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Review on Smart Algae Bio Panel and its Growth Forecasting Using Machine Learning

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Abstract - **The world is facing major issues associated with the reliance on fossil fuels for energy supply, including rising prices, greenhouse gas emissions, and the risk of depletion. Various technologies have been developed for fixing carbon dioxide, which contributes to global warming. Biological fixation using photosynthetic microalgae cultured on a large scale is a promising method. In this method, carbon should be either wholly stored in the algal biomass or substituted for fossil fuel. Algal biomass can be degraded to carbon dioxide or methane, which is released to the atmosphere. The use of microalgae as a sustainable source of renewable energy and biofuels has garnered significant attention in recent years. One of the advantages of microalgae is their ability to accumulate high levels of lipids, making them a promising feedstock for biofuel production. Moreover, microalgae can be cultivated on non-arable land and can be grown using alternative water sources such as seawater, which further enhances their potential as a sustainable and environmentally friendly energy source. A photo bioreactor (PBR) is essential equipment for microalgal photosynthetic fixation of CO2. A PBR system implemented in a smart bio panel utilizes algae to trap sunlight energy and convert it into electricity, while also generating biomass as a by-product and acting as a CO2 scrubber. To make the system smart, machine learning algorithms were implemented to monitor and predict the growth rate of the algae Support Vector Machines (SVM) were used to predict the growth behavior of the microalgae, and the results showed that the SVM-based model can predict the growth rate of microalgae with a correlation coefficient of 90 percent. Microalgae biomass production heavily relies on photosynthesis, which only utilizes a small portion of the solar energy, mainly in the blue and red wavelengths. However, in traditional microalgae cultivation, the unused portion of the solar spectrum heats up the algae ponds and causes water evaporation, leading to increased salinity, especially in hot and semi-arid locations.**
Keywords: **Micro Algae, Machine Learning Algorithms, Bio-Fuel, Growth Forecasting**

Nomenclature:

PBR	Photo Bio Reactor
CH_2Cl_2	Dichloromethane
N_2	Nitrogen
Co_2	Carbon dioxide

I. INTRODUCTION

Microalgae have emerged as a promising technology for addressing challenges like an increase in CO2 emissions due to an increase in population and the need for a source of energy due to their ability to convert sunlight and CO2 into biomass and other useful compounds, including biofuels and food supplements[1].The microalgae have evolved to utilize the vast solar energy resource available on Earth and can convert this energy into a range of useful products, including biomass, biofuels, and animal feed and human food supplements. This makes microalgae a potential solution for meeting the increasing demand for food, energy, and other resources, while also addressing the need for sustainable and environmentally friendly production methods [2]. The use of microalgae as a sustainable source of renewable energy and biofuels has garnered significant attention in recent years. One of the advantages of microalgae is their ability to accumulate high levels of lipids, making them a promising feedstock for biofuel production.

Moreover, microalgae can be cultivated on non-arable land and can be grown using alternative water sources such as seawater, which further enhances their potential as a sustainable and environmentally friendly energy source [3]. By utilizing a closed system, a wider range of microalgae species can be cultivated successfully, which in turn expands the range of potential products that can be obtained [4]. Algae are a type of organism that resemble plants and possess Chlorophyll a, undergo oxygenic photosynthesis, and lack specialized organelles. Algae encompass a diverse group of organisms that include both prokaryotic and eukaryotic species and exhibit a wide range of sizes and structures. They can range from unicellular microalgae, which are less than 1μm in size, to multicellular macro algae that can reach lengths of up to 60 m.

Algae are capable of surviving in a variety of aquatic and moist environments, including marine and freshwater habitats, as well as in soils, salt lakes, and hot springs [5]. Several microalgae species have been identified as potential candidates for large-scale cultivation, but there is still a lack of conclusive information obtained through commercial trials to assess the suitability of most of these species. The ideal microalga for large-scale cultivation should be capable of growing well even under high biomass concentration and varying environmental conditions. Moreover, it should have the ability to produce a high concentration of the desired product, including high-value products, lipids, and hydrocarbons [6]. Compared to first and second generation biofuels, phototrophic microalgae represent a third generation biofuel with significantly higher productivity in terms of both biomass and oil content. For instance, open pond cultivation of microalgae can yield up to 73 tons of biomass per hectare per year, with oil content ranging from 25-40% [7].

Various technologies have been developed for fixing carbon dioxide, which contributes to global warming. Biological fixation using photosynthetic microalgae cultured on a large scale is a promising method. In this method, carbon should be either wholly stored in the algal biomass or substituted for fossil fuel. Algal biomass can be degraded to carbon dioxide or methane, which is released into the atmosphere. Substituting algal biomass for fossil fuel also reduces carbon dioxide release from fossil fuel. Botryococcus braurtii is a suitable organism for this purpose. This colony-forming green microalga is capable of producing and accumulating hydrocarbons amounting to 30-70% of its dry weight, making it a prime candidate for biological carbon dioxide fixation and production of liquid fuel [8].

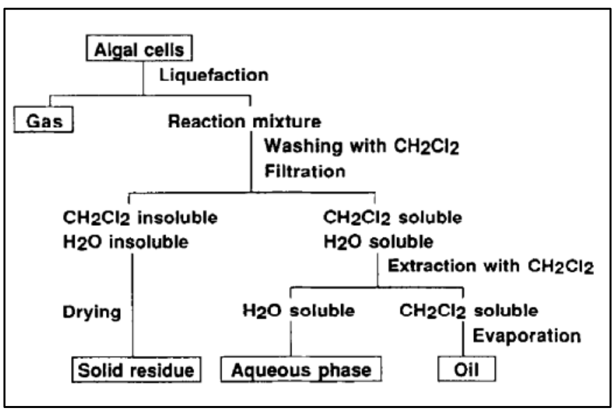

Fig. 1 Procedure for separating liquefaction products [8]

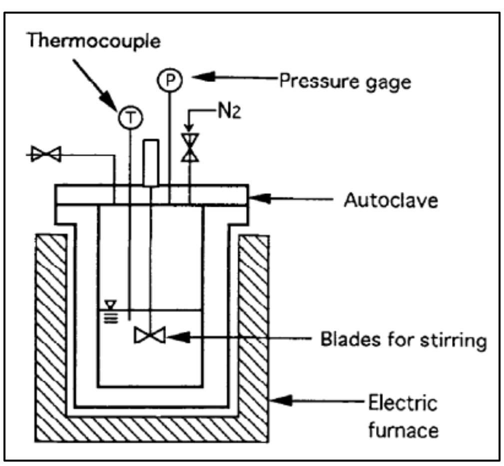

Fig. 2 Experimental apparatus for liquefaction [8]

Currently, there is no known microalgae species that can grow throughout the entire range of salinity levels, from low salinity to a state of salt saturation, while maintaining high levels of biomass productivity. Therefore, it is important to select multiple microalgae species that are capable of thriving within a broad range of salinity levels. These species should be carefully assessed based on their salinity tolerance, commercial applications, and potential advantages throughout the cultivation process [2].

A. Micro-Algae Cultivation Systems

There are two main types of microalgae cultivation systems: Open ponds and closed PBR.

1. Open Ponds

The cultivation of algae in open ponds involves several steps. First, a suitable location must be identified that receives ample sunlight and is sheltered from strong winds. Then, the pond must be prepared, which includes ensuring proper soil quality, leveling the land, and constructing a barrier around the pond to prevent contamination from outside sources. Next, water must be added to the pond, which can come from various sources, including freshwater or seawater. Nutrients such as nitrogen and phosphorus must also be added to the water to promote algal growth. This can be done through the addition of fertilizers or by recycling wastewater. Once the pond is filled with water, the algae culture can be added. This is typically done through the use of inoculants, which are small amounts of the desired algae species that are added to the pond [9].

The inoculants will grow and multiply, eventually filling the entire pond with the desired algae culture. During the cultivation process, the pond must be continuously monitored to ensure optimal conditions for algal growth. This includes monitoring water quality parameters such as temperature, pH, and nutrient levels. If necessary, additional nutrients may need to be added to maintain optimal growth. Finally, once the algae have reached their desired biomass, they can be harvested from the pond. This can be done using a variety of methods, including filtration, centrifugation, or sedimentation. The harvested algae can then be further processed to extract desired products such as lipids or proteins, which can be used for various applications including biofuels, animal feed, and nutritional supplements [10].

2. Closed Photo Bioreactors

Closed photo bioreactors are a type of enclosed system used for the cultivation of microalgae. The process involves growing microalgae in a controlled environment, typically in a cylindrical or tubular vessel made of glass or plastic. The vessel is designed to allow light to penetrate while preventing contamination from external sources [16]. The cultivation process begins by inoculating the photo bioreactor with the desired species of microalgae. The culture medium is then added, which typically includes a mix of water, nutrients, and carbon dioxide. The temperature, pH, and other environmental conditions are carefully monitored and controlled to optimize the growth of the microalgae [11].

Light is a critical factor in the cultivation of microalgae. To provide sufficient light, artificial light sources, such as LED or fluorescent lights, are used in the photo bioreactor. The light is typically provided in a cyclic manner to simulate day and night cycles and promote growth [12]. As the microalgae grow, they consume carbon dioxide and nutrients from the culture medium and produce biomass, which can be harvested for a variety of applications, including biofuels, food supplements, and pharmaceuticals [13]. Harvesting of microalgae from the closed photo bioreactor is typically done by separating the biomass from the culture medium using various methods such as centrifugation, flocculation, or filtration. The harvested biomass can then be further processed to extract the desired products [14].

TABLE I MICROALGAE SPECIES TESTED FOR MEDIUM- TO LARGE-SCALE BIOMASS PRODUCTION [16]

Chlorophyceae	*Neochloris oleoabundans; Scenedesmus dimorphus; Botryococcus braunii; Dunaliella tertiolecta; Nannochloris sp.; Chlorella protothecoides; Ankistrodesmus braunii*
Euglenophyceae	Euglena gracilis
Prasinophyceae	*Tetraselmis spp. (i.e., T. chuii and T. suecica)*
Haptophyceae	*Chrysotila carterae; Iscochrysis galabana*
Eustigmatophyceae	*Nannochloropsis spp. (e.g., N. salina, N. oculata, N. gaditana)*
Bacillariophyceae (diatoms)	*Cyclotella cryptica; Chaetacerous sp.; Skeletonema sp.*
Cyanobacteria (blue green algae)	*Arthrospira (Spirulina) platensis*

B. Extraction/Conversion of Algae

Microalgae have the potential to produce high-protein (e.g., Spirulina), high-carbohydrate (e.g., Chlorella), and high essential oil (similar to fish oil) products. Additionally, microalgae biomass can be transformed into renewable fuels. Figure 3 presents three different pathways for extracting and converting wet microalgae biomass (20% solid) into bioenergy [15].

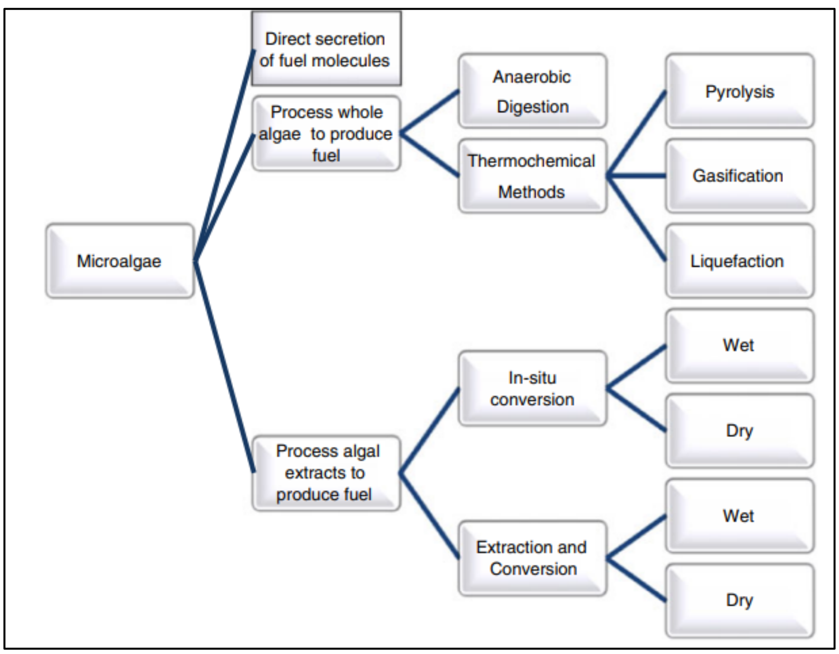

Fig. 3 Classification of methods of conversion from algae to fuel [15]

C. Conversion of Solar Energy to Biomass and Electricity

Microalgae biomass production heavily relies on photosynthesis, which only utilizes a small portion of the solar energy, mainly in the blue and red wavelengths. However, in traditional microalgae cultivation, the unused portion of the solar spectrum heats up the algae ponds and causes water evaporation, leading to increased salinity, especially in hot and semi-arid locations. Therefore, it would be beneficial to capture and convert this unused solar energy into electricity for on-site use during microalgae cultivation [16]. Photovoltaic greenhouses utilize photovoltaic modules in areas of the greenhouse where the reduction in overall Photo synthetically Active Radiation (PAR) would not affect plant growth. However, incorporating semi-transparent or opaque components in the greenhouse can diminish the PAR and lead to reduced productivity [17].

D. Non-Destructive Extraction Methods for Bio-Oil and Bio-Ethanol Production

The current microalgae to fuel (or chemical) processes face limitations in terms of economic viability due to the high costs and energy requirements for growth inputs, dewatering, and capital and operating expenses for the growth system [18]. Continuous efforts have been made to improve microalgae-based fuel or chemical production through advancements in growth, harvesting, and extraction systems. Despite the high cost and energy requirements for these processes, companies, research institutions, and governments persist in pursuing such systems with the belief that gradual improvements over time will lead to economic viability. However, some advocate for a new approach to biofuel production, known as "milking," which involves the continual secretion of the desired product from microalgae without the need to destroy and regrow the algae [16].

E. Use of ML for Algae Growth Monitoring

This research involves the development of a transmission hyper spectral microscopic imager (THMI) capable of detecting various microalgae species. Hyper spectral images obtained through trans-illumination provide high signal-to-noise ratios (SNRs), and the system exhibits spatial and spectral resolutions of 4 µm and 3 nm, respectively. An ROI extraction algorithm based on gray-level hyper spectral image data is employed to identify spectra from microalgae at specific positions. Transmission spectra, which reflect the absorption characteristics of pigments such as chlorophyll and carotenoids, are then utilized to provide spectral differences for further classification. The datasets are subjected to principal component analysis (PCA) and peak ratio algorithms for dimensional reduction before being classified using a linear support vector machine (SVM) classifier. The average accuracy, sensitivity, and specificity of this method were found to be 94.4%, 94.4%, and 97.2%, respectively, in distinguishing one species from the other two. Even when two species were mixed, they were identified using these classification methods. Additionally, a growth cycle of phaeocystis was simulated, and the corresponding growth stage was predicted using an RF model with a hyperspectral dataset, achieving a prediction accuracy of 98.1% [19].

II. LITERATURE SURVEY

Emeka G. Nwobaa *et al.,* [1] This paper describe a pilot-scale closed photo bioreactor that uses microalgae for biomass production and electricity generation. According to the abstract, the photo bioreactor uses a self-cooling system to maintain optimal temperature conditions for microalgal growth. The use of microalgae for biomass production and electricity generation is an area of active research and development, as it has the potential to be a sustainable and environmentally friendly source of energy. Microalgae are capable of converting sunlight and carbon dioxide into biomass and other useful compounds, such as lipids and carbohydrates, which can be used for a variety of applications, including biofuels, animal feed and human food supplements. The design of the photo bioreactor described in the paper is intended to address some of the challenges associated with microalgal cultivation, such as maintaining optimal growth conditions, preventing contamination, and maximizing productivity. The use of a closed system helps to minimize contamination risks and maintain a consistent growth environment, while the self-cooling system helps to regulate temperature and prevent overheating. This electrical energy can then be used for various purposes, such as powering pumps or other equipment within the photo bioreactor system. The IGP photo bioreactor's ability to produce up to 67 W m2 of electrical energy while sustaining > 14%, 14%, and 71% greater biomass production is an unmatched feature.

Ishika, T. *et al.,* [2] provides a critical review of the co-cultivation of saline microalgae for sustainable biofuel production. The authors discuss the potential advantages of co-cultivation, including enhanced nutrient utilization, reduced competition with other microorganisms, and increased productivity. Additionally, the article examines various cultivation strategies and technologies, such as open ponds and photo bioreactors, and their respective advantages and limitations. The authors also highlight the importance of selecting suitable microalgae species for co-cultivation and provide an overview of the lipid and biomass production potential of different microalgae species. Mathematical modeling can be employed to forecast the behavior of the investigated process by providing the necessary observations.

Borowitzka *et al.,* [3] discusses the potential of microalgae as a source of biofuels. The authors discuss various aspects of microalgae production, such as strain selection, cultivation systems, harvesting and extraction, and conversion to biofuels. The paper also highlights the challenges facing the commercialization of microalgae-based biofuels, such as the high cost of production, technical challenges in scaling up production, and competition with existing biofuels. The authors suggest that continued research and development are required to improve the economics and sustainability of microalgae-based biofuels. The paper provides a comprehensive review of the state of the art in microalgae-based biofuels and is a valuable resource for researchers and professionals in the field.

The conventional process of producing biodiesel typically involves using methanol (methanolysis), although some studies have shown that ethanol (ethanolysis) can produce a more environmentally friendly and less toxic fuel. However, the ethanolysis process tends to be more expensive [20]. Neither alcohol is miscible with triglycerides at room temperature, so mechanical stirring is used to increase mass transfer and form emulsions. In methanolysis, the emulsion formed is unstable and quickly separates into a lower glycerol-rich layer and an upper methyl-rich layer, whereas the emulsion formed in ethanolysis is more stable, making the separation and purification of ester more complex [20]. Producing algal oils for biofuels on a scale that can partially replace fossil fuels requires the efficient production, harvesting, and extraction of algal biomass, as well as the cost-effective conversion of lipids into fuels at a large scale [3].

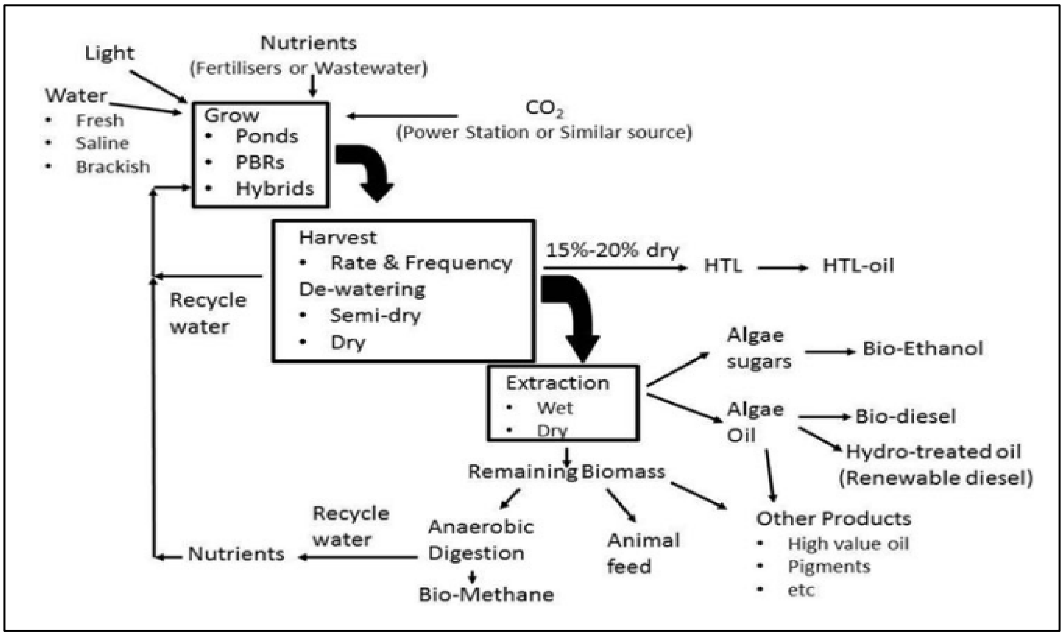

Fig. 4 Cultivation approach for saline microalgae in an open pond involves the use of solely seawater and recycled media [2, 6]

E. G., Parlevliet *et al.,* [4] focuses on the use of different light management technologies to improve the efficiency of algal photo bioreactors. The authors discuss the importance of light intensity, spectrum, and duration in algal growth and lipid production, and how these factors can be optimized using different technologies. The paper reviews several light management technologies, including the use of optical materials to enhance light distribution, light-emitting diodes (LEDs) to control light intensity and spectrum, and solar tracking systems to optimize the angle of incident light. The authors also discuss the use of light guides and diffusers to increase light penetration into the culture medium, and the use of reflective materials to increase light utilization efficiency. The authors present experimental results showing the effects of different light management technologies on algal growth and lipid production and discuss the potential applications of these technologies in large-scale algal cultivation systems. They conclude that light management technologies have great potential for improving the efficiency and scalability of algal photo bioreactors, and that further research in this area is needed to optimize the use of these technologies in commercial applications.

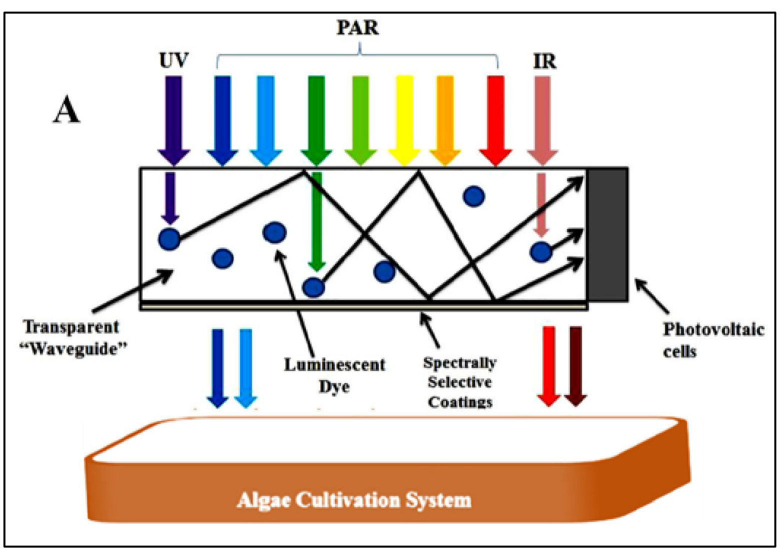

Fig. 5 Schematic shows the selection and filtration of wavelengths using a luminescent solar concentrator [4]

Moheimani, N. R. *et al.,* [6] Provides an overview of the historical and current developments in microalgae cultivation for biofuel production, as well as future perspectives. The article discusses the potential of microalgae as a sustainable source of biofuels due to their high lipid content and rapid growth rates. It covers topics such as the cultivation methods, including open ponds and photo bioreactors, as well as the use of wastewater and flue gas for microalgae cultivation. The article also examines the challenges associated with large-scale production of microalgae, such as high energy requirements and cost-effective harvesting and extraction methods. Finally, the article highlights some of the emerging technologies and developments in microalgae cultivation, such as genetic engineering and the use of nanotechnology for improved productivity and efficiency. Microalgae could be a potential solution for biomass production and a carbon-neutral fuel source in the future due to their significantly higher areal biomass yield compared to traditional terrestrial crops [6]. However, it would be unrealistic to expect a single solution to enable large-scale microalgae biomass production [21].

Zhang, W. [22] in this study, the authors used machine learning to predict and optimize bio-oil production from hydrothermal liquefaction of algae. They first collected experimental data on the hydrothermal liquefaction of microalgae to produce bio-oil and used this data to train a machine learning model. The model was then used to predict bio-oil yields under different operating conditions. The authors also used the model to optimize the hydrothermal liquefaction process by identifying the conditions that would maximize bio-oil yield. The results showed that the machine learning model was able to accurately predict bio-oil yield under different operating conditions, and that the optimized conditions identified by the model resulted in a significantly higher bio-oil yield than the initial experimental conditions.

The authors suggest that machine learning could be a valuable tool for optimizing biofuel production processes in the future [22]. Various biofuel production systems are utilizing artificial intelligence techniques, such as machine learning (ML), to advance the development of technologies like hydrothermal conversions and pyrolysis. These techniques are being used to predict and optimize the yield of char, oil, and gas products [23]. They also compared the prediction performance of Random Forest (RF) and multiple linear regressions for separately predicting the yield and Hydrogen (H) content of bio-oil obtained from biomass pyrolysis. The results showed that RF outperformed multiple linear regressions with an R2 value between 0.80 and 0.90 [24].

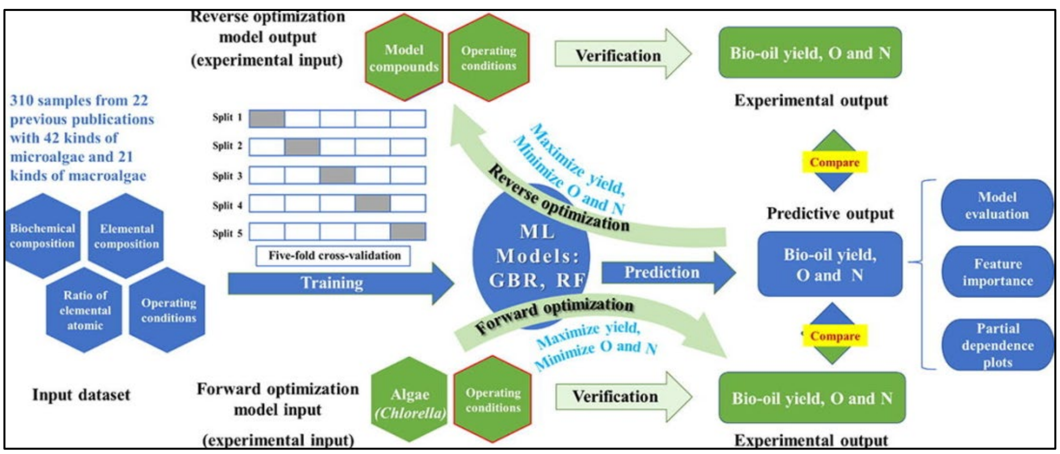

Fig. 6 Prediction of bio-oil production from hydrothermal liquefaction of algae [23]

III. CONCLUSION

Smart algae bio panels are a type of system that utilizes algae to capture carbon dioxide from the atmosphere and convert it into biomass through photosynthesis. These panels are becoming increasingly popular due to their ability to mitigate carbon emissions and provide a source of sustainable energy. To forecast the growth of algae in these panels using machine learning, several factors must be considered. Some of these factors include:

Environmental Factors: Algae growth is affected by a variety of environmental factors, including temperature, light intensity, and nutrient availability. These factors can be measured using sensors, and their values can be used as input variables for the machine learning algorithm.

Algae Species: Different species of algae have different growth rates and requirements. Therefore, it is essential to consider the specific algae species used in the panel when building the machine learning model.

Historical Data: Historical data on algae growth in the panel can be used to train the machine learning algorithm. This data can include measurements of algae biomass, nutrient levels, and environmental factors.

One of the advantages of algae bio panels is that they can be installed in a variety of locations, including rooftops, facades, and even urban landscapes, providing a source of renewable energy that is close to the point of use. Additionally, algae bio panels can be integrated with other systems, such as wastewater treatment plants, providing a dual benefit of producing energy and cleaning up wastewater. Generating electricity from algae has the potential to be a sustainable and environmentally friendly source of energy. However, there are still some challenges that need to be addressed in order to make algae-based electricity a viable option. One of the main issues is the cost of production, as the process of cultivating and harvesting algae can be expensive. The biomass produced from algae can be converted into various forms of biofuels, including biodiesel, bioethanol, and biogas. These biofuels have the potential to replace fossil fuels, reducing greenhouse gas emissions and mitigating climate change.

REFERENCES

[1] E. G. Nwoba, D. A. Parlevliet, D. W. Laird, K. Alameh and N. R. Moheimani, "Pilot-scale self-cooling microalgal closed photobioreactor for biomass production and electricity generation," *Algal Research,* Vol. 45, No. 101731, 2020.

[2] T. Ishika, N. R. Moheimani and P. A. Bahri, "Sustainable saline microalgae co-cultivation for biofuel production: a critical review," *Renewable and sustainable energy reviews,* Vol. 78, pp. 356-368, 2017.

[3] M. A. Borowitzka and N. R. Moheimani, "Sustainable biofuels from algae," *Mitigation and Adaptation Strategies for Global Change,* Vol. 18, pp. 13-25, 2013.

[4] E. G. Nwoba, D. A. Parlevliet, D. W. Laird, K. Alameh and N. R. Moheimani, "Light management technologies for increasing algal photobioreactor efficiency," *Algal research,* Vol. 39, No. 101433, 2019.

[5] M. A. Borowitzka, *Phycology. Els,* 2012.

[6] N. R. Moheimani, D. Parlevliet, M. P. McHenry, P. A. Bahri and K. De Boer, "Past, present and future of microalgae cultivation developments," *Biomass and biofuels from microalgae: advances in engineering and biology,* pp. 1-18, 2015.

[7] C. Posten and G. Schaub, "Microalgae and terrestrial biomass as source for fuels-A process view," *Journal of Biotechnology,* Vol. 142, No. 1, pp. 64-69, 2009.

[8] Y. Dote, S. Sawayama, S. Inoue, T. Minowa and S. Y. Yokoyama, "Recovery of liquid fuel from hydrocarbon-rich microalgae by thermochemical liquefaction," *Fuel,* Vol. 73, No. 12, pp. 1855-1857, 1994.

[9] K. Kumar, S. K. Mishra, A. Shrivastav, M. S. Park and J. W. Yang, "Recent trends in the mass cultivation of algae in raceway ponds," *Renewable and Sustainable Energy Reviews,* Vol. 51, pp. 875-885, 2015.

[10] R. L. White and R. A. Ryan, "Long-term cultivation of algae in open-raceway ponds: lessons from the field," *Industrial Biotechnology,* Vol. 11, No. 4, pp. 213-220, 2015.

[11] F. Lehr and C. Posten, "Closed photo-bioreactors as tools for biofuel production," *Current Opinion in Biotechnology,* Vol. 20, No. 3, pp. 280-285, 2009.

[12] P. L. Gupta, S. M. Lee and H. J. Choi, "A mini review: photobioreactors for large scale algal cultivation," *World Journal of Microbiology and Biotechnology,* Vol. 31, pp. 1409-1417, 2015.

[13] C. U. Ugwu, H. Aoyagi and H. Uchiyama, "Photobioreactors for mass cultivation of algae," *Bioresource Technology,* Vol. 99, No. 10, pp. 4021-4028, 2008.

[14] C. Y. Chen, K. L. Yeh, R. Aisyah, D. J. Lee and J. S. Chang, "Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: a critical review," *Bioresource Technology,* Vol. 102, No. 1, pp. 71-81, 2011.

[15] K. De Boer, N. R. Moheimani, M. A. Borowitzka and P. A. Bahri, "Extraction and conversion pathways for microalgae to biodiesel: a review focused on energy consumption," *Journal of Applied Phycology,* Vol. 24, pp. 1681-1698, 2012.

[16] N. R. Moheimani and M. P. McHenry, "Developments of five selected microalgae companies developing closed bioreactor biofuel production systems," *International Journal of Innovation and Sustainable Development,* Vol. 7, No. 4, pp. 367-386, 2013.

[17] J. Pérez-Alonso, M. Pérez-García, M. Pasamontes-Romera and A. J. Callejón-Ferre, "Performance analysis and neural modelling of a greenhouse integrated photovoltaic system," *Renewable and Sustainable Energy Reviews,* Vol. 16, No. 7, pp. 4675-4685, 2012.

[18] L. Lardon, A. Hélias, B. Sialve, J. P. Steyer and O. Bernard, "Life-cycle assessment of biodiesel production from microalgae," 2009.

[19] Z. Xu, Jiang, Y., Ji, J., Forsberg, E., Li, Y. and He, S. "Classification, identification, and growth stage estimation of microalgae based on transmission hyperspectral microscopic imaging and machine learning," *Optics Express,* Vol. 28, No. 21, pp. 30686-30700, 2020.

[20] G. Anastopoulos, Y. Zannikou, S. Stournas and S. Kalligeros, "Transesterification of vegetable oils with ethanol and characterization of the key fuel properties of ethyl esters," *Energies,* Vol. 2, No. 2, pp. 362-376, 2015.

[21] E. Eroglu, S. M. Smith and C. L. Raston, "Application of various immobilization techniques for algal bioprocesses," *Biomass and Biofuels from Microalgae: Advances in Engineering and Biology,* pp. 19-44, 2015.

[22] W. Zhang, J. Li, T. Liu, S. Leng, L. Yang, H. Peng and H. Li, "Machine learning prediction and optimization of bio-oil production from hydrothermal liquefaction of algae," *Bioresource Technology,* Vol. 342, No. 126011, 2021.

[23] J. Li, X. Zhu, Y. Li, Y. W. Tong, Y. S. Ok and X. Wang, "Multi-task prediction and optimization of hydrochar properties from high-moisture municipal solid waste: Application of machine learning on waste-to-resource," *Journal of Cleaner Production,* Vol. 278, No. 123928, 2021.

[24] L. Sheng, X. Wang and X. Yang, "Prediction model of biocrude yield and nitrogen heterocyclic compounds analysis by hydrothermal liquefaction of microalgae with model compounds," *Bioresource Technology,* Vol. 247, pp. 14-20, 2018.