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Research Paper

"Analysis of recent trends that has been opted in Algal based biofuels"

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Abstract
Background: *Due to inclination of the world towards the sustainable and renewable resources because of increased pollution, climate change and global warming caused by increased usage of fossil fuels haveled to the search for the formation of biofuels from the easily available resources that are found in our environment. Between these world energy crises, algae have made its name in the list to be used as a feedstock to make effective biofuels.*
Objectives: *The paper discusses will be discussing the commercialisation of the algae-derived biofuel along with the techniques and novel methods for the cultivation of different algal biomass, processing of the biofuels, conversion methods and its effectiveness in reducing the engine emissions.*
Methodology: *The paper analyses different techniques for the successful production of biofuel will be discussed along with the flaws that need to be amended to attain the most sustainable and environment-friendly energy source which can act as an alternative for fossil fuels.*
Conclusion: *The development and research in the production methods for biofuel require more integrated systems to overcome the challenges that the production system is facing currently. A proper effort should be made on the proper research to improve the efficiency of the methods in the technologies to meet the requirement as same as fossil fuels such as petroleum.*

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I. Introduction

Today's generation is using the fossil energy that has been produced from the dead and decayed remain of the organisms buried in the soil millions of years. The present petroleum refineries are thriving because of the dead and decayed of the phytoplankton. But the rapid depletion of the fossil fuels due to increased human demands and pollution has prompted the search of the non-renewable energy resources towards more sustainable options as the continues usage of the fossil fuel-based products has resulted in severe environmental damage and resulting into climate change(Li, Moheimani& Schenk, 2012). Many countries worldwide are joining hands together to think of a clean, renewable and sustainable alternative that has derived the attention of the experts towards biofuels. The biofuels can be produced from different biomass feedstocks which can help to make bio-oils such as biodiesel, bioethanol, biogas, and etcetera. Its demand has been increased recently in the transportation industries as well(Bagnoud-Velásquez, Refardt, Vuille& Ludwig, 2015). The usage of Microalgae benefits with the higher yield, greater lipid content and high growth rate along with this it requires less land area when compared to other bio-oil feedstock.

Algae is one among the diverse group of aquatic organisms that are present as unicellular as well as multicellular organisms in nature having essential elements required to be used as biomass feedstock and as they are available in abundance which makes it suitable feedstock for renewable fuel. This report is based on the research question **"Analysis of recent trends that have been opted in Algal based biofuels"**. Algae is considered by all countries for its potential to produce a high yield of biofuel in a comparatively shorter period of time. This report will be summarising the conventional and novel methods of algal biomass by going through an elaborated literature review, methodology, risk assessment, results and discussions and finally conclusion.

The stakeholders of this project include the team members and other persons who are indirectly involved with the project along with them the persons who associated with the gain or loss that the implementation of this project will offer and lastly the people who are minutely going to get affected by this project. These stakeholders can belong from some environment protection NGO, public sector institution or any private company that finds profit with the implementation of the introduced ideas.

Aims and Objectives

The primary aim of this project report is the question **"Analysis of recent trends that have been opted in Algal based biofuels".** As the usage of the algae as a feedstock has gained world attention due to its potential to provide clean and sustainable renewable resources. In this report, different technologies, advantages, and limitations of the commercialization of the biofuel will be discussed.

The prime objectives of this report are listed below:

- Understanding of the technologies for the production of the feedstock
- Conversion of the algae into biofuel
- Learning about different species of algae
- Land requirement for the production of the biofuel
- The benefits of algae fuel.

II. Literature Review

The algae-based biofuels are the most considered renewable resource in the research of biofuel technology as this biofuel will help to reduce the usage of fossil fuel which will help to reduce the pollution and harm created by the increased usage of petroleum-based products. Moreover, as the feedstock is present abundantly in nature the higher yields such as 10,000 gallons of biofuel can be obtained from one acre of land which is considered an advantage of algae feedstock over other biofuels(Karemore, Nayak & Sen, 2016). Algae biofuels produce 50grams of total carbon dioxide whereas the carbon dioxide obtained from fossil fuel is about 94.3 grams(Karemore, Nayak & Sen, 2016). Due to an increase in the world population, there is an increased requirement for an alternative of the transportation oil that is currently in use and increased researches in biofuels will help to decrease the dependence of the people on petroleum-based products.

The high yield from the algae one among the advantage as the algae species double in six hours which will promote the instant harvesting along with this the algae has a high level of hydrocarbons. Whereas the species of Jatropha can produce about 202 gallons of oil per acre. According to Malinda Griffth (2009) and his team, the microalgae are one among the bests alternative source of lipid which one among the essential requirement for the production of the biodiesel. The author also lists down the productivity of the 55 species of microalgae in which 17 are Chlorophyta, 11 Bacillariophyta and 5 cyanobacteria along with the other species of the algae. According to the inferences the average lipid content and biomass productivity for the microalgae that are cultured in the outdoor ponds and the photobioreactors under the nutrient-replete conditions.

Radakovitis and Jinkerson (2010) explain the intensive global research efforts to produce bio-oil from photosynthetic organisms. The researchers explain the potential of genetic engineering that will help to improve the microalgae to be used as the biofuel platform for the production of the starch-derived alcohols, alkanes, and biohydrogen. The author discusses the low energy methods to harvest the algae, the prevention of the occurrence of weeds in the ponds aiming mass production, having a cost-effective extraction technique. The author also explains that cyanobacteria havea unique metabolism that is necessary for the production of biofuels. In this research paper the author helps to identify the importance of the application of the genetic engineering to have good energy production eukaryotic microalgae in the early stage, many tools have also been built to enhance the microalgae systems.

Greenwell and Laurens (2010) have compared the production of the algal biofuel with the traditional crops. They also explain that due to the requirement of the large arable lands the algae fuel projects has been one among the disadvantage which overpowers the fact of attaining high production. Similarly,Hu.Q (2010) explains that the selection of the algal species for based on the factors that are in the algal feedstock is one among the most important aspect that needs to be considered and the lipids with higher lipid strain are not easy to grow in the open system as they can be easily invaded by the indigenous species. Thus, during the production of the species, it should be isolated from the surroundings so that they can grow easily. Kumar (2016) in his research explains the type of photobioreactor at a lower cost that can increase the yield at a minimal cost. Along with these authors many other authors have also giventheir researches on the methodology that can be adopted for the production of the algal biofuel. Holland (2014)explains the different production methods for the increasing algae growth for this he cultivated a number of algae species in the presence of Pink pigmented facultative methylotrophs bacteria which promoted the algal growth in a short period of time and increased yield results were obtained. Jyoti Prakash Maity (2014) in her research explains the selection, accumulation and production of bioenergy strains along with their advantages and technological development to produce biodiesel, ethanol, methanol, biogas and oil. The hybrid technologies that can produce the biofuels can help us to reduce the pollution as the production of the algal biofuel require carbon dioxide and along with it the coupling of the water treatment plants with algal production will also help to the attain good yield by the abundant growth of the microalgae(Li, Moheimani& Schenk, 2012). These are the key parameters that need to be considered for finding a viable technology for the production of algal biofuel.

This literature review helps to understand the different aspects of the biofuel obtained from the algal feedstock. It covers the technical viability for the production of the biofuel. Microalgae biomass has great potential to produce the most cost-effective and suitable biofuel that can help to replace petroleum-based products. As of now the cultivation process of the algal fuel is still expensive to overtake the fuel market as the open pond system is not a viable option for all the available strains. Whatsoever, algal biofuel still requires to be great research and development in its field. This literature survey helps to cover the different introduced methodologies, importance, constituents, requirement of different algal strains for the production of algal-based biofuel by referring to the researches given by different authors who are experts in this field. This Literature survey will act as a foundation for us to better understand the formed research question.

III. Methodology

In order to find an answer to the research question that we have put together under the head of Global trends of algal biofuel research, we took the help of online search engines. We together went through many online journals, project reports, and industrial reports on algal biofuels and the commercialization aspect of the algal biofuel. We held a literature survey which helped us to understand different aspects of the requirement of the algal biofuel and how it is commercially cost-effective. Different reviews by different authors along with the methods of conversions, its requirement, and the appropriate species of algae for biofuel gave us a broad view to list down the different methods that can help us to build a module to justify our research question.

The research papers that we went through suggested that the microalgae species can produce 15-300 times more of the bio-oil than the other traditional crops(Tighiri, 2017). Different species of microalgae that are used for the bio-oil production are phytoplanktons and microphytes. The microalgae are classified in diatoms, green algae, golden-brown and the blue-green algae. There are about 200,000 microalgae species that are considered for the production of the biofuel(Shurin, Burkart, Mayfield & Smith, 2016). The most appropriate species that can be utilized for the production of the fuel are *Botryococcusbraunii* due to the presence of the hydrocarbons, *Nannochloropsis salina* is another species which can help to yield more fuel and lastly *Dunaliella salina* that has high fatty acids content(Shurin, Burkart, Mayfield & Smith, 2016). The Nation Renewable Energy Laboratory of the United States affirms that these species are the popular strains that can be used for the production of bio-oil on a larger scale.

To find out recent trends in the algal biofuel it is necessary to go through the cultivation process grow algae there are two types of processes that are currently in use which are open pond and closed pond.

Open Pond Cultivation

The cultivation of algae in the open ponds can be meant the production of algae in lakes, lagoons or artificial ponds or containers. The commonly used system includes the shallow big ponds, tanks, circular ponds, and lastly raceway ponds. The nutrients for the growth of the feedstock can be provided with the help of runoff water that can be channelled from the nearby land areas from sewage or water treatment plants. To increase the pace of algal growth one can also pump the carbon dioxide bubble into the cultivation area (Karthikeyan, 2012). The open pond systems are comparatively cheaper and very fewer requirements needed to be considered and they have the largest capacity for the wide production of the algae.

Closed Systems

In contrast to open ponds the closed systems are basically closed with a cover of greenhouse which limits the massive cultivation as these systems are really small. It is a controlled system thus creates fewer problems in comparison to the open system. It requires less light and land for the growth of the algae. The high yielding varieties of algae are grown in photobioreactors which produce about 19,000 to 57,000 liters of oil in a year(Karthikeyan, 2012). The growth conditions of the algae can be controlled and regulated according to the requirement and climate as in colder regions closed systems can help to provide a heated environment all around the year for the production of the algae.

Photobioreactor

It is a translucent container that requiresa light source for the growth of the algae. It is a closed system and the essential nutrients are provided by the person looking after the bioreactor separately(Karthikeyan, 2012). Continuous operation and restocking take place which requires water, nutrients, air and carbon dioxide incorrect amounts. This can be made in the form of a tank bag or polyethylene sleeves.

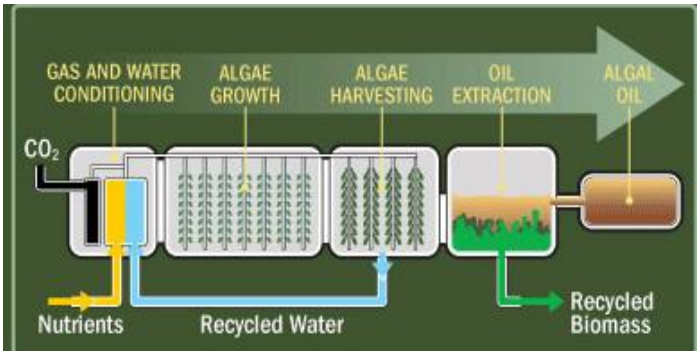


Fig 1: Bioreactor Process

Production of different algal biofuels

The production of the algal biofuels goes through different stems starting from the selection of the species of the algae, it's cultivation, harvesting, dewatering, extraction of the oil, conversion process to obtain required biofuel. The flow chart below describes the production chain of the algal biofuel. We analyzed that the cultivation process is really important and requires a cost-effective design that can also fulfill the requirement of the oil on a larger scale. The improvisation in the photobioreactors that are used is one of the major aspects to increase the production level. The researchers have found a cultivation system that has a passive membrane photobioreactor that has interior space in which algae can be cultivated and a porous membrane is present from where water, carbon dioxide, and other nutrients are passed in the interior side by still maintaining a physical barrier. Similarly, many researchers have come up with different ideas as given in the table below:

Table 1: *Patents related to the production of the microalgae*(Karemore, Nayak & Sen, 2016)

S.no.	Inventor/Company	The invention related to the cultivation
1	David A. Haxlebeck, Xiaoxi Wu	Expanding plug flow reactor, Carbon dioxide distribution system, Algae growth Pond design
2	Mark Holland, Patrick Bibello, Richard M. Carlton	Method to increase the algae growth
3	Do-Hyung Soo-JinHeo, Tae Ho Kim, Heung Sik Park, Affan Abu	Production plant for microalgae biofuel.

Harvesting

After the growth of the algae, they are separated with the help of techniques such as flocculation, micro straining, filtering, sedimentation and centrifugation. The techniques depend upon the extraction process and size of the microalgae that are being used for the extraction. Denser masses of the microalgae are removed with the help of chemical flocculation and bio-flocculation which is followed by filtration, sedimentation or centrifugation. The technique of centrifugation is more appropriate as about 20% of the algae can be obtained when compared to other techniques and thus has higher energy consumption rates (Karthikeyan, 2012).

Table 2: *Patent related to the Harvesting of the microalgae*(Karemore, Nayak & Sen, 2016)

S. no.	Inventor/company	The invention related to the Harvesting
1	Everett J. Nicholas, James Scott	Methods for Harvesting
2	William Berry, Mark Tegen, William Sutterlin	Harvesting microalgae suspended in and hydrophobic chemical
3	Edouard Kbakian	Device for harvesting

Oil Extraction

The harvested algae are dried and later on oil is extracted from them with the help of the techniques such as mechanical pressing, solvents and supercritical fluid extraction. With the help of mechanical pressing the about 75% of the oil is extracted from the harvest whereas chemicals such as n-hexane, benzene, ethanol, chloroform and diethyl ether are used as solvents that make the extraction of the fatty acids easier. The usage of n-hexane can help to obtain about 95% of the oil (Karthikeyan, 2012).

Conversion of bio-oil into biodiesel

There are 3 methods of conversion to obtain different products from the obtained biofuel, three processes of conversion include the chemical, biochemical conversion and thermochemical conversion. Different products that are obtained from this method are ethanol, biodiesel, biohydrogen, biogas, oil, charcoal, and fuel gas(Karemore, Nayak & Sen, 2016).

Table 3: *Process and technology used for the conversion of the biomass into biofuel*

PROCESS	TECHNOLOGY	BIOFUEL
CHEMICAL AND BIOCHEMICAL CONVERSION	Alcoholic fermentation	Ethanol
	Trans-esterification	Biodiesel
	Photo biological fermentation	Biohydrogen
	Anaerobic digestion	Biogas
THERMOCHEMICAL CONVERSION	Pyrolysis	Oil, charcoal
	Gasification	Fuel gas
	Liquefaction	Oil
	Hydrogenation	Oil

Table 4: *Patents related to the extraction and conversion of the biofuels* (Karemore, Nayak & Sen, 2016)

S. no	Inventor/company	The invention related to the extraction and conversion
1	Qingyu. Wu, Wenguang Zhou, Wei Xiong	Methods to produce biodiesel from high cell density cultivation
2	Aniket Kale	Methods to produce biofuel from algal biomass
3	James R Oyler	Production of oil through biological rupturing
4	Echevarria Parres, Antonio Jose	Apparatus and process for biodiesel production from algae.

Thus, the above mentioned are different trends and technologies that have been developed and are currently in use for the production of biofuel on a large scale. These steps which are used are not efficient enough to compete in the outer market with petroleum as the cost of the production is comparatively high. Thus, there is a requirement of the most efficient and cost-effective design.

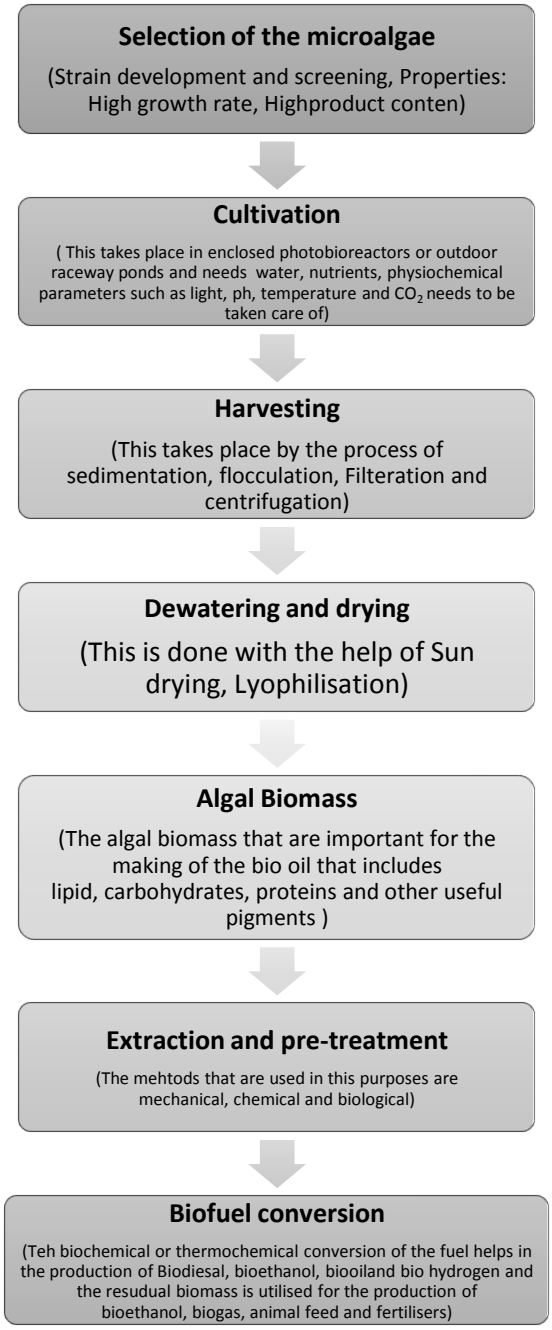


Fig 2: The flowchart below shows the different steps that are involved in the production of the algal biofuel(Karemore, Nayak & Sen, 2016)

Risk Assessments

Along with the advantages possessed by the algal-based biofuels, there are several challenges that these eco-friendly fuels have to face to become equivalent to petroleum which is a prime source of energy fuel in the market. With the currently available technologies, a barrel of the algal-based bio-oil may cost up to approximately US$300-2600 whereas the rate of petroleum in the market is about $40 to 80. Although there have been claims that in few regions a barrel of algae-based biofuel is $84. Thus, if this condition remains the same the algal fuel will not be able to hold down its position in the current liquid fuel-based market.

The other major risk that the algal biofuel industry face is the isolation of the strain, sourcing of the nutrient, harvesting, coproduce development, fuel extraction and refining of the fuel that has been extracted. These problems include the

- **Inefficient technology for the growth and harvesting of the algae**: Efficient strategies and plans are required for the circulation of the nutrient and proper light exposure to the light are the major aspects that need to be considered(Hannon, Gimpel, Tran, Rasala& Mayfield, 2010). This can be solved by designing

the cheap photobioreactors for large scale production and genetic engineering with few species of algae to make them more reliable are just a few options to tackle this problem.

- **Improvement of the oil extraction process**: This is one of the major problems that can be addressed with the introduction of efficient design(Hannon, Gimpel, Tran, Rasala& Mayfield, 2010). The current technologies for extraction purposes are expensive due to the induction of the equipment or the source of energy required to extract the oil.
- **Meeting the demands of the people**: It was noted that in 2008 the US alone required about 19,497,950 barrels of oil in a day(Hannon, Gimpel, Tran, Rasala& Mayfield, 2010). In order to replace the fossil fuel, the algal biofuel has to compete hard to match the market requirement by improvising the existing production, extraction and harvesting methods.
- **Water**: The requirement of a large amount of water is one of the major limiting factors for the commercialization of the algal-based biofuel(Hannon, Gimpel, Tran, Rasala& Mayfield, 2010). It requires a large amount of water to be grown in the non-arable land.

Along with this, the other factors that need to get addressed are the source of nutrient which is essential for the growth of the algae, protection of the crops from other invasive species, and lastly getting the price corrected so that people can easily prefer biofuel instead of petroleum.

IV. Results and Discussions

In this project report, we had to analyze the recent trends in the production of algal biofuel in different stages. Along with this our aim we also find out answers for our objectives for this project.

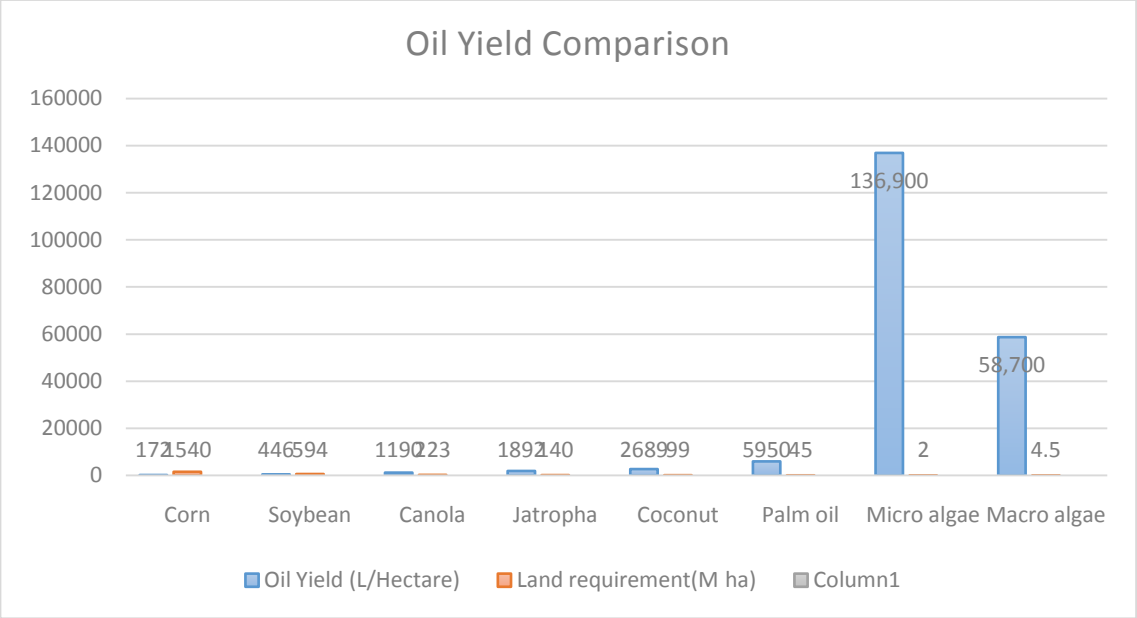
We discussed different methods for the production of the biofuel and along with that, we listed down the steps utilized in the production process and the findings owned by different inventors for the cultivation, harvest, extraction and conversion processes which have been listed in the form of table 1, 2, 3 and 4. The generalized conditions that are required for the growth of the algae are given in the table below along with its optimum range. There is a need to look for more cost-effective and sustainable design for the production purpose so that the high cost can be reduced and it is easy for biofuel to compete with the currently used biofuel.

Table 5: *The generalized conditions that are set for the culturing of the microalgae* (Karthikeyan, 2012)

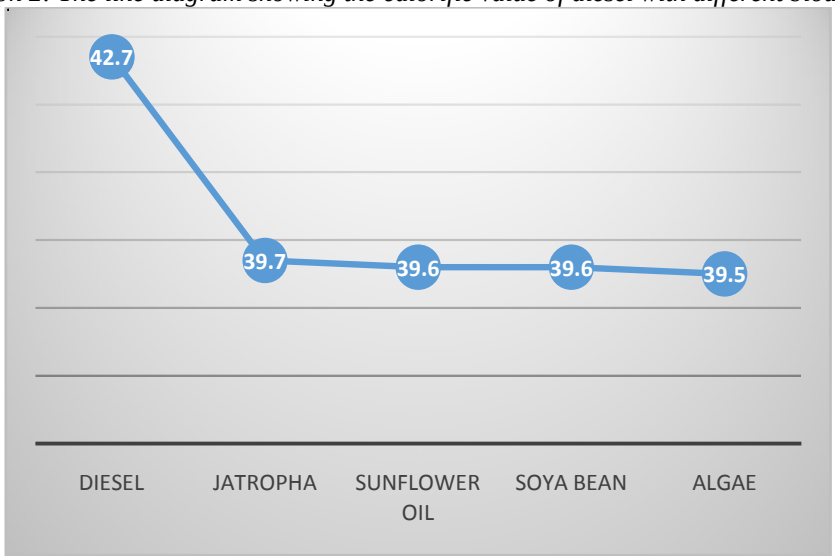
Parameters	**Range**	**Optimum**
Temperature (^{0}C)	16-27	18-24
Salinity (g.r)	12-40	20-24
Light Intensity (lux)	1000-10,000 which depends upon the volume and density of the feedstock.	2,500-5000
Photoperiod (Light: dark, Hours)	----	16.8- 24
Ph	7-9	8.2-8.7

The calorific value of the diesel which we use currently is 42.7% whereas that of algae is 39.5% as shown in the graph below. This value can be increased by going for more efficient algal strain modified with the help of the genetic engineering as the amount of yield that is obtained from algae biomass is much more when compared to other feedstock and the fossil fuel approximately 10,000 gallons of biofuel can be obtained from one acre of cultivation land. It is evident from graph 1 that the oil yield of microalgae in 2 M ha of land is 136,900 L/ ha. Along with the high yield, it is also necessary to obtain oil that has considerably high calorific value so that it can be used as an alternative for fossil fuels.

Graph 1: Comparison of the different oil yield and the land requirement.



Graph 2: The line diagram showing the calorific value of diesel with different biodiesel



The species of algae that are currently used and tested by the researchers are given below along with their lipid content. The most used species of algae that are being considered on a wider scale for the production is *Botrycoccusbraunnii*(Sun, 2011). In the risk assessment, different challenges that need to get addressed for the successful production of the different biofuels have been discussed that require up-gradation to make maximum use of algal biomass.

Species	**% Of the Lipid (Dry weight)**
Cyclotella cryptica	18
Dunaliella salina	18.5
Nitzschia sp.	45-47
Phaeodactylumtricomutum	20-30
Botrycoccusbraunii	54.2
Chlamydomonas sp.	23
Chlorella sp.	20-32
Chlorella vulgaris	14-22
Nannochloris sp.	20-35
Nannochloropsis sp.	31-68
Nannochloropsis salina	54
Spirulina plantensis	16.6

Tetraselmissueica	20-30
Isochrysis sp.	25-45

Table 6: Different microalgae species that are considered for the production of the oil. (Karthikeyan, 2012)

V. Conclusion

Algae is one of the most important feedstocks that is being considered for the production of the biofuel. In this report, various recent trends for the production of the algae-based fuel were addressed. Starting from the type of cultivation, harvesting and extraction process. Its comparison with petroleum helped us to realize that there is still a long way to achieve the target of the commercialisation of the algal biofuel as for now it lacks the capability to compete with petroleum which has already dominated the market. Its cost is one of the major challenges that need to get addressed. Although, the recent development in the research process to facilitate the production, harvesting and cultivation of the biofuel. The techniques such as integrating the production site with the waste streams containing wastewater and CO_2, the introduction of the most effective photobioreactors is certainly among the few challenges that have been addressed to meet the requirement of the petroleum in the market. There is a requirement for finding more efficient algal strains that can thrive in the local surroundings and have all essential nutrients for extraction purposes in important. The genomic resources, genetic tools, and genetic engineering methods will help to find more efficient methods to solve this issue in the future. Current researches are still limited to make an appropriate selection for the ideal microalgae species, along with the research and development a good source of investment is required for the proper development of the technology. The future cost-saving efforts of the oil-rich algae will be achieved with the help of the enhanced culture system engineering and generic engineering along with the utilization of the waste properly.

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