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A Review on Micro-algae cultivation for biofuels production integrating with the sugar factories

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Abstract : The possibility of using microalgae as a feedstock for the creation of biofuels for sustainable transportation has attracted a lot of interest. Despite its potential as biofuel sources, the large-scale production of biofuels from microalgae is still in doubt, partly because the method does not seem to be feasible and it turns out to be expensive in terms of both capital and energy. It is crucial to combine microalgal production with other methods in order to achieve low-cost nutrient and energy utilization. It is crucial to combine microalgal production with other methods in order to achieve low-cost nutrient and energy utilization. The ability of a sugar factory's wastewater and flue gas to promote the growth of microalgae for the generation of biofuel and biofertilizer is assessed in the current study.

I. INTRODUCTION

Microalgae have low environmental restrictions and high yields of biomass and lipid with high photosynthetic efficiency as a bioenergy source. Microalgae can thrive in seawater and wastewater as well as on non-arable terrain such as beaches, saline and alkaline soils, and deserts. Now a days microalgae is also used in the preparation of biodiesel. In order to produce biodiesel from microalgae, carbon resources from the environment must be recycled and integrated, which can help with the long-term objective of replacing petroleum use and lowering environmental pollution, thereby making a significant contribution to the global effort to achieve carbon neutrality. Most species are photoautotrophic, converting solar energy into chemical forms through photosynthesis.

Using the lipid in microalgae or the entire microalgae cell, gaseous fuels like biogas and hydrogen can be produced, as well as liquid fuels like ethanol and liquid hydrocarbons (Sanghamitra et al., 2020). In order to produce biodiesel from microalgae lipid by transesterification, methane must first be produced through anaerobic digestion, and then hydrocarbons or substances resembling crude oil must be produced through gasification and pyrolysis .

II. Algae types and their characterstics

Table.1 Algae types and their characterstics

Cyanobacteria	Cyanobacteria or blue-green algae are gram-negative bacteria which can survive at some of the harshest habitats on earth. Some of them are known to be able to do nitrogen fixation along with carbon fixation both of which are essential for life on earth.	*Prochlorococcus, Spirulina, Nostoc, Cyanothece, Anabaena*
Glaucocystophytes	Glaucocytophytes are relatively uncommon unicellular eukaryotic algae that contain plastid which is structurally similar to cyanobacteria. Glaucocystophytes are one of the descendants of the product of early endosymbiosis	*Cyanophora,* *Glaucocystis, Peliaina, Gloeochaete*
Rhodophytes	Rhodophytes or red algae are comprised of mostly multicellular photosynthetic eukaryotes. They are characterized by their distinctive red color due to the presence of red pigments such as phycobilisomes in their chloroplast.	*Batrachospermum, Chroodactylon, Bangia, Cyanidium, Compsopogon*

Chlorophytes	Chlorophytes or green algae are photosynthetic eukaryotes which contain chlorophylls as their main photosynthetic pigments	*Haematococcus, Chlorella, Dunaliella, Graesiella, Scenedesmus*
Euglenoids	Euglenoids are unicellular flagellated eukaryotes which exhibit both animal- and plant-like characteristics. Most Euglenoids are freshwater species while some are marine species	*Euglena, Discoplastis, Phacus, Colacium, Strombomonas*

III. METHODS OF CULTIVATING MICROALGE

The following qualities should be present in an ideal microalgae culturing system:
(1) Sufficient light source;
(2) Efficient material transfer across liquid-gas barrier;
(3) Straightforward operation procedure;
(4) Minimal contamination rate;
(5) Affordable overall building and production cost; and
(6) High land efficiency .

The open pond and photo bioreactor are the two basic categories into which microalgae cultivating systems can be divided. Each method has benefits and drawbacks.

The different methods to produce micro algae

1. Open pond

   One of the earliest and most basic methods of mass microalgae culture is open pond farming. Due to its significantly less expensive construction, maintenance, and operation costs, open ponds are commonly employed in the business. Other benefits of employing an open pond system are its simple setup, low need for energy, and ease of expansion [7]. There are just a few different kinds of open ponds, which include both natural bodies of water like lakes and ponds and man-made ones like raceway and circular ponds. In some circumstances, microalgae can also be grown in a tank-like container [8]. The benefit of being the most economical cultivation system is the open pond system. However, despite the extensive cultivation area, natural water microalgae cultivation has a rather low cell concentration, necessitating the use of a very effective harvesting technique. Additionally, problems like precipitation runoff, which influences the salinity and pH of microalgae, erosion of banks, which causes leaks, and increasing water turbidity may all have a substantial impact on the production of microalgae in open ponds [10]. The potential for protozoa and bacteria contamination, which renders the products poisonous and useless, is another problem that arises with open pond farming systems. Since only a few pollutants can thrive in these conditions, the best option to deal with this issue for now is to grow microalgae that can survive in extremely salty or alkaline environments [11,12]. Additionally, because the system is open, it is more difficult to regulate growth parameters like temperature and light intensity that could impact how quickly microalgae develop.

   One of the most popular open pond styles for the growth of microalgae is the raceway pond. In order to ensure that nutrients are distributed equally and to prevent sedimentation of the microalgae biomass, it is made up of a series of closed loop channels that are about 30 cm deep and paddlewheels. Due to its energy economy, raceway ponds have been regarded as one of the greatest open pond cultivation designs currently available. A single paddlewheel is needed to adequately agitate a 5-hectare raceway pond

2. Photo bioreactor

   A photobioreactor is a type of bioreactor used to cultivate phototrophs like microalgae in a closed system that prevents direct material exchange between the culture and its surroundings. A photobioreactor can get around a number of problems that open pond culture design frequently runs into. First, a bioreactor uses land more effectively than an open pond because of its smaller size. Second, the method offers the culture a closed, tightly regulated environment in which to grow, resulting in the production of a single strain, contaminant-free microalgae culture [20]. Furthermore, the tightly controlled culture environment can lead to increased nutritional and metabolic efficiency, which raises biomass production per unit of substrate. However, the photobioreactor's restricted scalability is the barrier to its widespread practical use. A photobioreactor is a type of bioreactor that is used to cultivate phototrophs, like microalgae, in a closed environment without allowing for direct material exchange. However, the photobioreactor's low scalability as a result of numerous design problems makes it uneconomic to be employed in large-scale production, which is the bottleneck of practical deployment. Additionally, the photobioreactor's highly controlled growth conditions are always associated with expensive capital and running costs.

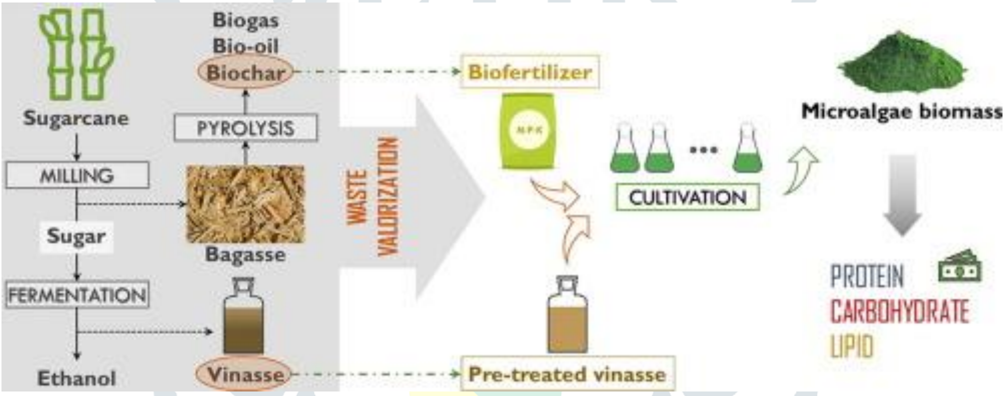
   Tubular photobioreactors: To maximize the capture of sunlight, a tubular photobioreactor is built up of long, transparent tubes made of glass or transparent plastic that are stacked in a horizontal, vertical, helical, or tilted orientation . Through the use of a mechanical pump or an air lift device, the microalgae culture is moved around the loop. Although the long tubes utilized in the bioreactor design may cause variations in substrate and product concentration throughout the tubes, the major problem of the tubular photobioreactor design is its low mass transfer across the system. In Germany and Israel, respectively, commercial-scale tubular photobioreactors are utilized to produce haematococcus and chlorella.

Vertical column bioreactors: A sparger that pumps air bubbles into the vertical cylindrical tubing of the vertical column bioreactor is used to homogenize the culture and allow the exchange of carbon dioxide and oxygen between the air and the microalgae culture. Due to the sparger's capacity to produce smaller bubbles that have a greater total surface area for more effective substance transfer, this culture system has the best gas-liquid mass transfer efficiency when compared to other systems. The design's simplicity also enables it to operate more efficiently and with less energy usage. The cylindrical container does not, however, offer the microalgae the amount of light needed for optimal photosynthesis. Commercial use of vertical column photobioreactors is challenging due to high building costs and challenges with reactor cleaning. Although there are various large-scale experimental reactors that have been created, including a 40-liter vertical column outdoor photobioreactor for the culture of Chlorella zofingiensis in Guangdong, China, commercial use of this photobioreactor design has yet to be discovered.

Flat plate bioreactors: On the other hand, a flat-plate photobioreactor is distinguished by a rectangular, transparent compartment with a depth of between 1 and 5 cm. Recirculating airlift system is used to mix the culture inside the reactor. Out of all photobioreactor designs, this one provides the most total surface area for illumination and little oxygen buildup, resulting in the highest photosynthetic efficiency . The microalgae cells in this photobioreactor, however, suffer stress damage due to the aeration design . Twin layer flat-plate and plastic sheet photobioreactors are just two examples of the cutting-edge designs that have been used to increase the flat-plate photobioreactor's effectiveness

IV. PROCESS DESIGN OF SUGARCANE PROCESSING MILL

The process design is based on the total nitrogen (TN) and total phosphorus (TP) contents in the wastewater effluent from the sugar mill and the vinasse from the annexed ethanol production plant of the factory. Photoautotrophic cultivation of the microalgae in ponds was assumed where the wastewater and the recycled nutrients from an anaerobic digestion step could be used as nutrient sources and the flue gas from the factory as a CO_2 source. It was supposed that the amount of CO_2 required would be based on the amount of nutrients in the waste effluents (the wastewater and the vinasse). Hence, the nutrients should be considered as the limiting resources.

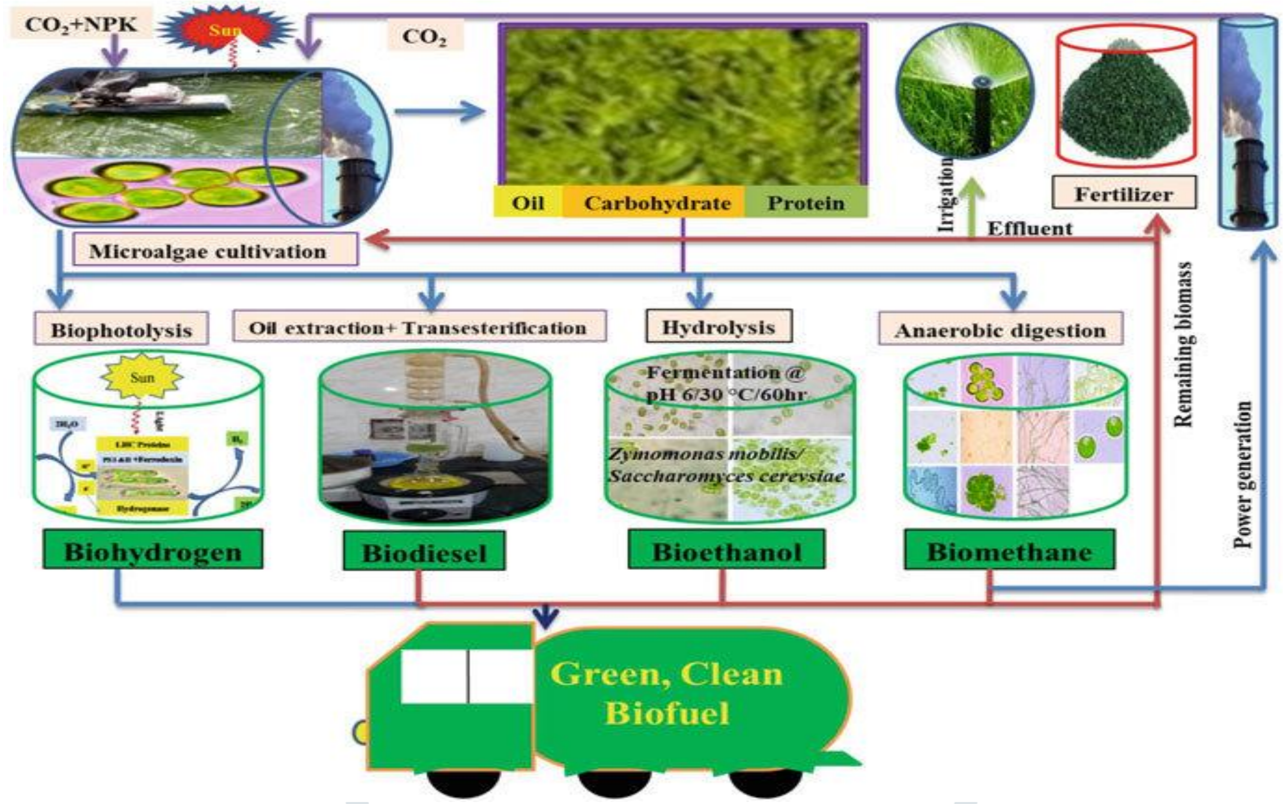


V. BIOMASS HARVESTING FROM MICROALGAE

It was believed that the biomass from the ponds would go through the three harvesting processes of settling, dissolved air floatation (DAF), and centrifugation. The assumption was that the 0.50 g/L (0.05%) concentration of diluted algal biomass from the pond would be sent to the settling process, which has a 95% algal removal efficiency, where it should be concentrated to 10 g/L (1% concentration) via auto-flocculation. Here, no electricity demand for mixing during coagulation was taken into account. The settled solids would then be sent to the DAF process, with an anticipated capture efficiency of 90% and an output of 60 g/L (6% solids concentration). It was predicted that the DAF will require 0.10 kWh/m3 of energy. Self-cleaning disc stack centrifuges with an assumed 95% algal retention rate and an energy consumption of 5 kWh/m3 of water extracted were used for centrifugation. In this case, the culture's concentration would be increased to 250 g/L (or 25%) . The lost biomass from each stage of harvesting was supposed to be collected by a filter and sent to the AD. The filtration procedure required 0.01 kWh of electricity per kilogram of algae.

i. BIOFUEL PRODUCTION

There are various methods for producing a biofuel from algal biomass. The paths employed in this investigation are highlighted in the picture. The criteria for selecting the optimum pathway to use the biomass depend on a variety of elements, including infrastructural accessibility, CO2 emissions, and other environmental concerns. In the current study, microalgae with a 30% oil content are taken into consideration to be used as a base value , which demonstrates that only 30% of the entire biomass will be utilized, for example, if the microalgae are used just for the manufacturing of biodiesel. Other methods for using lipid-extracted algae (LEA) must be used if material utilization is to be more. This is why it is crucial to produce biodiesel and biogas simultaneously, since it is both resource- and energy-efficient (as shown in the figure in blue and orange colors) . As a result, it is presumable that biomass will be used in the production of biofuels via a biodiesel-biogas pathway.



ii. BIODIESEL PRODUCTION

Cell disruption, oil extraction, and biodiesel transesterification should all be done during the biodiesel production process**.**

Cell disruption: To maximize the recovery of intracellular products during wet extraction, the algal biomass needs to be treated using the right technology in the cell disruption unit. High-pressure homogenization was taken into consideration for the current work. This technique was chosen because it is a well-proven technology in both the laboratory and the industrial setting and has become one of the most widely utilized techniques . Prior to moving the biomass with a 25 weight percent from the harvesting operations to extraction, it should be pressure homogenized for cell lysis and disruption . According to assumptions made by several researchers, pressure homogenization requires 0.20 kWh/kg of dry biomass at 90% efficiency, or a 25 wt% input. It is thought that the undisrupted algae in the homogenizer flow through the extraction (with no lipid recovery) to the digester with the residues.

Lipid extraction: Lipid extraction from algae is mostly performed either from wet algal paste or dry algal cake, with or without cell disruption. In the present study, lipid extraction from wet algal paste using the solvent extraction technique with pretreatment or cell disruption is carried out. It is supposed that lipid extraction should be performed using ethanol. Ethanol should be used because of its polar nature enabling it to penetrate the polar cell membrane of the lipids so that more cell material could be made free and be extracted. Moreover, ethanol has low toxicity and is available in the factory (ethanol is produced from cane molasses in Metahara factory). In some other extraction studies, a ratio of solvent to dry biomass of 5:1 (w/w) was used, and the same ratio was assumed for the present study. A lipid recovery of up to 97% was reported in the literature. However, for the present study, an 80% lipid recovery is considered as a base value. The lipid-rich solvent and the algae residue slurry are assumed to be separated through disk stack centrifugation. The algal residues should then be forwarded to the AD for the biogas production, while the algae oil–solvent solution should be forwarded to a stripping column where the ethanol would be separated from the oil and recycled, leaving a 99.50% pure lipid stream. The electricity requirement for the extraction step is assumed to be 0.28 kWh/kg per dry biomass while a thermal energy of 1.30 kWh/kg per dry biomass was accounted. Solvent loss in circulation and lipid loss in the stripper are thought to be 5.20 g ethanol/kg of oil and 5 wt.%, respectively .

Biodiesel Transestrification: The extracted lipids would be transported and converted to biodiesel by transesterification using methanol in the presence of sodium hydroxide as a catalyst (1 wt.%). The methanol-to-fatty acid mass ratio in the reactor was assumed to be 1:10. An 80% (wt.%) conversion rate of oil to biodiesel was assumed in the reactor as a base value. Electrical and thermal energy requirements for the transesterification were expected to be 3.80 × 10-4 and 0.68 kWh/kg of converted oil, respectively. The density and energy content of the biodiesel were accounted to be 900 kg/m3 and 42 MJ/kg, respectively.

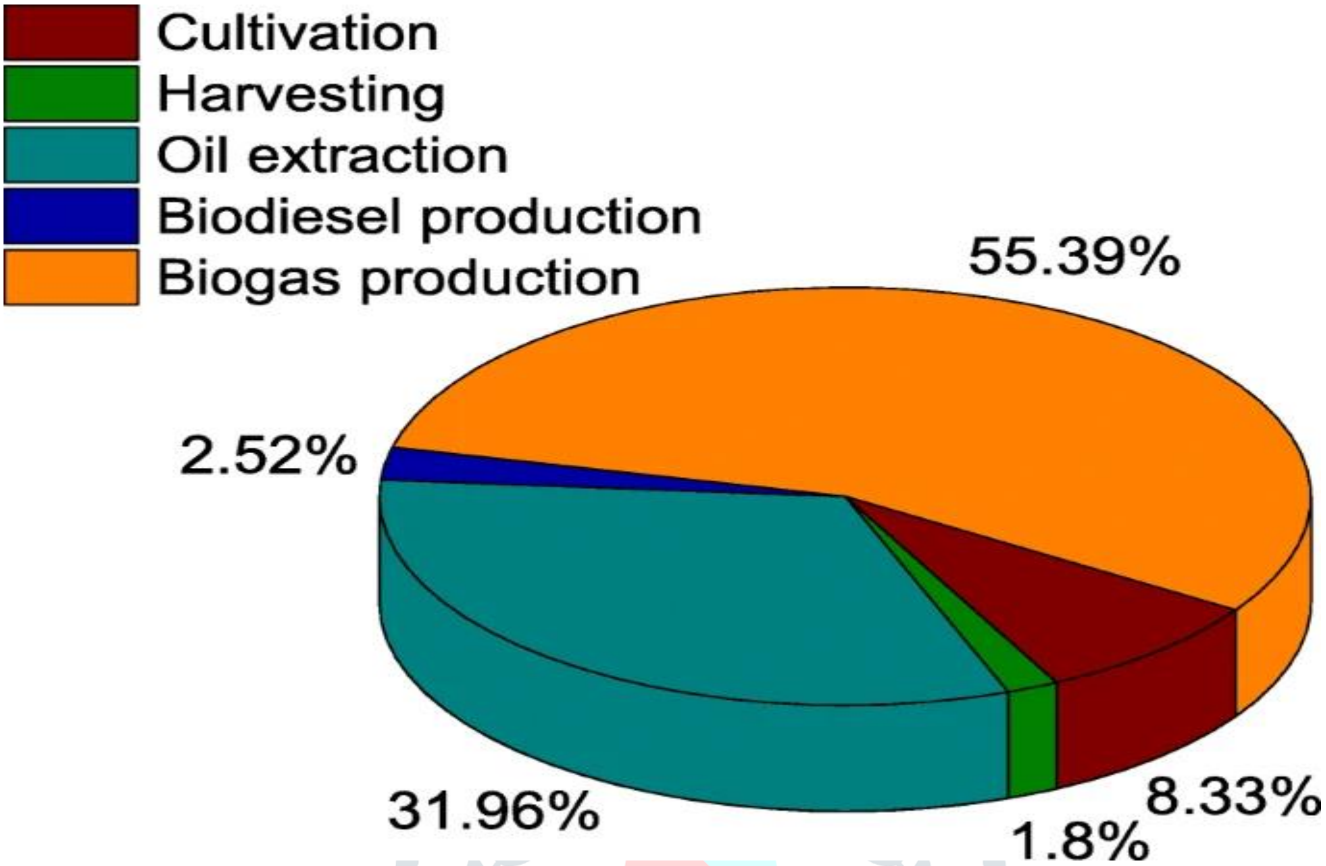
iii. BIOGAS PRODUCTION

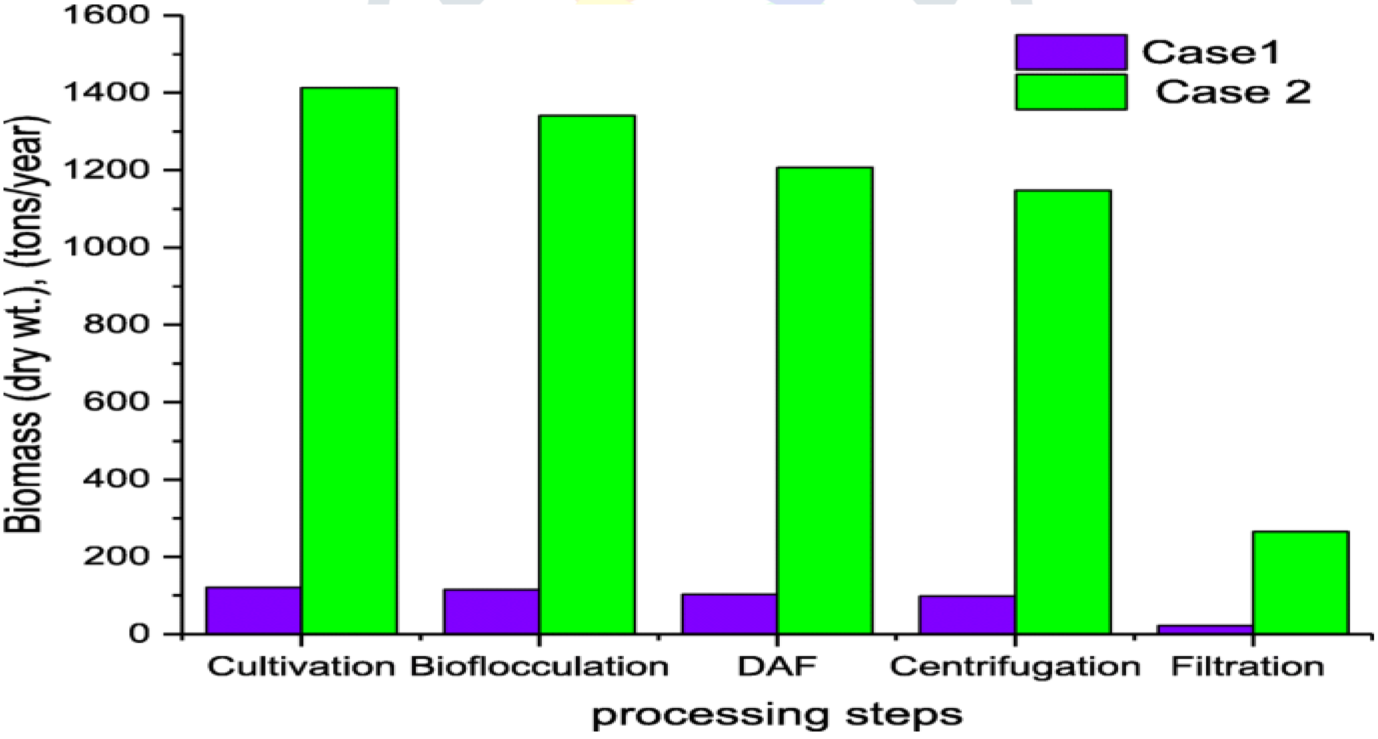
In the biogas production model, it is assumed that the inflows to the AD are derived from five process steps. These include the vinasse, a by-product in ethanol production; the primary sludge from the wastewater primary treatment stage; the algae residues (lipid-extracted algae (LEA and the undisrupted algae) from the oil extraction step; the filtered algae in the harvesting section; and crude glycerol, a by-product from the transesterification step in the biodiesel production.

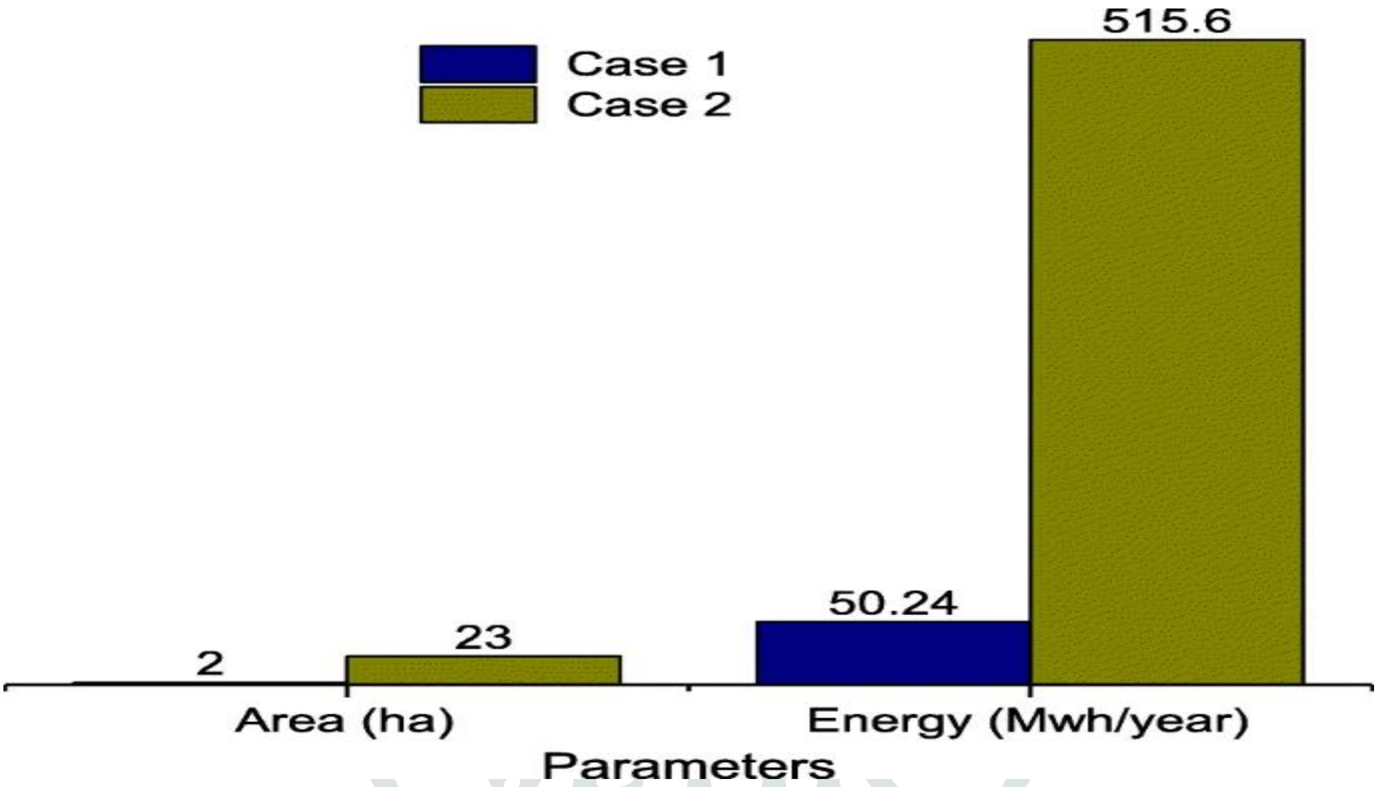
Biogas is commonly used to generate electricity and/or heat. Biogas can also be used as transportation fuel after purifying it into biomethane. Metahara sugary factory produces bioethanol to be used as transportation fuel by blending it with petro-diesel. Along with this bioethanol, in the present study, it is intended to deliver the biogas and the biodiesel, which would be produced in the coupled process, to the energy grid of the country and subsequently to be used as transportation fuel.

IV. RESULTS AND DISCUSSION

i. Energy required for each process step by percentage







The current status of bioenergy generation in India shows an increasing growth trend, but the progress is slow. Biomass-based projects contribute less than 3% of the power generation in India, while the other major sources include fossil fuels (58.2%), and solar (14.6%), hydro (12.7%), and wind (10.2%) energy as of the year 2022. However, the projected biomass power potential at the pan-India level based on the time series analysis is expected to increase to 32,937.83 MWe and 35,994.52 MWe by the years 2025–26 and 2030–31, respectively. This target can be achieved by improving and implementing a strategic plan for maximizing the availability of biomass since, out of a total of 990 MMT of agriculture-based biomass produced annually in India

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VII. CONCLUSION

The wastes from the factory have a high potential for production of microalgal biomass and microalgal biofuel, biodiesel, and biogas. The potential for producing microalgal biomass, microalgal biofuel, biodiesel, and biogas from the factory's wastes is very high. Additionally, the integration of the processes demonstrates the production of a crucial additional product called bio-fertilizer, which may make the synergy of the processes possible. The outcome demonstrates that the ethanol plant's vinasse is the main source of nutrients for the microalgae cultivation, as the majority of the nitrogen and phosphorus used by the pond's algae are derived from the vinasse after it has been anaerobically digested in the AD. The production of biodiesel in the integrated process was also shown to be highly impacted by the oil content of the algae, the nitrogen content of the wastes, and the extraction and transesterification efficiency, suggesting that enhancing these factors could help. It is well established that microalgae have tremendous potential as a source of biofuel, food and high value bio-compounds. However, the limitations in productivity of microalgae and the drawbacks of bioprocessing technologies render the fully utilization of microalgae biomass to be impractical. Therefore, more work needs to be done to further improve the existing technology. For instance, more advanced culturing technique should be developed to increase the productivity of microalgae.

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