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Biofuel From Algae: A Sustainable Third-Generation Biofuel

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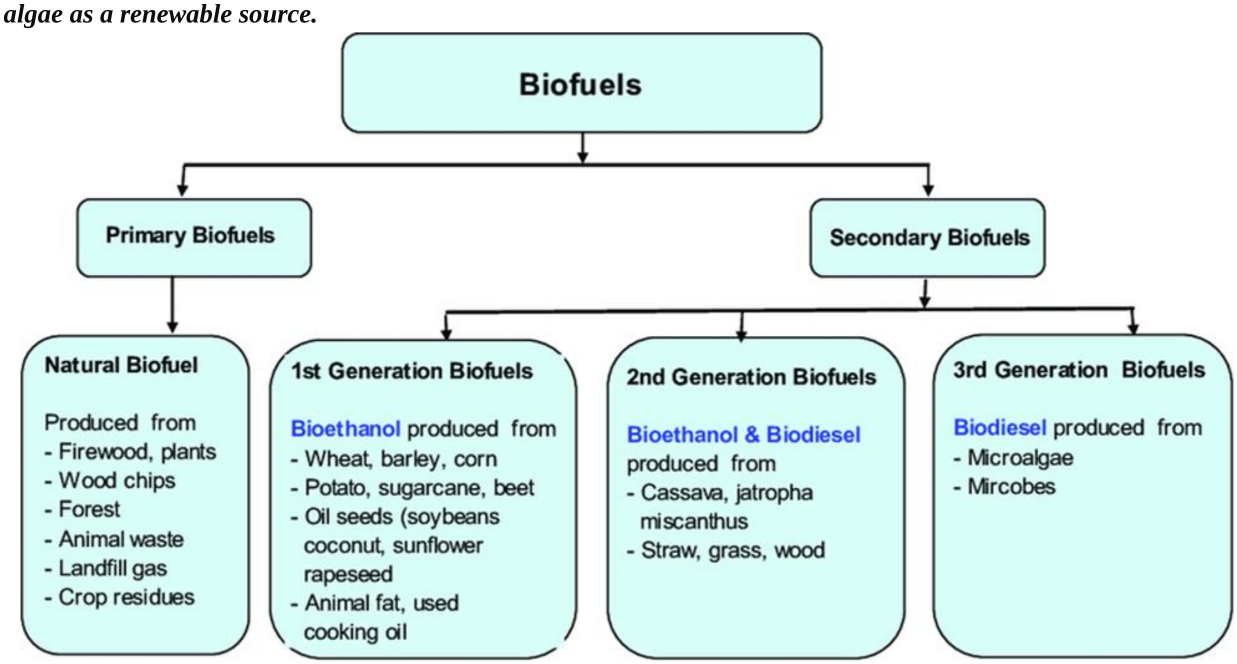
Abstract- Fossil fuel energy resources are depleting rapidly and most importantly the liquid fossil fuel will be diminished by the middle of this century. Production of biofuel from renewable sources is considered to be one of the most sustainable alternatives to petroleum sourced fuel. Biofuel from algae is an environmentally friendly energy source fuel produced through transesterification with short chain alcohols. The global market for biofuel has been growing rapidly during the past few years, and is poised for explosive growth in the next years. Biofuel production from algae can provide some distinctive advantages such as their rapid growth rate, greenhouse gas fixation ability and high production capacity of lipids. It reduces greenhouse emissions by 30-50% compared with than fossil fuels. This paper reviews the current status of biofuel from algae as a renewable source.

Indexed Terms- biofuel, microalgae, wastewater, nano additives, economy

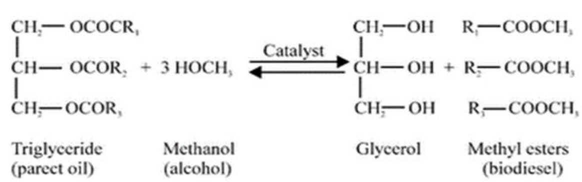
I. INTRODUCTION

The energy requirements of the global community are rising year by year. Currently fossil fuels are prominent source of transportation fuels and energy. The world's demand for oil is expected to rise 60% from current level by 2025. In the view of the increasing oil demand and the depleting oil reserves, development of innovative techniques for the production of biofuels from novel renewable biomass feedstock sources are gaining importance all over the world.



The first-generation biofuels possess notable economic, environmental and political concerns. The most alarming issue associated with the first-generation biofuels is that with the increase of production capacity, more arable agricultural lands are needed for the production of first-generation biofuel feedstock resulting in reduced lands for human and animal food production. The intensive use of fertilizer, pesticides on farming lands can reduce not only the food production capacity of lands but also cause significant environmental damage.

Main sources of second-generation biofuels are predominantly agricultural residues, waste, forest harvesting residues, wood processing residues and non-edible components of corn, sugarcane, beet, etc. However, converting the woody biomass into fermentable sugars requires sophisticated and expensive technologies for the pre-treatment with special enzyme making second generation biofuels economically not profitable for commercial production.



Third generation biofuel is currently considered to be a feasible alternative renewable energy resources for biofuel production overcoming the disadvantages of first- and second-generation biofuel:

- The potential for biofuel production from microalgae is 15 to 300 times more than the traditional crops on an area basis.
- Microalgae possess a very short harvesting cycle (1 to 10 days depending on the process) allowing multiple or continuous harvesting with significantly increased yield.
- Macro algal biomass contains high amount of sugar (at least 50%) which can be used for ethanol fuel production.
- Microalgae can rapidly grow on non-agricultural land or in brackish water.

II. ALGAL BIOFUEL PRODUCTION

Algae can be classified into two major groups based on their size, namely

1. Macroalgae (or seaweeds): consisting of multicellular organisms growing from 50 cm up to 60 m in length occur in near-shore marine coastal waters. Based on the composition of their photosynthetic pigments, macroalgae are classified into green (*Chlorophyceae*), red (*Rhodophyceae*) and brown (*Phaeaphyaceae*) species. The carbohydrates are the main organic constituent of most species ranging from 23 to 79% dry.wt.
2. Microalgae: unicellular organisms ranging in size from nano to millimeters, depending on the species, having chlorophyll as their primary photosynthetic pigment. Comparing to macroalgae, microalgae are generally more efficient converters of solar radiation into usable energy via photosynthesis due to their simple cellular structure. Microalgae are characterized by generation times that are usually higher than 24 hr, although some strains are able to duplicate their cells in less than 8 hours. This is mainly because they have more efficient access to water, CO2 and nutrients during photosynthetic growth.

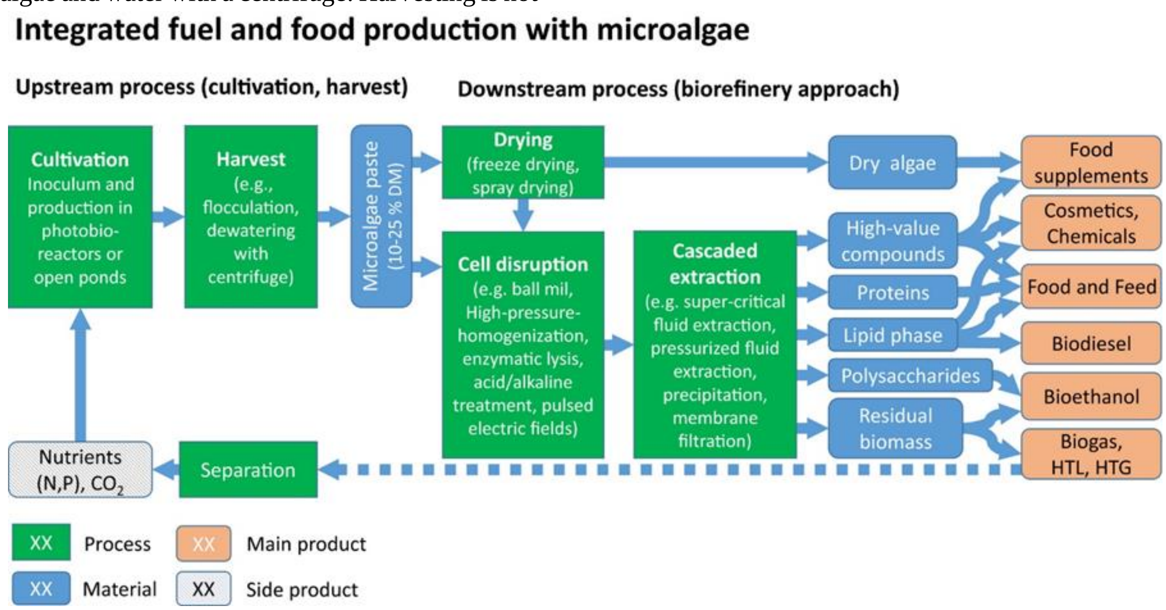
Microalgae	Oil content (wt% of dry basis)
Botryococcus braunii	25–75
Chlorella sp.	28–32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16–37
Dunaliella primolecta	23
Isochrysis sp.	25–33
Monallanthus salina	>20
Nannochloris sp.	20–35
Nannochloropsis sp.	31–68
Neochloris oleoabundans	35–54
Nitzschia sp.	45–47
Phaeodactylum tricornutum	20–30
Schizochytrium sp.	50–77
Tetraselmis sueica	15–23

Group	Species	Location	Lipid content (%,w/w)	Other uses
Red Algae	*Chondrus ocellatus*	Hawaii, USA	0.9	Used as thickener and stabilizer
	Porphyra perforate	Ireland, Canada, California	5.8	Edible sea weed
	Gloiopeltis fenax	Sea of south China	33.38	Sizing material in silk and other textiles
	Gracilaria crassa	Northern territory, Australia	11	Used as antiviral agent
	Gracilaria corticata	India	10.9	Animal feed
Brown Algae	*Hedophyllum sessile*	California	6.4	Traditional plant food
	Saccharina japonica	Hokkaido, Japan	1.2	Source of glutamic acid
	Nereocystis luetkeana	Cormorant Island	33.6	Edible sea weed
	Sargassam Sp.	Mandapam, Tamil Nadu	1.6	Source of medicinal value
Green Algae	*Caulerpa scalpelliformis*	India	24.4	Animal feed
	Ulva fenestrate	Sea of Japan	5.01	Edible as soups and salads
	Chaetomorpha linum	Tuscany, Italy	60	Used in aquarium
	Enteromorpha fasciata	Tamil Nadu	52.2	Edible sea weed

Process step	Macroalgae (or seaweeds)	Microalgae
Cultivation	natural stocks, drift material cultivation (near-shore systems, off-shore systems, open ponds)	cultivation (photobioreactors, open ponds)
Harvesting	manual mechanised	flocculation flotation sedimentation centrifugation filtration
De-watering/Pre-treatment	cleaning/washing crushing maceration	dewatering drying
Conversion to biofuels	biochemical processes: anaerobic digestion (AD) fermentation	biochemical processes: AD fermentation thermochemical processes: gasification hydrothermal liquefaction pyrolysis direct combustion trans-esterification and biodiesel production

Basic steps for turning Algae into biofuel

- Cultivation: Algae are cultivated either in open ponds or in closed photobioreactor systems, which are transparent containers designed to allow light through to algal cells. Both systems must be agitated and circulated to prevent sedimentation, allow the even distribution of nutrients, and expose algae to light and carbon dioxide.
- Harvest: This step involves separating algae from their liquid growth media, for example, by filtering the water to remove algal cells or by separating algae and water with a centrifuge. Harvesting is not necessary for systems with algae or cyanobacteria that secrete compounds from which fuel are made into the culture medium.
- Recovery: This step involves extracting fatty liquids from algal cells or recovering fuel precursors from the culture medium. The residue left after lipids have been recovered can be recycled for nutrients, or may be useful as a coproduct.
- Downstream processing: Algal lipids, biomass or secreted products are processed into fuels.



- Types of systems

1. Open Raceway Pond: Open Pond systems are the most common system of algal cultivation. Open pond system uses shallow ponds, from about one acre to several acres in size, in which the algae are exposed to natural solar radiation which they convert into biomass. It often uses 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 or requirement of the process.
2. Photobioreactor: A photobioreactor is closed system in which 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 size oriented vertically or horizontally. One of the main advantages of PBR is that they can better match the ideal condition and growth requirement of particular types of algae not easily grown in open ponds. They can also prevent or at least reduce invasion by weed algae, zooplanktons that could affect the cultures.

Production system	Advantages	Limitations
Raceway pond 	Relatively cheap Easy to clean Utilises non-agricultural land Low energy inputs Easy maintenance	Poor biomass productivity Large area of land required Limited to a few strains of algae Poor mixing, light and CO2 utilisation Cultures are easily contaminated
Tubular photobioreactor 	Large illumination surface area Suitable for outdoor cultures Relatively cheap Good biomass productivities	Some degree of wall growth Fouling Requires large land space Gradients of pH, dissolved oxygen and CO2 along the tubes
Flat plate photobioreactor 	High biomass productivities Easy to sterilise Low oxygen build-up Readily tempered Good light path Large illumination surface area Suitable for outdoor cultures	Difficult scale-up Difficult temperature control Small degree of hydrodynamic stress Some degree of wall growth
Column photobioreactor 	Compact High mass transfer Low energy consumption Good mixing with low shear stress Easy to sterilize Reduced photoinhibition and photo-oxidation	Small illumination area Expensive compared to open ponds Shear stress Sophisticated construction

III. ECONOMICS AND CURRENT STATUS OF MICROALGAL BIOENERGY PRODUCTION IN VARIOUS COUNTRIES

Currently the cost microalgae oil is for more expensive than one of petroleum oil, for example: Chisti (2007) estimated that the price of annual output 10,000 tons of microalgae which contain 30% lipid is $2.80/litre (equal to 10.50/gallon) exclude conversion cost, marketing cost and tax.

The price of microalgae oil directly relates to the petroleum oil. There is a calculation equation can explain the relationship between algae oil and petroleum oil.

$C_{microalgae\ oil} = 25.9 * 10^{-3}. C_{petroleum}$ (C = Cost)

(The unit of microalgae oil cost is $/gallon, the unit of petroleum oil cost is $/barrel)

The equation resulted that for achieving competitive superiority of microalgae oil, the price of microalgae oil must be under $2.59/gallon if petroleum oil price at $100/barrel.

In November 2006, the U.S. Green Energy Technology Company and Arizona Public Services Company co-operate to establish a microalgae production system in Arizona State. The yield of biofuel reached 5,000-10,000-gallon acre per year.

In 2001, The National Energy Board of the United States launched “Mini-Manhattan Project”. In 2010, the U.S. could achieve microalgae production industrialization and produced microalgae oil reached about millions of barrels per day.

The president Barack Obama declared that the government will invest $24 million in biofuel production during his speech in University of Miami.

China is also paying attention to the microalgae bioenergy development. In 2008, Shandong University of Science and Technology used the thermal power plant and chemical plant flue gas as sources of carbon dioxide to supply microalgae cultivation in the tower dimensional cultivation reactor. In 2010, the Chinese academy of Sciences and China Petroleum Chemical Cooperation held a meeting about" Microalgae Biodiesel Technology Projects".

Hainan Greenbelt microalgae Biotechnology Company has been built a microalgae cultivation experimental base in Ledong County; the microalgae oil content can reach to 28 – 32%.

The new Austrian technology company is brewing a huge plan. They invested to microalgae ecological base in the Daqi of Inner Mongolia.

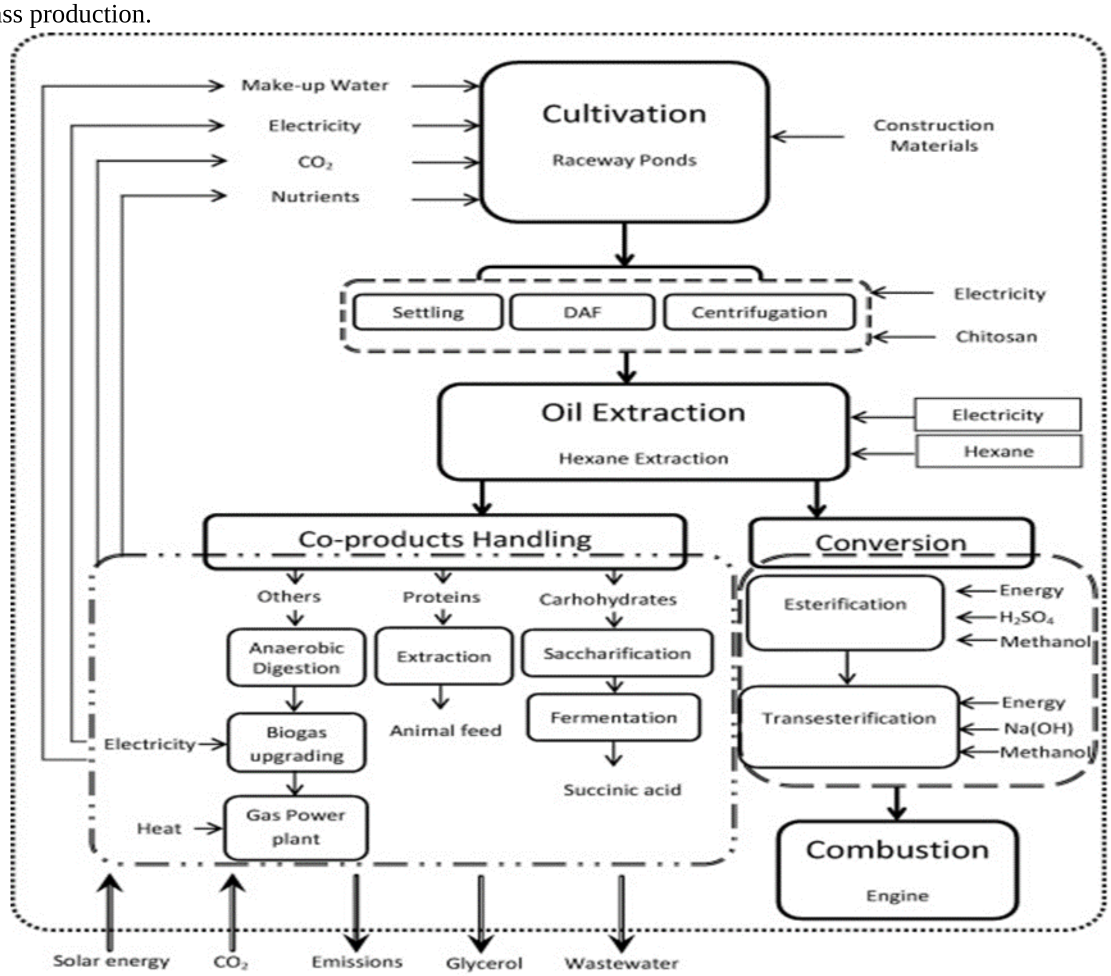
In 2007, an algae production plant in north part of Sweden was set to be built by Umea Energi. This project is headed by Swedish University of Agricultural science. The project is focusing on the wastewater reclamation of algae production process, CO2 sequestration from flue gas, and valuable algae biomass production.

In September 6, 2011, the European Union launched an algal bioenergy development action plan that will be set to the Algae development Project during the next four years.

In Malaysia, various industries and research institutes have demonstrated mass cultivation and biomass production of various micro algae in different industrial waste water. Recently, Algatech Industry has demonstrated mass cultivation of microalgae in the open raceway pond and the possibility of conversion of the lipid into biodiesel.

IV. LIFE CYCLE ASSESSMENT

Life Cycle Assessment is a useful way to be usually used to analyses the environmental impacts of a product or a set of production system from manufactory, usage stages to final recycling stage.



Clarens et al. (2010) and Lardon et al. (2009) published their own Life Cycle Assessment (LCA) reports to analyses the sustainability of microalgae production system. Clarens et al. (2010) based on the boundary of "cradle to farm gate", which means that from cultivation to biofuel generation. This report mentioned that less arable land is used in the microalgae cultivation and eutrophication. And biofuel outputs of microalgae are much higher than other terrestrial crops. However, microalgae need more energy consumption and water resource than other biomass feedstock. Besides, during the production process, some of green gas emission may lead to environment pollution if these waste gases could not be reused better. This is the draw back in sustainability. The LCA of Lardon et al. (2009) based on the "cradle to fuel combustion" boundary which means that "from cultivation process to biofuel use process". The analyzed results of Lardon showed that the superiority of microalgae cultivation is less land usage than terrestrial crops. But the negative view from Lardon et al. (2009) showed that microalgae cultivation process needs to use more fertilizer (nitrogen and phosphorus) than other bio-feedstocks, only if the excess nitrogen and phosphorous can be recycled better.

V. BIOFUEL PRODUCTION FROM ALGAE USING WASTE WATER

The overall current production and harvesting techniques of microbial biomass and downstream processing of microalgae to produce biofuels and other bioproducts of value is still too expensive to ensure a competitive production price for biofuels from algae. Waste water derived from municipal, domestic, agricultural and industrial activities can potentially provide cost-effective and sustainable means of algal growth for biofuels. Many microalgae species such as Chlorella sp, Scenedesmus sp, Mioactinium sp, Actinastrum sp, Heynigia sp. Hindakia sp, Pediastrum sp, Chlamydomonas sp.have been tested and were proven to be able to utilize and remove N and P as well as other trace elements in the waste water. It is estimated that roughly 1 kg of biological oxygen demand removed in an activated sludge process required 1KWh of electricity for aeration, which produces 1kg of fossil CO2nfrom power generation. By constrast, 1 kg of biological oxygen demand removed by photosynthetic oxygenation requires no energy inputs and produce enough microbial biomass to generate methane that can produce 1 KWh of electric power.

VI. MICROALGAL BIOFUEL PRODUCTION WITH NANO-ADDITIVES

Microbial biofuel can be integrated with nano-additives application to accelerate yield and improve the efficiency of biofuel utilization in petrol and diesel. Nano-additive such as nano-fibres, nano-magnets, nano-crystals, nano-droplets, nano-sheets. Nanotechnology applications can be entailed in different stages from microalgae cultivation to micro-algae biofuel application in fuel engines due to durability, recyclability, adsorption efficiency, catalytic performance, stability, crystallinity, economic advantages, high storage capacity, excellent biofuel yield and environmental –friendly characteristics. Magnetic nano-particle (NP) powder has been enumerated to the microalgae cell suspension in the photobioreactor cultivation process to flocculate cells in uniform distribution of nutrients and light all over the reactor. Nanotechnology is being applied for enzyme immobilization, since nano-structures broadens the immobilization surface area causing high loading power of enzymes and stability of immobilized enzymes. The enzymes immobilization was investigated on various carbon nano-particles e.g., grapheme oxide (GO), multi-walled carbon nano-tubes (MWNTs), oxidized-MWNTs (O-MWNTs) and fullerene (C60). Cost effectiveness of nano-crystals for an industrial application which may hinder the commercial perspective, since many nano-crystals are quite expensive.

VII. CURRENT RESEARCH STATUS IN INDIA

As India is a fast economic growing country, it is heavily industrialized. It consumes almost five times more diesel fuel than gasoline, whereas, almost all other countries in the world use more gasoline than diesel fuels. In India search for alternative energy sources is of special importance and the use of biofuel is comparatively much more important for us than rest of the countries.

Under the New Millennium India Technology Leadership project, researchers have claimed to have run a car on B-20 biodiesel derived from marine microalgae. The project was initiated jointly by CSIR and the Ministry of Earth Sciences, along with researchers from nine institutions, including CSMCRI, IIT-Kharagpur, IICT-Hyderabad, NIOT-Chennai, and NIO-Goa. The biodiesel was prepared from mats of microalgae found growing naturally in the West coast India by CSMCRI.

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 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. 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.

Another research Centre i.e. Dr. MGR Algae Biofuel Research Centre, TamilNadu has also launched a biodiesel project from micro algae at Sivakas, one of the highest CO2 emission town in Tamil Nadu and also a very hot place.

VIII. RECENT ADVANCES IN PRODUCTION TECHNOLOGY

Biochar catalyst can be used in transesterification, biohydrogen, biomass hydrolysis. Co-culturing filamentous fungi with targeted microalgae is a superior method to efficiently accumulate and harvest the total biomass. Ultraviolet mutagenesis can be used to induce genomic mutation in microalgae and thus enhance the production of lipid content, but the screening process is convoluted and labor-intensive. The utilization of molecular biology method such as CRISPR/Cas9 with guided RNA for genetic modification in algae has opened up new avenues to meet the future energy demand. Microalgae harvesting by chitosan-based flocculants has received extensive attention, due to the outstanding structural features, biodegradability, applicability to various types of microalgae species and environmental friendliness. The impact of weather and market fluctuations should also need to be considered during biofuel production.

The use of artificial intelligence (AI) method in optimizing the efficiency of a vaccum drying process. Three AI-based models were developed to model the vaccum drying process, specifically an artificial neural network (ANN), a support vector machine (SVM) and an extreme gradient boosting machine (XGB). Machine-based reverse and forward optimization were implemented with experimental verifications. The verifications were acceptable, showing great potential of ML-aided Hydrolysis and liquefaction for producing desirable bio-oil.

CONCLUSION

Rapid industrial development, depletion of mineral oil reserves and rise in atmospheric CO2 require the development of carbon-neutral renewable alternatives. Biofuel production from microalgae is supposed to provide technical and economic feasibility that has the potential for CO2 sequestration. In terms of greenhouse gases emission, the biofuels produced from microalgae is generally carbon neutral. Biodiesel or bioethanol production from algae biomass cannot be commercially viable unless by-products are optimally utilized. The lipid or the oil part is around 30% of the total algae biomass and the remaining 70% is currently wasted which can be as nutrients, pharmaceuticals, animal feed or bio-based products. Economic feasibility of biofuels from microalgae can be enhanced by using efficient methods of biomass harvesting and drying metabolic plus genetic engineering and system biology approaches, selection of efficient strains, high-value co-products strategy and linking microalgal production with waste water treatment. Biofuel derived from microalgae appear to be the only current renewable source that can potentially completely substitute fossil fuels.

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