OUTLINE FOR AN ALGAE BIOFUELS REPORT

I. **Preface:** currently no area of alternative fuels is attracting more urgent interest on the part of investors and major institutional consumers of liquid fuels than the nascent industry for producing such fuels from algal sources. An estimated 250 companies have emerged as stakeholders at the time of this writing—up from less than twenty a year ago. Those companies include Shell, Chevron, Boeing, General Atomic, Virgin Airlines, Japan Airlines, and New Zealand Airlines, among others, along with scores of startups. The U.S. venture capital community is heavily engaged in promoting this industry as well, and recently a previously unknown startup, Sapphire Energy of San Diego, secured a $50 million dollar first investment round. The pace of both investment and company formation in this area is increasing rapidly, as is the involvement of airlines who view algal aviation fuel as the solution to the escalating cost of traditional petroleum based jet fuel.

II. **Executive Summary:** the cultivation of various species of algae as fuel feedstocks has won the support of many investors, major corporations, governments, and major users of liquid fuels concerned with future price and availability. Algae is favored over other biomass feedstocks by reason of its very high growth rate and its susceptibility to being produced in a quasi-industrial environment supposedly immune from the vicissitudes of weather, precipitation, and pest invasion. Algae is seen by many as constituting the principal basis of a second or third generation biofuels industry which would overcome the limitations and shortcomings that have hitherto confined biofuels largely to boutique markets.

A. **Principal drivers:** the principal drivers for promoting algae based biofuels are two in number; the ability of algae to sink carbon dioxide in the most effective manner by capturing directly the effluents of large point source carbon dioxide emitters such as fossil fuel fired power plants, cement plants, etc.; the purported scalability of algae installations and their ability to supply virtually unlimited amounts of liquid fuels to compensate for expected shortfalls in petroleum based fuels—all without making additional claims on arable land or diverting biomass from food production.

B. **Scope of this report:** this report aims to be comprehensive. Coverage and analysis will fall into the following categories:

1. **Industry overview**: industry origins; where the industry is now in the volatile present; and possible scenarios for growth and development that lie ahead. This section acknowledges the immaturity, instability, and lack of any single direction today, in other words, the basic inchoateness of the business.

2. **The nature of the feedstock and its competitive position with respect to other biomass feedstocks as well as to remaining fossil fuel resources.**

3. **Industry segments**: the algal biofuels business roughly divides according to the type of feedstock used. Most producers are looking to use single celled micro-algae cultivated in controlled quasi-industrial environments. Others seek to harvest algal blooms occurring in the wild. Still others strive to harvest macro-algae or seaweed occurring in the wild state or in offshore marine plantations involving semi-controlled conditions.

4. **Cultivation and processing techniques**: the two are rather closely conjoined because, unlike other fuel crops, algae is generally grown and processed in the same facility, at least it has been thus far in pilot installations.

5. **Fuels that can be produced from algae**: algae can be a source of **lipids** for biodiesel, **hydrocarbons** for petroleum substitutes, and various **alcohols**.

6. **The economics of production:** there is no doubt that biofuels can be produced from algal feedstocks; the real issue is the economics of doing so. Accordingly, economics is a major focus in this study.

7. **The competitive position of algae with respect to other fuel sources.**

III. State of the Industry:

the cultivation of algae for commercial profit already takes place on a modest scale, primarily in order to produce nutrients, food supplements, cosmetics, and other high value products. The scale of cultivation is relatively modest, and the pricing of products is such that production efficiencies have not been pursued with extraordinary ardor. Commercial cultivation of algae for actual fuel production has not occurred anywhere in spite of numerous efforts on the part of many researchers and entrepreneurs throughout the world.

A. A brief history:

algae has long been recognized as a potential source of fuel, and much research occurred in Japan and in the U.S. in the nineteen seventies and eighties toward developing commercial algal fuel production. Such research efforts were prompted by the petroleum price shocks of the period but persisted long after oil prices had stabilized. Initial efforts involved both closed and open systems, discussed below. The Japanese researchers, as befitting the colder climate of their homeland, tended to concentrate on closed, temperature controlled bioreactor systems based upon latest development in fiber optic light pipe technology which was used for distributing light to the growing organisms. American researchers focused, for the most part, on open pond systems exposed to the elements. Japanese efforts resulted in systems having fairly high yields but prohibitively high costs and low energy efficiencies. American projects, on the other hand, suffered from low yields. Thus, though early development efforts have to be considered failures, but they did provide a valuable knowledge base to be utilized when interest in algae revived during this decade.

B. **Current algae revival**: until the latter half of 2006 algae was merely one tiny sub-segment of the larger biofuels industry, and only a handful of firms had emerged to promote it. Present day attempts to initiate commercialization stem from a number of root causes.

1. **Growing acceptance of biofuels in general**. First generation biofuels have succeeded in finding large and growing markets, primarily on environmental grounds. The parallel notion that algae cultivation is essentially Green and carbon neutral also greatly assists algae fuel advocates, and, has coincidentally been advanced by most biofuels producers, though not without prompting dissent within the environmental community. We have detected no organized environmentalist opposition to algae to date, however.

2. **Perceived inadequacies in the potential of traditional biofuel feedstocks for meeting future demands:** industry critics are already alleging that biofuels manufacturers are making claims on arable land sufficient to cause food shortages. In this context algae appears as a condign solution.

3. Parallel criticisms to the effect that **biofuel agriculture** as it is practiced today is **unsustainable and environmentally harmful**.

4. The general perception that the cultivation of algae for fuel constitutes **the perfect solution to our current energy and environmental problems**: algal biofuel firms have been extraordinarily successful self promoters, and have effectively emphasized all of the positive attributes associated with various strains of algae and various production methods while neglecting to mention that such positive attributes are never present in toto in a single species or in a single cultivation or harvesting technique. In other words, they have assembled a sort of phantom best of breed composite which they have presented to the press and to the public as if it were a real entity capable of being pressed into production.

5. **High tech cachet**: algae has been positioned by its supporters as a biotechnology play as much as an energy industry investment initiative. New energy technology companies, except when they are seen as adjuncts of more volatile sectors such as IT or telecom, have generally not exhibited the same rapidly appreciating valuations we see in hot biotech stocks, and, insofar as algae is associated with genetic engineering programs, micro-filtration, and other cutting edge developments, it is often perceived as offering a better and more rapid return on investment.

C. Devil's advocacy: algae detractors are neither visible nor vocal, but they have managed to marshal some counterarguments that must be confronted, and these are considered in detail elsewhere in the text.

1. Algae have never been successfully raised as a fuel crop on a commercial basis in the past.

2. No clear alternative to the failed approaches of the past has been presented by any of the new entrants into this nascent industry.

3. Successful manufacturing industries are characterized by standard techniques and not by proprietary technologies owned by individual intellectual property holders. Multifarious approaches, such as characterize the algae fuel industry today, virtually preclude the economies of scale in core infrastructure necessary to achieve volume production at reasonable costs.

4. The basic positive correlation between capital cost and crop yields still appears to hold, which means that algae promises to be a very capital intensive industry.

IV. The nature of the Feedstock:

Algae refers not to a single species or genus, as is the case with competing fuel crops, but to a whole class of organisms consisting of over a million species altogether by current estimates, and including a multitude of hierarchies and subcategories within the larger class. While obviously some similarities obtain across this vast domain, individual species differ markedly in their pertinent characteristics including growth rates, range of temperatures tolerated, nutritional requirements, overall hardiness, yield of useful products, and susceptibility to transformation either through genetic engineering or selective breeding.

A. Algal fuel crop candidates:

one indication of the relative immaturity of the industry is the lack of consensus as to the identity of the more promising candidates. Researchers have constructed profiles of the ideal species for fuel production, but no species identified to date has conformed to the profile in all salient respects. Most but not all researchers are seeking candidates with **high lipid contents**, lipids being substances which can be easily and economically transformed into commercial biodiesel fuels by proven production processes. Ideally, high lipid or oil content will be combined with **high growth rates** and the ability to **thrive under extremes of temperature and the presence of competing species of algae of no commercial interest**. The ideal strain should also be easy to remove from the water filled vessels in which it has been cultivated. So far no altogether satisfactory species has been found, and many in the industry are now pinning their hopes on genetically modified strains.

B. The class and its divisions:

algae are among the oldest living organisms and among the simplest photosynthetic plants. In the hundreds of millions of years since their first appearance algae have evolved into a bewildering diversity of forms.

1. The core division, **macro-algae** and **micro-algae**:

a. **Macro-algae**: also known as giant algae or seaweed, these multi-cellular species are almost exclusively found in marine environments, and have long been harvested commercially for the production of various products. Few species produce appreciable quantities of lipids, but still a number of firms are eyeing macro-algae as fuel feedstocks because they require neither arable land nor physical infrastructure for their cultivation. The cultivation and harvesting of giant algae for energy purposes must be considered a fundamentally different industry from that concerned with the production of fuels from micro-algae.

b. **Micro-algae** are single celled organisms that tend to occur in dense concentrations. They are found in both fresh and salt water and anchor the ocean's ecosystems, providing the ultimate source of nutrients for most of the ocean's other inhabitants. As such they comprise an estimated quarter of the world's total biomass. They fall into four distinct groupings.

1.) **Diatoms**: diatoms have been extensively investigated for use as a fuel feedstock. They are predominant in salt water environments.

2.) **Green algae**: these are prevalent in fresh water. They have also been extensively researched as fuel feedstocks.

3.) **Blue**-green algae: these species, which tend to resemble bacteria, have also been subject to much research as possible fuel sources. They have a unique ability among algae to fix nitrogen from the atmosphere.

4.) **Golden algae**: golden algae are similar to diatoms but are more complex anatomically. They have been less extensively researched as fuel feedstocks.

C. Requirements for algal cultivation: these are subject to frequent misunderstandings and to pervasive misinformation which vastly understates the metabolic requirements of the organisms and the very special conditions that are necessary to maximize growth and productivity.

1. Like all photosynthetic plants algae need sunlight in order to synthesize the fats, carbohydrates, and proteins that go to make up the protoplasm of which these creatures are constructed. Most algae do not tolerate direct sunlight well, and many species benefit from exposure to fluctuating light sources. The provision of such intermittent lighting can greatly complicate the design of the bioreactor.

2. Algae growth patterns are highly dependent upon ambient temperature, and freezing nights can arrest growth even when daytime temperatures are high. Optimal growth in most cases occurs in environments where ambient temperatures are relatively invariant seasonally and over the course of the

day such as the Hawaiian Islands, or, alternately, in artificial temperature controlled environments.

3. Like all photosynthetic plants algae require **carbon dioxide**, and, being roughly 50% carbon by composition, they cannot sustain high growth rates without access to gaseous carbon dioxide in concentrations far higher than are present in the atmosphere. This fact is often ignored by proponents of algae fuel who somehow imagine that hundreds of tons of biomass are going to be produced over the course of a few days by the simple process of the algal clumps respiring atmospheric air. A moment's reflection will reveal that the gas transfer mechanisms present in these organisms cannot possibly permit the accumulation of carbon in such quantities in any reasonable time frame.

4. Algae also need large amounts of **oxygen** and **nitrogen** in order to grow. Some species can fix nitrogen from ammonia, while others can only thrive in the presence of solid nitrogenous nutrients such as fertilizer runoff. Algae also require silicon, sulfur, phosphorous, and other trace minerals to maintain healthy growth. These basic requirements, which are common to nearly all plants, are frequently ignored in discussions of algal biofuel, and instead the notion is advanced that air, water, and sunlight are all that is required to raise a huge algae crop for fuel.

5. Providing algae with sufficient oxygen can be challenging because the organisms tend to accumulate in dense mats that impede the circulation of oxygen rich water. Either a water pumping system must be utilized to aerate the algae culture or a bubble aeration system must be substituted. Both require power inputs.

D. Production issues relating to plant physiology, metabolism, and behavior: most of those seeking to utilize algae as a fuel feedstock are seeking to harvest the lipids and utilize the remainder of the biomass to produce various co-products. This strategy places a premium on species which naturally produce large amounts of lipids per unit of biomass. Unfortunately, high lipid contents are only had at a price.

1. Lipid rich species of algae are not particularly common, and **all identified to date have been deficient with respect to other important attributes**. Lipid levels can be manipulated by various means, but all techniques for raising lipid concentrations known today result in a reduction of the growth rate because, in effect, nutrients are being robbed from structural components comprised of carbohydrates and proteins and stored as fat.

2. Lipid concentrations are most commonly increased by starving the algae culture of certain nutrients such as nitrogen or silicon. Growth of the culture virtually ceases in such instances, but the ratio of fats to other compounds shifts.

3. Most of the truly lipid rich species have not proved particularly hardy,

and have generally been supplanted by undesirable native species when attempts have been made to raise them in open ponds.

4. Many research projects have been undertaken to find some mechanism for stimulating lipid production while retaining high growth rates, or, alternately, breeding or engineering a strain that had truly best of breed characteristics across a broad spectrum of attributes. No such attempt has achieved verified success, though many claims of success are circulating through the investment community.

V. Production strategies and technologies: most companies attempting to produce algae aim to utilize micro-algae and raise monocultures within manmade containers rather than natural watercourses. A few companies base their business plans on harvesting algae in the wild, especially in places where "algae blooms" occur as a result of concentrations of manmade nutrients from soil runoff or waste accumulation.

A. Production infrastructure: the early division among algae cultivators between those favoring three dimensional bioreactors and those committed to open artificial watercourses has persisted. These still represent the fundamental approaches.

1. **Three dimensional structures**: three dimensional bioreactors are elevated structures intended to exploit the vertical dimension to increase the amount of algal biomass that can be supported by a given acreage.

2. Three dimensional structures fall into two major categories, those using **rigid structures** throughout and those seeking to contain the algae culture in **flexible pouches** suspended from a framework.

a. Rigid structures have been subject to more prototyping and experimentation than have soft structures, but still the technology cannot be said to be mature. The algae contained within the structures must be properly and precisely aerated and supplied with sunlight and shade. Because of the light requirements for growing algae, the structural materials of choice will be either glass or transparent plastics such as polycarbonates or acrylics. Some have suggested that bioreactors of this sort are really a species of greenhouse reactor, and are apt to share the high capital costs of conventional greenhouses used for growing terrestrial plants. One could further argue that aeration and circulation systems would push the price higher still. The counterargument would be that the growth of algae biofuels industry and the use of modular fabrication approaches would inevitably drive the price of reactors down. Such rigid bioreactors will also require additional subsystems for transporting smokestack effluents in considerable volumes into the bioreactor itself, and those themselves will impose a significant additional cost factor, though one that might be borne by the emitter rather than by algae cultivator—this being one of many issues in this nascent industry that have yet to be sorted out.

b. **Soft constructions**: soft bioreactors use much cheaper structural materials than the rigid variety and it appears to be highly modular, permitting one to add capacity in any increment at will. We believe, however, that these construction techniques limit the operator's choices in achieving circulation and aeration control. They simply don't lend themselves to supporting internal pipelines, impellers, or agitators. Still, this represents a fresh, interesting approach and one that may improve upon the demonstrably marginal economics of the older rigid bioreactor production techniques.

3. **Open ponds and raceways**: these consist of shallow watercourses, generally placed within excavations on vacant land. In some cases they will be provided with transparent coverings to limit the incursion of undesirable species. Most commonly they consist of fairly narrow channels designed to support moderate, steady currents which would provide aeration and would distribute nutrients. Although the results achieved with open ponds were disappointing in the past, they still have many adherents due to the relatively low cost of building the supporting infrastructure and the minimal requirement for costly, high tech components. Open pond algae farms are best attempted with native species which can naturally resist invasion within their particular habitats, and they are unlikely to achieve acceptable yields unless both a source of concentrated CO_2 and other nutrients is provided—in other words, the system requires inputs. The University of Alabama has performed considerable research on augmented pond systems utilizing agricultural waste inputs, and University researchers have concluded that real commercialization is probably feasible. Anticipated yields are far below the theoretical maxima cited by industry promoters, however, are comparable those of the higher yielding terrestrial fuel crops such as the oil palm or the Chinese tallow tree.

4. **Hybrid systems**: some technology firms have proposed that a combination of closed bioreactors and open ponds is the optimal approach. The algae culture would be incubated in the closed reactor and allowed to reach a certain mass before being placed in the open. It would then complete its growth cycle in the outdoors, and would achieve its ultimate harvest yield within the cheaper outdoor infrastructure. The approach seems plausible but there is yet no conclusive empirical evidence that it possesses any decisive superiority.

B. Products: most algae advocates have focused on the production of lipids and the subsequent production of biodiesel from them. Biodiesel manufacturing is relatively simple process with a good energy return on investment, excellent scalability in both directions, and a good energy return on investment. The end product presents certain problems, however, being unsuitable for use in very cold temperatures and being mildly corrosive. Long term storage can also be problematic. Perhaps the biggest problem, however, is that the middle distillate market within the personal transportation sector is limited, especially in the United States. For these reasons certain algae producers have announced their intention of producing alcohols or hydrocarbons resembling refined petroleum products.

1. **Biodiesel**: biodiesel usage has been growing briskly in many parts of the world, particularly in Southeast Asia where some particularly high yielding oil crops are cultivated. Current production is quite low—certainly less than a billion gallons per annum—and further expansion of the industry is constrained by the fact that most oil crops only yield lipids from their seeds and generally produce less than 100 gallon per year per acre. Algae, with its promise of oil yields of thousands and perhaps tens of thousands of gallons of oil per acre, seems the perfect solution to the problems of the industry—if such yields can be achieved and sustained on a commercial basis.

   a. Biodiesel is limited in terms of certain markets. Because it gells at relatively low temperatures it is unsuitable for jet aircraft.

   b. Biodiesel production requires large volumes of alcohol, and if biodiesel were to become a very high volume motor fuel the capacity of the ethanol and methanol industries to keep pace might become an issue.

   c. Biodiesel may not ultimately be competitive as a motor fuel if inexpensive forms of "green diesel" appear in the market.

   d. Lipids could be widely utilized in the production of such green diesels according to processes developed by UOP, Neste Oil, and others. If such processes prove cost effective, traditional methyl ester biodiesel could disappear from many markets.

2. Schemes have been developed for **producing ethanol from algal biomass**, and attempts have also been made to develop strains of algae which will secrete ethanol directly. No such methods are close to commercialization. Our view is that ethanol has a limited appeal as a motor fuel and cannot compete with either traditional hydrocarbons or mixed alcohols provided that either can be produced and sold at competitive prices. Since both hydrocarbons and mixed alcohols can be produced from algal biomass by various means, algae cultivators face a choice here.

3. **Hydrocarbons, including green gasoline and green diesel:** a number of companies and academic researchers are working in this area. Many means exist for converting plant biomass, regardless of origin, into hydrocarbons, and such techniques could be brought to bear on algal biomass. Alternately, some researchers have launched genetic engineering projects for producing fundamentally new types of organisms that could produce hydrocarbon metabolically. Several terrestrial plants are capable of doing so in the natural

state, but no real industry has developed to date based upon the exploitation of such species.

4. **Mixed alcohols**: we have yet to identify a firm attempting to produce mixed alcohols from algal biomass, though it is technically possible to do so.

C. Co-products: algae produce carbohydrates and proteins. High value cosmetics and nutrients can be produced from algae and lower value products such as animal feed.

D. Fuel producing processes: these naturally vary according to the type of fuel produced, and, for the most part, differ from those processes applied to more conventional feedstocks in only two particulars, namely, the additional processes required to remove algae from the watery medium in which it is cultivated, and those techniques for extracting lipids from the resulting algal biomass. Often an additional drying and pressing stage is required as well.

1. **Producing biodiesel from algae:** after lipids have been extracted from the algal feedstock the oil will be blended with approximately 10% alcohol, generally methanol, and the resulting mixture agitated by any of several methods. The alcohol molecules will bond with the triglyceride oils where they will replace molecules of glycerine which must be removed from the mixture. Glycerine is considered a fairly low value co-product, but recently techniques have been developed for transforming it into ethanol and liquid hydrocarbons.

2. **Producing ethanol from algae**: algae that happen to produce starch or sugars can serve as feedstocks for more or less conventional ethanol production via fermentation. Attempts have also been made to develop strains of algae that will synthesize ethanol by normal metabolic processes. Yet another family of techniques utilizes initial gasification of the entire biomass followed by conversion of the resulting syngas into ethanol either through catalytic processing or through the agency of certain types of *clostridium* bacteria. Ethanol production from algae has received far less attention than biodiesel production.

3. **Producing hydrocarbons from algae**: a number of firms claim success in this area without disclosing the specifics of their processing technologies. Several techniques are already established for producing hydrocarbons from terrestrial plant biomass, techniques which utilize gasification, pyrolysis, supercritical steam, hydrocarbon solvents, and various catalytic processing methods used to augment all of the above. None of these techniques has really established itself commercially due to the generally poor economics they exhibit compared to conventional petroleum production, but in most cases the cost differential arises from the relatively high cost of harvesting and transporting low energy density biomass not from the capital or operational expenses associated with the actual production plant. But if biomass can be grown as quickly as cheaply as algal biofuel proponents insist, them some of the more established conversion techniques may prove commercially viable for

once. The possibility also exists of developing a strain of algae that can produce hydrocarbons directly. The hanga tree of the Philippines has such an ability, producing a form of natural gasoline in its fruit. The petroleum nut tree is another example of such a terrestrial species. No one to our knowledge has ever derived hydrocarbons directly from algae, however, though the possibility of producing such a strain through genetic modification cannot be ruled out.

E. Economics of production: in this section we attempt to itemize the costs that are likely to be incurred with all of the more established approaches.

VI. Algae and carbon capture: when the Federal Government launched the acquatic plants program for producing biofuels back in the nineteen eighties, global warming concerns were already on the minds of the progenitors. Algal fuel advocates knew that the best way of maximizing algae's growth potential was by providing a CO_2 rich atmosphere, and they assumed that the best way of obtaining such an atmosphere was by capturing smokestack effluents from large point source emitters of CO2. Today a large proportion of algae fuel development companies profess to be seeking relationships with such point source emitters in order to nourish their algae cultures. The assumption behind such schemes is that either the point source emitters themselves will purchase algae bioreactors or that partnerships may be forged between algal fuel companies and industries having large carbon footprints. The cost of capturing the effluent would be at least partially offset by the revenue from selling algal fuel feedstocks or finished fuel products made from such.

A. Two models of carbon management applicable to algal biofuels: the economics of carbon management are still uncertain due to the changing nature of carbon regulations and finance, and due to the fact that in the world's largest economy, namely, the United States, mandated control of emissions is not in place on the Federal level. Needless to say, the situation of the point source emitter is rather different when emissions are capped than when emissions are unregulated.

1. **The unregulated carbon marketplace**: this is the situation within the United States as a whole although individual states and regional associations of states have put regulations in place. In this environment a firm may attempt to limit its carbon footprint to some extent to enhance its public image but will be unlikely to adopt expensive countermeasures apt to put it at a competitive disadvantage. Companies who can sell their emissions however, or otherwise derive positive cash flow from them, might still be inclined to desist from

releasing CO_2 emissions into the atmosphere. If those emissions can be diverted into an algal bioreactor and converted into living biomass that is itself a valuable feedstock for fuel production, then a company's carbon footprint problem might be said to have been solved, and solved in a manner that works to the company's financial advantage if it operates the algae facility itself or if it is provided by some kind of revenue by an independent operator. An added benefit, one enjoyed by the society as a whole, is that the carbon cycle for fuel is closed and any transportation system relying on algal fuel can in theory become carbon neutral.

2. **The regulated carbon marketplace:** where carbon caps and/or taxes are in place then the large point source emitter faces a disincentive. Carbon mitigation becomes a cost of doing business, and if CO2 can be removed from smokestack effluents by an algal biofuel producer, then the emitter may evade penalties or the need to purchase offsets. The algal biofuel producer, if he is independent of the emitter, will have less incentive to offer even nominal payment for the CO2, and might even attempt to charge the emitter the equivalent of a tipping fee since the emitter is facing potentially heavy exactions if he can't dispose of the carbon he generates.

3. **Carbon networks**: some observers envision the develop of a carbon network pipeline system for transporting CO_2 from emitters to various disposal sites such as permanent geological storage, reservoirs intended for enhanced oil and gas recovery, and various industrial plants including algae farms for transforming the gas into other carbon compounds.

B. Economics and effectiveness of algal carbon capture: some prior studies indicate that algae constitutes at best a partial solution for carbon capture even for an individual point source emitter. Here we will explore the issues of capital costs and carbon pricing as well as the manner in which carbon funds might play in this market.

VII. Market Context: algae competes with other biomass feedstocks and ultimately with fossil fuel feedstocks as well.

A. The petroleum incumbency: the petroleum industry, needless to say, is absolutely dominant as a supplier of both liquid transportation fuels and heating oil. This incumbency has never seriously been challenged by any alternative fuel in the past, but, such is the intensity of current concerns regarding cost and supply integrity, that alternatives now receive serious consideration from bulk users. The airline industry particularly is attempting to secure contracts with suppliers of alternative fuels, provided those fuels are compatible with existing aircraft engines and that price guarantees can be provided. Given the many claims on the part of algal fuel developers that they will be able to undersell oil companies on large contracts, the airlines have already been made some investments in support of the still embryonic algal fuels industry.

1. Most major financial institutions that have issued reports on biofuels are skeptical of the potential of biofuels in particular or in general for robbing major market share from the petroleum industry any time soon. Algae itself has seldom been considered as a special case by economists because it is so far from being established at present.

2. We believe that algal fuels can only compete successfully with fossil fuels in major markets if the most optimistic claims of developers in terms of price and yield are met in commercial operations.

B. Algae's other competitors: algae competes with liquid fuels derived from unconventional fossil resources such as coal, natural gas, oil shale, methane hydrates, and peat, as well as with first generation biofuels and the other second generation biofuels.

1. **Unconventional fossil fuels:** the unconventional fossil fuels most likely to figure prominently in energy markets in the midterm are gas-to-liquids and coal-to-liquids fuels. Gas-to-liquids facilities were built out fairly quickly in the opening years of this decade but new construction has stalled. A number of commercial coal-to-liquids plants are currently under construction, principally in North America, but they will not come on line until the next decade. Both gas-to-liquids and coal-to-liquids production methods appear to be economically viable and technically feasible, but the problem of containing carbon emissions remains. If it is not solved cost effectively these industries may be stillborn.

2. Other biofuels: the biofuels groups divides up into first and second generation types.

a. **First generation biofuels** consist of **ethanol** and **biodiesel** made from food crops. These have come under increasing criticism from major financial institutions and economic development agencies and are blamed for rising food prices. We do not see a bright future for these fuels.

b. **Second generation biofuels** are made from waste biomass and specialized fuel crops that can be raised on marginal land. They may take the form of familiar fuels such as ethanol or biodiesel, or they consist of formulations resembling refined petroleum products. Other chemical compositions having no prior appearance in the marketplace could be produced as well. Second generation biofuels, also known as advanced biofuels, include algal biofuels but are not restricted to such. Currently, they are almost entirely experimental and have achieved no real market penetration. Nevertheless, they appear more likely than their first generation predecessors to secure real markets. We believe that natural constraints in the supply of biomass that can be safely allocated to fuel production will limit the role of nonalgal based advanced biofuels, but industries built upon their production and distribution will grow nonetheless.

3. **The electric option**: the possibility also exists that the use of liquid fuels in transportation may decline dramatically and may eventually be restricted to marine and aviation transport. A carbon constrained future may dictate a transportation regime where stored electricity is utilized for traction rather than internal combustion engines within the personal transport realm. New forms of automated electrical transportation systems may find favor as well.

VIII. Company listings with technology and market assessments: scores of companies around the world have announced programs for the development of algal biofuels. Some of these firms are highly specialized, and algae is their sole business. Others are involved in other areas of biofuels as well. Still others are diversified manufacturing and research companies who see algal biofuel as a promising new industry.

A. Firms currently active in algal fuel research.

1. A2BE.
2. Algae Biofuels.
3. Algodyne.
4. Algoil.
5. Aquaflow Bionomics.
6. Aurora Biofuels.
7. Bionvitas.
8. Blue Marble Energy.
9. Bioking
10. Bodega Algae
11. Boeing Aircraft
12. Cellena
13. Chevron-Texaco
14. Circle Biodiesel
15. Community Fuels
16. Diversified Energy.

17. E-On.
18. Eon Energie
19. Energy Farms
20. Enhanced Biofuels and Technologies
21. General Atomics
22. Global Green SolutionsGreenfuels.
23. Greenstar.
24. GS Cleantech.
25. Hansa.
26. Honeywell.
27. HR Biofuel.
28. Imperium Biodiesel.
29. Inventure Chemical.
30. Japan Airlines.
31. Johnson Mathey.
32. Kent Sea Tech.
33. Kwik Power.
34. Menova.
35. Mighty Algae Biofuels.
36. Nanoforce Technologies.
37. New Zealand Airlines.
38. Neptune Industries.
39. OriginOil.
40. Petro Algae.
41. PetroSun.
42. Plenty Energy
43. Sapphire Energy.
44. SeaAg Inc.
45. Seambiotic.
46. Seaquest.
47. Shell.
48. Solazyme.
49. Solena.
50. Solix.

51. Targeted Growth.
52. Texas Cleanfuels.
53. Trident Exploration.
54. Vertical Algae Biofuels.
55. Vertigro.
56. XL Renewables.

B. Investment groups with involvement in algal fuels.

IX. Summary: our conclusion, tentative at best, is that algae is being oversold as fuel feedstock today. We believe that with the proper infrastructure and nutrients reasonably high yields can be obtained on marginal land, and that open pond or hybrid systems appear to exhibit the best economics at present. Optimized algae farms are likely to compare with the highest yield conventional oil feedstocks and may provide superior economics in some instances. We believe that algae cultivation in artificial environments is apt to be geographically restricted, however, and algae may remain an exotic fuel feedstock rather than constituting the norm as many advocates suppose. Schemes for utilizing species growing in the wild, such as macro-algae occurring close to shore or algal blooms in coastal area, may prove out on a small scale but are unlikely ever to provide the basis for a major industry.