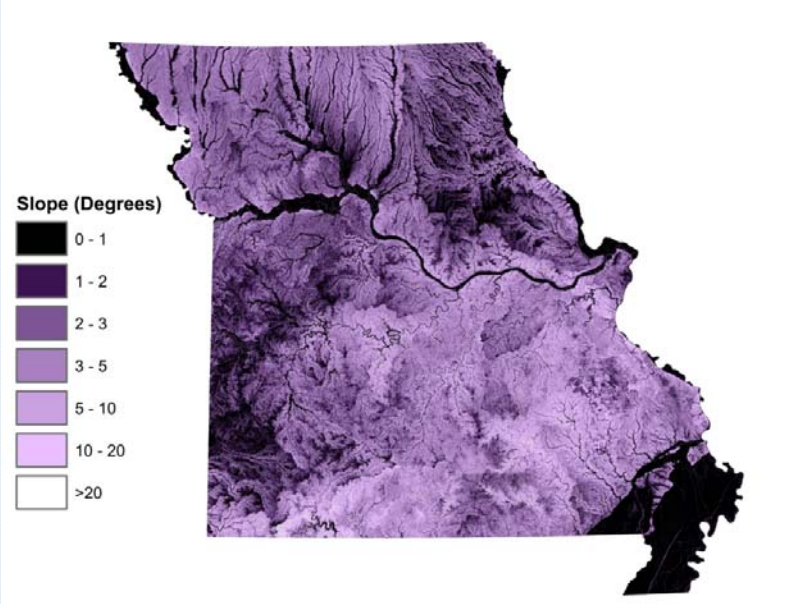
Section 7.
Analysis for Algae Production in Missouri

A variety of studies have speculated on the best place to grow algae, and Missouri does not show favorably in some of these assessments. These studies take a very broad brush at the siting requirements without looking at the details of the location, and Missouri is downgraded for two main reasons: cold winters and high agriculture land usage. Cold winters will affect production, but it is the cost per unit not the quantity per acre that is important. Hawaii with 12-month production will have better per acre quantities, but their land, labor, and utility costs are many times Missouri's. The second reason derives from a government priority not to use land presently engaged for food production, but it is Missouri's agriculture infrastructure that is one of its advantages, and ultimately algae would be another crop in a farmer's portfolio. Combined with the advantage of abundant fresh water (all the other sites presently in consideration will use salt water), the authors feel that a case can be made for siting algae production in Missouri.

We believe that a mature algae industry could find application throughout the state, but our analysis has indicated that the Bootheel section will show the most favorable, and could accommodate large or smaller scale facilities. We present below an analysis for the Bootheel in a Strength, Weakness, and Opportunity format.

The Missouri Bootheel

An area of the state that may have a unique opportunity for large scale production of algae is the Missouri Bootheel. The Bootheel consists of the counties of Dunklin, New Madrid, and Pemiscot. For the purpose of this study, the term will include the entire southeastern lowlands province, including all or parts of Ripley, Butler, Stoddard, Mississippi, Scott, Bollinger, and Cape Girardeau counties. The figure below shows the degree of slope for the state. The large dark area in the Southeastern corner of the state is the "Bootheel" and shows an area of approximately 4,000 square miles with less than 1 degree land slope, which makes it a potential location for large scale algae production.



The area was formally the flood plain between the Mississippi and the St. Francis rivers, now controlled by levees and canals. From the Mississippi River going west, the land raises almost imperceptibly for almost 40 miles until a slight rise is encountered at a north-south ridge called Crowley's Ridge. At 50 miles from the Mississippi River, the land starts to rise to meet the Ozark Escarpment, and it abandons its lowland character. For almost 100 miles from Cape Girardeau to the southern Pemiscot border, the elevation difference is only 70 feet. Flat land is essential to keep the construction and capital cost of the algae ponds low.

The Missouri Bootheel Strengths

Land: Large contiguous acres of low slope land, as discussed earlier, is critical for commercial scale algae production facilities. Land values have increased for the last several years along with economics of farming. Last year the average sale price for farm land in the region was about $4,000 per acre. This will be higher than some dry land areas of the Southwest, but is reasonable with the other resources available.

Water: The availability of water will be one of the key factors for algae production at a commercial scale. The Bootheel area is blessed with the availability of fresh water, and it contains the greatest volume of ground water per unit area than almost any other part of the United States. The Missouri Department of Natural Resources (DNR) estimates that 76 trillion gallons of water is contained in the groundwater of the Bootheel region. Several aquifers are present under the Bootheel lowlands, and are productive to various degrees; however, the Southeast Lowlands alluvial aquifer is the most prolific and widely used. This shallow aquifer underlies 92 percent of the Bootheel lowlands, and wells in the region typically produce 1,000 to 2,000 gallons per minute. At present, agriculture utilizes 287 billion gallons of water annually for irrigation with no apparent drawdown. Nearly 50 years of measurements has shown no decline in the aquifer, which perhaps is recharged by the 50 inches off annual rainfall in the region. Ground water is very shallow in the area, and ranges from 4 feet deep near the Mississippi River to up to 20 feet deep further to the west. The sustainable water from wells, reservoirs, and rainfall would appear to eliminate water use as an issue for algae production.

Solar Energy: Days with direct sunlight averages about 60 percent annually, and solar radiation data issued by NREL indicate 4.5 to 5.0 kWh/m^2/day average. This solar energy is adequate for algae growth.

Nutrients: There is a cluster of CAFO's located just to the north of the lowland area. These CAFO's have the potential to supply low cost nutrients for algae production.

Climate: Temperatures in the region are relatively moderate. The mean annual temperature is 60 degrees Fahrenheit, with summer average highs in the low 90s, and mid-winter average lows in the high 20s. Although the climate is mild and contains days in the 40s even in the winter, the region can experience some below freezing temperatures in 3 months of the year.

Carbon Dioxide Source: There are two coal-fired power plants located in the Bootheel near Sikeston and New Madrid. These power plants are potential sources for large quantities of CO_2 and waste heat that could be utilized by large scale algae production.

Location: The area is bordered by the Mississippi River, which provides access to efficient transportation of bulk biomass. Bunge maintains an oilseed crushing facility in Cairo, Illinois, which is just across the Mississippi River. The economy of the region is sluggish and the annual income is among the lowest in the state. Farm labor is available and wages are low. New development for an algae industry could provide a welcomed economic influx to the region.

Existing Biodiesel Infrastructure: Three Biodiesel production facilities are located in the Bootheel. Global Fuels, Dexter, Missouri; ME Bioenergy, Libourn, Missouri; Natural Biodiesel Plant, Hayti, Missouri, combine for 13 million gallons of annual production capacity.

The Missouri Bootheel Weaknesses

Land: The build out of significant algae production will displace acres currently in agriculture production. The primary agriculture in this area today is cotton, rice, and soybean farming.

This effect will be the same as almost any other region in the U.S., which has the natural resources available to grow algae. One perspective to keep in mind is that algae production is farming. Water, sunlight, and fertilizer are used to grow and harvest a plant biomass material. Therefore, any land that is converted to algae production is displaced from one type of agriculture to another.

Water: Water is readily available in the Bootheel; however, there will also be an elevated risk of floods. The area uses a network of levees and canal to control flooding. These structures are successful most of the time; however, there are years in which crop damage and loss occurs. There would be added risk by locating the significant capital infrastructure, needed for algae production, in a floodplain.

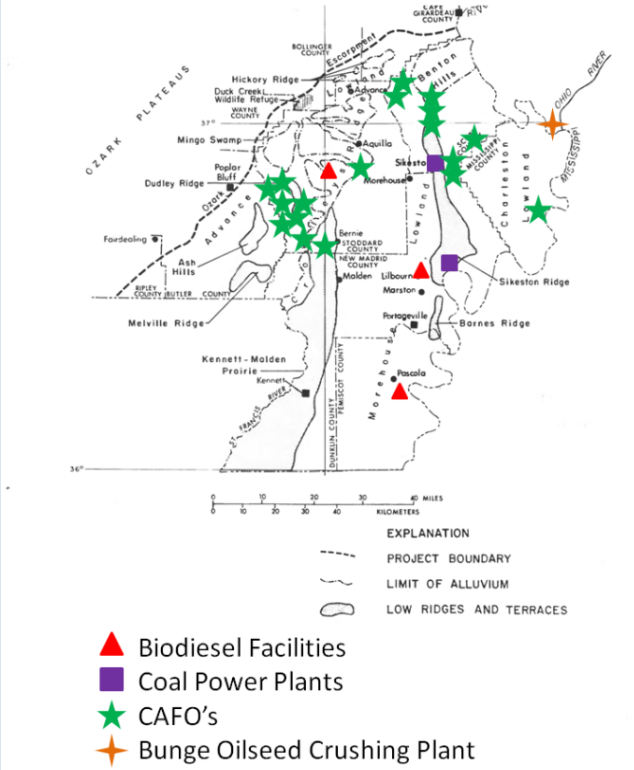
Solar Energy: Days with direct sunlight averages about 60 percent annually. Cloud cover can reduce solar radiation and if significant, algae growth rates. This would be viewed as negative when compared to the Sunbelt region, which receives direct sunlight over 80 percent annually. However, it is unknown the percent (if any) reduction this would cause on overall algae growth rates.

Climate: Strategies will be required to moderate the temperature extremes. However even these extreme are relatively small and have the potential to be solved by relatively minor efforts and minimize reduction in algae growth rates.

The Missouri Bootheel Opportunities

The adjacent figure uses a topography map of Missouri's southeastern lowlands province and an overlay of the existing facilities and infrastructure that could be utilized by an algae production industry. The previous Strengths section shows that the area has the needed natural resources to be well suited of algae growth, abundant water supply, sunlight, and flat land. Although this is a relatively small region, approximately 3,000 square miles, it could be the best suited for commercial scale algae production compared to any area in the United States. There is an oil extraction facility and three (3) biodiesel conversion facilities located within a 40 mile radius. Local CAFO's could provide an NPK nutrient source for algae growth, as well as a market outlet for the algae protein meal by-product remaining after oil extraction. These facilities could provide the foundation for a commercial scale algae farm to be successful. This is a unique opportunity for the state of Missouri to be a leader in a highly integrated algae production process.

Bootheel Lowlands BioDiesel, Coal Power, Oilseed Crushing and CAFO Overlay



Section 8. Recommendations

Although the algae biofuels industry is in a pre-commercial stage, Missouri has already taken a lead in the early R&D and technology development activities. In addition to its R&D capabilities, Missouri is an important player in the biofuels industry, has a dynamic farming community, and has land and climate conditions that are compatible with algae farming. The study concluded that Missouri has an array of characteristics that could enable it to play a large role in the development of a large scale algae industry. The study also concluded that a robust algae fuel and by-product industry could bring significant benefits to the farm, R&D, and manufacturing economy of the state. Therefore, the authors recommend that Missouri capitalize on the early accomplishments of the state's research institutions, and pursue certain policy initiatives that could provide a significant return on investment in the years to come. The authors make the following recommendations:

1. **Pilot Scale Facility.** The state should assist in the establishment of a pilot scale algae production facility on the order of 10 or more acres. This facility would have several functions, including the production of ton quantities of algae needed for process and product development, market trials of the products, and the development of by-products. The facility would also be used to measure algae strain and equipment performance under realistic conditions, and the collection of economic data beyond bench scale. We believe there is a need for this type of facility, and that industry and the Federal government would support it. We believe that a public-private partnership structure is feasible, with partners utilizing the site for proprietary tests or demonstrations. The location is to be determined, but with one candidate in the Bootheel area being the Delta Research Center run by the University of Missouri in Portageville (Pemiscot County).
2. **Cost Share for Federal Projects.** The state should encourage the Federal funding of large algae demonstration and pilot projects within the state by covering all or part of the cost share that is typically requested by government agencies for this type of demonstration projects.
3. **Algae Focus in the University.** The state should incentivize the University of Missouri to establish an interdisciplinary study section for algae that would involve biologists, chemists, agriculture scientists, engineers, economists, environmental scientists, and business management.
4. **Economic Business Development.** Establish a state economic business development entity that would promote the Missouri algae value proposition to the public, the farmer, product user, private companies, equipment manufacturers, engineering firms, and all those in the process chain. This commission would coordinate and pursue business development activities for algae throughout the state. We recommend that the MTC be the champion in this regard, and establish a commission with initial state funding. This commission would be a clearing house to make accessible data regarding R&D, grant programs, incentives, and other development activities involving algae throughout the state. The commission would be especially helpful to startup companies in this field and would reach out to the strong agribusiness sector in Missouri.

5. **Farm Initiative.** The state should support an awareness or education initiative to make Missouri's farmers and diverse farm interests aware of the technology, advantages, and by-products of algae. The focus would be on the interrelation between algae and other agriculture needs such as the use for fish or animal meal, use of nutrients from CAFO, treatment of waste water, and other applications. The goal is to bring the farmer and the farm more in to the process of developing an algae industry in Missouri. We recommend that the State's Extension Agents be given the mandate to lead this program and to interface with the activities of the business development champion in Item 4. This program should also be in coordination with any algae pilot production site established under Recommendation Number 1.
6. **Collaborations.** Establish collaborations with other states and international organizations that have mutually supporting interests and unlikely to be in a competitive situation. We recommend Missouri reach out to Arkansas and Tennessee as part of the Bootheel and upper Mississippi delta region that has promise for algae production along with common interests among the states. We also recommend Missouri establish appropriate and timely international collaborations. The European Algal Biomass Association recently compiled a directory of institutional and industrial stakeholders around the globe, and this directory can serve, in part, as a starting point for identifying strategic partners.
7. **Annual Algae Conference.** In keeping with the objective of nurturing and promoting the good algae-related science performed in Missouri, the state should capitalize on the success of the sold out *First International Conference on Algal Biomass, Biofuels, and Bioproducts* held this year in St. Louis. This specific venue is scheduled for San Diego in 2012, and is expected to be available to rotate to other cities, thereafter. This venue, with the state's assistance, should be sponsored and promoted to return to St. Louis with the goal of becoming "THE" algae event of the year for U.S. and international researchers and industries. This goal is achievable because there is no premier established venue for researchers in this field, and algae is frequently covered as a subpart of Biomass conferences. For next year, or any year that the conference is not in St. Louis, we would recommend that an algae summit be sponsored such that an algae event is held every year in St. Louis. This would bring a variety of visitors to Missouri, attract research funds, and lay the ground work for potential industries to locate here.