The Ethics of Adoption and Development of Algae-based Biofuels

Report prepared by the following person:

Lindsay McGraw

Co-chair of Working Group 9

Case Study 1 of the Adoption and Development of Energy Technologies (State of the Art Review)

Prepared under the outline framework of WG9 in the Ethics of Climate Change in Asia and the Pacific (ECCAP) Project, RUSHSAP, UNESCO, Bangkok

14 December, 2009

Comments to Lindsay McGraw (l.mcgraw@unescobkk.org) and Dr. Darryl Macer (d.macer@unescobkk.org)

Table of Contents[1]

1. Introduction

2. Algae-based Biofuel Technology
2.1 Introduction to Using Algae as a Feedstock
2.2 Previous Research into Algal Biofuels
2.3 State of the Art and Uncertainty
2.3.1 The State of Algal Biology
2.3.2 Feedstock Productivity and Cultivation
2.3.3 The State of Harvesting and Dewatering Technologies
2.3.4 The State of Extraction and Fractionation Technologies
2.3.5 Nanotechnology
2.3.6 Main Energy Products
2.4 Sector of Use
2.5 Steps Towards Development and the Future

3. Environmental Constraints and Socio-environmental Implications
3.1 Land
3.1.1 Fossil Fuel Displacement Potential
3.1.2 Scale of Operations and Impacts
3.1.3 Ecological Concerns
3.2 Water
3.2.1 Requirements for Production
3.2.2 Sources and Sovereignty
3.2.3 Opportunity for Wastewater Remediation
3.3 Climate
3.3.1 Requirements
3.3.2 Global Warming
3.3.3 CO_2
3.4 Other Resources and Resource-related Issues
3.5 Safety and Toxicity of Products and Bi-Products
3.6 Waste and Pollution

4. Issues in Research and Development of the Technology
4.1 Uncertainty
4.2 Contractor Consultations and Environmental Impact Assessments
4.3 Scale Up Technology
4.4 Costs and Raw Price of Energy
4.5 Public and Private Sector Investment and Partnerships
4.6 Current Policy Incentives
4.7 Access to Technology, IPRs and Technology Transfer
4.8 Siting and Plant Construction

5. Issues in Energy Production and Distribution
5.1 Resources

[1] This outline is a generic outline being used for case studies in WG9. Further case studies are invited.

5.2 Constancy of supply
5.3 Distribution of Energy
5.4 Decommissioning and Disposal

6. Socio-economic Impacts and Population Well-being
6.1 Countering Adverse Effects of Oil Price Increases on the Poor
6.2 Global Climate Change, Renewable Energy, and Livelihoods
6.3 Promoting Sustainability
6.4 National Impacts
6.5 Local Effects and Access to Energy
6.6 Security/Conflict and Independence

7. Potential for Algae-based Biofuel Development in Asia-Pacific

8. Conclusion

9. Summary Matrix of Ethical Impacts

10. References

11. Acknowledgments

12. Appendix

1. Introduction

Around the world there is a heightened awareness that commencement of immediate transitioning from fossil-based fuels to renewable sustainable energy sources is needed to lessen the impacts of the impending energy crisis as fossil fuel prices increase, reserves deplete, and environmental impacts, including climate change, accumulate. Energy is inextricably intertwined with the state of the environment, society, and the economy, making choices regarding energy development extremely challenging for decision-makers.

Energy choices must be made, however, with critical implications to the welfare of present and future generations, and the state of the environment and the Earth's life support systems. The detectable shift from anthropocentric utilitarian approaches that do not consider the protection of life forms other than those that are deemed useful to humans to an ecocentric perspective has accompanied the movement towards ecological ethical guidance providing for approaches that are better aligned with the tenets of sustainability. Whereas the ties between energy systems and economic growth have long been identified, the linkages between energy systems and social development, health, and the environment have only been brought to light more recently. Today, holistic approaches are expected for decision-making regarding energy choices and are expected to incorporate a host of broad factors resulting in much more than just a technical assessment.

A central ethical question to any particular energy technology or project is whether it will provide sufficient energy to meet the requirements to maintain and advance the long-term well-being and socio-economic progress of the entire community. How does this technology measure up compared to other alternatives? This case study is of a particular energy technology, reviewing the science, economics and ethics.

If the answer to the above question is positive for a particular energy technology then we have an alternative solution and option to meeting our energy challenges. No one technology has provided a clear answer for every situation or community. Rather, each energy technology application to a given situation is associated with various tradeoffs cutting across social, economic and environmental spheres, and temporal dimensions that remain difficult to assess due to uncertainties. In addition, public opinion and the formulation of priority schemes depend on values related to both science and culture. In determining the ethics surrounding algal biofuels, it is noted that a stand-alone analysis of the current state of the science and technology to assess the potential to provide sufficient energy is insufficient in itself for assessments of ethical implications relating to energy security, well-being and socio-economic progress of all stakeholders and decision-making.

As members of ecosystems and urban ecosystems, the ethical choice simply cannot be made without considering our ethical responsibilities towards all members of Earth's life community. Currently being one of the most daunting challenges facing human society, the search for appropriate energy solutions is more than a matter of technical feasibility as we are already stretching the resilience of the environment through its overuse by Earth's human population resulting in profound effects on the crucial global life systems. These changes to the landscape, water, climate and global systems in the pursuit of energy and energy use for production have numerous ethical implications in terms of present and future human and non-human generations. In the advent of uncertainty, we can acknowledge some advantage to err on the side of caution in terms of environmental and societal effects, however, the ethical, environmental, economic, and political ramifications of the analysis, and the precautionary principle add complexity to the energy problem.

How best does the production of algal biofuels fit into the overall energy challenge when attempting to balance all the ethical and moral dimensions with scientific, technological, and economic analyses? Would adoption of this technology affect the imbalance between energy consumption in industrialized countries versus developing countries by exacerbating or improving current energy equity injustice? Each energy technology has its strengths and weaknesses which need to be analyzed in terms of human values, and herein is an attempt to bring to light some of the issues that may come into play affecting the ethical dimensions that should influence the choice to adopt and develop algal biofuels.

This paper aims to identify and discuss the pertinent ethical issues affecting the adoption and development of algal biofuels on different scales through the understanding of the technology itself and where uncertainties and risks lie, and the socio-economic and environmental implications that may result from adoption of this technology under different circumstances. The identification of situations that may present risks to society and the environment as a result of advances in this technology and comparisons of these results with other technologies may help elucidate a legitimate and ethical path towards sustainable energy development. Though it is not sufficient to solely base decisions on the understanding of the state of the science and technology, it is crucial to assess these capabilities and the uncertainties embodied by the technology and how it may serve, or not, to satiate the energy demand of society without undermining the environment while upholding a host of desirable, progressive, and necessary goals for human society.

2. Algae-based Biofuel Technology

2.1. Introduction to Using Algae as a Feedstock

Motivated by the acknowledgment of depleting fossil fuels and the need to find new clean energy sources, interest has been generated in the further research and development of algae farms for the cultivation of microalgae which could then be harvested and/or processed into a number of energy products. The discovery of the fact that certain strains of microalgae contain upwards of 50% dry weight lipid (oil) content gained prominence during the Aquatic Species Program in the U.S., an effort prompted by the 1970s oil embargo which saw drastically increased oil prices, disruption of supply, and recession emphasizing the necessity to increase energy security. To date, there is still no commercial production facility for algal biofuels, however, there is a concerted effort with many stakeholders participating to produce a strategic plan for the development of an algal biofuels industry.

Microalgae are unicellular plant-like organisms that, through photosynthesis, convert solar energy into chemical energy and store this energy in the form of lipids, carbohydrates, and proteins. These cellular constituents can be used to derive a host of energy products including biodiesel, gasoline, and ethanol, these being of particular interest as they can be used as a transportation fuel, thereby curbing the dependency on foreign oil and increasing energy security, while being less environmentally detrimental than other fuels currently in use. In addition to these fuels, other energy products such as methane, biohydrogen, and other hydrocarbons can be elicited and produced from algae.

The general method of algal oil-based biofuel production begins with the cultivation of algae, which can be done in fresh or salt water, to significant yields, followed by harvesting and dewatering processes which result in a thick algal slurry. Extraction of the oil has typically been done by mechanical press after drying, however, research into a variety of extraction techniques in the laboratory are currently being explored, including genetic engineering such that algae excrete oil into the growth medium. Depending on the desired end product, the oil can be used directly after extraction or it can be refined into a different form.

Algaculture, the term used for farming algae, includes the cultivation of algae in open-air raceway ponds or vessels termed photobioreactors, and must take into account that high algae growth requires environmental conditions such that light, salinity, and nutrient levels must fall within a fairly narrow range. The determination of particular optimal ranges of physical factors that affect the growth of algae are strain specific and paramount to successful cultivation. Adding to complexity, oil accumulation in algae tends to be particularly high at times of environmental stress such as low light levels or limited nutrient availability which triggers storage, at the expense of higher biomass production rates.

Harvesting requires collecting and removing algae from the water in which it grows through different methods such as filtration, flotation, chemical flocculation using compounds such as aluminum sulphate or ferric chloride, or through the use of a centrifuge. The algal slurry which is removed is of a fairly dilute percentage of algae, between 5 and 7% total suspended solids. Before oil is extracted from algae, the algal mass is often dried in order to use a mechanical press to expel the oil which remains intact.

The main biochemical constituents of algae, which are lipids, carbohydrates, and proteins, can all be converted into different fuel forms, however, lipids have the most potential in terms of energy content. Depending on the desired final energy product, different processes will need to be undergone. For biodiesel, the primary processing steps will be extraction and transesterification, whereas for ethanol it will be fermentation, for methane it will be anaerobic digestion, for hydrogen it will be gasification, and for solid biomass it will be drying.

The final product desired and chosen will dictate which algal strains are appropriate as a feedstock and which conversion processes are needed as all steps of the process are interrelated. The significant work needed in assessing feedstock characteristics is highlighted here as an upstream boundary determining the processes and subsequent yield downstream.[2] The magnitude and complexity of determining optimality for algal biofuels are substantial as brute research in systematically analyzing algal strains keeping in mind the grander multivariable system is not a trivial task. In addition, understanding must be forged through innovative biological methods to uncover unknown particulars of biological mechanisms.

In the U.S., all the petroleum feedstock that enters a conventional petroleum refinery must leave as marketable products, and this conservation law also should be enforced for algae refineries of the future if they are to achieve significant market penetration, displace fossil fuels, and minimize adverse environmental impacts. Devising techniques that minimize waste through recycling is essential to protect the environment and yields benefits in terms of efficiency of energy use within the system. When full-cost accounting is utilized, the synergistic relationship between the environment and society is reflected in the economy. The protection of the environment, having positive effects on society, becomes the economically sound way to proceed, which also benefits society.

In addition to being less environmentally destructive than fossil fuels, the processes and products resulting from algal biofuel production embody some desirable characteristics that, when compared to other similar biofuel feedstocks, place algae at an advantage and an ethically strong choice for development. These include:

1. Algae have a very high theoretical per unit area yield compared to other feedstocks and fast algal growth rate.
2. Algae cultivation can be located on non-arable land including desert and other marginal lands.
3. Algae is not a significant food crop and therefore cultivation of algae for biofuel does not aggravate the debate of crops for food or fuel.
4. Many algae species thrive in saline water and therefore do not necessitate the input of fresh water for cultivation operations.
5. Algal biofuels are carbon neutral and do not exacerbate global warming.

[2] U.S. Department of Energy, National Algal Biofuels Technology Roadmap, 2008

6. Algal biofuels provide the opportunity to incorporate socially useful services such as wastewater remediation and CO_2 recycling.
7. Algal biofuels of the non-oxygenated variety, such as biodiesel, can use existing fuel distribution and delivery infrastructure more readily and end user equipment will require little or no modification.
8. Biorefinery and closed loop concepts encourage nearly self-sustained modular systems with solar energy and CO_2 from the system as inputs that have very little waste generated resulting in a host of energy and marketable products. Some of the energy is looped back into the system continuing the algae production.

An important consequence of this set of characteristics is that the agricultural land and fresh water are not needed for the development of algal biofuels and thus it does not aggravate food or fuel debate. More broadly, successful development and deployment of an algal biofuels industry counters food and energy insecurity. Human security, conceptually incorporating the freedom from fear, freedom from want, and freedom from cruelty and suffering[3] ties closely to energy accessibility, availability, and affordability. Energy deprivation needs to be reduced in order to decrease poverty which in turn increases human security. The possibility of such a high yield per unit area and high growth rate is particularly significant when considering the development of algal biofuels in order to displace fossil fuels for transportation. Biofuel from algae, in particular biodiesel from algae, it has been noted, could completely displace global demand for fossil fuels for transportation.[4]

Another element of human security that has risen dramatically is climate security. Climate security, in turn, affected by energy choices, requires the assessment of the impacts that algal biofuel development will have on the state of the environment and global warming. Combustion of algal biofuels will result in no net increase in CO_2 emissions and may act to slow CO_2 accumulation in the atmosphere. The integration of several conversion technologies could be incorporated into the biorefinery concept such that a combination of fuels such as biodiesel, green diesel, green gasoline, aviation fuel, ethanol, and methane as well as valuable co-products including oils, proteins, and carbohydrates could be produced at one facility. The option to use marginal lands rather than arable productive land provides for a realistic new option for desert management.[5]

Taking a more detailed look at the scientific and factual particulars of the above claims and their consequent implications on the bio-physical and socio-economic systems would serve as a foundation with which to compare and contrast algafuels with other energy technologies. A comprehensive thorough assessment of this nature, however, is a challenge of massive scale as such a task amounts to the analysis of all of the Earth's bio-physical systems and their interplay with human-constructed systems over variable temporal scales. Sophisticated trend analysis and modeling programs with insightful interpretation is required to allow for the possibility of making better choices regarding energy, yet perfect knowledge amounting to precise

[3] Acharya, International Conference on Human Security in East Asia (16-17 June 2007 Seoul, South Korea

[4] Chisti, 2007**,** http://www.orau.gov/algae2008/breakouts/chisti2007genrevalgaebd.pdf

[5] http://www.desertbiofuels.org/projects.html

prediction of the future will elude humans indefinitely in such analyses of stochastic phenomena. We can, however, identify that some decisions are decidedly more likely to have unfavourable outcomes whereas other decisions have a higher probability of bringing about the results we would like.

Often referred to as a second generation biofuel, algal biofuels, as a relatively new innovation, have been confirmed scientifically feasible, however, the scalability of current operations has proven to be an economic conundrum of significant challenge. Significant opportunities lie in the possibility of combining wastewater or other sources of nutrients to feed the algae and also obtaining CO_2 required from polluting industry to mitigate emissions. Support for the development of this technology has been gaining momentum within the international community and unprecedented financial capital is being invested in spite of the hurdles for mass production. Strides in biotechnology and nanotechnology[6] are bringing new solution ideas to the forefront and are likely to play a major part in making the technology economically viable. Research indicates that the land, water, and CO_2 resources available can support substantial biodiesel production and CO_2 savings.[7] In addition, analyses show that the land, water, CO_2 and other required resources available could easily support algal biofuels technology to produce substantially more biodiesel than any existing oilseed crop could provide.[8]

2.2 Previous Research into Algal Biofuels

The 1970s energy crisis spawned a new program in the U.S. called the Aquatic Species Program[9] which was originally intended for CO_2 mitigation research as it had been noted that aquatic species such as algae have a very high solar energy conversion ratio due to the high rate of photosynthesis that occurs. Subsequently, a relatively high amount of CO_2 is also taken out of the atmosphere. This comprehensive research confirmed that algae are able to convert 6% of the energy obtained from the sun, a relatively high proportion, into a usable energy form demonstrating possible appropriateness as an effective energy source. The theoretical maximum conversion ratio is approximately 11%.[10] At that time, it was noted that high lipid content was present, often over 30% and sometimes even 50%, in many algae species.

The Aquatic Species Program ran from 1978 to 1996 and is marked with scientific discoveries in the molecular biology and genetics of algae, a topic of relatively isolated interest with few researchers contributing to the area. For example, researchers were able to isolate the enzyme Acetyl CoA Carboxylase (ACCase) from a diatom which catalyzes a key metabolic step in the synthesis of oils in algae. The gene that encodes for the production of ACCase was isolated and cloned. This was the first report of the cloning of the full sequence of the ACCase gene in a photosynthetic

6 http://ecoworldly.com/2009/04/23/nanotechnology-to-aid-the-commercial-viability-of-algal-bio-fuel-production/

7 Chetri and Islam, Towards Producing a Truly Green Biodiesel

8 NREL, Aquatic Species Program

9, 8 NREL, Close out report: A Look Back at the Aquatic Species Program, http://www.nrel.gov/docs/legosti/fy98/24190.pdf

10 Putt, 2007

organism and from which researchers were able to develop the first successful transformation system for diatoms providing the tools and genetic components for expressing a foreign gene. The program enabled the first experiments in metabolic engineering as a means of increasing oil production. Researchers configured algae to overexpress the ACCase gene, hoping that increasing the level of ACCase activity in the cells would lead to higher oil production, however, increased oil production was unable to be demonstrated.

In addition, the Aquatic Species Program constructed outdoor ponds that demonstrated high efficiency in the utilization of CO_2. Careful control of pH and other physical conditions for introducing CO_2 into the ponds allowed for greater than 90% utilization of injected CO_2 highlighting the potential to mitigate CO_2 emissions with algae cultivation. The outdoor ponds were operated for a full year with a reasonable amount of infiltration of other species and relative control over the growth of algae. The experiment demonstrated that maximum daily yields of $50 g/m^2$ were achievable[11] and the importance of variables such as temperature conditions to yield such that temperature control equipment would likely be needed in many, if not all major installations.

The breadth of the research yielded advances in the science of manipulating the metabolism of algae that provide a platform from which to work in more current research.

2.3 State of the Art

As of today, it has been shown that it is scientifically and technically possible to derive the desired energy products from algae in the laboratory. The question lies, however, in whether it is a technology that merits the support and development to overcome existing scalability challenges and make it economically feasible.

The re-emergence of enthusiasm towards algal biofuels production, particularly as a transportation fuel, has driven significant advances in the science required at the respective steps of fuel production including algal biology, harvesting and downstream processing technologies. To date, the economics of algal biofuel production is passionately debated given the uncertainty in all stages of the science and technology of production in addition to the unpredictability of the economy, however, inclusion of externalities into consideration may tip balances within the argument.

Every step within the process from algal strains, harvesting methods, to oil extraction can and needs to be improved and refined. Research by big and small oil companies, universities, alternative energy companies, and governments into the numerous ways these fuels can be produced is resulting in new understanding through cooperation and participation that makes the prospect of an economical large scale system a more realistic venture. With the big push from business, governments, looking after the well-being of their people, are now seriously considering what outcomes would be generated from this technology.

---

[11] NREL, Close out report: A Look Back at the Aquatic Species Program.

2.3.1 The State of Algal Biology

Before algal biofuels can become economically feasible on the commercial scale, significant advances must be made in the understanding of algal biology and the mechanisms of growth, lipid production pathways, and photosynthesis in algae which could be instructive for the manipulation of biolipid productivity in addition to increasing biomass. Algal biology had previously been a relatively obscure field but many scientists are now drawn to learn more about these organisms which bodes well for the onset of many more breakthroughs in the science.

Microalgae use solar energy to convert CO_2 and water into organic macromolecules, namely carbohydrates, proteins and lipids. Triacylglycerols (TAGs) are the main storage compound in many algae under stress conditions, such as high light or nutrient starvation. Certain algal species naturally accumulate large amounts of TAG (30-60% of dry weight) and exhibit photosynthetic efficiency and lipids/oil production potential that is higher than terrestrial crop plants.[12] Photosynthetically, microalgae can convert 3-8% of solar energy into biomass whereas observed yields for terrestrial plants are about 0.5%.[13] Algae are able to utilize the CO_2 from the flue gases, nitrogen (N) and phosphorus (P) from wastewaters, and energy from sunlight in the photosynthetic process to create carbohydrates. The stored energy in the carbohydrates is utilized to run cell processes that sequester carbon into tissues in the form of proteins and lipids.

At this time, it is believed that the major pathway for the formation of TAG in plants and algae involves de novo fatty acid synthesis in the stroma of plastids and subsequent incorporation of the fatty acid into the glycerol backbone, leading to TAG accumulation. In algae, the de novo synthesis of fatty acids occurs primarily in the chloroplast. However, the regulation of synthesis of fatty acids and TAG in algae is poorly understood at the physiological, biochemical and molecular biological levels. As a result, the lipid yields obtained from algal mass culture efforts performed to date fall short of the high values (50-60%) observed in the laboratory, adding to the problem of achieving economic algal oil production[14].

Theoretically moderate estimates of productivity have not even been able to be confirmed in a laboratory setting let alone a field setting. The lack of understanding of TAG pathways is the root cause of lack of expected yield production. As a result, scientists are attempting to determine whether algae may have an alternative, or multiple pathways for TAG production and accumulation. Work is also being done to sequence the genome of several algae species including a large-scale EST sequencing of different oleaginous algae (such as *Pseudochlorococcum* sp. and *Haematococcus pluvialis*) under different cultural conditions.[15] Such studies will increase knowledge about the differential expression of genes under different environmental conditions and their associated oil production levels. Understanding the algal proteome, the set of expressed proteins of a genome at a given time under specific conditions, will

---

[12] Hu, 2008.

[13] Li et al., 2008. Biofuels from microalgae.

[14] Hu et al., 2008; Sheehan et al., 1998

[15] U.S Department of Energy, Biomass Program, National Algal Biofuels Technology Roadmap

provide information about photosynthetic carbon partitioning and lipid synthesis in algae.

There are many directions in which to explore in order to determine how algal metabolism works and how to best increase oil productivity within a cell. Through genetic manipulation, algae could be metabolically engineered to produce higher proportions of oil. Approaches that have been discussed include random and targeted mutagenesis and gene transformation. The cloning and transforming of genes that influence lipid synthesis or growth robustness in algal strains deemed appropriate for mass cultivation may improve the overall performance and sustainable production of TAG or other lipids[16].

2.3.2 Feedstock Productivity and Cultivation

Increasing algae bioproductivity makes for the greatest opportunity in terms of cost reduction.[17] Analysis of algal strains in order to identify appropriate strains will require a coordinated effort by the research community as there are at least hundreds of thousands of algae species. [18]

Several parameters are required in order to achieve a high feedstock productivity system. Algae cultures often go through blooms of high growth rate followed by crashes in population. A stable productive culture is required. Productivity analysis requires a system of standardized metrics in order to monitor environmental parameters to increase productivity. In addition, nutrient and water conservation and recycling are required.

To date there is no standardized equipment for algae farms for the production of algal biofuels. The two common design categories are open raceway ponds and photobioreactors with numerous hybrid designs that include some components of both systems.

Open raceway pond installations are presently the most common technology for algae farming. They are cheaper than photobioreactors, however, they allow the infiltration of other low-yielding species and non-yielding species. They are expansive shallow ponds and as such, light is in the form of natural solar radiation and mixing is required in order to disperse nutrients, and algal individuals.

Photobioreactors come in many shapes and forms and essentially are any enclosed vessel for growing algae. They theoretically should be higher yielding than open raceway ponds, but high yields have been unattainable to date. They are much more expensive than raceway ponds though they have the added advantage that they allow for the control of the growth medium including light and infiltration of other species. Some designs use natural light whereas others use artificial light for continual growth.

---

[16] Hu et al., 2008; Sheehan et al., 1998.

[17] U.S. Department of Energy, Biomass Program, National Algal Biofuels Technology Roadmap

[18] Please see http://botany.si.edu/projects/algae/introduction.htm
and http://www.algaebase.org/ for algae information, links, and algal species databases.

Every company has its own designs of its system and to date there has no commercial success but due to so many models, there are many possible improvements within the numerous systems.

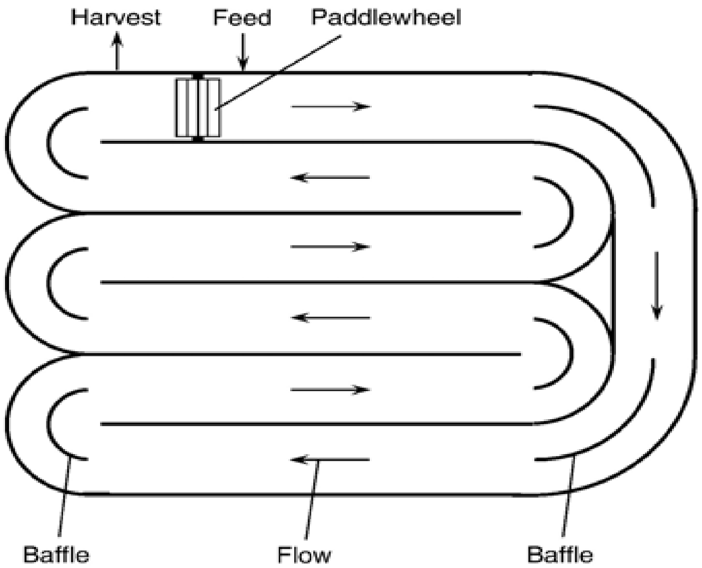


Figure 1: Raceway Ponds[19]

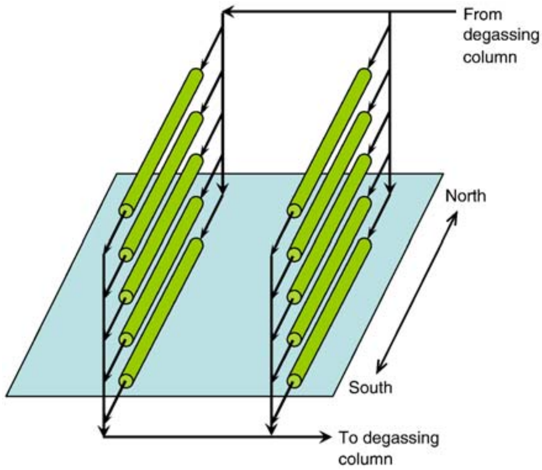


Figure 2: Photobioreactors lined in parallel maximizing natural light capture [20]

[19] Source: Chisti 2007 – Biodiesel from Microalgae
[20] Ibid

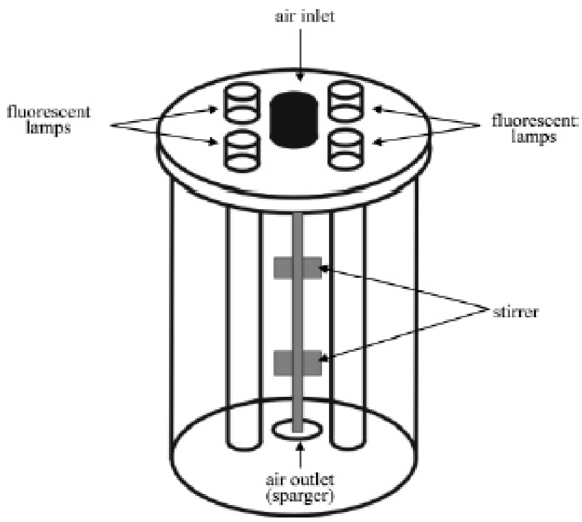


Figure 3: Photobioreactor design[21]

Table 1: Comparison of photobioreactor and raceway production systems[22]

Comparison of photobioreactor and raceway production methods

Variable	Photobioreactor facility	Raceway ponds
Annual biomass production (kg)	100,000	100,000
Volumetric productivity (kg m^{-3} d^{-1})	1.535	0.117
Areal productivity (kg m^{-2} d^{-1})	0.048 [a] 0.072 [c]	0.035 [b]
Biomass concentration in broth (kg m^{-3})	4.00	0.14
Dilution rate (d^{-1})	0.384	0.250
Area needed (m^2)	5681	7828
Oil yield (m^3 ha^{-1})	136.9 [d] 58.7 [e]	99.4 [d] 42.6 [e]
Annual CO_2 consumption (kg)	183,333	183,333
System geometry	132 parallel tubes/unit; 80 m long tubes; 0.06 m tube diameter	978 m^2/pond; 12 m wide, 82 m long, 0.30 m deep
Number of units	6	8

[a] Based on facility area.
[b] Based on actual pond area.
[c] Based on projected area of photobioreactor tubes.
[d] Based on 70% by wt oil in biomass.
[e] Based on 30% by wt oil in biomass.

Comparing yields from different cultivation systems can only be done on a theoretical basis as no large scale for high oil-yielding varieties of algae exist. However, it is illustrative to consider the potential both systems provide in order to estimate optimal capacities and land requirement for expected demand. Table 1 demonstrates that the same amount of biomass yields (100000 Kg/annum), should be able to be produced on a lesser amount of land by photobioreactors than for open raceway pond systems due to a higher volumetric productivity. It is also interesting that the oil yield for the

[21] Carvalho, 2006
[22] Chisti, 2007

same amount of biomass produced differs significantly (based on 30% oil wt in biomass, photobioreactors: 58.7 m^3ha^{-1}, raceway ponds: 42.6 m^3ha^{-1}), as there is an approximately 30% higher oil yield with photobioreactors according to this study. The environmental controls available to be used in a photobioreactor system in order to produce optimal light, temperature, and nutrient conditions should enable higher oil yield from the algae. Currently, however, the cost of photobioreactor cultivation processes continue to make for a much more expensive unit of fuel than raceways.

2.3.3 The State of Harvesting and Dewatering Technologies

Difficulties arise when attempting to separate and recover algae grown due to the fact that microalgae are typically very small (5-50 micrometres) and they form stable suspensions due to their negatively charged surfaces. Suspensions tend to be relatively dilute, adding to the difficulty in harvesting algae.

At this time, the harvesting step of algae is proving to be a challenging step both energetically and cost-wise.

2.3.4 The State of Extraction and Fractionation of Microalgae Technologies

If the whole algal cell is not going to be used for the refinement of biofuels, then certain constituents will need to be extracted. Depending on the constituent required for the final energy product, different techniques will have to be employed. The fractionation and extraction of oil from algal cells along with oil purification are particularly cost-intensive steps. Numerous techniques have evolved for the cellular fractionation and extraction of oil, however, these techniques have not made it out of the laboratory yet.

Methods being explored include:

1) Direct Transesterification of Lipids into FAMES Using Organic Solvent Systems
2) Mechanical Disruption (i.e., Cell Rupture)
3) Subcritical Water Extraction
4) Accelerated Solvent Extraction
5) Supercritical Methanol or CO_2
6) Milking

2.3.5 Nanotechnology

The American Chemical Society recently announced that the first economical process to make biodiesel out of algae oil has been developed and this includes the use of nanotechnology and catalysis.[23] Advances in nanotechnology are providing new routes of problem-solving for algal biofuel hurdles that had not been previously considered. Currently, researchers at the Ames Laboratory of the U.S. Department of Energy are growing several strains of algae to assess a "*nanofarming technology that uses sponge-like mesoporous nanoparticles to extract biofuel oils from the organisms*…*The new methods involve the use of mesoporous nanoparticles, which*

[23] American Chemical Society http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_ARTICLEMAIN&node_id=222&content_id=WPCP_012558&use_sec=true&sec_url_var=region1&__uuid=

extract the oil for processing from the living plants, without the need of the latter being destroyed in the process. This would considerably reduce the costs associated with this industry and also provide a boost for those seeking to enter it. The sponge-like materials are capable of collecting only small amounts of oil, but their numbers will be very large. Once the collection process is completed, a catalyst will be used to produce the biodiesel."

With the rapid development of nanotechnology, it should be expected that more novel ways will be devised to improve the efficiency of extraction processes in algae.

2.3.6 Main Energy Products

Because liquid transportation fuels used today are mainly derived from imported petroleum for many countries, products from algae that are able to displace these fuels would provide for benefits environmentally, socially, and economically. These products include biodiesel, jet fuel, gasoline, and ethanol which are all being researched as products from algae. This report will focus mainly on biodiesel as the energy product from algae, however, in terms of construction of farms and cultivation of algae, implications remain similar for other energy products. Other important energy products include gaseous compounds such as hydrogen and methane, conventional liquid hydrocarbons and oxygenates, and pyrolysis oil and coke.

Main energy products and their pathways are shown in Figure 4.

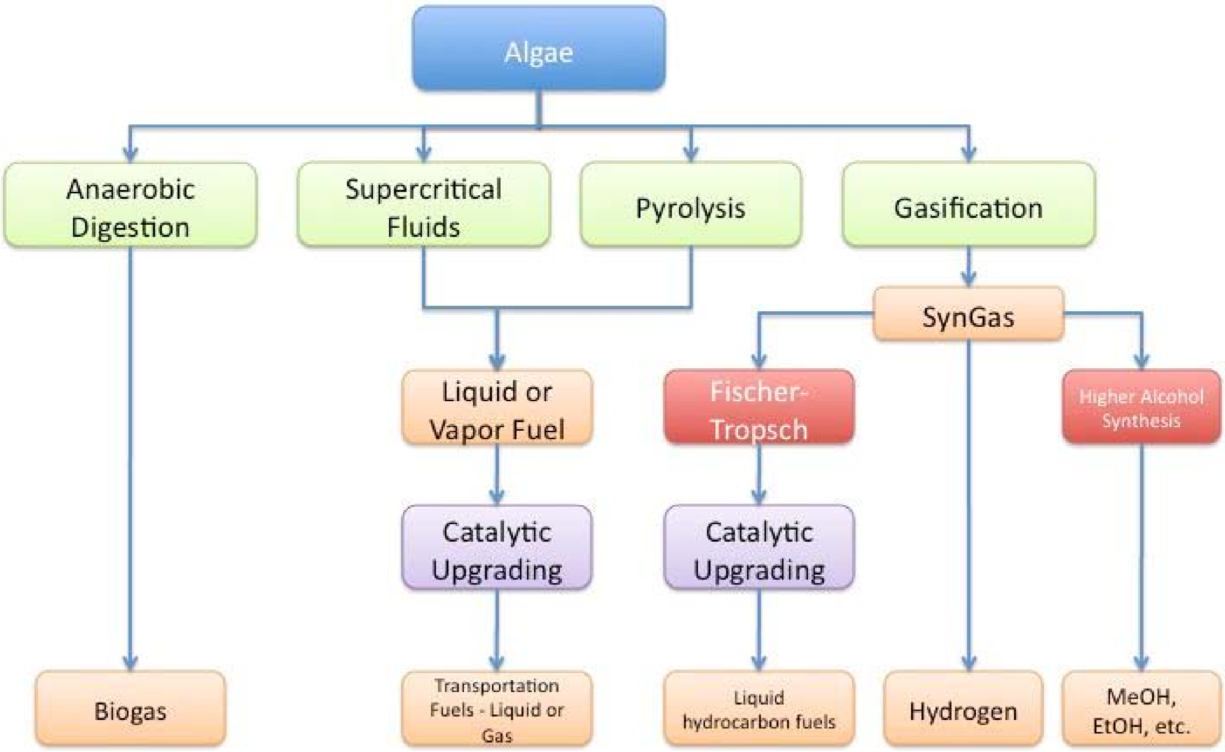


Figure 4: Conversion technologies using the whole algal cell
Source: DOE

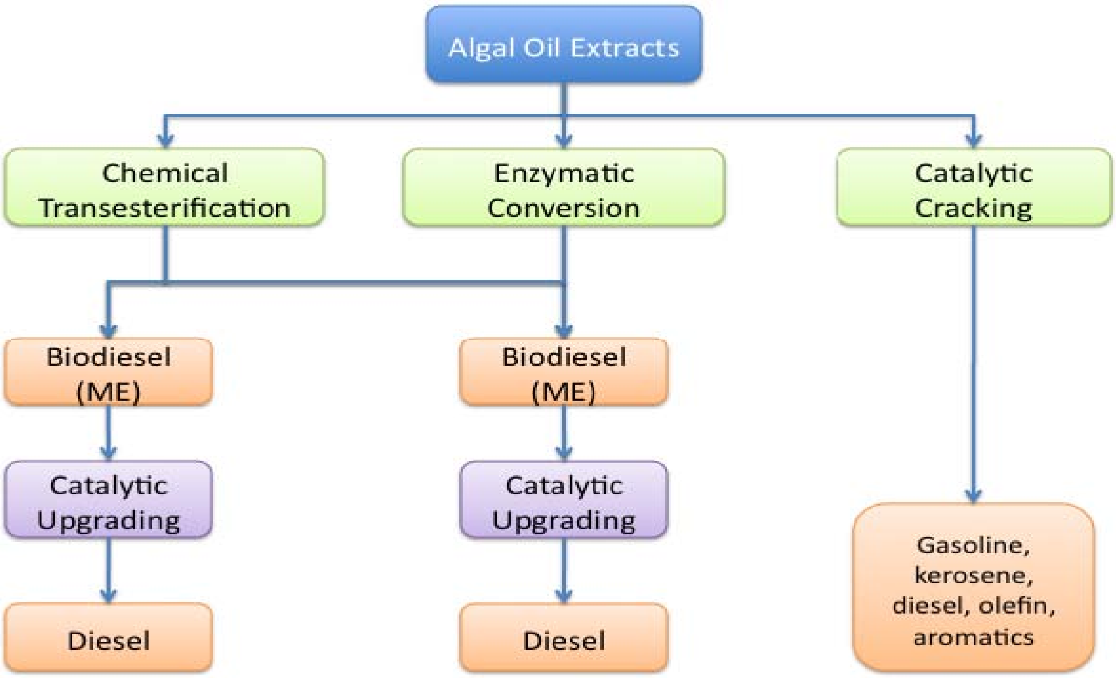


Figure 5: Conversion technologies using algal oil extracted from algal cells
Source: DOE

2.4 Sector of Use

The major sector being considered to use the biofuel is transportation, particularly the aviation industry. Over the past 5 years, interest in the development of algae-based biofuels has been intensifying within many sectors. The aviation industry is showing substantial enthusiasm and support for the biofuel industry as they have pledged to decrease their 3% contribution[24] to global warming by declaring to work towards carbon-neutral growth with aspirations to become carbon-free. The aircraft makers, Boeing Commercial Airplanes, for example, state that their interest in algal biofuels resides in the fact that algae is not part of the food system and therefore, will not exacerbate price increases for food items such as corn and wheat.[25] [26]

---

[24] IPCC has indicated the aviation industry is contributing 3% of climate change inducing greenhouse gases.

[25] (http://www.reuters.com/article/environmentNews/idUSL2229696620080422 Airline industry aims for 'carbon neutral growth')

[26] In January, 2009, Continental Airlines tested algae- and jatropha-based biofuels in a Boeing 737 commercial jet with one engine operating on a 50-50 blend of biofuels and conventional jet fuel, and the other using all conventional fuel for comparison. Six-hundred gallons of algae biofuel produced by Sapphire Energy, an algae biofuels company, were dropped in with no modifications required to the aircraft, to contribute to 2.5% of the fuel in one engine. A number of tests were conducted in flight with encouraging results. The engine using the biofuel mix burned 3600 pounds of fuel, a saving of 2.7% fuel as compared to the other engine which burned 3700 pounds of conventional jet fuel. These encouraging steps taken towards making algae biofuels a realistic option have in part been spurred by large investments by high-profile venture and investment partners. Sapphire Energy is attempting to commercialize the synthesis of energy that is chemically identical to petroleum which would allow for the development of “drop in” fuels for the transportation industry.

The U.S. military has put USD35 million towards the development of algae-based biofuels to make algae-based jet fuel commercially and technically feasible and to develop a replacement for its Jet Propellant 8 (JP-8) fuel for military jets.

Many algal biofuel startup companies are finding support and interest in collaboration with large multi-national companies. In June 2009, Algenol, an algae-based company and Dow Chemical Co., the largest chemical maker in the U.S., announced a partnership to build a USD50 million pilot plant at Dow's industrial complex in Texas that will test Algenol's ethanol producing technology on a large scale.

2.5 Steps Towards Development and the Future

Considering that the production of algal biofuels is an industry in its infancy, and that there is no production facility beyond research scale, careful planning of research and development resources and deployment with appropriate policy is necessary to bring the concept to fruition. Scientists warn that it may be a decade before the economics become favourable according to the state of the technology and advancements required, and they caution that those in business need to be responsible in their information-reporting not to embellish current status of operations and algae yield. Advances in these areas along with complementing policy choices for distribution and utilization schemes will improve the economics of algal biofuels production. A viable algal biofuels strategy can be constructed only after such details are clarified.

Information-sharing could significantly decrease duplication of research caused by uncertainty and reinforce efficiency. In the field of synthetic biology, for example, MIT has created a database for genetic parts, representing functional units, which to date is completely open for anyone to use.[27] Such an idea increases the resources available to scientists and enables them to build upon work done rather than starting from scratch which could benefit algae researchers. However, examples such as this are few, as numerous patents abound which have been criticized as likely to impede the development of the field and applications.[28]

Given the current economically unviable state of algal biofuel production, there are many who doubt the potential of such a technology. To better predict whether this technology is likely to be successful, we can analyse the historical development of other alternative energies' successes and failures, though high investment indicates an increase in the probability of a technology making market penetration. Alternative energy technologies are repositories of significant investment today, but are not immune to an overly rose-coloured outlook such that possible better choices are being clouded by vested interests, resulting in ripple effects such as policies that drive energy choices that may not be the most desirable.[29] However, it must be noted that this tendency during energy transitions may be simply a result of the fact that costs and benefits for different stakeholders differ when accounting for time frame of

[27] Registry of Standard Biological Parts: http://parts.mit.edu

[28] Please see Section 4.6 Access to Technology, IPRs and Technology Transfer

[29] http://www.renewableenergyworld.com/rea/news/article/2008/09/the-elephant-under-the-rug-denial-and-failed-energy-projects-53467, "The Elephant Under the Rug: Denial and Failed Energy Projects, Thomas R. Blakeslee

analysis.[30] In addition, it has been noted that "hype" of developments of new technologies by those seeking investment into the technology, and corresponding opposition by those involved in incumbent technologies is typical.

Renewable energy technologies have the tendency, as does technology in general, to decrease costs over time (See Figure 6). This trend is becoming more apparent for algal biofuels as well, as fossil fuel prices increase and as real environmental costs due to externalities of the system are included in economic equations. Historically, there have been relatively few true energy technology failures that saw large investment made, rather, technologies continue to be improved, even if they are not highlighted or used in the mainstream. Algal biofuels are generating interest due to their positive characteristics and as such, a more rapid development of the surrounding body of knowledge will enhance the likelihood of success.

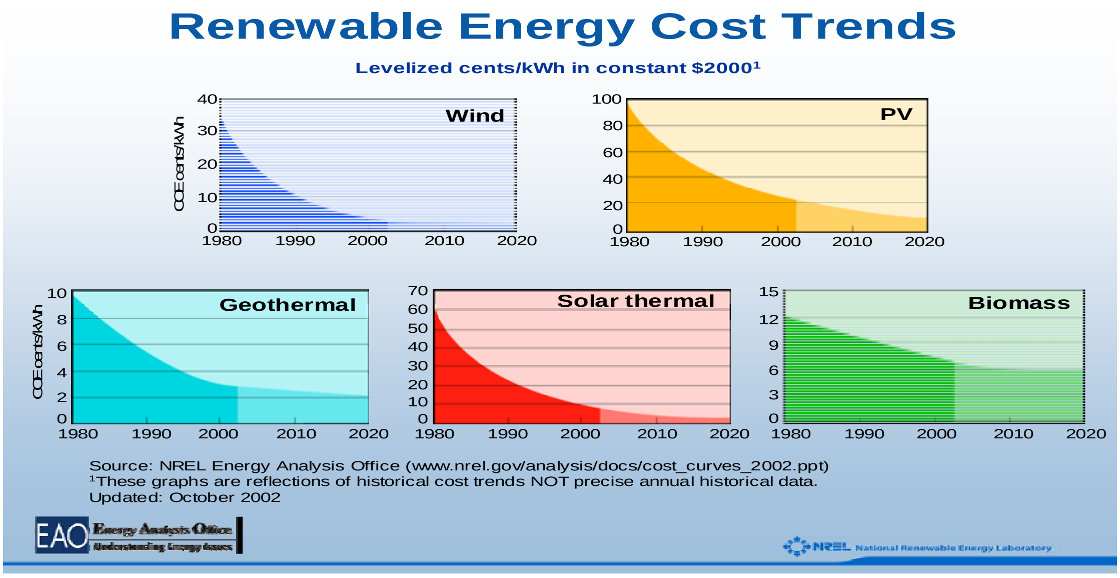


Figure 6: Renewable Energy Costs[31]

[30] René Kemp, Technology and the Transition to Environmental Sustainability: The Problem of Technological Regime Shifts.
[31] Energy Analysis Office NREL

3. Environmental Constraints and Socio-environmental Implications

3.1 Land

Land requirement is an extremely pertinent criterion for assessing the ethical implications behind developing algae farming and subsequent processing to displace fossil fuels for transportation. Returning to our central ethical question, whether this technology will provide sufficient energy to meet the requirements to maintain and advance the long-term well-being and socio-economic progress of the entire community, land requirement is a limiting factor that dictates the very first part of the question, that is, whether sufficient energy can be produced by this technology at all. It is also intimately implicated in the rest of the question, namely whether or not it should be produced. Real solutions for transportation fuels will address several important issues in terms of land requirements for fuel production. Firstly, the total capacity of production will be a function of yield per unit area and total available land which will dictate whether it is technically possible to displace a large proportion demand for transportation fuels for which supply continues to dwindle, or whether large scale production results in a disproportionately small fraction of biodiesel demand being satisfied compared to land used.

Secondly, the land required for energy production should not be arable land as competition between agriculture for food and fuel will ensue exacerbating increases in food prices further. As populations continue to grow the U.N. estimates that the global population will increase about 35% requiring an approximate 70% increase in global food production from 2005 levels to feed the population in 2050.[32] Though the demand for food is increasing, the scarcity of arable land will counter the expansion of agricultural output. Thirdly, the land required will be a part of or have importance to ecosystems, landscapes, or biome systems and all inhabitants within these systems, and determining impacts from development is significant to environmental security for humans and non-humans. For humans, land may hold not only tangible utility but also be associated with cultural and religious values that should be considered and valued.

Algae farming fares well regarding the first couple of issues in absolute terms, and also appears to fare much better than other biofuel feedstocks. The U.S. Department of Energy claims that in order to replace the total amount of petroleum based fuels used in transportation in the U.S., an area of approximately 15,000 square miles, or an area slightly larger than Maryland would be required.[33]

Triglycerides (TAGs) from current oilseed crops and waste oils cannot come close to meeting U.S. diesel demand which is upwards of 60 billion gal/yr. The entire U.S. soybean crop could provide approximately 2.5 billion gallons per year, or 4.2% of demand.[34] Replacing the current amount of diesel in the U.S. today with soy biodiesel

---

[32] FAO (2009)

[33] U.S. Department of Energy

[34] National Renewable Energy Laboratory, U.S.

would require half of the U.S. land mass to produce the crops. Even if there were sufficient lands to do this extreme amount of agriculture, such actions would be in contradiction to laws which stipulate that agricultural land must have been cleared or cultivated prior to December 19, 2007[35] and actively managed or fallow, and non-forested. In addition, the land needed would have to be arable and would compete with food crops. Clearly, these hurdles diminish the appropriateness of widespread adoption of soybean crops for biofuels.

Theoretically, algae farms should use about half of the land to produce the same yield of biofuel compared to the next highest yielding agricultural biofuel crop, that of palm which grows well only in certain parts of the world (Figure 7; Table 2). Although this is still a significant amount of land, an advantage with algae is the fact that it does not need arable land to grow and therefore they do not necessarily exacerbate the shortage of arable land required for food supply. Some argue that byproducts could even provide a significant food source. In fact, algae represent the only known feedstock that could possibly completely displace fossil fuel use for transportation in the U.S. and even the world.[36] This important point allows for the possibility that unsustainable fossil fuels be completely phased out in transportation protecting the energy and environmental security of future generations. Switching to renewable systems, including algafuels, would provide real numbers to work and live by demonstrating the relationship between land and energy production. Having the understanding of maximal energy transformation for human use on an on-going basis teaches us how to live more sustainably within the confines of the energy production of the system which is limited to the growth of algae which in turn is limited by the energy conversion ratio of the energy absorbed from the sun. Whenever possible, communities should aim to adhere to and be conscious of these limitations in their everyday life.

[35] U.S. Environmental Protection Agency
[36] U.S. Department of Energy

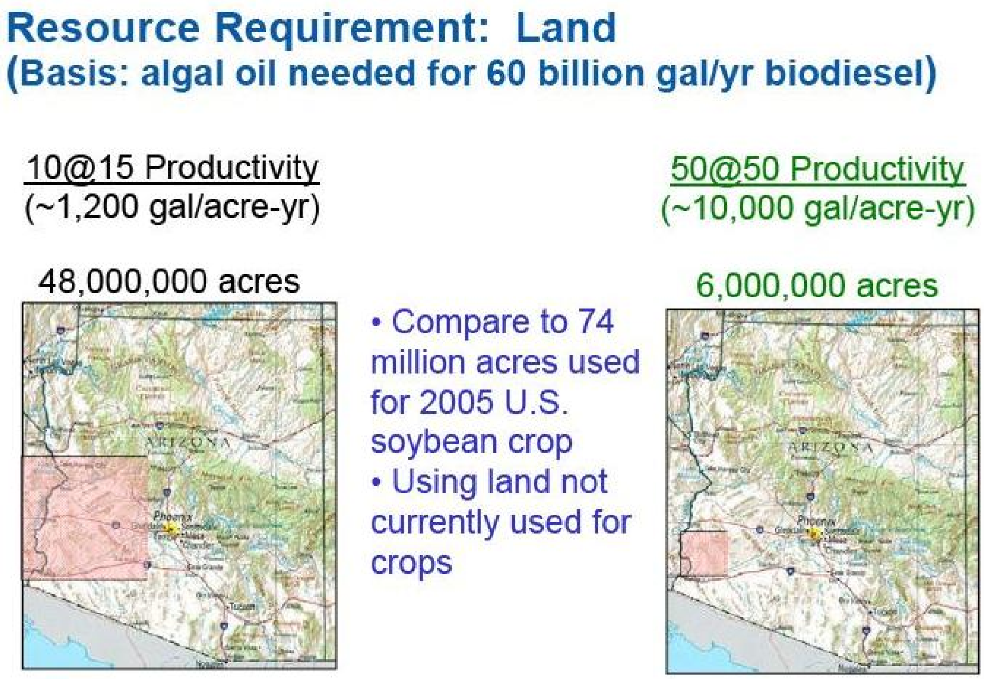


Figure 7: Land requirement needed to displace diesel demand in U.S by algae fuel

The approximate demand for diesel in the U.S. is upwards of 60 billion gal/yr. The figure on the left demonstrates the area of land needed to replace diesel demand under the assumption of a productivity of 10 $g/m^2/day$ at TAG 15%, or 1200 gallons/acre/yr, whereas the figure on the right demonstrates the amount of land needed with algal production at $50 g/m^2/day$ at 50% lipid content, or 10000gallons/acre/yr. (source: NREL)

Table 2: Oil yield in gallons per acre for biodiesel production*

Crop	Oil Yield litres / Hectare
Corn	170
Cotton	330
Soybean	453
Mustard seed	575
Sunflower	962
Rapeseed/Canola	1,198
Jatropha	1,905
Oil Palm	5,590
Algae (10 g/m2/day at 15% TAG)	11,320
Algae (50 g/m2/day at 50% TAG)	94,340

*The lower boundary estimate of algae production at 10 $g/m^2/day$ at TAG 15% still results in a yield that is double the next highest yielding crop, that of palm. In the U.S., soybean and corn are typically used.

3.1.1 Scale of Operations

Commercial-sized farms are likely to be on the order of hundreds of hectares. As an indication, Petrosun Biofuels has opened a commercial sized algae biofuels farm in Texas that is a 445 hectare network of saltwater ponds where 8 hectares will be dedicated to researching algal biofuel production until algafuel production becomes commercially viable. [37]

The amount of land used can be reduced with the increase of areal productivity ($g/m^2/day$) or lipid content (g/dry cell weight) of algae. Areal productivity using open raceway ponds will encounter upper limits related to the amount of light that penetrates the water surface, and lipid content. Photobioreactors transcend this light limitation when vessels are arranged vertically such that solar energy capture is maximized. This should result in a higher areal productivity.

The need to determine whether large scale operations provide for greater improvements to average well-being in the longer-term or whether an increase in localized operations may be better for sustainable well-being is increasingly recognized. In addition, algae farming on a very large scale will result in a disconnection and lack of integration between the environment and people. There is a call to investigate the strengthening of localization and its ethical implications on society and environment. The increase in size of operations will be the source of increasing economies of scale, however, benefits may be exaggerated as assessments are done within a flawed economic system wrought with market failures that continue to make the valuing of true costs very difficult. This situation demonstrates a more stark contrast of economics of the operations and the impacts that may occur to society such as increases in the use of fossil fuels for transportation of the biodiesel, fewer jobs through mechanization and computerization resulting in job insecurity, and mono-use of land impacting biodiversity. Mega projects should be analyzed thoroughly for their impacts regarding integration into the surrounding environment including human communities. Mega projects may force human populations into migration, and undervalue cultural and religious attachment to the land that contributes to well-being. Aside from the possible total obliteration of entire ecosystems and their inhabitants, animals, including intelligent, social animals that survive may be displaced and forced into migrating resulting in decreases in their well-being.

Medium-sized projects are perhaps more conducive to developing a system that strikes a balance in that they can be integrated into the culture and environment of the area of development, yet reap the benefits of being an operation that sees maximum true cost decreases through increased size. Medium-sized operations are less likely to have discernable influence over environmental systems than mega-projects.

3.1.2 Ecological Concerns

The investigation and assessment of algae farming for biofuels must incorporate the careful analysis of possible adverse ecological effects. As biofuels from other feedstocks require the use of arable land for cultivation, typically productive ecosystems would in part be converted to grow more crops resulting in massive measurable change to the structure and integrity of the land. In particular, when

[37] http://www.wired.com/autopia/2008/04/algae-farm-to-p/

pristine and complex ecosystems, such as rainforest, are utilized for such purposes, numerous impacts can be listed and the restriction of converting such lands for algae farming should be enforced. Land for algae biofuel endeavours should include marginal and desert lands, although in such cases, water availability and use is an important issue that is discussed in the next section. In this case, a seemingly positive land trait (ie. a rich, biodiverse ecosystem) may have negative energy equity implications as restrictions may be placed on the development of such lands and limit algal biofuel production. Developing countries that would reap immediate returns for the development of forests and decrease energy equity injustice should be compensated by ecosystem services payments or stewardship/management payments.

Marginal lands and deserts include ecosystems of value in their own right, typically consisting of flora and fauna that are highly adapted to the low moisture, high insolation environment. Expansive algae farms may exacerbate desertification and affect the unique biodiversity of such lands where there is still a lack of knowledge surrounding the highly adapted inhabitants of such ecosystems. Such environments are home to many succulents, insects and arachnids, lizards, birds, and mammals such as camels, anteaters, and hamsters, for example. The survival of some native species in deserts has been threatened by land clearing, changing fire regimes and climate, and the introduction of exotic plants and animals. The Australian Government has listed some desert species as endangered under the *Environment Protection and Biodiversity Conservation Act of 1999*.[38]

With the possibility of farming algae on non-arable land, it is unlikely that governments or businesses would overlook the obvious advantages to locating their farms on non-arable land purely for reasons of efficiency of land use, however, should this be done, many of the usual impacts for land-clearing for agriculture would ensue. Losses of habitat for flora and fauna may result in a decrease in biodiversity, loss of ecosystem services, such as air and water purification, and soil integrity may also be an issue depending on whether the system in place was open raceway ponds or photobioreactors.

3.2 Water

Water utilization is a significant environmental concern in the development of algal biofuels as water is the medium of growth and many of the world's aquifers are dealing with an unsustainable level of water extraction.[39] Salt water aquifers would, in this case, be the entities under threat resulting in the possible competition and dispute over a previously nearly untouched resource. Coastal operations present problems in coastal management as highly productive ecosystems are typical of coastal regions. Coastlines are naturally dynamic entities and movement will be artificially maintained through the construction of permanent structures under algal biofuels development. These issues can be managed to reduce changes to natural systems, but proper precaution is required.

It is estimated that algae biofuel production will necessitate a significant amount of annual water usage. NREL has estimated that in order to displace the entire U.S.

---

[38] www.deh.gov.au/cgi-bin/sprat/public/sprat.pl
[39] Refer to the ECCAP WG14 report.

diesel demand which is upwards of 60 billion gallons per year, the water usage would be within the range of 16 – 120 trillion gallons of saline water per year, whether for 50@50 or 10@15 productivity, respectively. Though these figures are striking, it should be noted for comparative purposes that approximately 22 trillion gallons of saline water is already extracted yearly from saline aquifers mostly for the cooling of power plants, and more than 4000 trillion gallons of vital and scarce fresh water is used to irrigate the U.S. corn crops[40]. The lower bound estimate of water use required to produce 60 billion gallons per year occurs under the assumption of 50 grams of biomass per m^2 collected per day that has a lipid content of 50%. The upper estimate of water use occurs under a less productive scenario where 10 grams of biomass per m^2 is collected per day where biomass contains 15% lipid.

More generally around the world, saline water will be the growth medium of choice for any sustainable algae operation and can be sourced from saline aquifers, from the sea, or of particular interest is the possibility to use by product water that emerges from oil production or from municipal wastewater. Saline water present in aquifers represents a resource that has seen relatively little competition for usage to date. The implementation of wide-scale algae farming for biofuel would raise new questions and concerns regarding saline water resources that need to be addressed in the development of such a technology. It is generally not desirable to have to transport the water needed over long distances as costs will increase dramatically in addition to the environmental and social impacts that may arise from the implementing pipelines for such a project.

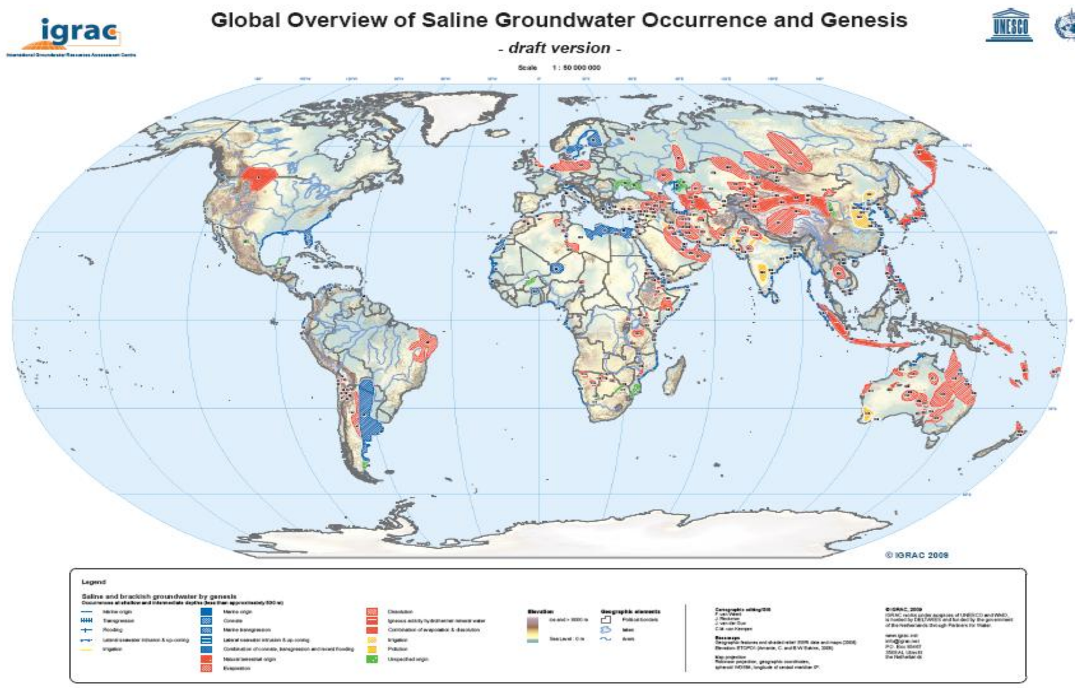


Figure 8: Global map of saline groundwater resources (Source IGRAC)

[40] USDA

Issues of importance are the effects of development of saline aquifers on fresh water resources, the development of saline aquifers for the use of the brackish or salt water itself and the depletion of the resource, and social and environmental impacts. As research has previously focused on fresh water resources, presently the geographical distribution of saline aquifers is not well-known and therefore, consequences of aquifer development may not be readily predictable. Cooperation between states may alleviate tension in order to develop peaceful solutions.

3.2.1 Impacts of Extraction of Saline Groundwater

The physical nature of the groundwater system is such that often salt and fresh aquifers are connected hydraulically, and therefore, development of either resource may impact the integrity of the other.[41] It is also possible that freshwater aquifers become infiltrated with saline water or vice versa as extraction affects the local subsurface hydrodynamic pressure regime. In addition, the groundwater system is often connected to surface water systems and manipulation of either system may impact both systems in terms of water flow and quality. Countries choosing to develop algaculture for biofuels well within their political borders and using unshared resources are more likely to freely manage the use of such resources with little resistance from other states. However, trans-boundary saline aquifers, which have not typically been the focus of water discussions, may prove more controversial as the resource gains value from a human standpoint as an input to the development of a commodity as important as energy.

Extraction of groundwater for algae farming may cause difficulties in transboundary groundwater management. Societies differ in their perception of rights to groundwater as in some cases, groundwater is linked to land ownership whereas others believe it is of common heritage such that everyone should have equal access in order to appease their basic needs. Particular views regarding water may be related and enforced by religion such as in Shari'a, where the 'right to quench thirst' is a basic principle, and/or in legal concepts such as those grounded in the early Roman idea of groundwater ownership following land ownership.[42] Technology for extraction of groundwater is advanced and is now the source of more than half of humanity's freshwater for everyday uses such as drinking, cooking, and hygiene, as well as twenty percent of irrigated agriculture globally and as a result, groundwater is the most extracted natural resource in the world.[43] To date, there is no international agreement that completely addresses groundwater resources, fresh or saline, that cross international boundaries and treaties between countries are few in number. Lack of technical information regarding the groundwater aquifers result in degradation and depletion of resources.

Currently, water from saline aquifers would be used for different purposes than those from fresh water aquifers, however, caution and planning should be taken as similar difficulties may arise for such resources. Saline water resources may become more important in the coming years in terms of desalination in order to reduce fresh water stress in water scarce regions which will add competition to its use. The U.S. Bureau of Reclamation and Sandia National Laboratories, claims that by 2020, desalination

---

[41] http://www.igrac.nl/

[42] FAO, 2001, http://www.fao.org/docrep/005/y4502e/y4502e07.htm

[43] http://www.i-s-e-t.org/groundand%20socexecsumm.html

along with water purification technologies will contribute significantly to ensuring a safe, sustainable, affordable, and adequate water supply.[44] Though it is a particularly strong advantage to be able to use saline water for the production of algal biofuels rather than fresh water, consideration of these impacts are still of significant importance as landlocked states may prefer to develop their own aquifers rather than importing water from other states. The sustainable use of aquifers requires that the rate of extraction cannot exceed the regeneration rate of water back into the aquifer.

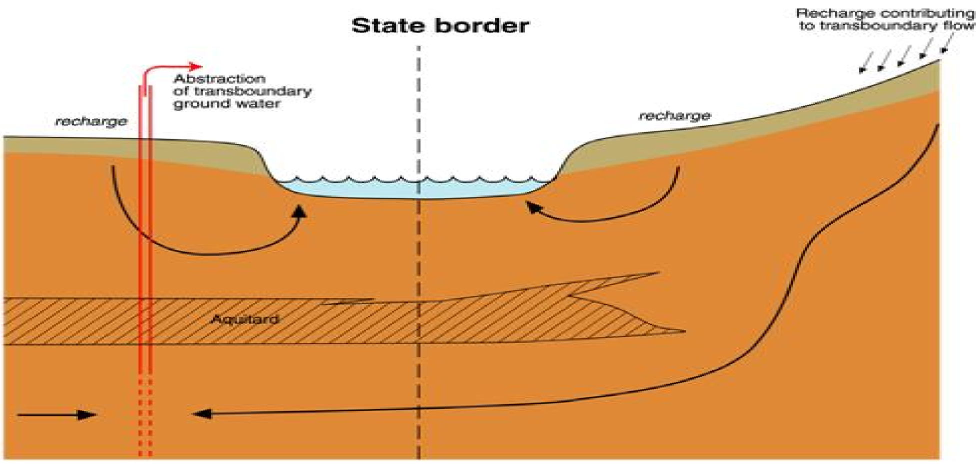


Figure 9: Illustration of water flows under state borders

3.2.2 Sovereignty and Ownership of Water and Groundwater

The issue of importance regarding sovereignty and ownership in algae production systems will relate to the use of water from oceans, saltwater land bodies, and saline aquifers. Of these, the most prominent issue is the use of saline aquifers. The International Law Commission's Draft Articles on the Law of Transboundary Aquifers (2008)[45] aims to "*ensure the development, utilization, conservation, management and protection of groundwater resources in the context of the promotion of the optimal and sustainable development of water resources for present and future generations*" by providing a legal regime by which to govern. Members of the UNILC and its parent body, the Sixth Committee of the United Nations, rejected the notion that aquifers could be collectively owned and that such resources were subject to equal ownership and potentially were humankind's 'common heritage'. Opposition referred to the UN General Assembly Resolution 1803 (XVII) on "Permanent Sovereignty over Natural Resources" and the terms were changed to "transboundary aquifer" which were defined to be a "groundwater body that is intersected by a boundary itself", where the boundary is an international political boundary, and "transboundary aquifer systems" where a purely domestic aquifer hydraulically linked to a transboundary aquifer would constitute a part of a transboundary aquifer system

[44] USGS Desalination of Groundwater: An Earth Science Perspective, http://www.orau.gov/algae2008/breakouts/alleyfssalinegw.pdf.

[45] Draft articles on the Law of Transboundary Aquifers (2008), Text adopted by the International Law Commission at its sixtieth session, in 2008, and submitted to the General Assembly as a part of the Commission's report covering the work of that session. The report, which also contains commentaries on the draft articles, appears in *Official Records of the General Assembly, Sixty-third Session, Supplement No. 10* (A/63/10).

and, thereby, also fall under the scope of the Draft Articles. States that had part of a transboundary aquifer or aquifer system were termed "aquifer states" and the following article delineates sovereignty.

A. Draft Article 3 – Sovereignty of Aquifer States

Each aquifer State has sovereignty over the portion of a transboundary aquifer or aquifer system located within its territory. It shall exercise its sovereignty in accordance with the present draft articles.

Sovereignty is to be exercised theoretically in accordance with the draft articles where a compromise has been made in the form of restrictions and obligations regarding what aquifer States can do with regard to the utilization of a transboundary aquifer by way of inclusion of Articles 4 and 5 which relate to equitable and reasonable utilization, significant harm, exchange of data, monitoring, etc. However, it should be noted that the qualitative terms used to express these restrictions and obligations remain a threat as they leave the possibility of bias and hidden agenda due to conflict of interest. The principles of equitable and reasonable utilization central to international water law[46] are written as follows:

B. Draft Article 4 – Equitable and Reasonable Utilization & Draft Article 5 – Factors Relevant to Equitable and Reasonable Utilization

Draft Article 4:

Aquifer States shall utilize a transboundary aquifer or aquifer system according to the principle of equitable and reasonable utilization, as follows:

(a) they shall utilize the transboundary aquifer or aquifer system in a manner that is consistent with the equitable and reasonable accrual of benefits therefrom to the aquifer States concerned;

(b) they shall aim at maximizing the long-term benefits derived from the use of water contained therein;

(c) they shall establish individually or jointly an overall utilization plan, taking into account present and future needs of, and alternative water sources for, the aquifer States; and

(d) they shall not utilize a recharging transboundary aquifer or aquifer system at a level that would prevent continuance of its effective functioning.

Draft Article 5:

1. Utilization of a transboundary aquifer or aquifer system in an equitable and reasonable manner within the meaning of draft article 4 requires taking into account all relevant factors, including:

(a) the population dependent on the aquifer or aquifer system in each aquifer State;

(b) the social, economic and other needs, present and future, of the aquifer States concerned;

(c) the natural characteristics of the aquifer or aquifer system;

(d) the contribution to the formation and recharge of the aquifer or aquifer system;

(e) the existing and potential utilization of the aquifer or aquifer system;

(f) the effects of the utilization of the aquifer or aquifer system in one aquifer State on other aquifer States concerned;

(g) the availability of alternatives to a particular existing and planned utilization of the aquifer or aquifer system;

(h) the development, protection and conservation of the aquifer or aquifer system and the costs of measures to be taken to that effect;

(i) the role of the aquifer or aquifer system in the related ecosystem.

2. The weight to be given to each factor is to be determined by its importance with regard to a specific transboundary aquifer or aquifer system in comparison with that of other relevant factors. In determining what is equitable and reasonable utilization, all relevant factors are to be considered together and a conclusion reached on the basis of all the factors. However, in weighing different utilizations of a transboundary aquifer or aquifer system, special regard shall be given to vital human needs.

---

[46] Eckstein, Gabriel, Commentary on the U.N. International Law Commission's Draft Articles on the Law of Transboundary Aquifers, 18 Colo. J. Int'l Envt'l L. & Pol'y 537 (2007)

The inclusion of these articles into the Draft Articles suggests different procedures depending on the given circumstances of the situation in question. Absolute sovereignty as written is curbed through the necessity of taking the wider framework into account. These limitations to freely extracting water are meant to prevent undue consequences of over-extraction, however, as the Articles embody the flexibility for parties involved to use their own discretion, there may be biased weightings agreed upon that may have adverse impacts on general well-being and the environment. The multiple agenda of members of differing social spheres creates conflict when attempting to make decisions that act in the best interest of the people. The economists, environmentalists, politicians, and ethicists will argue for differing positions when it comes to development. The precautionary principle becomes a difficult concept to implement when human lives, or political careers, or economic benefits are at stake. Independent monitoring by international bodies and non-governmental organizations is required to ensure congruence with the agreement particularly where governance is weak. These considerations placed on transboundary aquifers mirror issues required for sustainable management of the resource and place a natural limit on the potential for algae farming using local groundwater resources.

3.2.3 Opportunities for Wastewater Remediation

Microalgae production systems potentially could be used to provide biological cleaning services to unwanted wastewater that does not contain heavy metals. In this way, nutrition for the algae present in the wastewater is consumed by the algae enabling growth. Sewage effluent and industrial nitrogenous waste, such as that from aquaculture and wastewater treatment could also be mitigated and remediated through the use of microalgae growth. It was shown that the microalgal species *C. vulgaris* had a removal capacity from wastewater of 72% and 28% for nitrogen and phosphorus, respectively.[47]

3.3 Climate Required and Climate Change

High rates of algae growth require warm weather and high insolation. The regions, therefore best suited for the development of algae farms are those areas likely to be well-suited for solar energy in terms of climate.

[47] Mata TM, et al. (2009)

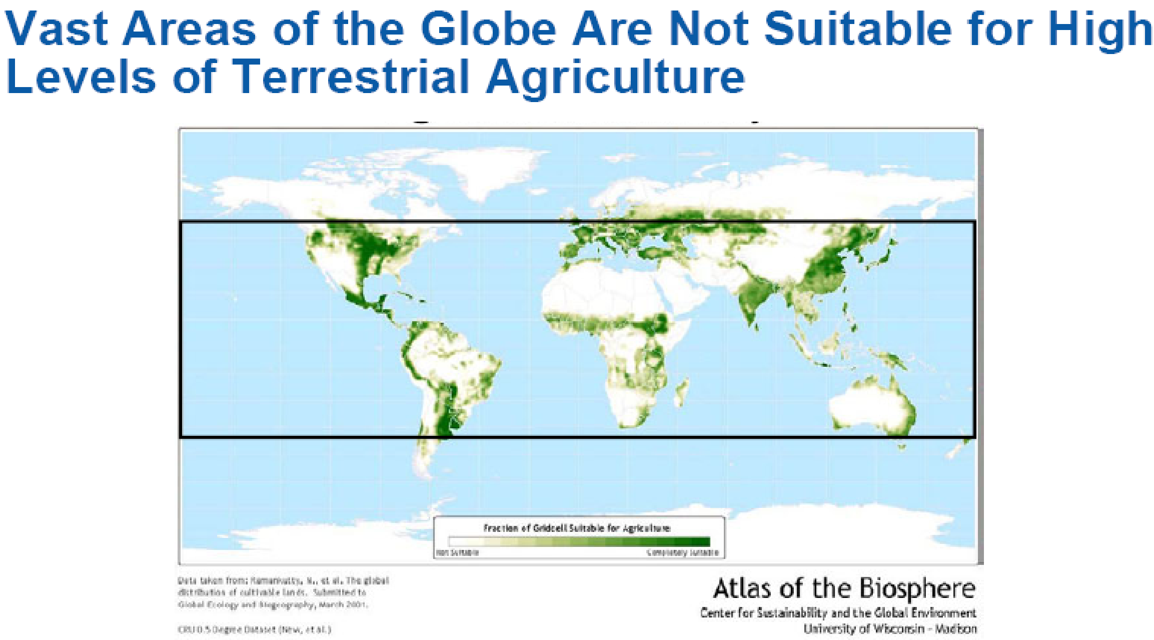


Figure 10: Suitable areas of the globe for algal cultivation
The areas of the world that are highly suitable for agriculture are dark in the figure and unsuitable areas are light. Areas unsuitable for agriculture possibly have a new option in the production of algae farms. Highly productive areas for agriculture and the development of algae should remain mutually exclusive categories for best land use. In addition, high insolation and warm temperature is required for high algal productivity and therefore, latitudes within a certain distance of the equator are best for locating algae farms.

3.1.1. Global Warming

The Intergovernmental Panel on Climate Change (IPCC) has provided irrefutable proof of the unprecedented current scenario of the impacts of anthropogenic activity on the Earth's life support systems. Human-induced climate change impacts the life of every living thing on the planet as the capability of most living organisms to live is reduced through the changes of the system to which members of the living community have been adapted through the millennia of evolutionary processes. It is a change that humans can make but it is a change that humans do not have the right to make.

Our choices of energy have been causing the increase in GHG emissions that are contributing to global warming. Climate change, demonstrating itself in terms of increased average temperatures, rising sea levels, increase in extreme weather events, and reversal or modification of long-standing weather patterns, have numerous repercussions. Increased floods and droughts will cause loss of life and disease, affect food production at times positively, at times negatively, however, with more erratic weather patterns food security decreases risking the increase of hunger felt by millions of people. Losses in wildlife, biodiversity, and from agricultural crops that had previously been successful will increase. Changes in weather and climate regimes provide scenarios of increased transmission rates of disease. Expansion of biofuels based on food feedstocks such as corn, sugar, and palm oil will increase the competition for arable land putting pressure on overall food production costs and prices and affect climate change mitigation effects of forests through deforestation. Losses in climate justice exacerbate social equity differences as the world's poor are disproportionately affected by climate changes, yet they contribute much less to the environmental degradation per capita that is causing climate change.

Developing countries dealing with climate change have additional complications arising from poverty, poor governance, incoherent national policies and developmental frameworks, environmental degradation, unrestrained population growth, and possibly political unrest.[48] Water stress is exacerbated by rising temperatures, lower precipitation levels, drought, increased evaporation and transpiration, and saltwater intrusion due to sea level increases. Impacts to the environment and wildlife are widespread and include loss of biodiversity, species extinction, loss of habitat, and climate stress.

Those aggravating climate change through massive fossil fuel consumption are less likely to suffer the consequences of their actions than their low-consumption developing country counterparts. Issues in accountability remain in debate between developed and developing countries where developed countries cite historical ignorance in the understanding of environmental systems. Now with the knowledge that damage is being done and where the extent of the damage is unknown, the application of the precautionary principle continues to be under-employed by rapidly expanding economies and well-established economies reluctant to alter the detrimental consumption patterns to which they have become accustomed. Although those ascribing to the consumptive philosophy require a paradigm overhaul in order to even attempt living sustainably, technological improvements are needed and the necessity to choose energy options that do not contribute further to climate change is clearly demonstrated. The combustion of algal biofuels will contribute no net increase of CO_2 emissions into the air as CO_2 released is equivalent to the amount sequestered in the algae over the course of its lifetime. In addition, algae farming should not contribute to deforestation or environmental degradation if developed wisely.

Without global agreements and cooperation, there will be unrelenting extraction of any fossil fuels that are found, regardless of the costs to the environment. Extraction of oil from expensive sources has begun, such as from the oil sands in Alberta, Canada, resulting in expansive environmental impacts. Canada has stated that it will be unable to meet its Kyoto Protocol targets as producing a barrel of oil from sands results in emissions three times greater than from a conventional barrel of oil.[49] Rapid development of algal biofuels could deter the rate of extraction of such expensive fossil fuels and curb emissions. Reports from the U.S. nuclear energy association predict that for approximately the next 100 years, fossil fuels will remain a prime source of energy and consumption will continue to increase under every model scenario. Increases in all other forms of energy will also ensue to appease increasing energy demand. As algal biofuels are carbon neutral, they would not contribute additional CO_2 to the atmosphere and can be used unblended, however, initially they would likely be mixed with traditional fossil fuels for transportation. This extension of the life of the fossil fuels reserve is an improvement to the current situation as emissions from the use of fossil fuels will also be slowed, in turn, possibly slowing

[48] Towards Climate Justice, Social Equity and a Sustainable Future, CANSEA – Climate Change Action Network South-East Asia

[49] New York Times, Rob Gillies http://www.nytimes.com/2008/08/25/business

the rate of global warming. Slowing the rate of global warming and its impacts allows more time for mitigation measures to be devised and adaptation to changes already present in addition to developing other renewable energy sources. The rate of climatic change is key to adaptation capabilities of human and non-human populations. Algafuels, as a transportation fuel with similar energy density to fossil fuels, could be instrumental in elongating fossil fuel reserves and provide fuel for the aviation industry.

3.3.2 CO_2

The amounts of CO_2 consumed for photosynthesis by algae are significant. In order to produce 60 billion gallons of biodiesel, the approximate demand in the U.S., it is estimated that between 0.9 and 1.4 billion tons, or 36% and 56% of U.S. current power plants' CO_2 emissions respectively would be consumed by algae biofuel production systems, at 10@15 productivity and 50@50 productivity, respectively. This, however, would necessitate extremely massive operations and land changes resulting in the possible adverse impacts that were previously discussed. As CO_2 represents a significant cost as an input if purchased, significant synergizing effects could be developed by capturing carbon dioxide emissions from industrial sources. CO_2 inputs represent a significant cost of operations, in the range of USD130 per tonne, however, there are many opportunities to develop CO_2-capturing systems from the industrial CO_2-emitting sources which could reduce costs over the longterm while providing incentive for CO_2 emitters to capture this greenhouse gas.

3.4 Specific Resource and Environmental Requirements

Salinity

Different strains of algae require either fresh water or brackish (salt) water to grow. Choosing strains that require fresh water to grow is unsustainable for operations on a large scale and exacerbate fresh water scarcity, and therefore, research should focus on those strains that grow well in salt water.

Evaporation and Precipitation

Of the two general design strategies, water in open pond systems are much more susceptible to evaporation and precipitation, whereas photobioreactors are not affected by precipitation at all, and there is a small amount of evaporation to contend with. Quantities of water that evaporate in open pond systems are not trivial and depend on factors such as temperature and insolation. Due to this on-going evaporation, salinity in open-ponds tends to increase over time, though precipitation counters this increase by some proportion. The maintenance of the salinity balance equates to additional costs as periodic drainage may be required.

Invasive Species and Pathogens

Microalgae, both in natural habitats and in aquaculture are often plagued by harmful contaminants such as viruses, bacteria, protists, fungi, and various grazers. Of greater concern, however is the possibility that the algae itself becomes an invasive species within natural ecosystems. Precautions should be taken to prevent contamination of natural environments with algal species that may be more robust and possibly creating blooms that quash aquatic communities.

Nutrients

Algae require a constant supply of several nutrients for optimal growth. Careful control of nutrient levels is critical as limitation of a key nutrient will have serious impacts on biomass productivity. At the same time, however, careful use of nutrient limitation (e.g., nitrogen, phosphorous, or silicon) is a known technique that can induce oil accumulation in the cells.[50] Too much of a particular nutrient may prove toxic to the algae. Also, unused nutrients in the culture medium pose a problem for waste water discharge. Although economics dictate that the bulk of water derived from the harvesting step must be returned to the cultivation system, where remaining nutrients can feed subsequent algal growth, a certain amount of water must be removed to prevent salt buildup. If this water contains substantial nitrogen and phosphorous, disposal will be a problem due to concerns regarding eutrophication of surface waters.[51]

Nutrients such as nitrogen, phosphorous, and iron are required to maintain high algae yields. Costs to the production system are significant should all fertilizer need to be purchased, however, other sources of nutrients may act to subsidize this cost and create efficiency while creating solutions to waste problems. Nutrients could come from wastewater whilst remediating the water, manure from animal farms, or by flue gases from power plants, which could decrease prices for nutrients while providing a useful service. Technologies that enable these kinds of environmental/energy synergies are those that must be developed.

A novel approach to providing nitrogen, its availability being a limiting factor of growth, is through the use of nitrogen-fixing cyanobacteria. As the eukaryotic high-rate oil-producing algae are unable to fix N_2 into usable forms, nitrogen-fixing cyanobacteria in co-culture with the oil-sythesizing eukaryotic algae could be used. This method is likely to have drawbacks regarding overall productivity however, as solar energy will be used for nitrogen-fixation rather than for carbon-fixation, the process leading to the synthesis of the desired product.

The main resources required for the algal biofuel development are nutrients, CO_2, and water. Microalgae have comparatively high inorganic and protein content proportions relative to terrestrial plants, and thus inorganic nutrient availability is important. Whether the most appropriate form of nitrogen is ammonia, nitrate, or urea is dependent upon the strain of algae grown and relative costs.

Resource Price and Availability

At a small scale, the costs of required nutrients appear trivial, however, at commercial scales these costs provide for significant barriers to economic feasibility. The additions needed in terms of nitrogen, phosphorous, and iron represent operating costs in the order of 6-8 cents per gallon of algal fuel in 1987 U.S. dollars with some uncertainty as nutrient prices tend to vary substantially over time.[52] This calculation takes into account a 50% rate of nutrient recycle. Availability of phosphorous may be

[50] Sheehan et al., 1998

[51] U.S. Department of Energy

[52] Benemann and Oswald, 1996.

a problem for algal biofuel production systems due to the limited global reservoir of this element.[53]

3.5 Safety and Toxicity of Products and By-products

When considering a fuel for commercial production, safety and toxicity are important factors that contribute to suitability. Minimizing chance of hazards and adverse effects contribute to human and environmental safety.

Biodiesel Flashpoint

The flashpoint of a fuel is the temperature that it becomes ignitable and is implicated in safety. According to studies done by the Southwest Research Institute, the flashpoint of biodiesel blends increases as the percentage of biodiesel increases. A higher flashpoint means that there is less chance of fire hazards and the fuels are safer to handle, store, and use than petro-diesel.

There exists little inhalation danger for humans unless the biodiesel is heated to produce vapours. Vapours or finely misted[54] materials may irritate the mucous membranes and cause irritation, dizziness, and nausea. Approved organic vapour/mist respirators should be used in such cases. Safety glasses, goggles, or face shield are recommended to protect eyes from mists or splashing. Biodiesel produces very mild skin irritation, milder than 4% soap and water solution.

Biodiesel is nontoxic and therefore acute oral toxicity rates are low and there is likely to be no hazards from ingestion incidental to industrial exposure. It is possible that gastro-intestinal symptoms similar to the effects of laxatives develop. The acute oral LD50 (lethal dose) of biodiesel is greater than 17.4 g/Kg body weight. By comparison, table salt (NaCL) is nearly 10 times more toxic demonstrating the innocuous toxicity levels of biodiesel.

Biodiesel Biodegradability

Biodegradability is important when considering impacts to the environment and its inhabitants should accidents or spilling occur. As petroleum fuel spills are a major source of contamination of the environment, it is important to determine the impacts that biodiesel would have as a replacement fuel. The biodegradability of a substance reflects how efficiently microorganisms break down complex constituent molecules into simpler components, typically CO_2 and water. Though biodiesel is non-toxic in reasonable amounts, it is not desirable to have them accumulate in the environment, particularly in waterways. Research has shown that biodiesel is readily biodegradable according to the standards set by the EPA (1982) and have a relatively high biodegradation rate in the aquatic environment and degrades more quickly than dextrose.[55] Tests indicate that biodiesel in aqueous solution was 95% degraded after 28 days. Biodiesel also increased the biodegradability of petro-diesel through cometabolism (the process in which microorganisms use a second substrate which otherwise would scarcely be attacked by the microorganisms when it is the sole source of carbon, in this case petro-diesel) when added and blended. The more

[53] U.S., Department of Energy, National Algal Biofuels Technology Roadmap, 2008.

[54] See NREL/TP-580-30004 15 September 2001

[55] Zhang, Biodegradability of Biodiesel in the Aquatic Environment.

biodiesel present in a biodiesel mixture, the faster the degradation rate occurs and the microorganisms metabolize the biodiesel and diesel components at the time at nearly the same proportional rate.

Biodiesel Emissions

Compared to regular diesel fuel, the ozone forming potential of biodiesel is less than 50%. Ground-level ozone presence is detrimental to human health as it can produce airway irritation, coughing, and pain when taking a deep breath, wheezing and breathing difficulties during exercise or outdoor activities, inflammation, aggravation of asthma and increased susceptibility to respiratory illnesses like pneumonia and bronchitis, permanent lung damage with repeated exposure. Effects of ground-level ozone on plants and ecosystems include interfering with the ability of sensitive plants to produce and store food, making them more susceptible to certain diseases, insects, other pollutants, competition and harsh weather. It can damage the leaves of trees and other plants, negatively impacting the appearance of urban vegetation, as well as vegetation in national parks and recreation areas, reducing forest growth and crop yields, and potentially impacting species diversity in ecosystems.[56]

Pure biodiesel contains nearly no sulfur and therefore the sulfur oxides and sulfates, which are major components of acid rain from current fossil fuels, are nearly eliminated. Unburned hydrocarbons contribute to localized formation of smog, carbon monoxide is a poisonous gas, and breathing particulate matter has been shown to be a human health hazard. There are substantial reductions of unburned hydrocarbons (-67%), carbon monoxide (-48%), and particulate matter in the combustion of biodiesel (-47%).[57]

Nitrogen oxides (NO_x), which contribute to localized formation of smog, may increase or decrease in emissions tests depending on the engine and/or testing procedures, however, pure biodiesel NO_x emissions will increase by a factor of approximately 10%. Because biodiesel does not contain sulfur the use of NO_x control equipment can be used to avoid these issues.

In addition to the above, other reductions in detrimental effects to human health in comparison to petroleum biodiesel include emissions contain a decreased concentration of known cancer-causing compounds such as polycyclic aromatic hydrocarbons (PAH) and nitrated polycyclic aromatic hydrocarbons (nPAH).[58]

3.6 By-products/co-products

The growth of algae, and the subsequent extraction of the oil to be refined, yields side products of value. Though the production of these additional materials indicates that there is less energy producing oil, the target product, the economics of the system can be enhanced through the development of industry for co-products.

[56] U.S. EPA. Air Quality Criteria for Ozone and Related Photochemical Oxidants (2006 Final). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

[57] U.S. Environmental Protection Agency, A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions.

[58] National Biodiesel Board

The potential for high value co-products is vast and enhances the economics of the processing of algae into fuel. Some of the high value fine chemicals and bioactive compounds that potentially may be extracted include pigments, antioxidants, beta-carotene, polysaccharides, triglycerides, fatty acids, vitamins, and biomass which are often used in pharmaceuticals, cosmetics, nutraceuticals, functional foods.[59] In general, the co-products from the production of algal biofuels do not pose any serious safety threats as remnants are made from the remaining constituents of algae. Such co-products may be useful for certain human health applications. Dietary supplements have been developed using a number of different algal species, including Spirulina, and the possibility of algae as a more significant source of human food are currently being promoted and is a realistic future outcome.

3.7 Waste and Pollution

Ideally, the algae farming-to-biofuel process will be a closed system with very little traditional forms of waste. The economics dictates that most of the water will need to be recycled and that efforts must incorporate the development of co-products deemed useful in order to minimize waste. The microalgae production systems will require energy to control the growth environment, the source of which is likely to be fossil fuels. As such, there will be a certain amount of emissions caused by the production process. As emissions contain CO_2 needed for the growth of the algae, capturing emissions to be injected into the growth medium is a concept those in the industry are attempting to develop. Industry emitting flue gases could be coupled with a microalgae production system where algae consume the CO_2. Emissions will still remain in the distribution process of the energy. Due to evaporation, salinity of the H_2O will be increased and potentially removed requiring solutions for wastewater included nutrients within the water.

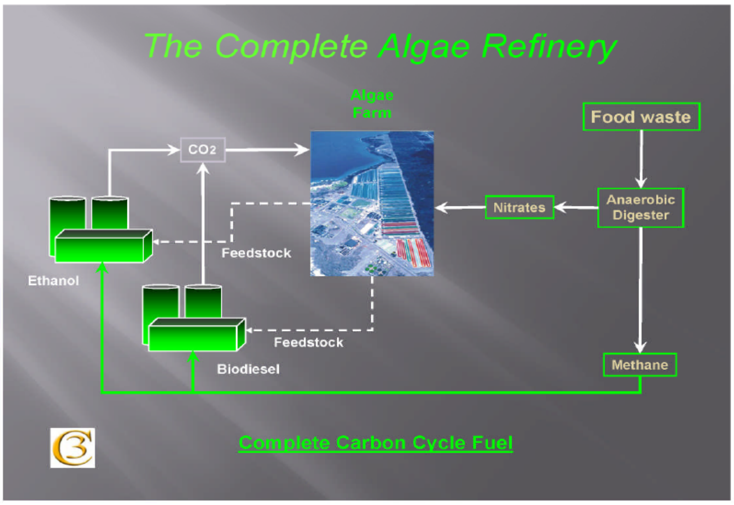


Figure 11: A scheme for a system for an algae refinery

59 Mata et al. (2009)

GMOs

The use of algal GMOs may prove to be a contentious issue, particularly should ocean cultivation and cultivation near sensitive water bodies take place. As the deployment of GM / any algae on a large scale produces the potential for toxin production and blooms with possible anoxic zones, among other unknown risks, care should be taken in these choices. Synthetic Genomics, a company who plans to use GMOs in algal biofuel production, awaits the approval of the government to use GMOs in algae cultivation.

Genetic manipulation processes in research are necessary to advance algal biology as the use of such tools is needed to demystify the mechanisms, processes, and conditions under which algae respond. The use of such tools may uncover how and which algal strains can be made most productive to a capacity that renders high-yield algal production possible.

Nano-particles

The advances in nanotechnology have spurred interest in its application to oil extraction in algae. Effects of the release of nano-particles into the environment are under research but still are not well understood and the precautionary principle may be the best safeguard against negative impacts.

4. Issues in Research and Development of the Technology

4.1 Uncertainty

As previous discussions of the state of the technology have demonstrated, a main conundrum in the adoption of algal biofuels is that the time frame of when the technology will be advanced enough to provide a commercial quantity of fuel is unknown. Given this challenge, a subsequent issue is how much monetary resources should be invested into this technology now rather than a number of other energy technologies. Of course the time frame of scientific development is interrelated to the economic structure and framework as increased funding into the technology increases its rate of development. Conversely, development of a successful technology which provides energy, expands the economy. As energy availability is related to GDP, it should be expected that success in this technology will increase GDP. GDP has previously been considered a proxy for well-being, a relationship that appears to hold in some circumstances, however, there is a need for improve interpretation of well-being and perhaps the Human Development Index (HDI) better serves this function.

In the case of government spending, budgetary resources that are put into energy could be used for a number of other social services and therefore, the energy choices affect populations' well-being also, and therefore prudent attempts must be made to strike a balance. Flexibility must be promoted in the refinement of the levels of investment to reflect the dynamism of the system and caution should be taken to incorporate lag time of the effectiveness of policy. Over-enthusiastic assessment of the state of the technology with wide scale investment and construction may cause supply disruptions in the future and divert funds from more immediate short-term energy. Under-assessment slows the progress of development of a plausible solution to transportation energy and the halting of detrimental environmental practices to extract fossil fuels. These uncertainties increase costs as contingencies must be planned for. As the properties of the fuel itself and the processes required to derive these transportation fuels are comparatively advantageous in many respects, a cautious balanced road towards development will better allow for flexibility when faced with unexpected circumstances.

4.2 Contractor Consultations and Environmental Impact Assessments

Although the scale of the land changes that would accompany the construction of an algae farm and plant are not as massive as that of a dam, for example, there is still the need for consultations with engineering professionals. Geotechnical engineers are needed to ensure the integrity of the rock and soil at the site. In addition, hydraulic and/or coastal engineers will be needed to ensure proper design of the conveyance of water needed as the growth medium, which may be extracted from different sources including aquifers, or oceans, or wastewater sources. The potential to combine wastewater treatment and/or carbon emission reductions through algal production facility design is best ensured by consulting with environmental engineers and industrial ecologists.

As for all energy projects, a thorough environmental impact assessment (EIA) is necessary to ensure significant adverse environmental impacts including the physical-chemical, biological (ecological), cultural, and socioeconomic components of the total environment, will be minimized. The EIA is usually undertaken after the choice of site and development plan have been formulated, therefore, groundwork by the developers for optimal site placement will be necessary as it is an obvious source of inefficiency. Community consultation and public participation throughout the EIA process from project planning to implementation is always important for the understanding of impacts and acceptance of the project.

EIA costs typically are less than 3% of the total project construction forecasts, however, some experts declare that more thorough EIAs are needed and that a 10% cost is more appropriate.

4.3 Scale Up Technology

Scaling up the technology for producing algal biofuels from research-scale facilities is proving to be one of the greatest challenges facing the industry. Conditions that are favourable for algal growth, including temperature, nutrients, growth medium, and light are more easily achieved in a laboratory setting. Achieving consistency of these variables throughout a larger volume is more difficult due to the nature of these physical quantities.

For example, due to the decreasing light penetration in water with depth, optimal light levels can only be achieving for a layer of water a few centimeters deep in open ponds. Another difficulty is maintaining the uniform concentration of nutrients and evenly-dispersed algae suspension throughout the growth medium. Rectifying this problem requires additional costs as construction of equipment and the use of additional energy is needed to maintain uniformity through mixing.

Scaling up produces a problem for maintaining the best temperature range for algal growth. As incident insolation penetrates the water allowing for algal photosynthesis, the water is heated unevenly with some algal individuals in the optimal temperature whereas others are not. For photobioreactor systems, one of the main hurdles to overcome in terms of scalability is achieving the mixing and gas exchange required for optimal growth at a low enough cost.

4.4 Costs and Raw Price of Energy

Every company has its own designs of its system with differing costs and to date there has no design yielding commercial success but due to so many models, there are many possible improvements within the numerous systems eventually reducing costs. Some estimates claim it would cost USD308 billion to build farms that would take care of US transportation fuel needs and USD46 billion for operation costs per year which when compared with the USD100-150 billion per year spent on imported oil, suggests a significant advantage.[60] These estimates were based on NREL's open raceway pond design in the study. The operating costs per hectare were estimated to be on the

---

[60] The Controlled Eutrophication Process: Using Microalgae for CO_2 Utilization and Agricultural Fertilizer Recycling

order of USD12000. These costs included power consumption, labour, chemicals, and fixed capital costs which included taxes, maintenance, insurance, depreciation, and return on investment. According to NREL's yield data, 3.65 million hectares of algae ponds would be required to replace transportation fuels in the U.S. which would have operation costs of USD46.2 billion per year. These costs will likely decrease as the technology improves, particularly as photobioreactor technology becomes more economical, and CO_2 input sources such as power plant emissions are incorporated.

The U.S. Department of Defense estimates that current production cost of algal oil currently exceeds USD20 per gallon and that for jet fuel, costs need to reach USD3 for economic viability.[61] A crude oil barrel contains 42 gallons from which petroleum gas, gasoline, oils, tar and asphalt are derived. A barrel of crude oil produces approximately 28 gallons of gasoline and therefore, a USD120 barrel of crude yields about USD100 worth of gasoline when gasoline costs USD3.60 a gallon. As algal fuel at USD20 a gallon would cost USD560, an algal biofuel production system is not economic until production costs decrease by a factor of five. Some claim that by reducing waste heat at adjacent utilities, the price can probably be brought down to USD5.50 a gallon. In addition, it is thought that by selling the proteins and other byproducts from the algae, the price can be brought to USD3.50 a gallon in the near term providing a scenario that comes closer to economic viability. In spite of the current cost barriers, over 50 companies and 20 universities are working on algae, primarily for the production of algal biodiesel. Some venture companies have estimated that costs may fall to USD1.70 by 2011 (72 USD/barrel). These scenarios come closer to economic viability.

According to reports, the cost of biodiesel from microalgae will differ significantly whether the production methods being used are photobioreactors, raceway ponds, or a hybrid version due to the difference in biomass production per unit area as conversion processes do not affect price. Estimates of the cost to produce microalgal biomass from photobioreactors is USD2.95/Kg, whereas the cost is USD3.80/Kg for raceway ponds.[62] These estimated costs assume that carbon dioxide is provided for free and refer to the specific systems of the study.

The top three emerging technologies also differ in their Estimated Net Cost of Production per litre:

- photobioreactors USD24.60/L (USD93.23/gallon)
- open raceways USD14.44/L (USD54.73/gallon)
- fermentors (as corn ethanol is produced) USD2.58/L (USD9.77/gallon)

With very enthusiastic assumptions in growth rate and yield, photobioreactor systems under different designs were not found to be competitive, even with economies of scale. Technological improvements could be made such as increased automation, genetically modified algae, higher oil yields, recycling of nutrients and water, and minimized light losses. However, main components such as concrete, glass and machinery, are unlikely to drop in price. Due to the limitation on how much oil and starch algae can produce photobioreactors cannot produce biofuels competitively today by a factor of 10 to 15 in comparison to fossil fuels.

---

[61] As of Dec. 24th, 2007, http://www.biofuelsdigest.com/

[62] Yusuf Chisti, "Biodiesel from Microalgae"

These are all just theoretical as companies have no yield data for an amount of time more than a few months.

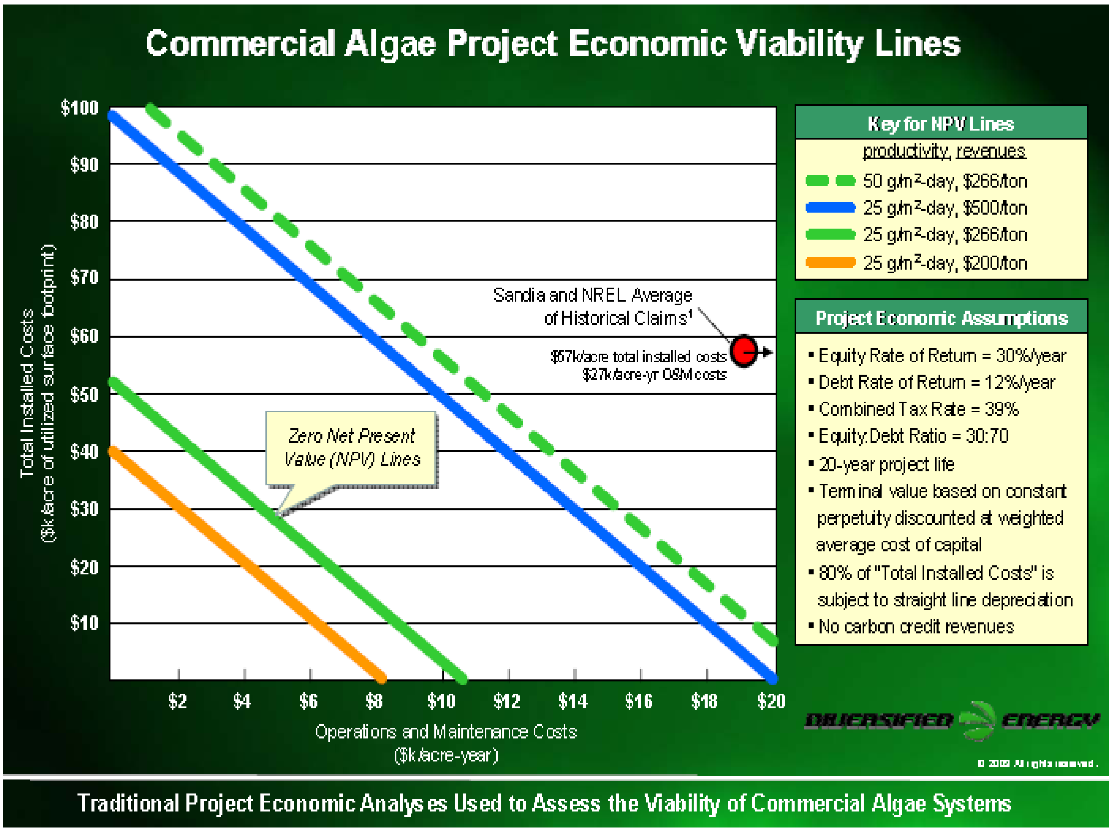


Figure 12: Economic analyses of algal systems

The graph in Figure 12[63] demonstrates the economics required for viable algae biodiesel production projects. This graph shows the net present value curves by taking into account the fact that the commercial marketplace cannot have unacceptable risk-return ratios when it comes to equity and debt financiers. This graph is the result of a comprehensive assimilation of current projects, yet many of the costs were vague and highly varied indicating a high level of error. Capital costs are broken down into algal biomass growth, harvesting, dewatering, and algae oil extraction systems. Other costs taken into account were engineering, permitting, infrastructure, installation and integration, and contractor fees. Operation and maintenance costs include nutrients, CO_2 distribution, water replenishment, utilities and land costs. Assumptions of these projects are a 20 year project life, an equity return of 30% and a debt return of 12%.

Some companies reported capital costs as low as USD10k/acre, whereas others report costs as high as USD300k/acre. This graph assesses what a project would require in terms of cost to make it economically viable. The two closest lines from the bottom left corner represent reasonable algae yields per day along with a sale price of intermediary products as being reasonable, however, no company has been able to get

[63] Hassania, 2009, *Algae Biofuels Economic Viability: A Project-based Perspective.*

their costs down along these levels. If a project achieves a level along one of the lines or below the line, the project is economically viable. This graph shows the difficulty of the situation for the algae industry. Companies cannot be economically viable without cutting costs drastically or selling their goods at a very high price. Note the position to the far right of NREL's estimated costs from the Aquatic Species Program research.

4.5 Public and Private Sector Investment and Partnerships

Until now, private sector investment has been sporadic in terms of funding algae research, and the lack of communication, collaboration and information-sharing resulted in the inefficient use of capital. Overlap and duplication of research by independently funded working groups impeded maximal potential progress resulting in a less advanced state of the art. However, results were not fruitless in these respective independent lines of research and there is much potential to combine gained knowledge amongst members of the industry.

Table 4: Selected companies and research bodies involved in algae biofuel development.

ALGAE FINANCE, INVESTMENT AND GRANTS - SELECTED PROJECTS

Organization	Investment	Project Scope/R&D
Sapphire Energy	$100 million in R&D from Bill Gates' Cascade Investments and Rockefeller Foundation	Algae for biocrude demonstration project in Las Cruces, California, and the production of renewable gasoline
Solazyme	$75 million in R&D finance so far from private investors, Chevron	Algae for biocrude, jet fuel and biodiesel in San Francisco, California
GreenFuels	$92 Million in project finance	Green fuels plans to produce 25,000 tons of algae for Aurantia SA in Spain
UK Carbon Trust	$40 million challenge for algae commercialisation by 2020	In October 2008, UK Carbon trust announced a fund to award up to $40 million in grants for algae projects
Aurora Biofuels	Raised a second round of funding of $20 million from Oak Investment Partners, Gabriel Venture Partners and Noventi	Aurora Biofuels is an algae-to-biodiesel startup with roots at University of California at Berkeley.
Algaelink	Undisclosed amount from KLM airlines, new Chinese ventures	New investments in the Netherlands based algae production manufacturer.
Petrosun	$40 million in funding from China	Formation of Petrosun China, a 50/50 joint venture with Shanghai Jun Ya Yan Technology Development
NREL	$25 million from 1970s to 1990s	Renewed investment in 2008 from Chevron,the US DOE, and several other firms.

source: Algae 2020 - Advanced Biofuels Markets and Commercialization Outlook from Emerging markets Online

Private sector investment into algae has surmounted USD900 million and continues to grow. Recently, the world's largest publicly traded oil company, ExxonMobil, announced that it would partner with Synthetic Genomics, an algal biofuels startup based in San Diego, in a USD300 million collaborative research and development program and invest another US$300 million in algal biofuels. This represents the largest single investment in algal biofuels to date.[64] ExxonMobil has spent two years researching the biofuels industry and algae biofuel potential finally choosing Synthetic Genomics, headed by renowned genetics scientists, to invest in.

Additionally, Dow Chemical announced on 29 June 2009 that they would partner with a startup, Algenol Biofuels, to build a demonstration plant that would use algae to turn CO_2 into a vehicle fuel or an ingredient in plastics. The process also produces oxygen, which would be used to burn coal more cleanly, allowing sequestration of the CO_2 produced from the coal to be used to grow more algae. The U.S. Department of Energy (DOE) is also considering providing economic stimulus funding for the demonstration plant that could produce 100,000 gallons of fuel a year.[65]

4.6 Policy Support and Economic Feasibility

Many of the world's governments are promoting biofuels through subsidies, tax incentives to motorists and implementation of regulation requiring the use of biofuel mixtures. Impacts of these actions vary depending on the crops used for feedstocks. Reports caution that possible results may include negative and ecologically counter-productive effects such as higher food prices and destruction of forests. Biofuel policy needs to acknowledge and differentiate between biofuels as they are not all produced equally.

Policies are needed to achieve a systemic implementation of renewable energy covering innovation in the energy sector from research and development to integration of the technology into the market place.[66] Research indicates that sustainable diffusion of renewable energy will affect the whole energy system and that there should be integration of supply- and demand-side perspectives, and that a successful policy for the speedy deployment of renewables should focus on the systemic innovation processes that characterize the development and sustainable diffusion of renewables specifically[67] Additionally, though growth for renewables is steady, it is unlikely that targets will be met within the current framework.

Current Scenario

The algal biofuels industry has been changing rapidly over the last several years. Five years ago, scientific skeptics were numerous and myriad start-up companies appeared to be flailing in an under-developed industry. Investment was not always used very efficiently with the competence of start-ups varying widely. However, interest was maintained and advances were made setting the stage for the current scenario. The recent announcements of big business partnering with algae venture companies in the U.S. demonstrates the mutual influence and interrelationships of business and government policy. From the onset of research into algae, the lack of economic feasibility had plagued the technology from gaining the support in terms of policy and investment needed for advancement. When the largest chemical and oil companies in the U.S. announced, after careful analysis by teams of scientists, that they were backing algae biofuel companies with the largest investments into the technology to

[64] as of Aug. 21, 2009
[65] according to news reports
[66] Jacobsson, 2000
[67] Tsoutsos, 2005

date, the government took note. The support, coming with little current policy incentive, demonstrates the strong belief by business that scientific barriers can be overcome and that the technology has the potential to be developed economically and profitably, however it is also well known that the business and financial community is one that takes substantial risks.

The response by the Environmental Protection Agency (EPA) was to heed such developments by considering the inclusion of algal biofuels into the renewable fuels standard (RFS) after measuring the effects algae biofuels have on greenhouse gases (GHGs). Inclusion of algae into the RFS policy strongly encourages its development. It is debatable to say that this is a clear-cut case of business driving policy because of the extensive analysis by scientists on behalf of these companies to determine wide-scale technical feasibility.

Those in the algae biofuel industry are keen on maintaining the forward momentum such that legislation has been developed by lawmakers that would amend the Clean Air Act to include algae-based biofuel in the renewable fuel program and amend the Internal Revenue Code of 1986 to include algae-based biofuel in the cellulosic biofuel producer credit. The bill can be viewed on the web.[68]

The EPA, under the Energy Independence and Security Act of 2007, is responsible for revising and implementing regulations to ensure that gasoline sold in the United States contains a minimum volume of renewable fuel. The Renewable Fuel Standard program requires the volume of renewable fuel required to be blended into gasoline to increase from 9 billion gallons in 2008 to 36 billion gallons by 2022. The new RFS program regulations (RFS2) are being developed in collaboration with refiners, renewable fuel producers, and many other stakeholders.[69]

The proposed specific targets for 2010 in the U.S. include 0.06% from cellulosic biofuel, 0.71% from biomass-related diesel, 0.59% from advanced biofuel, and 8.01% from renewable fuel from other sources. Algae-based fuels could be considered under the advanced biofuel or bio-based diesel portion of the RFS, according to the proposed rule. The EPA is encouraging involvement of different stakeholders and requesting comments on the expanded RFS2 proposal that falls in line with congressional mandates.[70]

The U.S. Department of Energy (DOE) recently announced[71] that up to USD 85 million would be available from the American Recovery and Reinvestment Act for the development of algae-based biofuels and advanced, infrastructure-compatible biofuels. This development encourages leading scientists and engineers from

---

[68] http://www.eenews.net/public/25/12009/features/documents/2009/08/03/document_pm_01.pdf

[69] U.S. EPA, http://www.epa.gov/OMS/renewablefuels/index.htm#prla

[70] New Renewable Fuels Standard: http://www.epa.gov/OMS/renewablefuels/420f09023.htm

[71] DOE Announces Recovery Act Funding of up to $85 million for Algal and Advanced Biofuels – July 16, 2009

universities, private industry, and government to collaborate and increase the rate of advancement towards economic viability and deployment. The funding will focus on algal biofuels research and development to make the fuel competitive with traditional fossil fuels as well as the creation of a smooth transition to advanced biofuels that use current infrastructure.

From InsideEPA.com**:**

"Advanced biofuels such as algae-based fuel and cellulosic ethanol are expected to supplement or possibly replace corn-based ethanol. EPA had originally planned to wait to include algae-based biofuels in the RFS, arguing improvements in harvesting, dewatering and lipid extraction were needed to make the fuel economically competitive with other feedstocks, according to the proposal. But the agency's expected inclusion of algae in the RFS may help boost efforts to commercialize the technology of farming algae, using it to sequester CO_2 and then turning the algae either into a biofuel or a chemical.

On a July 20 conference call on development of algae for fuels and chemicals, sponsored by the Biotechnology Industry Organization, leading experts in the field discussed challenges and opportunities for commercializing the technology and how algae-based fuels can play a key role in climate change legislation pending in Congress because of its reliance on CO_2. On the call, Ed Legere of Algenol Biofuels said the pending climate bill could vastly help spur the technology. "The game is changing politically and that makes a market for micro-algae," he said, adding that any cost imposed on CO_2 is "an opportunity for algae companies."

Noting that CO_2 capture and sequestration (CCS) systems to bury CO_2 underground is an extremely expensive process fraught with technical and legal challenges that does not put the CO_2 to use, Legere said using CO_2 to produce algae-based fuel could be a win/win situation. For example, a power plant could put in an adjacent algae farm and use the CO_2 to grow the fuel or use the algae to make other useful products, rather than spending $500 million for a CCS system that simply buries the CO_2. A bonus is that the CO_2 used for algae does not need to be compressed, saving additional money. "Forward-thinking companies are already looking at this," he said. "If cap-and-trade is a reality at $30 a ton [of CO_2 emitted], then large emitters are looking at hundreds of millions in costs coming their way." However, Legere admitted that using CO_2 generated from power plants to grow algae is still a long way off and that algae biofuels developers initially will seek to use CO_2 streams from industrial processes that are cleaner than coal, with fewer toxins, and have a manageable flow rate of 5 to 100 tons an hour, rather than the 400 tons an hour released by a typical 500-megawatt coal plant.

Also on the panel, Steve Gluck of Dow Chemical noted that government support is vital to algae developers, who still need to overcome challenges of scale. Gluck added that Dow is seeking to put algae on a level playing field with other fuels and hopes the government will be "responsive and quick" in deciding whether to allow genetically modified hybrid algae to be grown for fuel.

Additionally, Tom Byrne of XL Renewables said it appears the government is behind algae. In addition to EPA including it in the RFS, DOE July 15 announced up to $85 million in economic stimulus funding grants to develop algae-based biofuels, including the possible funding for the Dow demonstration plant. "So the U.S. is jumping behind it . . . seeing the potential. They understand not all the questions are answered yet but see it can be achieved," Byrne said. XL Renewables has a 1.5-acre *demonstration algae production facility in Arizona. Byrne said capital costs including harvesting and processing equipment are about $40,000 per acre while the company is harvesting about 25,000 tons of algae per acre but hopes to boost that to 100,000 tons. Additionally, he said algae-based biofuel would cost about 30-cents a gallon."*[72]

Policy and reduction in operation and maintenance costs will be instrumental in pushing the technology forward. In addition to policy referring directly to algal biofuels, the policies in place for biofuels in general are numerous and provide significant incentives for the development of the industry. This will have a trickle-down effect to the efforts put into the development of algae biodiesel. Higher fossil fuel prices provide incentive to put a greater effort into the technology and the extensive economy-wide cap and trade system that will be put in place will have the similar effects as increasing the price of fossil fuels, although the efficiency of such a system will be difficult to refine. Hundreds of millions of dollars are being put into the research and increased collaboration between researchers is needed to reduce duplication of research and to include novel innovations such as wastewater treatment and the consideration of genetically altered strains of algae.

In the U.S., plug-in hybrid electric vehicles will be introduced to the mass consumer market in 2010 with a goal of one million vehicles to be in operation by 2015. Although there is a policy shift towards the adoption of electric vehicles in some countries which would decrease the demand for algal biofuels for that purpose, fuel cells (chemical engines that produce electricity through a electro-chemical reaction) and electric motors will not replace jet engines in the commercial aviation industry, an expanding industry, and therefore, a need for energy dense liquid fuels will persist.[73] The future usefulness of liquid transportation energy is then assured.

There is also the issue of energy density and high performance required. Tests in jet engines show that algae jet fuel provides higher fuel economy than regular jet fuel.[74] When compared to other biofuel sources, the most attractive feature of algae biodiesel, is the amount and type of land required for production. Other biofuels require significantly more land that must be arable in order to produce what is a relatively small amount of usable energy. Although less land area is involved in algae production than needed for other bio-crops, there remains significant surface area required to match current U.S. consumption of petroleum-based fuels. Open systems, such as raceways and ponds, are currently the most economical and practical systems. At this moment, the majority of this energy required to run systems would come from fossil fuels.[75]

The typical problems that previously arose for other renewable energy, namely high costs of production, exist and present problems for financing. The short-term high costs require high value co-products to offset the expenses until major scalability

[72] Reproduced essentially verbatim with the permission of the publisher Inside Washington Publishers. "EPA shows positive interest in algae", http://www.lawofrenewableenergy.com/2009/07/articles/biofuels/epa-shows-positive-interest-in-algae/index.html

[73] http://www.boeing.com/news/releases/2001/q4/nr_011127a.html

[74] From reports

[75] http://www.fao.org/docrep/w7241e/w7241e05.htm

issues are solved. On the other hand, when a long-term view is taken, refinement of the process to target the main product, energy, results in high oil yield with reduced costs. Infrastructure becomes established, benefits mount[76].

4.7 Access to Technology, IPRs and Technology Transfer

Continual research and advances are being made in all aspects of the technology, stepping towards commercial facilities. Certain companies have promoted the sale of their own photobioreactor designs, however there have been no successful use of such devices on a commercial scale resulting in losses by start-up companies and their investors, demeaning the credibility of the industry.[77] Access to the technology will not be restricted on a country by country basis by international bodies for any form of security reasons due to the relative safety of the technology. Limitations may be present due to intellectual property rights and country economies. Within countries, energy products will reach citizens through typical fueling stations or within public transportation systems.

Patents tend to be a driver for both research motivation and secrecy which highlights the current system dilemma: Intellectual property rights are a driver for research as they represent the reward for innovation and the promise of monetary returns for that innovation, hence the importance of protect information within a company, yet secrecy implies the cost of what would have been gained had collaboration ensued.

In addition, society, which benefits from the new technology, does not do so fully when highly restrictive IPR systems are in place. Presently, numerous patents are being filed for the plethora of growing tanks, bags, and other attempts at creating yield-producing photobioreactors. Biotechnological patent applications abound for processes developed to manipulate algal cell components that serve a specific function. IPRs have been an issue for technology transfer within industrialized countries and for transfer to developing countries. Due to the importance of finding safe, non-polluting sources of energy, concessions and agreements could be made by those countries who formulate economically and scientifically sound designs.

Solutions to the technology transfer dilemma have been drawn out before, for example, when the world came together in the challenge to phase out CFCs, halons, and other chemicals in order to halt ozone depletion.[78] A compromise was agreed upon for the technology transfer required to phase out old refrigeration, propellant, and foam technologies that use these chemicals in developing countries by way of using the Multilateral Fund for the Implementation of the Montreal Protocol of 1987 which was furnished by developed countries according to the scale of contributions

[76] DOE , Algal Biofuels Roadmap

[77] http://www.engineeringnews.co.za/article/lsquodeadrsquo-biofuelfromalgae-initiative-leaves-a-stink-2007-06-15

[78] Protecting the ozone layer: the United Nations history, Stephen O. Andersen, K. Madhava Sarma, Lani Sinclair http://books.google.co.th/books?id=zuesUPcIOq8C&pg=PA124&lpg=PA124&dq=cfc+reduction+in+developing+world+history&source=bl&ots=dg3rSoyiOu&sig=RBJXXDPx9e4nXke9cRpy66eBSJE&hl=th&ei=IRWeStLYG9WOkQW_6uDkBA&sa=X&oi=book_result&ct=result&resnum=1#v=onepage&q=&f=false

decided upon by the United Nations. Costs from existing patents and designs as well as incremental royalties were incorporated into the plans and paid out by the fund, while developing economies received the newer technologies, and developed countries helped fix the ozone depletion, which was argued had benefitted their earlier development.

Although the complexity of the ozone issue is not as high as for the fossil fuels/energy dilemma, nor are the linkages to economic status as direct, parallels can be drawn and lessons can be taken from the success of the ozone example. Technology transfer protocols need to be developed such that new innovations that would benefit all can be expeditiously transferred according to a well-regulated process. This, as a goal, indicates the precaution that must be taken to avoid the development of new technologies by use of excessive and restrictive patents. This is a particularly important issue for the development of algal biofuels as the rapidly evolving field of synthetic biology is accompanied by numerous applications for patents where some claim the situation is akin to patenting the basic capacitors, resistors, and valves used by electrical engineers. [79]

Examples of Patents

1) Company Name: Origin Oil

Patents Pending 2008:[80]

1) Helix BioReactor™
2) Quantum Fracturing™
3) Cascading Production™
4) Live Extraction™
5) Single-Step Extraction™

Origin Oil has developed a suite of patent-pending technologies and processes related to algae biofuel production. For example, they have developed a proprietary process for harvesting the oil from the algae once grown. The process of “Quantum Fracturing,” utilizes electric pulses to break down the algae cells and release the oil before a simple gravitational process is used to separate it. According to Origin Oil, this system could save 90% of the energy used in traditional methods. The Helix BioReactor™ is an algae growth system that is said to grow multiple layers of algae biomass 24 hours a day with daily harvests. The Helix BioReactor™ features a rotating vertical shaft with low energy lights arranged in a helix or spiral pattern, which results in a theoretically unlimited number of growth layers. Additionally, each lighting element is engineered to produce specific light waves and frequencies for optimal algae growth. Live extraction™, analogous to milking the algae, is a process by which oil is extracted without killing the algal cell which allows each individual to produce more oil during its lifetime and Single-Step Extraction™ reduces multiple step harvesting processes to one.

2) Company Name: Synthetic Genomics

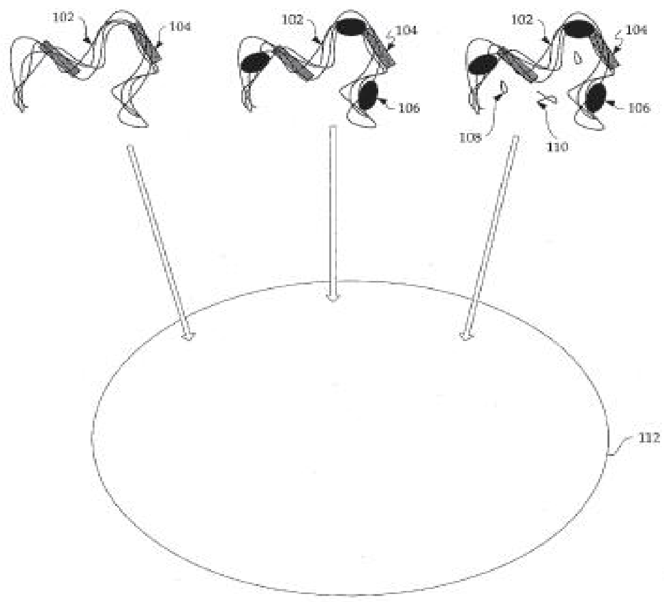
[79] The Public Domain, James Boyle, available online: http://www.thepublicdomain.org/

[80] www.OriginOil.com

SGI is a San Diego biotech company that develops biofuels using genetic engineering and other genomic and microbiological techniques. SGI plans to use its proprietary tools and technologies in genomics, metagenomics, synthetic genomics and genome engineering to develop superior strains of algae for commercial scale production of biofuels. SGI owns several pending patent applications relating to these tools and technologies.

Patents Pending:[81]

1) **U.S. Application No. 2007/0264688** ('688 application) is entitled "Synthetic genomes" and is directed to methods of constructing synthetic genomes and introducing them into vesicles (cells or synthetic membrane-bound "cells"). The '688 application describes generating small nucleic acid fragments, assembling them into cassettes, cloning the cassettes, assembling the cassettes into a genome, and transferring the synthetic genome into a biochemical system. The end products produced by the biochemical systems have various applications such as energy sources (e.g., hydrogen or ethanol), therapeutics and industrial polymers. According to the '688 application, selection and construction of synthetic genome sequences (as opposed to conventional genetic engineering techniques) allows for easier manipulation of genetic sequences and construction of novel organisms and biological systems.
2) **U.S. Application No. 2007/0269862** ('862 application) is directed to methods for installing a genome into a cell or cell-like system. The genome may comprise supercoiled nucleic acid molecules with scaffolding proteins. The nucleic acids may also have ribosomes.



The supercoiled nucleic acid molecules may be accompanied by small molecules and single stranded nucleic acid molecules. The genomes are introduced into a membrane bound aqueous volume such as a lipid vesicle.

[81] http://www.greenpatentblog.com/

Claim 1 of the '862 application is broad: 1. A method for making a synthetic cell, the method comprising obtaining a genome that is not within a cell; and introducing the genome into a cell or cell-like system.

3) **U.S. Application No. 2009/0176280** is directed to a method for isothermal amplification of small amounts of DNA or cell-free cloning of the DNA.
4) **U.S. Application Pub. No. 2007/0037196** and
5) **U.S. Application Pub. No. 2007/0037197** relate to in vitro methods for joining two double-stranded DNA molecules
6) **U.S. Application No. 2007/0122826** relates to a minimal essential gene set that codes for a free-living organism.

SGI's portfolio of patent applications implies the goal of extending the limits of existing genetic engineering methods and a desire for better techniques which SGI may have found in its synthetic genome technology.

3) Company Name: Sapphire Energy
Sapphire Energy claims to have proven the feasibility of using algae to make Green Crude fuel that can serve as a substitute for crude oil.

Patents Pending:[82]

1) 20090123977 System for capturing and modifying large pieces of genomic DNA and constructing organisms with synthetic chloroplasts 05-14-2009**:** The functional analysis of genes frequently requires the manipulation of large genomic regions. A yeast-bacteria shuttle vector is described that can be used to clone large regions of DNA by homologous recombination. Also described is a method for isolating entire genomes, including chloroplast genomes, or large portions thereof, and manipulating them. In addition, described are methods for determining minimal genomes, minimal pathway requirements, and minimal organelle genomes.

Please see the Appendix for additional algae biofuel related patents.

4.8 Siting and Plant Construction

A number of factors relating to the placement of an algal biofuel production system determine the economic viability, the environmental sustainability, and the benefit/cost ratio to society. Having a water source in proximity to the site is important as water usage is significant and the implementation of a pipe system is costly economically and environmentally. There is significant advantage in attempting to utilize flue gases emitted from polluting industry for CO_2 requirements. Although the technology is not advanced enough at this time, and the quantities of emissions from these industries is far higher than could be dealt with by algal biofuel plants in the near term, forethought regarding this goal in the placement of the facility is highly advisable. It is possible that algal biofuel production becomes part of the mitigation strategy for climate change in the sense that CO_2 usage becomes more efficient as additional benefits obtained per unit CO_2 are produced before being the gas is released into the environment. This, however, should not be used as an argument to avoid emissions reductions in a climate change strategy but could be used

[82] (Source: http://www.faqs.org/patents/asn/39943**)**

to enhance the efficiency of the energy system. Placement of the facility in proximity to such opportunities should be taken advantage of wherever possible. Consideration of a site where nutrients are available at a cheaper cost such as from animal farm operations or incorporation of wastewater into the system that provides a useful societal service which could yield additional benefits. Not only do the economics dictate that these considerations occur for plant construction, but the environment also necessitates these improvements. Ideally, the combination of all of these advantageous factors could provide a near-closed loop system where wastes are recycled and energy produced by the system is used to run the system. Although it would be advantageous to build a plant with all these geographical attributes, the fragility and importance of the environment in the area must be taken into account, as well as the impingement and impacts on communities.

5. Issues in Energy Production and Distribution

5.1 Constancy of supply

Seasonality

Algae growth is highly dependent on physical variables such as insolation, temperature, and water chemistry. As insolation and temperature are highly seasonal quantities in many parts of the world, seasonality becomes an extremely important factor in choice of development. As production is seasonally dependent, oscillating levels of algal biofuel production should be expected and safeguards to energy security should be put in place. Regions with warm temperatures year round with little seasonal variation are better suited for algal biofuels production.

5.2 Distribution of Energy

5.2.1 Transportation Method and Infrastructure Required

Biodiesel is transported by heavy-duty tanker trucks, trains, or barges. This transportation of biodiesel to the fueling stations requires energy and results in emissions by the transport vehicles. Lifecycle assessment of the transportation of biodiesel from a hypothetical processing plant to fueling stations under the assumption that the fuel must be transported 100 miles simulating the transfer of the fuel from one end of a large urban area to the other indicates that different quantities of materials and resources will be used for transportation. The transportation of 1 Kg of biodiesel by tanker truck is estimated to use 0.16 MJ total energy[83].

Fueling infrastructure for biodiesel continues to be developed alongside traditional fueling stations. The possibility of developing a pipeline distribution model of biodiesel exists, which may be the most economical option, however, research into this option remains to be done.

5.2.2 Storage

Containment of large quantities of fuel must be secure as to not be released into the environment. Barge oil spills must be avoided as environmental effects would have high consequence. For smaller quantities, the non-toxic and biodegradable nature of biodiesel results in storage concerns relating more to maintaining conditions such that the fuel remains stable. Long-term storage of biodiesel presents problems such as hydrolytic and oxidative degradation. Due to the characteristic poor oxidation and thermal stability of FAMEs, the duration for stable storage may be as short as four weeks, however, with careful storage it can be extended. This short shelf life of biodiesel, which depends on light, water, heat, and air conditions, affects energy security as continual use and/or replenishment must be made as stockpiling for crisis situations can only be done in the short-term. Storage and handling procedures used for petro-diesel are adequate for biodiesel and the fuel should be contained in an environment that is clean, dry, and dark.

---

[83] http://www.tpub.com/content/altfuels05/3813/38130195.htm

5.2.3 Drop-in potential/Usage Infrastructure

The differing energy end products of algae imply different handling and usage methods, however, none of these products require radical changes to the current infrastructure for transportation fuels. Should ethanol be the desired energy product, storage tanks must be made of corrosion-resistant materials and engines require modifications. These challenges have been tackled through the development of the ethanol biofuel industry. Biodiesel and green diesel have complete drop-in potential as direct substitutes for diesel with no engine modifications required.

In addition, biodiesel dispensing equipment does not need to be modified for blends of 20% biodiesel or lower, unless there is an issue with specific elastomers that are not compatible with B20. Minor issues such as occasional fuel filter plugging has been reported, therefore filtering the biodiesel fuels entering or leaving the tank may be advisable. Some exposed parts of the dispensing systems may need protection from freezing in cold climates. Tank cleaning is recommended before switching to B20 fuels. Biodiesel, just as regular diesel, will gel at colder temperatures.

5.3 Decommissioning and Disposal

The adoption of this technology will require the consideration of decommissioning the structures of the algae farms. The lifespan of algae farms is unknown, however, if we note that the materials of construction such as concrete, glass, and machinery are similar coal-fired powerplants which have a lifespan of approximately 50 years[84] and dams which must be relicensed every 50 years[85] we may estimate that the length of time for algae farms is similar. Initial continual monitoring will be required to ensure the integrity of the equipment and pond structures. The farms, likely to cover many hectares of land, are also likely to change the land considerably. Therefore, assessment of the decommissioning of the operational structures and whether total or partial removal is the best option to restore the land to more natural conditions must be done. Dismantling the structures requires the total removal of the built structures to previous conditions and is the most costly option. Decommissioning could leave part of the structures in place, restoring some of the functionality of the underlying ecosystem. This level of decommissioning is much cheaper and would likely leave water ponds in place. The water in these artificial saline ponds could be released into the environment in time due to the natural disintegration of building materials allowing seepage. Adverse impacts resulting from the release of saline water into the environment include:[86]

1. Infiltration into fresh water sources used for human drinking water such as groundwater or lakes.
2. Affected plant growth as the presence of soil moisture causes plants to exert more energy extracting water from the soil and exacerbating plant stress. For this reason, increased soil and water salinity potentially can reduce crop yield and agricultural production.
3. Physiological effects or even death to the livestock who drink saline groundwater.

---

[84] http://www.nytimes.com/2006/06/11/business/worldbusiness/11chinacoal.html
[85] S. Wolf, Policy Brief: Dam Decommissioning: Managing the Klamath Basin
[86] IGRAC http://www.igrac.nl/

4. Impacts on ecosystem integrity and inhabitants. Groundwater-dependent ecosystems which include many aquatic and terrestrial systems may experience general biodiversity loss and species shifts towards salt-tolerant biota.

It is therefore necessary to have environmental measures including control equipment and clean-up plans for land and water to prevent adverse impacts of these kinds.

6. Socio-economic Impacts and Population Well-being

6.1. Countering Adverse Effects of Oil Price Increases on the Poor

Fossil fuel prices are likely to continue to increase in price as supply of cheap oil dwindles and more expensive sources are used. Impacts upon the poor have been documented and include cost increases on petroleum and petroleum products for cooking fuels, transportation, electricity, lighting fuels, petroleum-based fertilizers, and some agricultural products.[87] Research done by the UNDP indicates that in Asia-Pacific, surveyed households experienced a 74% increase in price overall for their energy needs between 2002-2005.[88] Accessibility of energy severely compromised by this increase, families became unable to afford the energy needed for day to day use and decreased their consumption of energy products. As a result, there had been cutbacks on many basic living comforts such as lighting and transportation. Direct and indirect effects to health and education due to lack or reduction of transportation resulted. Increase in energy prices for the poor increases population malnutrition and famine. As the poor revert back to biomass fuels, the gender and vulnerable persons equity gap widens as women and children are particularly vulnerable to the increases of pollution at home, and spending more time fuel gathering.

Part of the strategy to reducing oil price vulnerability and subsequent adverse effects includes diversifying fuels including renewable energy. Even though renewable energy has high initial capital costs, over time costs are offset by lower operating costs. Adopting appropriate renewable energy can have significant environmental benefits, possible increases in employment, reduced import dependence, and burden on foreign exchange. The provision of other high quality energy choices that are affordable will enable the poor to counter some of the impacts of rising oil prices. Algal biofuels become more economically viable with increasing oil prices and would provide a much needed alternative and possible alleviation of some of the negative impacts associated to oil price increases. Diversification of fuel sources decreases dependence on fossil fuels increasing energy security. Algal biofuel development stimulates the economy of the area, providing employment, income, and industry. Over time with decreasing costs, algal biofuels become more affordable and therefore more available to all.

[87] Refer to ECCAP WG 7 on energy equity.

[88] Overcoming Vulnerability to Rising Oil Prices, UNDP

6.2 Global Climate Change, Renewable Energy, and Livelihoods

Climate change is increasingly undermining human security by reducing the quality and access to natural resources that are important to sustain livelihoods. Climate change is also likely to undermine the capacity of states to provide the opportunities and services that help people to sustain or improve their livelihoods. These impacts of climate change on human security are likely to increase the probability of violent conflict on the global level.[89] Being carbon-neutral over the lifetime of the algae, the burning of algal biofuels will not result in a net increase in CO_2 emissions and can aid in the slowing of global warming through the displacement of the burning of fossil fuels. All negative impacts avoided by the adoption of this technology results in the decreased burden felt by Earth's systems and therefore should be a considered a partial mitigation strategy for climate change. The world's most vulnerable populations to climate change have their health, food security, environmental security, provision of water resources, employment and incomes at stake. Their needs must be taken into account as they tend to not be the decision-makers of the world and broad-based pro-poor economic growth with sustainable resource management should be sought to represent their needs.

Renewable energy solutions remain an integral part to achieving Millenium Development Goals (MDGs) including the Eradication of Extreme Poverty, however, bioenergy development requires policies enacted that protect threatened ecosystems in order to assure that the social and environmental benefits outweigh the costs for longterm sustainability. Lack of energy for basic needs such as cooking food when raw subsistence foods are inedible, and for lighting and heating are demonstrative of the tight energy-poverty link. The energy that is used by the majority of the world's poor are traditional fuels such as wood, dung, biomass, and crop residue which are sources of energy that are often detrimental to health and do not provide high enough energy content to improve living conditions. The provision of a safe and dependable energy is a necessary condition before other social problems linked to poverty, such as safe water supply, health care, education can be properly tackled. Algae farming has the potential to stimulate the economy, provide jobs, and alleviate poverty. The potential job creation in developing countries could provide social and economic benefits through the development of an algae industry.

This technology, if developed to viability would represent a positive step towards sustainability. Populations are expected to continue growing requiring an approximate 70% increase in global food production from 2005 levels. Agriculture must be expanded as the demand for food increases, yet the scarcity of arable land will prove challenging. The intensification of the agriculture for food or fuel dilemma will occur with energy crops that use arable land, whereas algal biofuel production eliminates this issue completely; non-arable land for algal biofuel production, arable land for food agriculture. Tackling abject poverty and human security can then be put to the top of the agenda with one conflict of interest eliminated. The massive intra-generational equity injustice demonstrated by the approximate 1/6 of the world

[89] Jon Barnett, 2007

population experiencing hunger should clearly direct arable land use towards agriculture for food production. Energy, however, is required for agriculture production and energy deprivation is a defining characteristic of poverty. Renewable energy must be part of the equation to decreasing global poverty as fossil fuels will continue to become more scarce and less affordable. Algal biofuels may allow for increased independence on foreign energy thus increasing the energy security of many countries including those with a high level of poverty.

The possibility that algal biofuels may be able to completely displace fossil fuel used for transportation is an advantage over other vegetable or agriculturally-based feedstocks. Such feedstocks, which play a central role in world food markets, cannot completely displace fossil based transportation fuels whereas the high acreage yield of between 5 and 60 of algal biofuel allows for this possibility.[90] Currently, the edible crops such as corn and palm spur controversy over the use of arable land for energy development and the food or fuel debate. Jatropha *curcas* has seen interest as a non-edible crop that is said to be drought-resistant, able to grow on marginal and waste lands, and even in saline soils. However, its toxicity to humans has lead to countries such as Australia banning its use in addition to citing the plant being a difficult to control weed with low yields. Debate also ensues regarding the definition of wastelands and the crop's use of water resources. Please see Table 2 for comparisons of different species and their relative production capabilities for biodiesel and note the high theoretical yield of algae.

6.3 Promoting Sustainability

Finding a sustainable renewable energy source would mark a significant breakthrough in our energy dilemma. With a developed algal biofuels technology, rural communities with the appropriate resources could integrate the fuel's development into their strategy empowering and enriching the community. Because the maximum amount of energy that can be transformed is directly related to the amount of the sun's rays, sustainable living is promoted as learning to live within the carrying capacity is better understood and the sense of what a community should be consuming can be linked to the amount of energy the land is producing. Such developments may educate communities and translate into enhanced community life. The shift from high carbon to low carbon allows for an increase in community resilience as communities that are living more sustainably will be able to deal better with problems as they arise.

Sustainable development of an energy system presents many challenges as the common understanding between sustainable development and the environment is still lacking as relationships extend beyond the limitations of current scientific knowledge. The science-politics interface is crucial to environmental regime-building where there must be improved efficiency through the utilization of natural synergies not only in environment but in social contexts as well.

[90] Tyson et al., 2004

6.4 National Implications

As developing domestic sources of energy are the key to promoting energy security, and as diversification of energy sources protect a nation from market fluctuations, and dependency on oil-producing regions is reduced, and we may suspect a positive effect from development of algal biofuels.

If adoption and significant development of algal biofuels could be successful, it could provide for such benefits to the states that choose to be involved as oil production worldwide depletes. As oil prices increase due to depleting oil reserves, people conserve energy and contribute to recession resulting in excess demand which drives oil prices down again. Demand increases for oil again as economies heat up once more and the result is a very difficult set of fluctuations to overcome for those countries that depend on foreign oil. Algal oil will have some linkages to oil prices due to fertilizer costs and energy usage, however, it provides national energy security and can be the source of export revenue.

There are hurdles to overcome as indication of national well-being has typically been measured by GDP which has driven states to produce as much energy as they can, as an increase in a country's GDP is directly linked to the amount of energy they have available. However, there is a need to rethink the GDP as a key indicator for population well-being and economic prosperity as many have noted, including Nobel Laureate Joseph Stiglitz, that there has been a disconnect between the data and what households feel and that from a wider societal stance. The use of GDP as an indicator for well-being promotes national policies that drive up consumption through inefficient and irresponsible wasting of resources. However, for developing countries with high levels of poverty, increased consumption of energy and its relationship to well-being is stronger. Providing economic stimulus for such countries, algal biofuel production would provide jobs, energy availability and security, while encouraging infrastructure development and social development such as better health services. With the framework for transferring this technology to developing nations, the development of algal biofuels, which diversifies a nation's portfolio, may help to close the energy equity gap between developed and developing countries.

Policy-makers and developers will have to consider any influences of development of these production facilities on migration issues. Particularly in developing countries where the rights of residents may be under-valued, there may be particular cause for caution. Large scale development is likely to have greater impact in these cases and proper public consultation and compensation mechanisms should be put in place.

This technology would allow for countries to become more energy secure and more food secure. Eliminating the competition between energy development and food crops allows more freedom to organize food and energy systems. In this way, food sovereignty within countries can be promoted enabling localization of food systems such that rather than increasing trade-based solutions to hunger problems, capacity is built for a country to grow its own food.

Job Creation

In the U.S., according to the Algal Biomass Organization[91], the algae industry is having significant impact on green-collar job creation and is stimulating the economy. They estimate that over the next three to four years, approximately 11 700 direct jobs will be created, with an additional 30 000 jobs from indirect sources. Similar benefits could be reaped in developing countries around the world.

6.5 Local Effects and Access to Energy

The location for an algae farm involves several parameters and is crucial to an economically sound production system, and therefore it is possible that the choice of location may impinge on existing communities. Small rural communities and indigenous peoples are of particular risk from landscape changes as they are more directly dependent on the land. Adverse effects through landscape changes in terms of recreational and non-recreational uses, required migration, pollution or any other impacts typical of large developments must be assessed. In addition, there may be conflict between national interests, such as development, versus local interests, such as religious traditions that require careful mitigation. Conversely, positive impacts may result such as job creation, access to biofuels, and economic stimulation of the region, and other possible enhancing cultural effects.

In order for individuals to be able to appease their basic needs, personal security, social responsibilities, and engage in creative endeavours, energy must be available to them. The costs of algal biofuels to the public should be low enough to ensure accessibility for the poor. The difficulties that arise from considering energy technologies requiring massive infrastructure development is partially offset in algal biofuels production due to the current fuel distribution infrastructure which can be modified to accommodate these fuels.

6.6 Energy Security/Conflict and Independence

Though the exact proportion of algal biofuels out of total renewable fuels that will be used in the future is unknown, their use would diversify energy sources and yield positive benefits in terms of energy security. In the U.S., the EPA estimates that the value of the decrease in imported petroleum for their country would be about USD16 billion in 2022 due to increased volumes of renewable fuels mandated by the Renewable Fuel Standard (RFS2). Net U.S. expenditures on petroleum imports in 2022 are projected to be about $208 billion.

In addition to these gains, according to a study by the Oak Ridge National Laboratory (ORNL), it is estimated that the total energy security benefits associated with a reduction of U.S. imported oil is USD 12.38/barrel from reduced dependence on any one energy source resulting in reduced strategic and financial risk and decreased potential of supply disruption. Based upon the $12.38/barrel figure, total energy security benefits associated with this proposal are USD 3.7 billion (2006$).[92] These studies demonstrate the economic savings associated to reducing energy dependency and provide compelling reason in itself to strive for energy security.

[91] http://www.algalbiomass.org/

[92] U.S. Environmental Protection Agency

Environmental Security

Assessment of the benefits and costs that would be incurred through adoption of this technology must be done in terms of green accounting such that natural capital and ecosystem services are not treated as free or unlimited. Costs of environmental degradation and depletion of resources incorporated into accounting mechanisms will promote protection of the environment and sustainability.

7. Potential for Algae-based Biofuel Development in Asia-Pacific

The Asia-Pacific region is currently undergoing massive economic expansion, population increases, urbanization, and industrialization. Increases in energy demand and consumption are necessarily intertwined throughout these processes which improve the livelihoods of the residents of Asia-Pacific. Asia-Pacific, which is home to more than half the world's population and 2/3rds of the world's poor, socio-economic development is greatly needed as the majority of these people live with little or no electricity and access only to lower grade fuels for lighting.[93] In the witnessing of impacts borne of past economic development of developed countries, this development which does improve the wellbeing of the residents of the region, creates a significant dilemma.

Countries in the region who find a foothold in some economic niche strive to develop economically as quickly as possible. In many cases, the rapid development is not emphasizing energy efficiency, value and protection of pristine forests and ecosystems, resulting in aggressive frontier economic development. Developing countries argue that they should be allowed to develop as developed countries did, without the restrictions of emission targets. The need to develop responsibly is paramount in the quest for sustainability but in relative country by country standings, it is not in the economic interest of developing countries to adhere to the suggestions of developed countries. The onus is on developed countries to act in good faith and lead the way contributing as much or more to the solution than developing countries. Cooperation, responsibility, and accountability need to be recognized in order to reach a compromise, otherwise, the global socio-economic and environmental systems are poised to crash.

Environmental Factors
Many countries within the Asia-Pacific region may benefit greatly from the possibility of farming algae as a biofuel feedstock. In addition, climatic variables such as temperature are also appropriate for the technology. Seasonality will impact potential as high yields will only occur if favourable conditions are present for most of the year.

Biodiesel Demand
Though the European Union produces 90% of world biodiesel, they are unable to meet the demand due to favourable subsidies and high renewable fuel targets. Exportation of biodiesel to the European Union could be very profitable to many countries in the Asia-Pacific region.

The Clean Development Mechanism (CDM)
The Clean Development Mechanism was created in conjunction with the development of the Kyoto Protocol to allow developing countries to be engaged in activities that reduce greenhouse gases to benefit through the accumulation and right to sell Certified Emissions Reductions (CERs) for profit. Article 12 of the Kyoto Protocol identifies the purpose of the Clean Development Mechanism to "assist Parties not

---

[93] UNDP, Overcoming Vulnerability to Rising Oil Prices, Options for Asia and the Pacific, 2007.

included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitment."

There is potential for countries in Asia-Pacific who develop algae-farming operations to possibly benefit from the CDM. Countries that are non-Annex 1 and are therefore eligible to sell CERs earned from emission reductions to other countries may benefit from the CDM in the context of the development of algal biofuels. It is unclear at this time whether algal biofuel operations will qualify for CERs due to the fact that even though CO_2 can be harnessed and injected into the algal growth medium and then taken up by the algae, the main product of operations, namely liquid biofuels, release CO_2 when combusted. This scenario reflects a sort of recycling, or double use of the cost of polluting. Should substantial co-products be produced that incorporate a significant amount of carbon that subsequently remains within the product, there is a more direct CO_2 sequestration effect.

Critics claim that for the overall effectiveness for the CDM mechanism is limited as developed countries purchase CERs rather than offsetting their emissions domestically. [94] Additionally, critics note that there is no global benefit because those who offset sell their CERs to another industry who pollute in their place because the polluter that buys the offset avoids the obligation to reduce its own emissions.

Though it is unclear at this time how exactly the CDM will be implicated within algal biofuel production activities, there are those who are venturing to adapt systems to comply with CDM standards. For example, in Bangladesh, a consortium of researchers from European universities and private companies will attempt to make use of the CDM in the design of an open pond algae farm that will also use additional photobioreactors while using existing waste resources. Viewing the project within an experimentation context will yield increased knowledge in the practical elements to implementing algae farming under CDM standards.

Recommendations for Asia-Pacific

There is the development of a concerted effort amongst developed countries to solve fuel supply shortages, and in particular fossil-fuel based transportation supply shortages and dependencies. Algal biofuels is proving to be an option generating much enthusiasm due to its high potential and desirable attributes. The magnitude of the effort that is being orchestrated is significant, around USD 1 billion in major U.S. developments, with scientists, industry, and government attempting to coordinate in order to bring costs down and efficiency up.

Regional development of this technology will prove to be non-uniform due to climate variability, economic capacity, and political circumstances the region. As a renewable option for transportation fuel, countries in Asia-Pacific should be monitoring the development of this technology and forming partnerships with researchers. The establishment of an algal biofuels industry in Asia-Pacific would promote trade and partnerships amongst nearby countries.

---

[94] http://www.internationalrivers.org/node/2851

Possibilities of developing a regional financial architecture relating to energy are already underway in Asia-Pacific to enable energy solutions. The efforts will be expanded under the COP15 process agreements, although specifics are still evolving. Regional financial cooperation generating aggregate demand and fostering inclusive development would integrate members of the region and provide connectivity. The Asia-Pacific region does not have an algae association comparable to the European Algal Biomass Association, or the National Algal Biomass Association to date, however the Second Algae Biofuel Summit 2009, was held in India 8 Sept 2009.

Contributions towards this research from developing countries insofar as spearheading the initiative are likely to be limited, however can be complementary to ongoing research. Traditionally, research and development have occurred primarily in technologically and economically advanced countries. Except for P.R. China and Brazil, the top ten largest economies in terms of GDP are also the leaders of technology intensity. Partnerships between developed and developing countries could be very beneficial to countries in Asia-Pacific in order to be on the forefront of the likely future incorporation of algal biofuels into the energy landscape.

8. Summary Matrix of the Ethical Impacts of Algal Biofuels

A summary of ethical impacts with explanatory comments is presented in tabular form. Reference is also made to ECCAP WG1 report, and the WG1 activity to develop a map of different ethical principles relating to the environment.

	Ethical Impacts	***Explanation***
Development of algal biofuels in general	***Humans***	
	Inter-generational equity (+) Precaution (+)	By finding alternative sources of energy now rather than ignoring the fact cheap oil will end in the medium term, we take the ***precaution*** to protect ***future generations*** so they will have infrastructure and working farms generating algal biofuels in addition to increasing the chance of having some fossil fuels left for their use in the future. Development of algal biofuels allows the provision of energy-dense liquid fuels for future generations as fossil fuels will eventually deplete.
	Freedom (+) Poverty eradication (+) Dignity (+) Access to energy (+) Per Capita Consumption of Energy (+/-)	Access to energy promotes ***freedom*** and improved well-being, reduces poverty by providing basic electricity, lighting, transportation, access to social services. These provisions improve ***well-being*** and decrease ***poverty*** allowing life lived with ***dignity***. The aforementioned items are meant particularly in relation to developing countries with significant proportions of poor residents. ***Increases in per capita consumption*** in energy in such countries will aid those whose basic living needs are not, or scarcely, met (+). In developed countries, the addition of a new liquid transportation fuel will ***promote per capita fuel consumption*** essentially disincentivizing energy conservation (-) in countries that are already over-consuming.
	Global Responsibility (+) Common Concern (+) Sustainability (+)	The state of the environment and the planet's life community is a ***concern common*** to all humanity. Due to the

	Resilience (+)	anthropogenic causes of degradation, humanity has a ***global responsibility*** to stop destruction and rectify damage. Energy options that are less detrimental to these entities provide choices that allow movement towards ***sustainable living***. Attempting to live sustainably within the limitations of the environment allows increased ***resilience*** by communities who are better able to deal with emergencies and disruption of energy supply.
	Intra-generational equity (+) Distributive Justice (+/-) Global energy equity (+) National autonomy (+) Energy Security (+) Peace (+)	***Intra-generational equity*** is promoted through the possibility of new sources of renewable energy in a ***distribution*** that is independent of the underground fossil fuel sources. The distribution is based on climatic variables that may ***exacerbate distributive injustice*** in some cases as some countries in great need may not have much potential with this energy technology. Usually, however, energy deprived countries do have warm temperatures and insolation. Diversifying energy sources will increase ***energy security*** and this particular technology allows countries that are rich in solar energy to be able to benefit from it more, potentially providing an increase in well-being. Algal biofuels production is ultimately limited by the Sun's energy and therefore, the possibility of improved ***global energy equity*** exists as countries will be able to develop this biofuel under appropriate technology transfer schemes. Through the development of its own energy, ***national autonomy*** and ***energy security*** increase as a state is not as dependent on imported energy.

	Environment and non-human life in absolute terms: Biodiversity (-) Right to life (-) Environmental non-interference (-) Wildlife habitat (-) Access to resources (-) Environment and non-human life with comparable technology (+)	Any form of energy development consumes space for the capture or transformation of energy. This is the case for algal biofuels as farms that require land need to be constructed. Land that is no longer available reduces the ***habitat*** available to the life community that existed there before, ***increasing competition for space and resources***. This decrease in habitat is linked to decrease in number of ***species*** and numbers within ***populations.***
	Environment and non-human life in comparative terms: (+)	The consideration of alternative energy technologies that may be used for the intended purpose of this technology, liquid transportation fuels, results in noting that algal biofuels are advantageous to the environment comparatively.
Land	Eradication of poverty (+) Food Security (++) Energy Security (+) Energy Provision Capacity (+) Environment in comparison to development of other technologies (+) Absolute Value of Impact on Environment (-) Biodiversity (+/-) Maintenance of natural structure of nature (-)	One of the most significant implications of choosing algal biofuel development is the fact that arable land does not need to be used. The major implication is that while ***energy security*** is being advanced, arable land can be used for increasing human food agriculture for the increasing global population. ***Food security*** may be increased on the local, national, regional and global levels. Whereas fossil fuels reside underground, biofuels differ in that the procurement of energy requires ongoing insolation over a surface area that must be dedicated to energy development which represents a significant amount of ***land use change.*** Loss of land for other uses will exist for humans, but more importantly in this case is the loss of land and habitat for wildlife will ensue***. [biodiversity (-)]*** The yield per acre higher than any other feedstock, the ***energy capacity*** is very high, and since less land would be required for the same amount of energy, habitat for wildlife is preserved. ***[biodiversity (+)]***

Water	Fresh Water Security (++) Food Security (++) Right to water (+) Sovereignty (+) Aquifer Integrity (-) Environment in absolute terms (-) Environment in comparison to other technologies (+), Eradication of poverty	Fresh water is not used for energy development and therefore, ***fresh water security*** is enhanced for ***humanity*** and ***non-humans***. Energy technologies that do not need fresh water allow fresh water to be used for agriculture enabling the possibility of providing increased ***food security.*** Water extraction may have an impact on ***ecosystems*** near the point of extraction and also on the ***integrity*** of the groundwater systems. Countries that are aquifer states will possess ***sovereignty*** rights over its use and may use it for algal biofuel technology. However, sovereignty may have a negative impact on the environment as the groundwater resources can include very complex inter-linkages with surface waters.
Climate and Climate change	Climate Justice (+) Climate Change (+) Precaution (+)	Algal biofuels have a neutral effect on carbon emissions when they are burned. Algal biofuels development cannot readily provide incentive enough to stop emissions caused by combustion of traditional fossil fuels and therefore global warming is likely to continue, though at a ***slower rate.*** Comparative or business as usual scenarios demonstrate a positive impact on ***climate change*** in comparison to algal biofuel incorporation in the energy portfolio.
Safety and Toxicity of Products and Bi-Products	Safety to life community (+/-)	Products and bi-products are ***non-toxic*** which has a positive impact in terms of human and non-human life. ***Large spills*** by barge transportation of the fuel are a risk that could impact the environment greatly having devastating effects on local populations.
Waste and Pollution	Environment (+) Economy (+/-) Society (+)	Water and nutrients will have to be ***recycled*** for economic feasibility. Very little waste and pollution coming from a closed system where any ***CO_2 emissions*** generated from running the plant would be fed to the algae. Comparatively, algal biofuels are a very strong technology in this regard. This is positive also in terms of economics as there will be little cost to mitigation measures for ***toxic substances***.

Economics	Current Costs (-) Renewable Energy Cost Trends (+) Public/ Private Investment (+) Policy and Incentives (+)	***Economic viability*** is currently the main hurdle to overcome for this technology. Current costs associated to the ***state of the science*** and technology are significant and are a main factor working against development. History has shown that over time, technology ***costs decrease*** with scientific and technological advances. Unprecedented investment by ***private*** companies have spurred ***public*** investment encourage the development of the technology.
Policy	Cap and Trade (+) Taxes (+) Renewable Fuel Standard (+)	***Cap and Trade*** schemes that are being implemented by a variety of states act to increase the cost of fossil fuels thereby promoting the development of other energy sources. ***Policy incentives*** aimed at increasing renewable energy will promote development.
IPRs	Human Well-being (+/-) Technology Transfer (-)	Overall the benefit to developing ***innovation*** will increase human well-being, however, restrictive IPRs may be an issue working against ***technology transfer*** that would provide energy to the most needy.
National	National energy security (++) National autonomy (+) Food Security (+) Food Sovereignty (+) Employment (+) Energy Competition (+) Economic Stimulation (+)	A new source of energy to be produced on previously unproductive land will allow for greater ***national energy security*** for all who develop and may even have a positive benefit to those who do not develop as there will be less ***competition*** for energy from other countries. Countries can plan their food systems allowing greater ***food sovereignty and security*** by using non-arable land for development. Development stimulates the ***economy*** and provides ***employment*** opportunities.
Small Scale	Migration (-) Right to Property (-) Employment Opportunity (+) Community Resilience(+)	Though forced ***migration*** would be unacceptable in many countries, residents of developing nations are more susceptible due to weak governance and their ***right to property*** may be undermined. Small scale developments may increase ***community resilience*** to unforeseen events.

Science	Rate of Development (+)	With the onset of ***new policy, incentives, massive investment in the private and public spheres***, more researchers than ever are making forging new understanding in the science required to make algal biofuels ***economically feasible***. The rate of development of the technology is currently very rapid encouraging viability.

9. Conclusion

As the future need for energy dense liquid fuels for the aviation industry and other uses is assured in reference to current and foreseeable science, renewable alternatives to liquid biofuels are few. In comparison to the impacts expected of other technologies and traditional energy sources, algal biofuels have many advantageous characteristics that would act to slow environmental degradation and most likely improve the well-being of many members of humanity. Algal biofuels hold the potential to displace a large proportion of traditional fossil fuels used for transportation as areal yield and growth rate indicate. By putting in the effort to invest and develop the technology now, we set immediate rewards that could be had from further traditional fuel source development aside, and consider the livelihoods of future generations and promote more sustainable solutions for energy.

The previous discussion demonstrates that the existence of an algal biofuels industry is desirable in terms of the overall ethical benefits with humanity being the prime beneficiaries and the environment and non-human members of the life community only benefiting insofar that there exist more detrimental energy choices that could have been made. Care must be taken in planning as the combination of algal fuels with non-renewable fossil fuels could provide false security and complacency. An efficient, effective energy system requires that all relevant stakeholders are collaborating while engaged in their relative roles in order to assure appropriate levels of support and incentive. Algae biofuel production systems will be no different and stakeholders within different groups will need to share expertise, concern, and effort to ensure a balanced approach towards algal biofuels development. Communication amongst government, the private sector, trade organizations, academia, NGOs, and the public will help the formulation of the strategy for algal biofuels.

Within the discourse surrounding algal biofuels, we hear of both endorsement and skepticism coming from scientists who have differing views on the ability of this technology to make a dent in demand for fossil fuels. The members of the business community who are involved have invested in the technology in hopes of profiting. Their endorsement is subject to the conflict of interest for their desire of the adoption of the technology and their understanding that influencing the general public to support the technology is conducive to investment. The global discourse between the hard scientists and the business community regarding the energy challenge does have an ethical dimension as sensitivity towards attempting to include the many facets of the energy challenge is expected from all members of the community. However, technical scientists and business people tend to be focused on their expertise rather than the holistic perspective that clearly analyzes the ethical advantages and disadvantages of the technology. Social scientists and sustainability scientists are needed to liaise with different stakeholders and take look at algal biofuels from the centre in order to provide governments, who have the responsibility of making choices on their populations' behalf, with the information to make the best decisions possible.

As world economies were built on cheap oil, for cheap oil, halting fossil fuel use altogether would likely incur profound hardship due to the inefficient collapsing of economic and social systems which would likely result in more extensive poverty and hunger. The development of algal biofuels is consistent with current infrastructure inferring the continued use of fossil fuels. As more expensive sources of fossil fuels are beginning to be developed at the expense of the environment, the more rapidly algal biofuels can provide for a significant proportion of demand, the more rapidly a phase-out of fossil fuels can begin. Algal biofuel use would represent an improved situation to singularly using fossil fuels as the mix of algal biofuels with fossil fuels will lessen the economic and environmental impacts of fossil fuel depletion through the buying of more time to explore and develop other renewable technologies.

Although the energy challenge, along with climate change, population increases and subsequent food demand increases on a planet of limited resources represents a difficult web of interrelated issues that appears wrought with contradicting goals, determination to tackle the problem should persist. Solutions for energy sources are required as part of the equation towards enabling humans to live sustainably and integrated as part of the environment. Theoretically, there is enough arable land to grow enough food for the increasing population but land is unlikely to be used optimally for agriculture as energy crops are likely to be grown on arable land for biofuels amongst other uses. Food, being a more fundamental necessity than energy for well-being enhancement, should, then, take priority to uphold the human right to life. This makes the use of arable land for biofuels questionable and the choice of algal biofuel production highly desirable as no arable land is required. In addition, algae cultivation does not exacerbate fresh water stress as saline water can be used for operations. Algal biofuels may act to slow impacts of global warming and will not contribute to additional CO_2 emissions. Additional benefits such as wastewater remediation and carbon recycling should be sought.

Governments subsidizing fossil fuel operations are choosing a short-term solution aiming for immediate gratification. Though such decisions will falsely indicate prosperity through GDP measurements, these choices impede development of real energy solutions. Those going for the fossil fuel grab at this time, irrespective of the consequences should hold in heart that the world is paying closer attention to accountability and responsibility and may demand compensation for selfish and damaging governing.

The current economic situation is that large-scale production of algae biodiesel is not yet viable as a solution to displace petroleum-based fuels. The technology to efficiently produce biodiesel from microalgae is not yet competitive with more advanced and emerging renewable technologies such as wind, solar, geothermal, and other forms of biomass. At present production efficiencies, algae biodiesel has an approximate cost greater than USD20 dollars per gallon. However, with policy support and incentives, the algal biofuel industry will continue to develop and assuming that this technology follows renewable energy cost trends, costs will decrease to eventual economic viability. By assessing the viability of algae projects from a true market perspective, it is clearly apparent that total installed costs and operation and maintenance costs will be a major hurdle to future commercialization. Technologies must be developed to reduce costs and increase yields. This can be accomplished only through a focused, comprehensive, and well-funded R&D program. In parallel, the industry should consider business models that not only look at the bioenergy potential of algae through the transportation fuels market, but also consider other higher-value products in order to make the economics achievable.

From this holistic analysis of algal biofuel production, it is clear that the technology embodies desirable characteristics for the environment (in comparative terms) and society. At this time, the challenge lies in making the technology economically viable. With supportive policy for advancement in research, development, and deployment, algal biofuels could eventually alleviate a number of energy related problems. The potential exists, however, and may be quite likely in some cases, for nation-states to focus on development within their own state boundaries under-weighing the more critical needs of developing countries. A coordinated effort by countries with the means to expedite their knowledge and expertise to those developing countries as to avoid under-development of the technology is required.

Continued awareness-raising amongst the public along with bolstering of energy law and standard-setting is needed along with international coordination and cooperation. Choosing and adopting this technology wisely, based on its ethical merits, could prove to empower communities, promote justice and equity, protect the environment, promote selflessness and global harmony while minimizing suffering if due diligence is maintained.

13. References

1. Acharya, A., (2007), The Nexus Between Human Security and Traditional Security in Asia, International Conference on Human Security in East Asia (16-17 June 2007, Seoul, South Korea).
2. Andersen Stephen O., et al., (2002), *Protecting the ozone layer: the United Nations history*, United Nations Environmental Program, London: Earthscan Publications Ltd. http://books.google.co.th/books?id=zuesUPcIOq8C&pg=PA124&lpg=PA124&dq=cfc+reduction+in+developing+world+history&source=bl&ots=dg3rSoyiOu&sig=RBJXXDPx9e4nXke9cRpy66eBSJE&hl=th&ei=IRWeStLYG9WOkQW_6uDkBA&sa=X&oi=book_result&ct=result&resnum=1#v=onepage&q=&f=false
3. Aden, A., (2007), *"Biomass and Biofuels: Technology and Economic Overview"*, P.E.National Renewable Energy Laboratory (NREL).
4. Barnett, J., and Adger W.N., (2007), *Climate Change, Human Security and Violent Conflict*, School of Social and Environmental Enquiry, University of Melbourne, Australia.
5. Benemann, John, *Opportunities & Challenges in Algae Biofuels Production, 2008 – 2009,* Dr. John R. Benemann. All rights reserved.
6. Benemann, John, *The Controlled Eutrophication Process: Using Microalgae for CO2 Utilization and Agricultural Fertilizer Recycling,* Agricultural & Biological Engineering Dept., Clemson University, Clemson, USA.
7. Benemann, J. and Oswald, W., (1996), *Systems and Economic Analysis of Microalgae Ponds for Conversion of* CO_2 *to Biomass*, Pittsburg Energy Technology Center under Grant No. DE-FG22-93PC93204. http://govdocs.aquake.org/cgi/content/abstract/2004/915/9150050.
8. Carvalho, Ana P., et al., (2006), *Microalgal Reactors: A Review of Enclosed System Designs and Performances,* Escola Superior de Biotecnologia, Universidade Cato´lica Portuguesa, Portugal. Biotechnol. Prog., 22, 1490-1506.
9. Chisti, Yusuf, (2007), *Biodiesel from microalgae*, Biotechnology Advance,s 25 294–306.
10. Claussen, E. and R. W. Fri, (2004), *A Climate Policy Framework: Balancing Policy and Politics - A Report of an Aspen Institute Climate Change Policy Dialogue* (November 14–17, 2003).
11. Collantes, G. O., (2008), *Biofuels and the Corporate Average Fuel Economy Program: The Statute, Policy Issues, and Alternatives*, Energy Technology Innovation Policy, Belfer Center for Science and International Affairs, John F. Kennedy School, Harvard University.
12. Demirbas, A., (2007), *The Importance of Biodiesel as a Transportation Fuel*, Sila Science, TR-61035.
13. Department of Energy, U.S. (2009), National Algae Biofuels Technology Roadmap (Draft).
14. Eckstein, Gabriel, (2007), *Commentary on the U.N. International Law Commission's Draft Articles on the Law of Transboundary Aquifers, 18 Colo. J. Int'l Envt'l L. & Pol'y 537.*
15. Foxon, T., P. Pearson, Z. Makuch, M. Mata, (2004), *Informing Policy Processes That Promote Sustainable Innovation: An Analytical Framework and Empirical Methodology*, Technology and Strategic Management..

16. Goulder, L. H., S. H. Schneider, (1999), *Induced technological change and the attractiveness of CO_2 abatement policies*, Resource and Energy Economics 21: 211–253.
17. Hassannia, Jeff H., (2009), *Algae Biofuels Economic Viability: A Project-Based Perspective*, Diversified Energy Corporation. Available at www.diversified-energy.com.
18. Interlaboratory Working Group, (2000), *Scenarios for a Clean Energy Future* (Oak Ridge, TN: Oak Ridge National Laboratory; Berkeley, CA: Lawrence Berkeley ORNL/CON-476, LBNL-44029, and NREL/TP-620-29379.
19. International Law Commission at its sixtieth session, (2008), *Draft articles on the Law of Transboundary Aquifers,* Official Records of the General Assembly, Sixty-third Session, Supplement No. 10 (A/63/10)).
20. Jacobson, Mark Z., (2007), *Effects of Ethanol (E85) Versus Gasoline Vehicles on Cancer and Mortality in the United States*, Dept. of Civil and Environmental Engineering, Stanford University, Stanford, California**,** jacobson@stanford.edu Environmental Science and Technology.
21. Jacobsson, S. and A. Johnson, (2000), *The diffusion of renewable energy technology: an analytical framework and key issues for research*, Available at doi:10.1016/S0301-4215(00)00041-0 .
22. Johnston, Matthew, (2006), *Evaluating the Potential for Large-Scale Biodiesel Deployments in a Global Context*, Universtiy of Wisconsin-Madison.
23. Kemp, René (1994), *Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts*, Futures 26(10): 1023-46.
24. Li, Y., Horsman, M.,Wu,N., Lan, C. Q., Dubois-Calero, N., (2008), *Biofuels from microalgae*, Biotechnol. Prog. *24*, 815–820.
25. McGowan, F. (1991), *Controlling the greenhouse effect the role of renewables*, Energy Policy, Vol. 19 No.2, pp.110-8.
26. Norberg-Bohm, Vicki, (1999), *Stimulating 'Green' Technological Innovation: An Analysis of Alternative Policy Mechanisms*, Policy Sciences: 13-38.
27. National Renewable Energy Laboratory, *Close-out Report: A Look Back at the Aquatic Species Program*
28. Putt, R.,(2007) "*Algae as a Biodiesel Feedstock: A Feasibility Assessment*", Center for Microfibrous Materials Manufacturing (CM^3) Department of Chemical Engineering Auburn University, Alabama.
29. Peterson, Charles and Moller, Gregory. "Biodegradability, BOD4, COD and Toxicity of Biodiesel Fuels", University of Idaho Biodiesel Education
30. Pienkos, P. T., (2007), "*The Potential for Biofuels from Algae*", Algae Biomass Summit, San Francisco, CA, National Renewable Energy Laboratory, National Bioenergy Center.
31. Putt, R., (2007), *Algae as a Biodiesel Feedstock: A Feasibility Assessment (Draft),* Dept. of Chemical Engineering, Auburn University, Alabama.
32. Sheehan, J., Dunahay, T., Benemann, J., Roessler, P., (1998). *A Look Back at the U.S. Department of Energy's Aquatic Species Program – Biodiesel from Algae*, National Renewable Energy Laboratory.
33. T.D. Tsoutsos, Y.A. Stamboulis, (2005), *The sustainable diffusion of renewable energy technologies as an example of an innovation-focused policy,* Technovation 25 753–761.
34. Vignolo, T., A. d'Artigues, and J. Percebois, (2007), *The time-inconsistency of alternative energy policy*, Economics Bulletin, Vol. 1, No. 1 pp. 1-7.

URL:http://economicsbulletin.vanderbilt.edu/2007/volume1/EB-07A10001A.pdf

35. U.S. DOE, EIA, 2001, *Emissions of Greenhouse Gases in the United States 2001*, Report No. DOE/EIA-0573 Washington, DC: U.S. Department of Energy, Energy Information Administration, December 2002.
36. Zhang, Xiulin, Biodegradability of Biodiesel in the Aquatic Environment.

.

News Articles

1. "CEO envisions a Gulf Coast algae boom", *Houston Chronicle*, Aug. 8, 2009, Brett Clanton, Copyright 2009, http://www.chron.com/disp/story.mpl/business/6565247.html**.**
2. **"**Algae in the Air: 5 Startups Turning Algae Into Jet Fuel**",** Josie Garthwaite http://earth2tech.com/2008/12/24/algae-in-the-air-5-startups-turning-algae-into-jet-fuel/**.**
3. "EPA shows positive interest in algae", Renewable + Law, 27 July 2009, Blair Carter, http://www.lawofrenewableenergy.com/2009/07/articles/biofuels/epa-shows-positive-interest-in-algae/index.html
4. "Algae Farm to Produce 4.4 Million Gallons of Experimental Jet Fuel", 8 April 2008, Dave Demerjian, http://www.wired.com/autopia/2008/04/algae-farm-to-p/.
5. "The Elephant Under the Rug: Denial and Failed Energy Projects", 8 Sept., 2008, Thomas R. Blakeslee, http://www.renewableenergyworld.com/rea/news/article/2008/09/the-elephant-under-the-rug-denial-and-failed-energy-projects-53467.
6. New York Times, Rob Gillies, http://www.nytimes.com/2008/08/25/business.
7. http://www.biofuelsdigest.com/**.**
8. "EPA shows positive interest in algae", http://www.lawofrenewableenergy.com/2009/07/articles/biofuels/epa-shows-positive-interest-in-algae/index.html.
9. http://www.engineeringnews.co.za/article/lsquodeadrsquo-biofuelfromalgae-initiative-leaves-a-stink-2007-06-15**.**

Websites

http://botany.si.edu/projects/algae/introduction.htm
http://www.algaebase.org/ for algae information, links, and algal species databases.
Registry of Standard Biological Parts: http://parts.mit.edu
New Renewable Fuels Standard: http://www.epa.gov/OMS/renewablefuels/420f09023.htm
http://www.wired.com/autopia/2008/04/algae-farm-to-p/
www.deh.gov.au/cgi-bin/sprat/public/sprat.pl
http://www.igrac.nl/
http://www.fao.org/docrep/005/y4502e/y4502e07.htm**,** (FAO, 2001).
(http://www.fao.org/docrep/w7241e/w7241e05.htm)
http://www.i-s-e-t.org/groundand%20socexecsumm.html
http://www.orau.gov/algae2008/breakouts/alleyfssalinegw.pdf, USGS Desalination of Groundwater: An Earth Science Perspective.
http://www.algalbiomass.org/

Acknowledgments

The report writer thanks Dr. Darryl Macer for guidance and comments. This report is open for revision and expansion under the Ethics of Climate Change in Asia and the Pacific (ECCAP) project, initiated by UNESCO Bangkok: http://www.unescobkk.org/energyethics. This report will be updated as further sections are added.

There will be further case studies develop under the framework of WG9 of the ECCAP project, using a similar framework to allow comparison.

Appendix: Selected patents related to algae production systems

Source: http://www.freepatentsonline.com/result.html?p=1&query_txt=algae+fuel&sort=relevance&srch=top

1	US20090113790	**ALGAE PRODUCTION** Methods and systems for algae production are provided, the methods and systems generally comprising providing at least one body of water having an algae population in suspension, growing algae,...	1000
2	US20090081743	**TRANSPORTABLE ALGAE BIODIESEL SYSTEM** A portable system and method for producing biofuel from algae are disclosed. In the portable system, a chemostat and a plug flow reactor formed from plastic bladders are interconnected. Further, an...	830
3	4341038	**Oil products from algae** Oil products and a high nitrogen content residue are obtained by growing halophilic algae in saline solution, harvesting an algae-salt water slurry, solvent extracting said slurry, and recovering...	789
4	US20090126265	**ALGAE CULTIVATION SYSTEMS AND METHODS** Embodiments of the present invention relate to algae cultivation systems and methods. In an embodiment, an algae cultivation system is included. The algae cultivation system can include a...	697
5	US20090119980	**ABANDONED MINE DISCHARGE ALGAE CLEAN UP** Disclosed herein is a new method of producing biodiesel fuel using algae grown on the polluted water from mine acid water drainage ponds. By directly using the water from the mines the necessity of...	671
6	3645040	**UNBALANCED CULTURE METHOD OF ALGAE PRODUCTION** Interruption of algal-bacterial symbiosis by high-intensity light permits increased algae production.	660
7	US20090170184	**SYSTEM FOR FERMENTATION USING ALGAE** The system for fermentation using algae of the present invention includes a first reactor and a second reactor being in fluid communication with each other. A first valve placed between the first...	629
8	US20080311649	**Pressurized flexible tubing system for producing Algae** An apparatus for producing algae circulates algae fluid through flexible reactor tubing that is at least partially translucent to sunlight. The reactor tubing lies flat when not pressurized....	629
9	US20090151241	**METHOD FOR PRODUCING ALGAE IN**	626

		PHOTOBIOREACTOR The present method transfers carbon dioxide in increased concentrations using perfluorodecalin for growth of algae in a photobioreactor. First, a perfluorodecalin solution is provided and mixed...	
10	US20080155890	**CONTROLLED GROWTH ENVIRONMENTS FOR ALGAE CULTIVATION** A method for cultivating algae can include providing a body of water in a substantially enclosed system. The enclosed system can have a length of channel and a cover. The method can optionally...	622
11	5500086	**Method for producing pulp from green algae** Method for producing pulp by using an alga containing cellulose in the cell wall and having the long algae body with the ratio of length to width being 10 to 200 as an ingredient by giving no...	617
12	US20080228542	**Method and apparatus for cultured sea algae** A method and apparatus for utilizing, processing, distributing and an accompanying business model for sea algae, particularly forced cultured kombu, to prevent the expansion of global warming, by...	612
13	6391238	**Method of producing algae cultivating medium** Raw material of algae cultivating medium molded body is manufactured by mixing a mixture containing inorganic material, curing material and algae cultivating nutriment, molding the mixture to...	604
14	US20080248956	**Methods of Controlling Algae With Thaxtomin and Thaxtomin Compositions** Methods of treating and/or controlling algae including contacting algae with an effective amount of one or more thaxtomins are disclosed. One or more thaxtomins are applied to algae contaminated...	595
15	US20090151240	**Algae intensive cultivation apparatus and cultivation method** An apparatus for carrying out algae intensive-cultivation while conducting an environmental control most suitable for growth of algae in an artificial environment including dissolved gas, light,...	592
16	US20090077863	**PROCESS OF PRODUCING OIL FROM ALGAE USING BIOLOGICAL RUPTURING** A process for production of biofuels from algae can include cultivating an oil-producing algae, extracting the algal oil, and converting the algal oil to form biodiesel. Extracting the algal oil...	577
17	4442211	**Method for producing hydrogen and oxygen by use of algae** Efficiency of process for producing H 2 by subjecting algae in an aqueous phase to light irradiation is increased	570

		by culturing algae which has been bleached during a first period of irradiation in...	
18	US20090197994	**ALGAE FIBER-REINFORCED BICOMPOSITE AND METHOD FOR PREPARING THE SAME** Disclosed herein are an environmentally-friendly biocomposite prepared from a mixture, as a reinforcement, of algae fibers extracted from algae and a polymeric reagent by means of high-temperature...	570
19	US20090203116	**System to improve algae production in a photo-bioreactor** This invention provides a method of delivering light internally to a Photo-Bioreactor growing algae for production of Biodiesel fuel. The invention also provides an improved method of delivering...	557
20	US20070275856	**Composition For Growth Of Diatom Algae** The present invention relates to a composition for a copious bloom of diatom algae comprising macro and or micro nutrients adsorbed on metalate modified silica sol. The present invention further...	554
21	US20090081748	**INTEGRATED PROCESSES AND SYSTEMS FOR PRODUCTION OF BIOFUELS USING ALGAE** A process for production of biofuels from biomass can include depolymerizing a biomass to form a feed. The feed can be formed by autotrophically growing algal biomass and extracting the feed...	550
22	US20090077864	**Integrated Process of Algae Cultivation and Production of Diesel Fuel from Biorenewable Feedstocks** An integrated process has been developed for producing diesel boiling range fuel from renewable feedstocks such as plant and animal fats and oils and for cultivating algae or greenhouse plants. The...	543
23	US20080127364	**Switchable photosystem-II designer algae for photobiological hydrogen production** A switchable photosystem-II designer algae for photobiological hydrogen production. The designer transgenic algae includes at least two transgenes for enhanced photobiological H 2 production...	542
24	US20090130747	**System and Method of Enhancing Production of Algae** The present invention relates to a system and method of enhancing production algae, comprising a container containing liquid, algae and plates made from a kind of material for absorbing and...	540
25	5356664	**Method of inhibiting algae growth on asphalt shingles** A method of inhibiting algae growth on an asphalt shingle surface exposed to varying humidity using a	535

		blend of copper-containing algae-resistant granules and non-algae-resistant granules. The...	
26	6199317	**Materials for growing algae and artificial fishing banks** Vitreous, algae growing materials, release stably ferrous ions, over long periods of time. The duration of ion release can be controlled as desired by adjusting the particle size of the materials....	528
27	US20070269864	**Designer proton-channel transgenic algae for photobiological hydrogen production** A designer proton-channel transgenic alga for photobiological hydrogen production that is specifically designed for production of molecular hydrogen (H_2) through photosynthetic water splitting....	525
28	6083740	**System for purifying a polluted air by using algae** A system for purifying a polluted air by using algae such as Spirulina is capable of reducing carbon dioxide (CO_2), nitrogen oxide (NO_x) and/or sulfur oxide (SO_x) in the polluted air and...	519
29	5661017	**Method to transform algae, materials therefor, and products produced thereby** Disclosed is a method to transform chlorophyll C-containing algae which includes introducing a recombinant molecule comprising a nucleic acid molecule encoding a dominant selectable marker...	518
30	US20070202582	**Process for the production of ethanol from algae** The present invention describes a process for the production of ethanol by harvesting starch-accumulating filament-forming or colony-forming algae to form a biomass, initiating cellular decay of...	507
31	7507554	**Process for the production of ethanol from algae** The present invention describes a process for the production of ethanol by harvesting starch-accumulating filament-forming or colony-forming algae to form a biomass, initiating cellular decay of...	506
32	4532210	**Process for producing hydrogen by alga in alternating light/dark cycle and environmental aerobic/microaerobic conditions** Hydrogen is biologically, effectively produced by an alga in an alternating light/dark cycle which comprises alternating a step for cultivating the alga in water under aerobic conditions in the...	501
33	7135308	**Process for the production of ethanol from algae** The present invention describes a process for the production of ethanol by harvesting starch-accumulating filament-forming or colony-forming algae to form a biomass, initiating cellular decay of...	493

34	5994268	**Photocatalytic surfacing agents with varying oxides for inhibiting algae growth** Self cleaning mixtures that use photoactive agents with varying oxides, along with mixing the photoactive agents with carbon, noble metals and cobalt phosphide that inhibit the growth of algae are...	492
35	6027900	**Methods and tools for transformation of eukaryotic algae** Genetic fusions for use in genetic engineering of eukaryotic algae employ a promoter from a light harvesting protein fused to a protein of interest. The fusions can be introduced and selected using...	490
36	US20070048848	**Method, apparatus and system for biodiesel production from algae** The present disclosure concerns methods, apparatus, compositions and systems relating to closed bioreactors for algal culture and harvesting. In certain embodiments, the system may comprise bags...	482
37	4111879	**Composition for inhibiting adhesion of shellfish and algae** A composition for inhibiting an adhesion of shellfish and algae comprises a resin, a medium and a N-arylmaleimide having the formula ##STR1## wherein X represents hydrogen or halogen atom; Y 1 ...	479
38	5382475	**Pigmented algae-resistant granular materials and composites sheets including same** Long-term algicidal granules show improved color fastness over previously known granules. The granules have a ceramic coating comprising three layers, the first two of which have a copper compound...	458
39	US20060151402	**Process for suppressing the growth of green algae in aqueous systems** The process for suppressing the growth of green algae in aqueous systems, such as lakes or rivers, comprises introducing carbon dioxide, preferably industrially produced carbon dioxide, into the...	454
40	US20090029445	**ALGAE GROWTH SYSTEM FOR OIL PRODUCTION** A biological growth reactor vessel for the cultivation of micro-algae, diatoms or other unicellular organisms, especially for oil production, is described which incorporates a dispensing rod to...	451
41	US20030034299	**Process for the treatment of industrial effluents using marine algae to produce potable water** The invention relates to a process for the treatment of industrial effluents using marine algae to produce potable water which process comprises the steps of: (i) contacting diluted effluents with...	414

42	6929942	**Process for the treatment of industrial effluents using marine algae to produce potable wafer** The invention relates to a process for the treatment of industrial effluents using marine algae to produce potable water which process comprises the steps of: (i) contacting diluted effluents with...	414
43	7118700	**Method for inhibiting algae growth in water tanks and apparatus therefor** A method of inhibiting the growth of algae and like organisms in plastic water tanks exposed to sunlight comprises providing an outer tank surface operative to reflect off a substantial portion of...	402
44	6593275	**Use of prolines for improving growth and other properties of plants and algae** Increasing the concentration of prolines, such as 2-hydroxy-5-oxoproline, in the foliar portions of plants has been shown to cause an increase in carbon dioxide fixation, growth rate, dry weight,...	398
45	5880067	**Photocatalytic surfacing agents with varying oxides for inhibiting algae growth** Self cleaning mixtures that use photoactive agents with varying oxides, along with mixing the photoactive agents with carbon, noble metals and cobalt phosphide that inhibit the growth of algae are...	388
46	US20080223011	**Apparatus and method for cutting and harvesting infestations of aquatic vegetation and/or skimming algae/floating vegetation** A harvester and method for harvesting aquatic algae or floating vegetation in shallow areas of water bodies, such as lakes is described. The harvester is manually operated. The harvester includes a...	370
47	5270175	**Methods and compositions for producing metabolic products for algae** Soluble metabolic products, such as ethanol, are produced by growing modified algal cells in a growth medium and recovering the products from the growth medium. The algal cells are modified to...	351
48	US20080299643	**Systems and Methods for Large-Scale Production and Harvesting of Oil-Rich Algae** Systems and methods for the growing of microorganisms such as algae, yeast, and bacteria are described. Seed fermentation units are associated with final fermentation ponds in various arrangements....	329
49	US20080096267	**Systems and methods for large-scale production and harvesting of oil-rich algae** Systems and methods for the growing of microorganisms such as algae, yeast, and bacteria are described. Seed fermentation units are associated with final fermentation	328

		ponds in various arrangements....	
50	6702948	**Mobile diesel fuel enhancement unit and method** A method for filtering algae, comprising receiving a generator shut-off signal indicating that a generator associated with a fuel tank having fuel has shut off; and upon receiving the generator...	322