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Review Article

An Overview on: Next Generation Cost Effective Biofuel Production from Algae

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A B S T R A C T

Biofuels reduce greenhouse emissions by 30-50% compared with than fossil fuels. However, nearly half of the biofuels have greater environmental costs than petrol. So, it is needed to have new cost effective and eco-friendly technology for fulfill our energy demand. There are three generation of biofuels existed (first, second and third generation). Algae fuel also known as algal biofuel, is an alternative to fossil fuel of third generation technology. Algae biofuel production from algae is considered to be attractive source of energy. Recent advances in technology and the energy crisis have ignited interest in agriculture farming for making different kind of biofuels by using different types of waste agricultural materials. Among all biofuels, algal fuels have some attractive characteristics that are algae can be grown with minimal impact of fresh water resources and require no specific growing condition. Different species of algae are being currently used globally to produce 'Green biodiesel' which may be used in diesel engine. In this paper, we focused on biofuel fuel production from algae.

Introduction

Now a day, biofuel is driving important attention because of being not only a renewable energy source but also non-toxic, biodegradable and its impact on environment and climate (anil singh *et al.*, 2015). They can be broadly defined as solid, liquid or gas fuel consisting of or derived from biomass i.e. biological material from living organisms. Liquid biofuels allow solar energy to be stored and also to be used directly in existing engines and transport infrastructure when compared with other forms of renewable energy such as wind, tidal and solar (http://www.wyss.harvard.edu). The most popular forms of biofuels are biodiesel and bioethanol. Others are green diesel, vegetable oil, biogas and syngas. According to their development, biofuels are categorized in three generations on the basis of production techniques and raw materials (http://biofuel.org.uk/types-of-biofuel.html).

First generation biofuels: from sugar, starch, vegetable oil or animal fats.

Second generation biofuels: from non-food crops.

Third generation biofuels: from Algae.

As sustainable production of renewable energy is a hot topic of global debate and now it is clear that first and second-generation biofuels are limited in their ability to achieve targets for biofuel production, climate change mitigation and economic growth. Despite the potential they also have others drawbacks such as requirement of massive quantities of agriculture land, raw material and water for irrigation (Barnwal BK., *et al.,* 2005). The third-generation biofuels *i.e*. Algae biofuel definitely deserve more research and faster development because they certainly have a lot of more advantages than disadvantages and could provide reliable source of energy in years to come. In different studies, it is found that algae can yield over 30 times more energy per unit area in comparison to first and second-generation biofuel production strategy. U.S. Department of Energy also identified algae to produce 100 times more oil per acre than soybeans or any other terrestrial oil-producing crop (S. Kim and B. E. Dale., 2004).

Biofuel history

The idea of using Algae as a source of food, feed and energy goes back more than half a century. Production of methane gas from algae was proposed in the early 1950s and received a big impetus during the energy crisis of the 1970s, when projects were initiated to produce gaseous fuels (hydrogen and methane) (Kay RA *et al.,* 1991). The ASP researchers worked primarily on growing algae in open ponds, making significant contributions to our understanding of growing algae for fuel (Blanken *et al.,* 2015). Thousands of different species were isolated and tested, the impacts of different nutrient and CO_2 concentration were documented, the engineering challenges of mass- producing algae addressed and a solid foundation of algae-fuel research built. But in 1995, faced with financial constraints and cheap oil, the DOE made the decision to terminate the program. In recent years, things have changed. Exploding global demand for transportation fuels, concerns about “peak oil”, increasing impacts of atmospheric CO_2, the United States increasing importation of fuel and the energy security risks that come with that has fueled a rebirth in the interest of biofuels in general and algae-based biofuels in particular (Benemann *et al.,* 1996).

Advantage in biotechnology, such as the ability to genetically engineer algae to produce more oils and convert solar energy more efficiently, have unleashed new possibilities not feasible during ASP years. Most of the activity in algae research and commercial production has been in the united states. However, now algae biofuels are also being researched around the world in both developed and developing nations in Europe, Asia and elsewhere. The US-based Algal biomass organization is a leading voice for the industry and a source for information on the companies involved in advancing the technology (Hu, Q *et al.,* 2008). Biofuel production from different raw materials with specialized techniques along their products types summarized in (table 1).

Algae biofuel production

A number of algae production technologies are currently under development from open ponds and closed photobioreactors, from fermentation tanks to hybrids systems, to some that combine these various methods. Simply but there is no single way to grow algae at commercial scale and this versatility is one of algae's strengths. In most cases, the approach taken is designed solely to maximize algae growth for production of fuel chemicals or other industrial products. How exactly these systems operate is often a function of where they are located and the desired end-product. This section takes a look at several innovative types of algae growth systems currently being deployed across the United States (Darzins *et al.*, 2010).

Production techniques

Open Pond Systems

Open pond systems are the most common system of algae cultivation, already used commercially in the United States to produce nutritional products and treats wastewater. In recent years, many companies have begun focusing on this growth model for biofuels and chemicals (Benemann *et al.,* 1996). In fact, open ponds were the focus of the department of Energy's Aquatic species program in the 1980s and 1990s. Open pond systems use shallow (typically one-foot deep) ponds, from about one acre to several acres in size, in which the algae are exposed to natural solar radiation (sunlight) which they convert into biomass (Venkataraman *et al.,* 1982). Typically, the ponds are called raceway ponds because their shape resembles a race track. They often use paddle wheels or other water moving devices to keep the algae circulating. The harvesting method is often a two-stage process based on the particular properties of the algae and requirements of the process. A fraction of the pond water is generally harvested every day, and the algal biomass within the water is concentrated. The biomass is then processed further, for example to extract the oil for conversion into biodiesel, jet fuel or some other oil-based product. The residue or even the entire biomass, can also be dried and used for animal feeds (Borowitzka *et al.,* 1996). Open pond systems for the production of biofuels are already under development. For example, Sapphire Energy is developing a commercial-scale open pond production facility in southern New Mexico and is aiming to produce millions of fuels annually by 2017.

Closed systems

A Photobioreactor (PBR) differs from an open in that the algae enclosed in a transparent vessel, which can be as simple as a greenhouse, but more generally is a tubular bag-type or panel design, in many shapes and sizes oriented vertically or horizontally. Some systems even use additional artificial light to help boost production and a few rely exclusively on artificial lights. One of main advantages of PBRs is that they can better match the ideal condition and growth requirements of particular types of algae not easily grown in open ponds. They can also prevent or at least reduce invasion by weed algae, zooplankton that could affect the cultures (Quinn *et al.,* 2011).

Fermentation

Some researchers and companies are pursuing an alternative approach to growing algae using sunlight: growing them in the dark on sugars in a so-called "heterotrophic" fermentation. The algae convert the sugars to oil and biomass, which can be converted into biofuels, chemicals, nutritional products, cosmetics, etc. San Francisco-based company Salarymen, the pioneer of this method, has already produced tons of thousands of gallons of algae-based fuels as part of their research and development agreement with the Defense Logistics Agency to provide the US Navy with significant quantities of advanced HRD-76 marine diesel fuel and HRJ-5 aviation fuel (Yazdani *et al.,* 2007). These fuels have been successfully tested at 50/50 blends with petroleum in vehicles ranging from an MH60S Seahawk helicopter to a Riverine command boat among many other platforms. Salarymen is also producing renewable oils for the chemicals, nutrition and skin and personal care space utilizing today's existing industrial scale fermentation capacity (Hon-Nami *et al.,* 2006).

Hybrid systems

While most companies have chosen to focus exclusively on open pond systems, others on PBRs and a few on fermentation. Some companies are seeking to leverage the advantages of each systems by using 'hybrid' processes that combine two or more of the above methods (Sharif Hossain *et al.,* 2008). These can be small PBRs that inoculate large ponds, larger PBRs used in combination with ponds or ponds and fermenter used sequentially. The objective of hybrid systems is to maximize the individual advantages of each process. An Ohio-based company with operations with operations in Hawaii, uses this type of system (Sharif Hossain *et al.,* 2008).

Integrated systems

This category leverages the ability of algae to treat wastewater by absorbing nutrients and CO_2, while breaking down and removing unwanted, even toxic materials. The algal biomass produced during such wastewater treatment processes can then be used to generate methane, produce fertilizers and can also yield oil and other liquid fuels (Benemann *et al.,* 1982). The common thread in any integrated system is that the waste-whether it be dirty water or even polluted air – acts as an input during the growth phase. In other words, the contaminants that algae are able to clean from the air and water serve as 'food' for the algae in their growth cycle (Béchet *et al.,* 2013). By removing nutrients, something that algae can do very efficiently, algal blooms in lakes and coastal waters can be prevented or minimized solving a major environmental issue (Bennion *et al.,* 2015).

Bioprocess Algae, is also utilizing a closed photobioreactor system for a facility in lowa. The company's photobioreactor are large vertical columns that use not only natural light but lasso the waste heat CO_2 from a nearby first-generation ethanol plant (http://biofuel.org.uk/first-generation-biofuel.html). Accelergy corporation has developed a proprietary biological carbon capture and recycle technology, which passes CO_2 (from a source like a coal power plant) through a photo bioreactor that is growing concentrated algae. Once the growth cycle is complete, the algae is blended with proprietary additive to produce a biofertilizer which is then used on crops which then continuing to capture CO_2 from the atmosphere as it grows.

Excretion processes

Many companies are working to modify algae to produce biofuel through "excretion." That is, instead of storing oils in the biomass, the algae would excrete useful chemical into the culture or medium in which they are grown (Johnson *et al.,* 2010).

Table.1 Raw materials for biofuels production with specific technique and products

Raw material	Technique	Product	Product type
Vegetable oil and animal fat	Hydrotreatment	Biodiesel	Hydro-treated biodiesel
Algae	Fermentation, extraction and Esterification	Biodiesel etc.	Algal biodiesel
Lignocellulosic material	Advanced hydrolysis & fermentation	Biomass-to-liquids(BTL): Fischer-Tropsch(FT)diesel synthetic (bio) diesel	Synthetic biodiesel
Lignocellulosic material	Advance hydrolysis and fermentation	Cellulosic bioethanol	Bioethanol

Fig.1 Schematic diagram of Different steps in algae biofuel production at commercial level

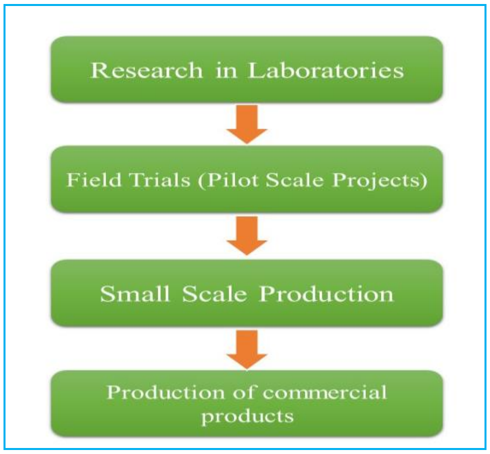
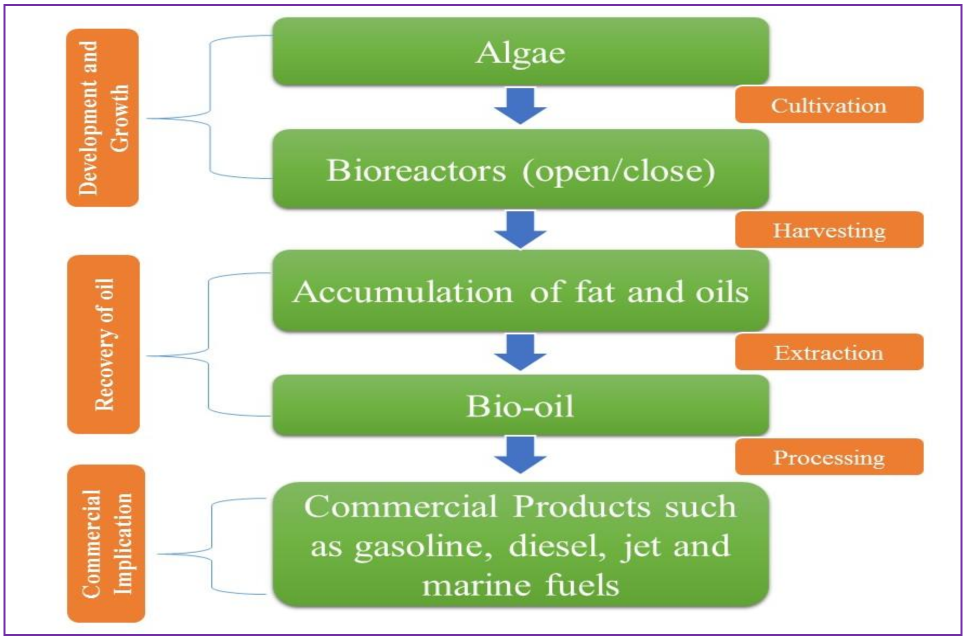


Fig.2 Algae Biofuels: Culture to commercial products



This approach has the advantage of requiring only an initial and small amount of algal biomass that would continually produce oils, avoiding the need for harvesting and processing which can add significantly to the overall coat. Ethanol, butanol, fatty acids, hydrocarbons, gaseous fuels, and many more useful products all can be excreted by modifying the algae (Huesemann *et al.*, 2016). San Diego-based synthetic Genomics is working with Exxon on this type of approach. There's no doubt that the algae industry has just scratched the surface of how best to grow and harvest algae. Even within these five areas of production there is much room for innovation and additional breakthroughs and it will be fascinating to see the evolution in the coming years.

Benefits to India from algae biofuel

As India is a fast-economic growing country, it is heavily industrialized and is striving to meet basic energy demands of its people, which should be at par with emerging economic development. India's transportation fuel requirements are unique in the world. It consumes almost five times more diesel fuel than gasoline, whereas, almost all other countries in the world use more gasoline than diesel fuels (http://www.biodieseltechnologiesindia.com /whatbio.html). Currently, for meeting fuel requirements, India is most dependent on coal. Use of coal resource is indispensable for achieving the goal of 'energy to all'. Indian coal production is the 3rd highest in the world according to the 2008 of Indian Ministry Mines estimates[36]. Coal is the cheapest but also the dirtiest fuel. Domestic production of biofuels would mean less pollution from coal power plants and less impact on climate change. Thus, in India search for alternatives energy sources is of special importance and the use of biodiesel is comparatively much more important for us than rest of the countries. Biomass is the fourth largest energy source in the world and the first in India. Every year, plants store 10 times the present annual consumption of energy (Sorensen, B 1997). The study of biomass energy is of particular importance for India in view of the extreme dependence of most rural areas on local energy resources. Also, the high rate of population growth, rising prices of commercial energy carriers, viz. electricity gas and petroleum products, suggest that biomass energy consumption will increase (Shukla *et al.*, 1997).

Using algae to produce biofuel will not compromise production of food, fodder and other products derived from crops. Every now and again, new attempts are made at tapping the potential of algae, even though analysts seem to think that the petrol prices recently have not been high enough for algal biofuel to become competitive.

Current research Status in India

Under the New Millennium India Technology Leadership project (NMITLI), researchers have claimed to have run a car on B-20 biodiesel derived from marine micro algae. The project was initiated jointly by CSIR and the Ministry of Earth Sciences (MoES), along with researchers from nine institutions, including CSMCRI, IIT-Kharagpur, IICT-Hyderabad, NIOT-Chennai and NIO-Goa (https://india.gov.in/new-millennium-indian-technology-leadership-initiative-csir). The biodiesel was prepared from mats of microalgae found growing naturally in the West coast of India by the Bhavnagar-based Central Salt Marine and Chemical Research Institute (CSMCRI). CFTRI, Mysore has developed a technology for the production of the green alga, *Scenedesmus acutus* and blue-green alga, *Spirulina platensis* in clean water to suit Indian conditions. *Spirulina* is the most promising alga in view of its amenability to low level technology. India's Institute of Chemical Technology is aiming to reduce the cost of producing oils from algae from Rs 500 per litre to roughly INR Rs 20 per litre. Using a combination of careful selection of algal species plus genetic engineering to produce higher oil production, ICT researchers believe they can bring the price of algal fuels down to earth. In Karnataka, a company operating in the alternative energy sector *i.e.* World Health Energy Holdings, Inc. is setting up a 250-acre commercial algae biodiesel farm with a $100 million budget. Along-with algal oil, this project will also produce fish feed. In its first phase, this project is utilizing GB3000, a proprietary algae enhancement technology, used for rapidly and efficiently growing algae for biodiesel production. Another research center i.e. Dr. MGR Algae Biofuel Research Center, Tamil Nadu has also launched a biodiesel project from micro algae at Sivakasi, one of the highest CO_2 emission town in Tamil Nadu and also a very hot place. Not only for biofuel production, algae are also useful in many different ways. Experience gained on algal production technology in India indicates the scope for applying this at the rural level for use in the production of animal feed (K. Sudhakara *et al.,* 2012).

Algae Biofuel: throughout advantages

Tiny biological factories – this word is used for algae, for describing their efficient ability of transforming carbon dioxide and sunlight into energy, as a result of which they can double their weight several times a day. Algae fuel overcomes a major question "Land use for food or fuels?" As algae do not need agriculture land, it can be easily grown in waste/degraded land or sea water, sewage, industrial effluent etc. Now a day, production of biofuel from algae is probably the most cost-effective technology. It appears to be the only source of biodiesel that has the potential to completely replace fossil diesel as oil content in microalgae can exceed 80% by weight of dry biomass. Advantages of algae biofuel can be summarized as:

Fast growth i.e. short harvesting cycle (only 1–10 days), it permits several harvests in a very short time frame.

It consumes carbon dioxide, thus helps in overcome problem of carbon dioxide, which is a greenhouse gas mostly responsible for climate change problem.

Algae can grow in salt water, freshwater or even contaminated water at sea or in ponds, and on land not suitable for food production. Thus, do not affect freshwater resources, can be produced using ocean and waste water.

No need of herbicide and pesticide.

Microalgae produce value-added co-products or by-products (e.g. biopolymers, proteins, polysaccharides, pigments, animal feed and fertilizer).

Choice of algal strains and biofuel production strategies

In production of algae biofuel, a key consideration is the choice of algal strain (H.M. Amaro *et al.,* 2012). There exist approximately 100,000 known species around the world. More than 400 new specimens are described each year. The DOE's National Renewable Energy Laboratory (NREL) has identified approximately 300 species of algae, as varied as the diatoms (genera Amphora, Cymbella, Nitzschia) and green algae (genus

Chlorella) as potentially good sources of algae to biodiesel production. Research into algae for the mass-production of oil is mainly focused on microalgae; organisms capable of photosynthesis that are less than 0.4 mm in diameter, including the diatoms and cyanobacteria; as opposed to macroalgae, such as seaweed. The preference towards microalgae is due largely to its less complex structure, fast growth rate and high oil content (for some species). Diatoms or Bacillariophytes are unicellular, microscopic algae. These organisms are widely spreaded in salt water where they constitute the largest portion of phytoplankton biomass. Most commonly studied algae, for their suitability as a mass-oil producing crop, across various locations worldwide are *Botryococcus braunii*, *Chlorella*, *Dunaliella tertiolecta*, *Gracilaria*, *Pleurochrysis carterae* (also called CCMP647), *Sargassum* (with 10 times the output volume of *Gracilaria*), *Nitzschia sp.*, *Nannochloropsis sp.*, *Schizochytrium sp*. In addition, due to its high growth rate, *Ulva* has been also investigated as a fuel.

Opportunities for India

A major part of India is covered by water. The coastal regions of India are 7,517 kilometers (4,700 mi) long. The twelve major rivers of India cover an area exceeding 2,528,000 km^2 (976,000 sq. mi). According to expert's algae farming in less than 2-3 percent of India's total land can make the country self-sufficient in liquid fuel. The estimate yield of algae in on acre of wasteland can be 30 times more than Jatropha and not just this, algae farming also provide solution to food verses fuel debate. Most Indian experts suggest that the Sundarbans delta, a remote deltaic marshland, can be used for algal cultivation and extraction of biodiesels. The Sundarbans delta, an archipelago of some 100 islands spread over 4,262 sq. km. on the Indian side of the Bay of Bengal, is becoming the incubator of ecology-friendly energy sources, which is the world's largest mangrove swamp. Currently, the effort to try out algae cultivation in order to extract bio-diesel is going on here. Successful completion of this work will lead to a new era in area of India's alternative energy resources (M. Kumar *et al.*, 2012).

Algae have been in contention as one of the major source of biofuel in future. Cultivation of algae does not necessarily need prime agricultural land and can be grown under desert like conditions using brackish and saline waters that are unfit for terrestrial crops the water used for algal cultivation does not compete for agriculturally important activities. Algae biofuel production is an Ecofriendly as well as cost effective techniques for biofuel production. Due to safe and less pollution during combustion, it is implementing globally. Algae biofuel produced by algae and different species of algae are known for algae biofuel production. Green biodiesel produced by algae. Algae biofuel is alternate to liquid fossil fuels. The yield of algae fuel is higher than existed technology. Biodiesel produced by algae can be used in diesel engine and fulfilled the demand of fuel as raw energy. Algae biofuel is safe and ecofriendly. Algae biofuel improving our environment in terms of lacking, harmful gases as they burnt during combustion. Finally, algae biofuel is safe and might be fulfilled our energy demand in future as alternate of fossil fuel.

References

Amaro, H.M., C. Ângela, A.C. Macedo and F.X. Malcata. Microalgae: An alternative as sustainable source of biofuels? Energy, 2012, 44, 158-166.

Anil Singh, Alok singh, "A comparative overview of Bio-ethanol production from Organic Residues of Agro waste Materials", European Journal of Biotechnology and Bioscience, vol. 3, no. 3, pp. 11-14, 2015

Anoop Singh, Poonam Singh Nigam and Jerry D. Murphy, 2011, Renewable fuels from algae: An answer to debatable land based fuels, Bioresource Technology, Volume 102, Issue 1, Pages 10-16.

Bajhaiya, A.K., S.K. Mandotra, M.R. Suseela, K. Toppo and S. Ranade. Algal biodiesel: The next generation biofuel for India. Asian J. Exp. Biol. sci., 2010, 1, 728-739.

Barnwal BK, Sharma MP. Prospects of biodiesel production from vegetables oils in India. Renew Sustain Energy Rev 2005;9:363–78.

Béchet, Q., A. Shiton, and B. Guieysse. 2013. “Modeling the effects of light and temperature on algae growth: State of the art and critical assessment for productivity prediction during outdoor cultivation.” Biotechnology Advances 31 (8): 1648–63.

Benemann, J. R. and W. J. Oswald. 1996. Systems and Economic Analysis of Microalgae Ponds for Conversion of CO2 to Biomass. U.S. Department of Energy

Benemann, J. R. and W. J. Oswald. 1996. Systems and Economic Analysis of Microalgae Ponds for Conversion of CO2 to Biomass. U.S. Department of Energy

Benemann, J. R. and W. J. Oswald. 1996. Systems and Economic Analysis of Microalgae Ponds for Conversion of CO2 to Biomass.” U.S. Department of Energy

Benemann, J. R., R. P. Goebel, J. C. Weissman, and D. C. Augenstein. 1982. Microalgae as a source of liquid fuels. Final technical report. (No. DOE/ER/30014-T1). EnBio, Inc: Fairfield, CA.

Bennion, E. P., D. M. Ginosar, J. Moses, F. Agblevor, and J. C. Quinn. 2015. “Lifecycle assessment of microalgae to biofuel: Comparison of thermochemical processing pathways.” Applied Energy 15: 1062–71.

Blanken, W, P. R. Postma, L. de Winter, R. H. Wijffels, and M. Janssen. 2016. “Predicting microalgae growth.” Algal Research 14: 28–38. doi:10.1016/j.algal.2015.12.020.

Borowitzka, M. A. Closed algal photobioreactors: design considerations for large-scale systems. J. Mar. Biotechnol. 1996, 4, 185-191.

Bracmort, K. 2014. Algae’s Potential as a Transportation Biofuel. Congressional Research Service Report 7-5700.

Brennan, L. and P. Owende. 2010. “Biofuels from microalgae—A review of technologies for production, processing, and extractions of biofuels and co-products.” Renewable and Sustainable Energy Reviews 14: 557–77.

Chand, P., Chintareddy, V.R., Verkade, J.G., Grewell, D. 2010. Enhancing Biodiesel Production from Soybean Oil Using Ultrasonics. Energy & Fuels, 24(3), 2010 2015

Darzins, A., P. Pienkos, and L. Edye. 2010. Current Status and Potential of Algal Biofuels Production. IEA Bioenergy Task 39. Report T39-T2.

Darzins, A., P. Pienkos, and L. Edye. 2010. Current Status and Potential of Algal Biofuels Production. IEA Bioenergy Task 39. Report T39-T2.

Hon-Nami, K. 2006. “A unique feature of hydrogen recovery in endogenous starch-to- alcohol fermentation of the marine microalga, Chlamydomonas perigranulata." Applied Biochemistry and Biotechnology 131(1–3): 808–28.

http://advancedbiofuelsusa.info/category/states/states-ohio/

http://biofuel.org.uk,"Biofuel.org.uk,16 APL 2017

http://biofuel.org.uk/first-generation-biofuel.html

http://www.biodieseltechnologiesindia.com/futurebio.html

http://www.biodieseltechnologiesindia.com/whatbio.html

http://www.wyss.harvard.edu/.

https://arpa-e.energy.gov/?q=slick-sheet-project/fuel-bacteria-co2-water-and-solar-energy,"

https://india.gov.in/new-millennium-indian-technology-leadership-initiative-csir

Hu, Q., M. Sommerfeld, E. Jarvis, M. Ghirardi, M. Posewitz, M. Seibert, and A. Darzins. 2008. "A Microalgal triacylglycerols as feedstocks for biofuel production: Perspectives and advances." The Plant Journal 54 (4): 621–39.

Huesemann M., J. Van Wagenen, T. Miller, A. Chavis, S. Hobbs, and B. Crowe. 2013. "A screening model to predict microalgae biomass growth in photobioreactors and raceway ponds." Biotechnology and Bioengineering 110 (6): 1583–94. doi:10.1002/bit.24814.

Huesemann, M, M. Wigmosta, B. Crowe, P. Waller, A. Chavis, S. Hobbs, B. Chubukov, V.J. Tocco, and A. Coleman. 2016b. "Estimating the Maximum Achievable Productivity in Outdoor Ponds: Microalgae Biomass Growth Modeling and Climate Simulated Culturing." In Micro-Algal Production for Biomass and High-Value Products. S. P. Slocombe and J.R. Benemann (eds). Boca Raton, FL: CRC Press, Taylor and Francis, LLC.

Johnson, M., and Z. Wen. 2010. "Development of an attached microalgal growth System for biofuel production." Applied Microbiology and Biotechnology 85 (3): 525–34.

Kay RA. Microalgae as food and supplement. Crit Rev Food Sci Nutr 1991; 30:555–73

Kim, S., and B. E. Dale, "Global potential bioethanol production from wasted crops and crop residues,"Biomass and Bioenergy, vol. 26, no. 4, pp. 361–375, 2004.

Kumar, M., M.P. Sharma and G. Dwivedi. Algae Oil as Future Energy Source in Indian Perspective. International Journal of Renewable Energy Research, 2013, 3, 913-921.

Quinn, J. C., K. Catton, N. Wagner, and T. H. Bradley. 2011. "Current Large-Scale US Biofuel Potential from Microalgae Cultivated in Photobioreactors." Bioenergy Research 5(1): 49–60.

Shakeel A. Khan, Rashmi, Mir Z. Hussain, S. Prasad and U.C. Banerjee, 2009, Prospects of biodiesel production from microalgae in India, Renewable and Sustainable Energy Reviews, Volume 13, Issue 9, Pages 2361-2372.

Sharif Hossain, A. B. M., A. Salleh, A. N. Boyce, P. Chowdhury, and M. Naqiuddin. 2008. "Biodiesel fuel production from algae as renewable energy." American Journal of Biochemistry and Biotechnology 4 (3): 250–4.

Sharma, Y.C., B. Singh and J. Korstad. A critical review of recent methods used for economically viable and eco-friendly development of microalgae as a potential feedstock for synthesis of biodiesel. Green Chemistry, 2011, 13, 2993-3006.

Shukla, P.R (1997), Biomass Energy in India, Conference Proceedings – Biomass Energy: Key Issues and

Priority Needs, International Energy Agency, Paris, France

Solazyme. 2014a. "Solazyme Announces U.S. Commercial Production of Renewable Algal Oils at Iowa Facilities." Press Release. January 30, 2014.

Sorensen, B (1997), Renewable Energy and Environment Policy, in Rural and renewable energy: perspectives from developing countries - Ed. Ramana P.V, TERI, New Delhi, India.

Sudhakara, K., M. Premalathab and M. Rajesha. Large-scale open pond algae biomass yield analysis in India: a case study. *International Journal of Sustainable Energy*, 2012, 1, 1-12.

Venkataraman, K. Madhavi Devi, M. Mahadevaswamy and A.A. Mohammed Kunhi, 1982, Utilisation of rural wastes for algal biomass production with Scenedesmus Acutus and Spirulina Platensis in India, L.V. Agricultural Wastes, Volume 4, Issue 2, Pages 117-130.

Yazdani, S. S. and R. Gonzalez. 2007. "Anaerobic fermentation of glycerol: A path to economic liability for the biofuels industry." Current Opinion in Biotechnology 18:213–19.