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Biomass - Resource for Sustainable Development

Bhawana Pathak, Shalini Chaudhari and M. H. Fulekar
School of Environment and Sustainable Development
Central University of Gujarat
Sector 30, Gandhinagar 382030

Email: mhfulekar@yahoo.com

Abstract:

Renewable energy generation from the Biomass is and will become a primary source substituting energy generation from fossil fuel. Biomass available in abundance can be used for energy generation using different technology. In the present paper biomass energy sources including biofuel generation in the first generation, second generation and third generation have been highlighted. Biodiesel productions from algal species employing latest technology are also discussed. Few case studies have been cited in the paper. Different technology can be developed to generate a renewable energy using Biomass.

Introduction

The increasing industrialization and motorization of the world has led to a steep rise for the demand of petroleum-based fuels [1, 2]. Today fossil fuels take up 80% of the primary energy consumed in the world, of which 58% alone is consumed by the transport sector [3].Progressive depletion of conventional fossil fuels with increasing energy consumption and GHG emissions have led to a move towards alternative, renewable, sustainable, efficient and cost-effective energy sources with lesser emissions [4,5,8,9]. India, with its vast population and limited natural resources for meeting its energy requirements, needs to maintain its momentum of growth and this can be made possible only with a clear strategy for use of best possible energy options available. India needs to have a long term strategy for meeting its energy needs by 2050 and a short term goal of 2020 which can be small steps towards attaining energy security by 2050. The broad vision behind energy policy must be to meet energy demands reliably with energy which is clean and affordable and this must be done in an environmentally sustainable manner using different fuels and forms of energy, as well as new and emerging sources to ensure supplies at all times[10].Renewable energy sources such as solar, wind, hydro, geothermal and energy from biomass and waste have been successfully developed [Table-1]and used by different nations to limit the use of fossil fuels.[11] Renewable energy is a promising alternative solution because it is clean and environmentally safe. They also produce lower or negligible levels of greenhouse gases and other pollutants when compared with the fossil energy sources they replace [12, 13].

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The concept of the alternative energy is to get the other sources of energy to replace or substitute the need of crude oil and also to reduce the environmental degradation i.e. Global warming, climate change. The major sources of alternative energy include hydro, solar, wind, geothermal and biomass energies. Around 2.6 billion people rely on fuel wood, charcoal, and dung for cooking and heating. Fuel wood consumption has increased 250% since 1960, faster than the growth in population in some countries. When people think of renewable energy, most think of solar (photovoltaic, PV) and wind energy and do not realize that bioenergy is a major component of renewable energy, even in industrialized countries [14].

Biomass is the fourth largest sources of energy in the world, providing about 14% of primary energy. Every year in the world several million tons of agricultural wastes are being disposed through different ways such as incineration, land applications and land filling. This global waste has a high potential as a bio-renewable energy resource and can be turned into high-value byproducts. Developing countries, as a whole, derives 35% of their energy from biomass and in many, it offers over 90% of the total energy used in form of traditional fuels, e.g. fuel wood and dung. Since 90% of the world's population may reside in developing countries by 2050, biomass energy is likely to remain a substantial energy feed stock [6].

Table 1: **Renewable Energy Sources Potential**

Source technology	**units**	**Potential /availability**	**Potential exploited**
Biogas plant	Million ton	12	3.22
Biomass based power	MW	19500	384
Efficient wood stoves	Million ton	120	33.86
Solar energy	MW/Sq.km	20	1.74
Small hydro	MW	15000	1398
Wind energy	MW	45000	1367
Energy recovery form waste	MW	1700	16.2

**Source: Planning Commission

Various forms of biomass such as vegetation, animal dung and plant products are providing safe and convenient sources of energy as in the form of biogas and liquid fuel. Biomass can play a major role in reducing the reliance on fossil fuels by making use of thermo-chemical conversion technologies. In addition, the increased utilization of biomass based fuels will be instrumental in safeguarding the environment, creating new job opportunities, sustainable development and health improvements in rural areas [15].Within these, biofuels are the most environment friendly energy source. As concern about global warming grows, there is increased interest in biofuels, which also stems from the fact that home-produced fuels relieve, to some extent, the reliance on imported oil and political vagaries in its supply and price [10]. Hence, biofuels are being explored to replace fossil fuels. Biofuels are favorable choice of fuel consumption due to their renewability; biodegradability and generating acceptable quality exhaust gases [11].

Therefore there is an urgent need to enhance substantially and energy availability at a rapid pace to have a reasonable access. Availability of energy with required quality of supply is not only key to sustainable development, but also the commercial energy has a direct impact and influences on the quality of service in the fields of education, health and infact, even food security India has recorded impressive rates of economic growth in recent years, which provide the basis for more ambitious achievements in the future. Energy is the prime mover of economic growth. The search for renewable energy sources has become the key challenge in this century in order to stimulate a more sustainable energy development for the future.

Biomass energy

Biomass refers to material of biological origin excluding material embedded in geological formations and transformed to fossil. Biomass can directly or indirectly be converted to biofuels which can be of solid, liquid or gaseous forms. Major sources of biomass for energy purposes are various types of woody and herbaceous biomass, biomass from fruits and seeds (e.g. energy crops) as well as biomass mixtures like animal or horticultural by products etc. Biomass is available in abundance and is cheap and its better utilization is to convert it to energy rich products using suitable processes. Biomass has been the most important energy source for humans since the discovery of fire, and today it is still the main source for almost half of the world's population. The need to increase the use of renewable energy is fundamental to make the world energy matrix more sustainable.

In present day scenario, once again its utilization for generation of energy has gained momentum because of limited availability of the conventional energy resources as well as environmental concern due to GHG emissions. In the past decade there has been renewed interest in the biomass as a renewable energy source worldwide. The major reasons for this are as follows. First of all technological developments relating to the conversion, crop production, etc. promise the application of biomass at lower cost and with higher conversion efficiency than was possible previously. In Western Europe and in the US, the second main stimulus is food surpluses producing agricultural sector. This situation has led to a policy in which land is set aside in order to reduce surpluses. In these regions, a number of factors associated with surplus land, such as the de-population of rural areas and payment of significant subsidies to keep land fallow, have provided sufficient driving force to the introduction of alternative, non-food crops desirable. Thirdly, the potential threat posed by climate change, due to high emission levels of greenhouse gases, the most important being CO2, has become a major stimulus for renewable energy sources in general. When produced by sustainable means, biomass emits roughly the same amount of carbon during conversion as is taken up during plant growth. The use of biomass therefore does not contribute to a build up of CO2 in the atmosphere. India is very rich in biomass and has a potential of 16,881MW (agro-residues and plantations), 5000MW (bagasse cogeneration) and 2700MW (energy recovery from waste). Biomass power generation in India is an industry that attracts investments of over INR 600 cores every year, generating more than 5000 million units of electricity and yearly employment of more than 10 million man-days in the rural areas [17].

Combustion to produce thermal energy is the traditional way of using biomass, which is what humans have been doing since they discovered fire. The positive benefits of wood combustion to human well-being and longevity were undoubtedly enormous, but there were also costs. The transition in developing regions of the world from traditional technologies using biomass to more efficient technologies using fossil fuels (propane, butane) results in a dramatic improvement in indoor air quality and increased life expectancy.

Advanced technologies are now under development to convert biomass into various forms of secondary energy including electricity, gaseous and liquid biofuels, and even hydrogen. The purpose of biomass conversion is to provide fuels with clearly defined fuel characteristics that meet given fuel quality standards. Depending on the conversion of biomass in principal three main pathways come into consideration (Scheme 1.1): (i) the thermo-chemical pathway, (ii) the physical-chemical conversion pathway, (iii) the bio-chemical conversion pathway. Those processes provide biofuels in the form of solids (mainly charcoal), liquids (mainly biodiesel and alcohols), or gases (mainly mixtures with methane or carbon monoxide), which can be used for a wide range of applications, including transport and high-temperature industrial processes. These pathways are [18] introduced as follows[Fig -1].

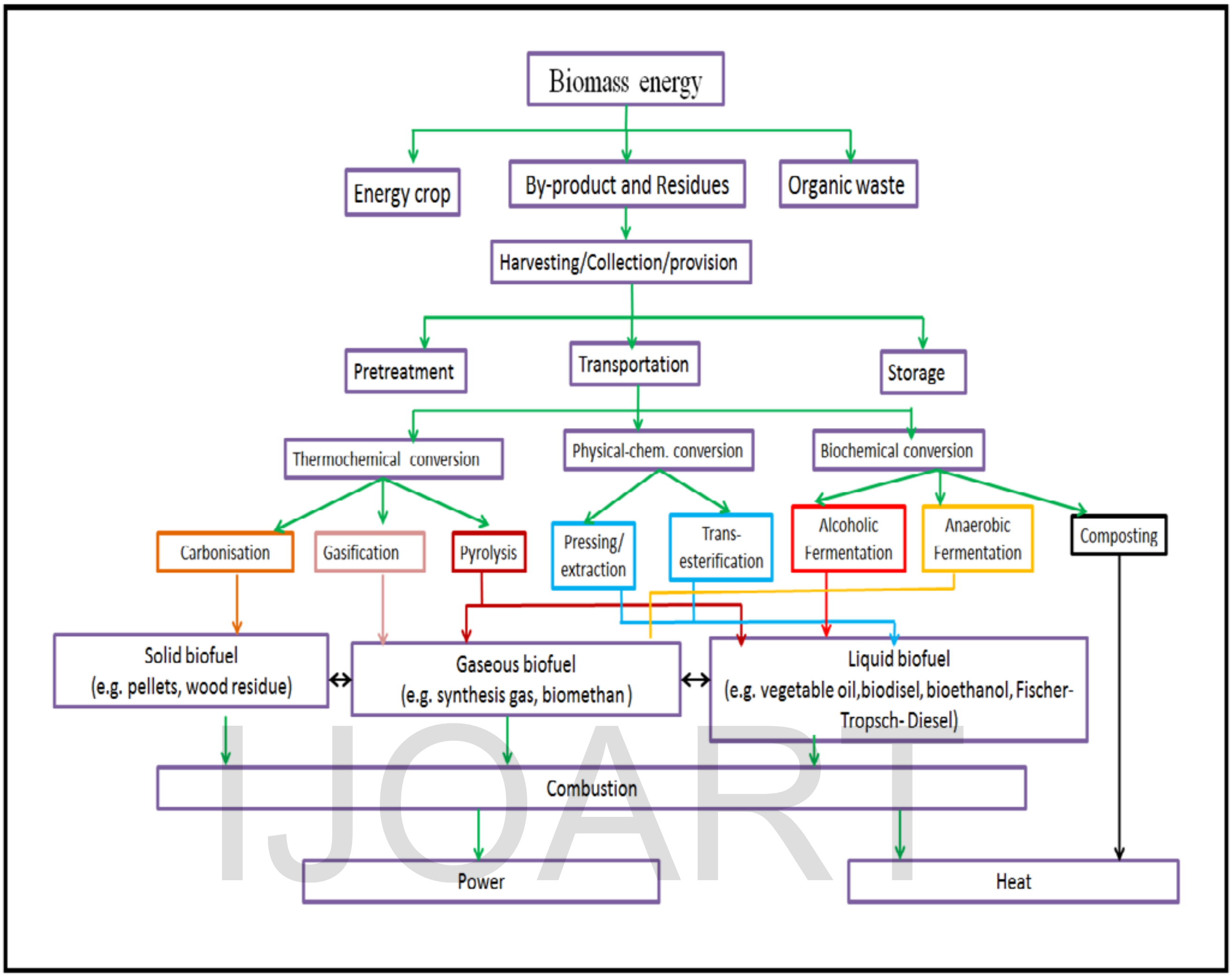

Figure 1: Basic pathways for the provision of final energy derived from biomass (19).

Biofuel

Biofuel is a renewable energy source produced from biomass, which can be used as a substitute for petroleum fuels. An increasing number of developed and developing countries found biofuels as a key to reducing reliance on foreign oil, lowering GHG emissions and meeting rural development goals [19,20]. Between 1980 and 2005, worldwide production of biofuels increased by an order of magnitude from 4.4 to 50.1 billion liters [21,22], with further [Fig-2]dramatic increases in future [23].Biofuels are referred to liquid, gas and solid fuels predominantly produced from biomass. A variety of fuels can be produced from biomass such as ethanol, methanol, biodiesel, Fischer-Tropsch diesel, hydrogen and methane [24].

Biofuels have emerged as one of the most strategically important sustainable fuel sources and are considered an important way of progress for limiting greenhouse gas emissions, improving air quality and finding new energetic resources [25]. Renewable and carbon neutral biofuels are necessary for environmental and economic sustainability. People will always need fuel for living and heating, and since the demand for oil has increased, production from large oil fields is declining at the rate of 4-5% annually, subsequently the world production of oil is expected to peak in coming years. The European Council in March 2007 endorsed a mandatory target of a 20% share of energy from renewable sources in overall energy consumption by 2020 and a mandatory 10% minimum target to be achieved by all Member States for the share of biofuels in transport sector by 2020 [26]. Different countries have adopted different measures to introduce biofuels. The economics of each fuel vary with location, feedstock, and several other factors. Political agendas and environmental concerns also play a crucial role in the production and utilization of biofuels. There are a number of technologies existed and several under development, for production of biofuels such as fermentation of sugar substrates, catalytic technology to convert ethanol to mixed hydrocarbon, hydrolysis of cellulose, biobutanol by fermentation, transesterification of natural oils and fats to biodiesel, hydrocracking of natural oils and fats, pyrolysis an d gasification of various biological materials, etc. [1].

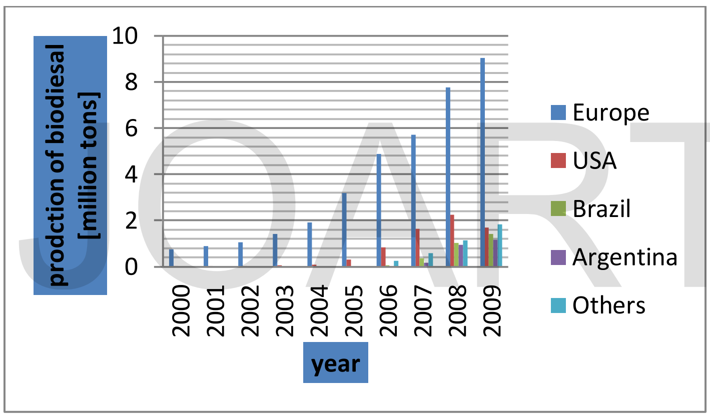

Figure: 2 Worldwide potential of biodiesel production from year 2000-2009.(58)

Liquid biofuels

Liquid biofuels are being researched mainly to replace conventional liquid fuels (diesel and petrol). A recently popularized classification for liquid biofuels includes[Fig-3] "First-Generation" and "Second-Generation" biofuels [28]. The primary distinction between them is in the feedstock used. Research work is in progress for the production of "third-generation of biofuels" [29].

The first-generation

First-generation biofuel is ethanol made by fermenting sugar extracted from crop plants and starch contained in maize kernels or other starchy crops [29]. Bioethanol is usually produced out of organic based matter with high contents of sugars fermentation by enzymes produced from yeast. The yeasts convert six-carbon sugars (mainly glucose) to ethanol, because starch is much easier than cellulose to convert to glucose. Initially the sugar of raw materials is separated after that fermentation processes use yeast to convert the glucose into ethanol. The distillation and the dehydration are used as the last steps for reaching the desired concentration (hydrated or anhydrous ethanol) that can be blended with fossil fuels or directly used as fuel. When the used raw materials are grains, usually hydrolysis is used for converting the starches into glucose [30]. The conventional processes used only the germs of the seeds or grains for ethanol production that represents a small percentage of the total mass of the plant, generating a significant amount of residue.

Biodiesel produced from straight vegetable oils of oleaginous plants by transesterification processes or cracking is another well-known first-generation biofuels. Transesterification can use alkaline, acid or enzymatic catalyzers and ethanol or methanol, and produces fatty acid (biodiesel) and glycerine as by-product [31]. In the biodiesel production process also a small fraction of plant biomass is used and left a large fraction as residue. First-generation fuels are in existence and being produced in significant commercial quantity in a number of countries. The viability of the first-generation biofuels production is, however, questionable because of the conflict with food supply [28]. The utilization of only a small fraction of total plant biomass reduced the land use efficiency. The first-generation biofuels have high production cost due to competition with food. The rapid expansion of global biofuel production from grain, sugar, and oilseed crops has raised the cost of certain crops and food stuffs. These limitations favor the search of non-edible biomass for the production of biofuels.

Second-generation liquid biofuels

Second-generation liquid biofuels are generally produced by two fundamentally different approaches i.e. biological or thermochemical processing, from agricultural lignocellulosic biomass, which are either non-edible residues of food crop production or non-edible whole plant biomass (e.g. grasses or trees specifically grown for production of energy). The main advantage of the production of second-generation biofuels from non-edible feed stocks is that it limits the direct food versus fuel competition associated with first generation biofuels. Feedstock involved in the process can be bred specifically for energy purposes, enabling higher production per unit land area, and a greater amount of above-ground plant material can be converted and used to produce biofuels. As a result this will further increase land use efficiency compared to first generation biofuels. As stated by Larson [29], it is believed that the basic characteristics of feedstocks holds potential for lower costs, and significant energy and environmental benefits for the majority of second-generation biofuels. It appears evident from literature [32] that production of second-generation biofuel requires most sophisticated processing production equipment, more investment per unit of production and larger-scale facilities to confine and curtail capital cost scale economies. To achieve the potential energy and economic outcome of second-generation biofuels, further research, development and application are required on feedstock production and conversion technologies.

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The future production of ethanol is expected to include both the use of traditional grain/sugar crops and lignocellulosic biomass feedstocks [32-35]. Second-generation biofuels share the feature of being produced from lignocellulosic biomass, facilitating in the use of low cost, non-edible. Feedstocks, resulting in a limit between direct food and fuel competition [36].Second-generation biofuels can be further classified in terms of the process or method used to convert biomass to fuel, i.e. biochemical or thermochemical. Few second-generation biofuels such as ethanol and butanol are produced through the biochemical process (these will be discussed in detail later in this article), whereas all other second-generation fuels are produced thermochemically.

Thermochemical biomass conversion involves processes that require much more extreme temperatures and pressures than those found in biochemical conversion systems. Certain essential characteristics differentiate thermochemical process from biochemical process, including the flexibility in feedstock that can be accommodated with thermochemical processing and the diversity of fuel outcome that is produced [37]. Thermochemical production of biofuels begins with gasification or pyrolysis. The former is generally more capital-intensive and requires large-scale production for economic benefit; however, the final product is a clean finished fuel that can be used directly in engines

Third-generation liquid biofuels

Alternate energy resources akin to first generation biofuels derived from terrestrial crops such as sugarcane, sugar beet, maize and rapeseed place an enormous strain on world food markets, contribute to water shortages and precipitate the destruction of the world's forests. Second-generation biofuels derived from lignocellulosic agriculture and forest residues and from non-food crop feedstocks address some of the above problems; however, there is concern over competing land use or required land use changes [38]. The latest generations of biofuels researchers are now directing their attention past agricultural substrates and waste vegetable oils to microscopic organisms. Therefore, on the basis of current scientific knowledge and technology projections, third-generation biofuels specifically derived from microbes and microalgae are considered to be a viable alternative energy resource that is devoid of the major drawbacks associated with first and second-generation [1] biofuels.

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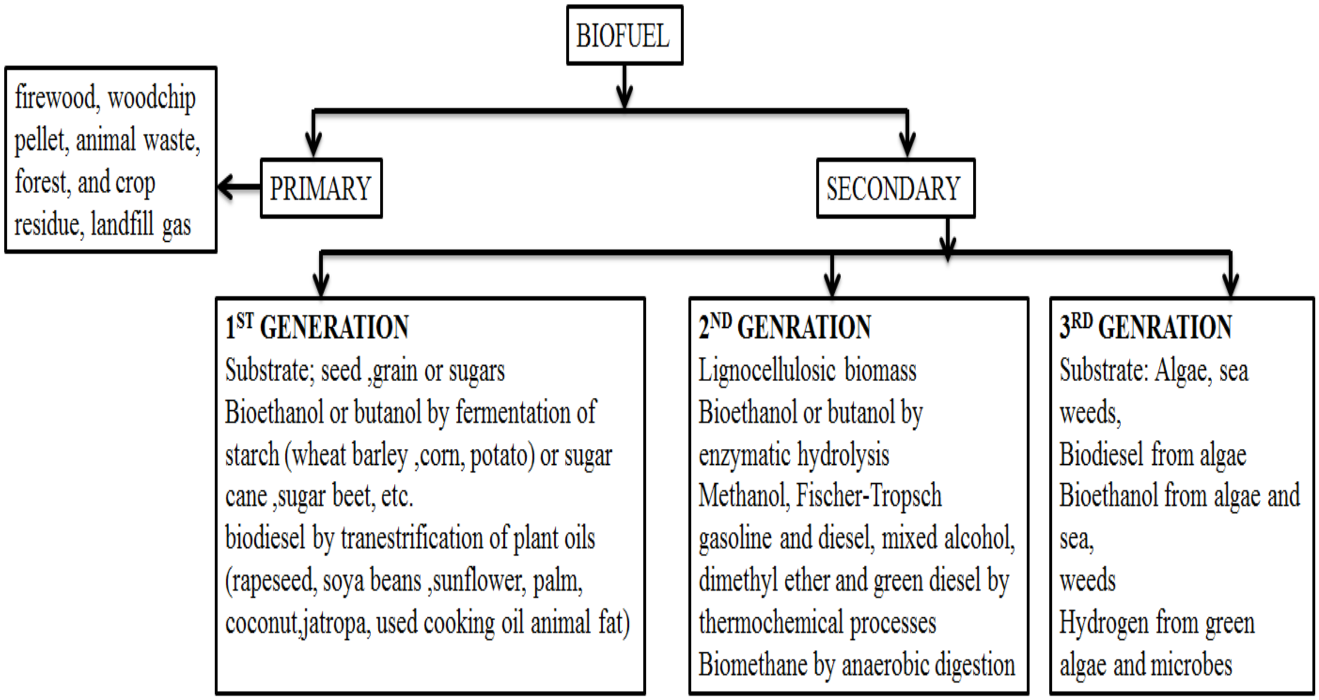

Figure: 3 Classification for liquid biofuels

Algal biofuel

The algal organisms are photosynthetic macroalgae or microalgae growing in aquatic environments. Macroalgae are classified into three broad groups based on their pigmentation: (1) brown seaweed (Phaeophyceae); (2) red seaweed (Rhodophyceae) and (3) green seaweed (Chlorophyceae).

Microalgae are microscopic photosynthetic organisms that are found in both marine and freshwater environments. Microalgae are fast-growing beasts with a voracious appetite for carbon dioxide Biologists have categorized microalgae in a variety of classes, mainly distinguished by their pigmentation, life cycle and basic cellular structure. The three most important classes of microalgae in terms of abundance are the diatoms (Bacillariophyceae), the green algae (Chlorophyceae), and the golden algae (Chrysophyceae). The cyanobacteria (blue–green algae) (Cyanophyceae) are also referred to as microalgae.

The algae that are used in biofuel production are usually aquatic unicellular green algae. This type of algae is a photosynthetic eukaryote characterized by high growth rates and high population densities.[40] Microalgae have been estimated to have higher biomass productivity than plant crops in terms of land area required for cultivation, are predicted to have lower cost per yield, and have the potential to reduce GHG emissions through the replacement of fossil fuels [41]

Algal biodiesel

Biodiesel is usually produced from oleaginous crops, such as rapeseed, soybean, and sunflower and from palm, by a mono-alcoholic transesterification process, in which triglycerides reacts with a mono-alcohol (most commonly methanol or ethanol) with the catalysis of enzymes [42]. However, the use of microalgae and cyanobacteria can be a suitable alternative because algae are the most efficient biological producer of oil on the planet and a versatile biomass source [Table-2] and may soon be one of the Earth's most important renewable fuel crops [42]. Biodiesel from the photosynthetic algae which grow on CO2 has great potential as a biofuel. These organisms are being seriously considered as a substitute for plant oils to make biodiesel. Producing biodiesel from algae provides the highest net energy because converting oil into biodiesel is much less energy-intensive than methods for conversion to other fuels [43].

Table 2: Comparison of biodiesel yields from microalgae with other best oilseed crops

Plant source	**Seed oil content (% oil by wt. in biomass)**	**Oil yield (L oil/ha year)**	**Land use (m2year/kg biodiesel)**	**Biodiesel productivity (kg biodiesel/ha year)**
Microalgae high oil content	70	136900	0.1	121104
Microalgae (medium oil content)	50	97800	0.1	86515
Microalgae (low oil content)	30	58700	0.2	51927
Palm oil	36	5366	2	4747
Castor	48	1307	9	1156
Sunflower	40	1070	11	946
Canola/Rapeseed	41	974	12	862
Jatropha C.	28	741	15	656
Soybean	18	636	1728	562
Corn	44	172		152

**Biodiesel from Microalgae Final Degree Project 25/01/2010 Anna Aullon Alcaine

Selection of algal species

Due to the variation and diversity of microalgal lipids, selection of oleaginous microalgal strains suitable for biodiesel production will require screening large number of microalgal strains. The first large-scale collection and screening of oleaginous algae dates back to 1978, when the Aquatic Species Program (ASP) was launched by U.S. National Renewable Energy Laboratory (NREL) for production of biodiesel from high lipid-content algae. With 8 years of effort, over 3,000 strains were collected and eventually around 300 species were identified as oil-rich algae [44]. Recently, some studies on screening of oleaginous microalgae were reported, focusing on optimizing culture conditions to increase lipid productivity and evaluation of the potential for biodiesel production [45, 46, and 42]. The main indexes determining the potential of microalgal strains as biodiesel feedstock are growth rate, lipid content, and lipid productivity as follow [Table-3]:

Table 3: The potential of microalgal strains as biodiesel feedstock are growth rate, lipid content, and lipid productivity

Microalgae species	Class	Lipid content (%, w/w)	Lipid productivity (mg l-1 day-1)
C. protothecoides	Chlorophyceae	15-58	1214
Chlorococcum sp.	Chlorophyceae	19	54
Chlorella sorokiniana	Chlorophyceae	19-26	45
D. salina	D. salina	6-25	116
Ellipsoidion sp.	Eustigmatophyceae	27	47
Nannochloropsis sp.	Eustigmatophyceae	21-36	49
Nannochloropsis oculata	Eustigmatophyceae	22-30	113
Neochloris oleoabundans	Chlorophyceae	29-65	112
Pavlova salina	Prymnesiophyceae	31	49
Pavlova lutheri	Prymnesiophyceae	36	50
Phaeodactylum tricornutum	Bacillariophyceae	18-57	45
Scenedesmus sp.	Chlorophyceae	20-21	46

Technology for Growing Algae

The multiple pathways to cultivating microalgae and cyanobacteria, it is premature to predict whether algal cultivation in closed (e.g., photobioreactors), open (e.g., open ponds) or hybrid systems will prevail in the industry. Broadly speaking, algae can be cultivated [Table-4] via photoautotrophic or heterotrophic methods, both varying in their challenges and advantages:

Table: 4 The following technologies are used for production of algae:

S.N	Cultivation technology		Advantages	Challenges
1	Photoautotrophic Cultivation	Closed Photo bioreactors	• less loss of water than open ponds • Superior long-term culture maintenance • • Higher surface to volume ratio can support higher volumetric cell densities	• Scalability problems • Require temperature maintenance as they do not have evaporative cooling • May require periodic cleaning due to biofilm formation • Need maximum light exposure
		Open Ponds	• Evaporative cooling maintains temperature • Lower capital costs	• Subject to daily and seasonal changes in temperature and humidity • Inherently difficult to maintain monocultures • Need maximum light exposure
2	Heterotrophic Cultivation		• Easier to maintain optimal conditions for production and contamination prevention • Opportunity to utilize inexpensive lignocellulosic sugars for growth • Achieves high biomass concentrations	• Cost and availability of suitable feedstocks such as lignocellulosic sugars • Competes for feedstocks with other biofuel technologies

***Source 59**

Method for Biodiesel production form algae

Pressing and homogenization essentially involve using pressures to rupture cell walls, in order to recover the oil from within the cells. Milling on the other hand, uses grinding media (consisting of small beads) and agitation to disrupt cells. These methods are usually used [Table-5] in

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combination with some kind of solvent extraction. Solvent extraction entails extracting oil from microalgae by repeated washing or percolation with an organic solvent. Hexane is a popular choice due to its relatively low cost and high extraction efficiency. Supercritical fluid extraction involves the use of substances that have properties of both liquids and gases (i.e. CO2) when exposed to increased temperatures and pressures. This property allows them to act as an extracting solvent, leaving no residues behind when the system is brought back to atmospheric pressure and RT Enzymes can also be used to facilitate the hydrolysis of cell walls to release oil into a suitable solvent. The use of enzymes alone, or in combination with a physical disruption method such as sonnication, has the potential to make extractions faster and with higher yields. The use of sonication alone can also enhance the extraction process immensely due to a process called cavitation. Ultrasonic waves create bubbles in the solvent, the bubbles burst near the cell walls of microalgae, which produce shock waves, causing the contents (i.e. lipids) to be released into the solvent [47, 48]. Osmotic shock, a less-employed procedure, makes use of an abrupt lowering of osmotic pressure that causes cells to burst and release their contents [49].

Table 5: Outlines steps of the downstream processing used in extracting oil from microorganisms.

S.N.	**Extracting Methods**	**Advantage**	**References**
1	**Pressing**	Easy to use, no solvent involved	50
2	**Solvent Extraction**	Solvents used are relatively inexpensive; results are reproducible	51 , 52
3	**Superficial - fluid extraction**	Non-toxic (no organic solvent residue in extracts);'green solvent' non-flammable and simple operation	53, 54
4	**Ultrasonic- assisted**	Reduced extraction time; reduced solvent consumption; greater penetrations of solvents into cellular materials; improved release of cell contents into bulk medium	55,56

Physicochemical Properties of Micro-algal Biodiesel:

To assess the potential of biodiesel as a substitute of diesel fuel, the properties of biodiesel such as density, viscosity, flash point, cold filter plugging point, solidifying point, and heating value were determined. A comparison of these properties of biodiesel from microalgal oil with diesel

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and ASTM biodiesel standard is given in Table 6. It can be seen that most of these parameters comply with the limits established by ASTM [57] related to biodiesel quality. The microalgal biodiesel showed much lower cold filter plugging point of –11°C in compared to than diesel while the viscosity and acid value is higher than diesel. The Table 6 shows that the fuel properties of micro- algal biodiesel are comparable to diesel fuel.

Table 6: Comparison of properties of micro-algal biodiesel with diesel and ASTM biodiesel standard:

S.N	Properties	Biodiesel from microalgae oil	Diesel fuel	ASTM biodiesel standard
1	Density ($kg·L^{-1}$)	0.864	0.838	0.84 - 0.90
2	Viscosity ($mm^2·s^{-1}$, cP at 40°C)	5.2	1.9 - 4.1	3.5 - 5.0
3	Flash Point (°C)	155	60	Min 100
4	Solidifying point (°C)	–12	–50 to 10	-
5	Cold filter plugging point (°C)	–11	–3.0 (max –6.7)	Summer max 0, Winter max < –15
6	Acid value (mg KOH·g–1)	0.374	Max 0.5	Max 0.5
7	Heating value (MJ·kg–1)	41	40 - 45	-
8	H/C ratio	1.81	1.81	-

Case study:

1. **Culture and biofuel production efficiency of marine microalgae *chlorella* and *Skeletonema costatum***

Microalgae can be a potential source for biofuel production because of number of advantages including higher photosynthetic efficiency, higher biomass production. Moreover, biodiesel from microalgae oil is similar in properties to the standard biodiesel, and is more stable to their flash point values.

In the present research study, a microalga is cultured under indoor and outdoor systems with high density and biomass. Their chemical analysis showed high lipid content (28.2 and 21.6% respectively) and fatty acid methyl esters (FAME) content. Fatty acid such as palmetic acid (16:0), oleic acid (18:1), was reported to be high in *C. marina and S. costatum. S. costatum* is containing more eicosapentaenoic acid (EPA). Marine diatoms, S. *costatum* is efficiently converting the algal oil into biodiesel (87%) followed by C. marina which is produced the 70%

of the biodiesel. Biodiesel yield of presently studied marine microalgae was being comparatively higher than those crops. It is clearly implied that, marine microalgae *C. marina* and *S. costatum* were considered as a promising feedstock [60] for biodiesel production in near future.

2. Large-scale biodiesel production from microalga *Chlorella protothecoides* through heterotrophic cultivation in bioreactors:

An integrated approach of biodiesel production from heterotrophic Chlorella protothecoides focused on scaling up fermentation in bioreactors was reported in this study. Through substrate feeding and fermentation process controls, the cell density of C. protothecoides achieved 15.5 gL^1, in 5 L, 12.8 g L^1 in 750 L, and14.2 g L^1 in 11,000 L bioreactors, respectively. Resulted from heterotrophic metabolism, the lipid content reached 46.1%, 48.7%, and 44.3% of cell dry weight in samples from 5 L, 750 L, and 11,000 L bioreactors, respectively. Transesterification of the micro algal oil was catalyzed by immobilized lipase from Candida sp. 99–125. With 75% lipase (12,000 U gL^1 , based on lipid quantity) and 3:1 molar ratio of methanol to oil batch-fed at three times, 98.15% of the oil was converted to monoalkyl esters of fatty acids in 12 h. The expanded biodiesel production rates were 7.02 g L^1, 6.12 g L^1, and 6.24 g L^1in 5 L, 750 L, and 11,000 L bioreactors, respectively. The properties of biodiesel from Chlorella were comparable to conventional diesel fuel and comply with the US Standard for [61] Biodiesel (ASTM 6751).These results suggest that it is feasible to expand heterotrophic Chlorella fermentation for biodiesel production at the industry level.

Conclusions:

In the global trend of increased primary energy consumption and large carbon dioxide emission into the atmosphere, it is necessary to raise production of energy from renewable resources, as well as promote cleaner alternative fuels than oil refined products. Algae are among the fastest growing plants in the world, and about 50% of their weight is oil. Algae can be grown almost anywhere, even on sewage or salt water, and does not require fertile land or food crops, and processing requires less energy than the algae provides.

The micro-algae are considered as one of the most promising feedstock's for future bio-diesel production in India. The advantages of micro-algae are their wide- spread availability, higher oil yields and reduced pressure on cultivable land. The difficulty in efficient bio- diesel production from algae lies not only in the extraction of the oil, but also developing an algal strain with a high lipid content and fast growth rate.

Ultimately, Algae-based biofuel offer the potential to have a profound impact on the future welfare of the planet by addressing the pressing issues of alternative energy resources, global

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warming, human health and food security. Nonetheless, we believe the time is now to implement the advanced technologies, which are based on sustainable and renewable systems, to address current international issues.

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