TRANSFORMING TRASH TO TREASURE: A REVIEW ON OPPORTUNITIES AND CHALLENGES IN USING AQUATIC WEED AS RESOURCE FOR BIOETHANOL PRODUCTION

Abstract

Biofuels are relevant from an economical, ecological, and social perspective since they are crucial in tackling a number of key worldwide concerns. Attention has been shifted from first generation feed stocks other types of feedstock to ensure food security to the world. Aquatic weeds have been difficult to contain in order to stop their global growth. They not only pose threat to environment and water bodies but also huge sums of money and labor must be diverted when they are removed from water systems in order to safely manage and dispose of the waste. The aquatic weeds have the potential to be both profitable and advantageous when utilized as a resource. In this work, we tried to explore the suitability of aqua weeds as feed stocks for production of bioethanol as to meet growing global demand for clean and safer energy. The suitability of aquatic weed as feed stock for bioethanol was addressed due to its high protein, carbohydrate, and fat content. We also discussed current challenges and process intensified techniques to convert this waste to a valuable product. Finally we concluded this topic with some insights into future scope of making these aquatic weeds as a regular feedstock for bioethanol production.

Keywords—Aquatic weed; Bio-Ethanol, Biofuel,Clean Energy

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I. INTRODUCTION

One of many major challenges that today 'world facing is to reduce the dependency on fossil fuels. The gap between energy demand and depleting conventional feed stocks has been increasing day by day thereby forcing researchers, energy industries and policy makers to think of sustainable process especially through waste management. Between 2019 and 2030, the demand for energy was predicted to increase by 12%[1]. The forecasted bioethanol production in 2023 is around 119 billion L.

Biofuel is a form of sustainable energy made from organic matter, usually plants or compounds produced from plants. Biomass is the term used to describe the organic material used in the manufacturing of biofuels. There are various kinds of biofuels, such as:bioethanol, biodiesel, biogas and biojet fuel. When opposed to fossil fuels, biofuels provide a number of environmental advantages. As the carbon dioxide emitted during their combustion is balanced by the carbon dioxide absorbed during the growth of the biomass, they can aid in reducing greenhouse gas emissions. They can also aid in the decrease of air pollutants that lead to smog and other health problems. However, there are certain difficulties with biofuels as well, such as the competition for resources and land for food production as well as potential effects on food costs. The kind of feedstock used, the farming techniques used, and the overall energy efficiency of the production process all have a significant role in how sustainable biofuel production is. In recent years, attention has been placed heavily on municipal trash, lignocellulosic waste, microalgae, fungus, and other biomass as biofuel feedstocks. This scope of this work is limited to bioethanol production from waste aquatic weeds in view of consequences posed ever growing demand for bioethanol. Fermentation of ligninocellulose biomass is already reported in literature by authors as potential process for bioethanol production[2]–[4]. In the process of identifying eco friendly feed stocks with low production cost, the production of bio-fuel from aquatic weeds has been gaining interest due to its diversified advantages.

II. BIOETHANOL

Bioethanol is a type of sustainable biofuel created from biomass, such as plant materials, agricultural byproducts, and organic waste, is known as bioethanol or simply ethanol. With the molecular formula C_2H_5OH, it is an alcohol predominantly made of carbon, hydrogen, and oxygen. Through a fermentation process, yeast or bacteria transform the sugars and starches in biomass into ethanol, which is then produced as bioethanol.

1. **Sequential Procedure of Bioethanol Production:** The primary step of bioethanol production process involves feed stock selection among the variety of biomass sources available like corn, sugarcane, wheat, barley, switchgrass, wood chips, agricultural waste, and even switchgrass. The next important step includes pre-Treatment in order to simplify complicated structures and make the carbs more fermentable. Saccharification is a process, where enzymes are utilized to break down the biomass' complex polysaccharides (such as starches and cellulose) into simple sugars like glucose. The crucial part of the ethanol production process is fermentation in which yeast or bacteria ferment the sugars created during saccharification to produce ethanol and carbon dioxide. This procedure is comparable to that of making beer. After fermentation, the mixture is distillated to remove the water and other byproducts and leave only the ethanol. To

further concentrate the ethanol, a dehydration phase may occasionally be performed. In some situations, ethanol made for fuel or industry may be denatured, which means that small amounts of hazardous compounds are added to render it unfit for human consumption and stop tax fraud.

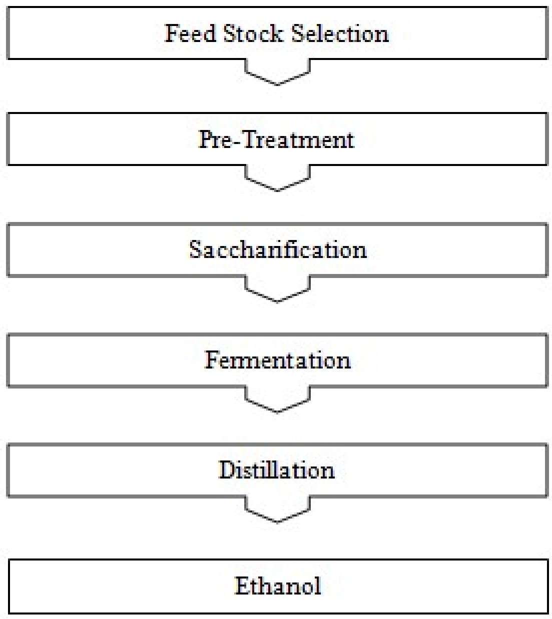

Figure 1: Processflow Diagram for bioethanol production

2. **Applications of Bioethanol:** To make ethanol-blended fuels like E10 (10% ethanol and 90% gasoline) or E85 (85% ethanol and 15% gasoline), bioethanol is frequently combined with gasoline. These blends assist in lowering greenhouse gas emissions and dependency on fossil fuels and can be utilized in ordinary gasoline engines with some adjustments. Because the carbon dioxide emitted during its combustion is balanced by the carbon dioxide absorbed during the growth of the biomass feedstock, bioethanol is regarded as a renewable and environmentally benign fuel source. As a result, compared to the use of fossil fuels like gasoline or diesel, it helps to reduce net carbon dioxide emissions. Additionally, employing bioethanol can encourage more sustainable energy practices and less reliance on depleting fossil fuel supplies.

3. **Advantages of Bioethanol Over Ethanol:** Because they both relate to the same chemical substance, ethyl alcohol (C_2H_5OH), the terms bioethanol and ethanol are frequently used synonymously. While "bioethanol" particularly refers to ethanol produced from biomass or renewable resources, "ethanol" is sometimes used to denote alcohol produced from a variety of sources. Let's contrast the production processes and environmental effects of ethanol versus bioethanol. Bioethanol possess several special features over to ethanol produced from conventional methods in the following aspects.

   - **Raw Material:** Ethanol can be made from a number of different plants, including corn (maize), sugarcane, wheat, barley, and other starchy or sweet plants. It can also be made from waste products like leftover food and agricultural byproducts.As was previously indicated, the term "bioethanol" refers specifically to ethanol produced from biomass, which can include plant materials like corn stover, sugarcane bagasse, switchgrass, wood chips, and other agricultural leftovers that are not used for food.

- **Sustainability:** The production of ethanol from food crops like maize has sparked worries about possible rivalry with food production as it can have an impact on food prices and food security. On other side, bioethanol, which is made from biomass other than food, is thought to be more sustainable because it lessens the competition for resources between the production of food and fuel. It makes use of waste products or crops developed especially for bioenergy production.

- **Ecofriendliness:** Ethanol's environmental impact is influenced by the sources of its feedstock and the farming methods used in its production. For instance, the manufacturing of maize ethanol has come under fire for its potential to cause deforestation, an increase in pesticide use, and water contamination.

  When compared to ethanol obtained fom food crops, bioethanol made from non-food biomass, particularly waste materials, can have a reduced environmental impact. Being a component of the carbon cycle, it encourages the use of renewable resources while lowering greenhouse gas emissions.

- **Ethanol Energy Balance:** Depending on the production processes, transportation, and other elements, the energy balance of corn-based ethanol can change. Depending on the study, corn ethanol may have a moderate positive energy balance (producing more energy than it consumes) or a smaller or negative energy balance.Compared to corn ethanol, bioethanol produced from non-food biomass or waste materials typically has a more positive energy balance since it makes use of materials that are frequently regarded as trash or byproducts.

  In conclusion, the type of feedstock used to produce ethanol and bioethanol differs significantly. Bioethanol is ethanol made from biomass, which is seen as a more environmentally friendly and sustainable solution than ethanol made from food crops like maize. It encourages the utilization of renewable resources, lowers greenhouse gas emissions, and prevents potential conflict with the production of food.

III. AQUATIC WEED

Plant species known as aquatic weeds flourish in or close to bodies of water, including wetlands, rivers, lakes, and ponds. These plants, which can be either native or introduced species, flourish in water habitats. While certain aquatic weeds are crucial in providing habitat and food for different aquatic creatures, others can spread quickly and upset the ecosystem.

1. **Types of Aquatic Weeds and Availability:** Among several types of aquatic weeds available, the following list of aquatic weeds gained more interest due to their diversified features discussed below.

- **Water Hyacinth:** The invasive floating plant known as the water hyacinth (Eichhornia crassipes) is renowned for its quick growth and capacity to form dense mats on the water's surface, preventing water movement and sunlight penetration.

  Water lettuce(Pistia stratiotes). It is a different invasive floating plant, can cover water bodies and produce rosettes of leaves, which lowers oxygen levels and hinders other aquatic life.

- **Duckweed (Lemna spp.):** It is a little floating plant that grows quickly. Although some aquatic species may find it useful as a food source, too much duckweed can cover the water's surface and reduce light transmission.

- **Elodea Canadensis:** It is sometimes known as common waterweed, is a submerged aquatic plant that is native to North America and is frequently used in aquariums. It might, however, turn invasive and displace local plants in some places.

- **Azolla Filiculoides:** The water fern, or Azolla filiculoides, was brought to Europe, North and Sub-Saharan Africa, China, Japan, New Zealand, Australia, the Caribbean, and Hawaii after being imported from its original warm temperate and tropical regions of the Americas.It is a floating aquatic fern with extremely rapid growth that can cover the entire lake in only a few months by spreading over lake surfaces. Each plant is between one and two centimeters across, with margins that are pink, orange, or red. It branches freely and divides into smaller portions as it grows. In temperate locations, it largely dies back in the winter and only manages to survive by using submerged buds because it is not tolerant of freezing temperatures.

- **Salviniamolesta:** It is a free-floating plant that floats on the surface of a body of water rather than attaching to the soil. The fronds have a bristly surface due to the hair-like strands that combine at the end to form eggbeater forms. They are 0.5–4 cm long and broad.They are used as a waterproof covering.

- **Hydrilla (Hydrilla verticillata):** It is another invasive submerged plant, hydrilla (Hydrilla verticillata), can create dense underwater mats that affect ecosystems and reduce water flow.

- **Typha spp.:** It is also known as cattails, are a family of wetlands plants that can be found along the water. They are useful for giving different wildlife habitat and food sources, yet they have the potential to invade other ecosystems aggressively.

- **Watermilfoil (Myriophyllum spp.):** It is a family of submerged aquatic plants that can accumulate into dense underwater mats that obstruct native plant communities and impact water flow.

2. **Biochemical Properties of Aquatic Weed:** The specific makeup of aquatic weeds can vary depending on the water's quality, the availability of nutrients, the amount of light, and the plant's stage of development. Additionally, different aquatic weed species may have distinctive metabolic profiles, resulting in differences in their physical and chemical characteristics. For ecological study and the creation of successful management plans for invasive aquatic plant species, it is crucial to understand the makeup of aquatic weeds. However, aquatic weeds generally consist of both organic and inorganic parts. Based on data reported by several authors with respect to the biochemical composition of various aquatic weeds, the main elements that aquatic weeds often contain are summarized below.[5], [6], [15], [16], [7]–[14]

   - **Water:** Because weeds are aquatic plants, water makes up a sizable component of their makeup and is crucial to their survival and development.

   - **Carbohydrates:** Aquatic weeds are full of carbohydrates, primarily in the form of sugars (such as glucose and sucrose) and starches. Through photosynthesis, carbohydrates are created and used as a source of energy by plants.

   - **Proteins:** Proteins, which are made up of amino acids organized in particular sequences, are essential parts of aquatic weeds. Proteins are essential for the structure, development, and several metabolic activities of the plant.

   - **Lipids:** Aquatic weeds are rich in lipids, such as fats and oils. Lipids are necessary for the development of cell membranes as well as serving as energy stores.

   - **Cellulose and Hemicelluloses:** These complex carbohydrates, cellulose and hemicellulose, give the cell walls of plants their structural support.

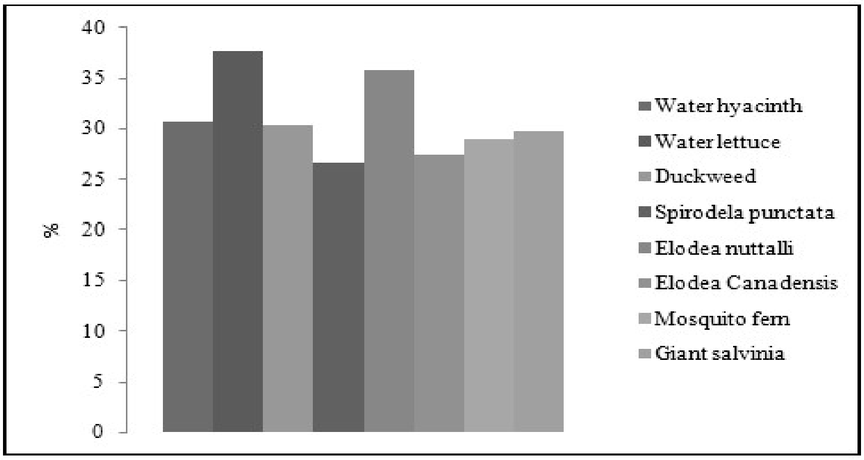

Figure 2: Comparison of Cellulose content in variety of Aquatic weeds

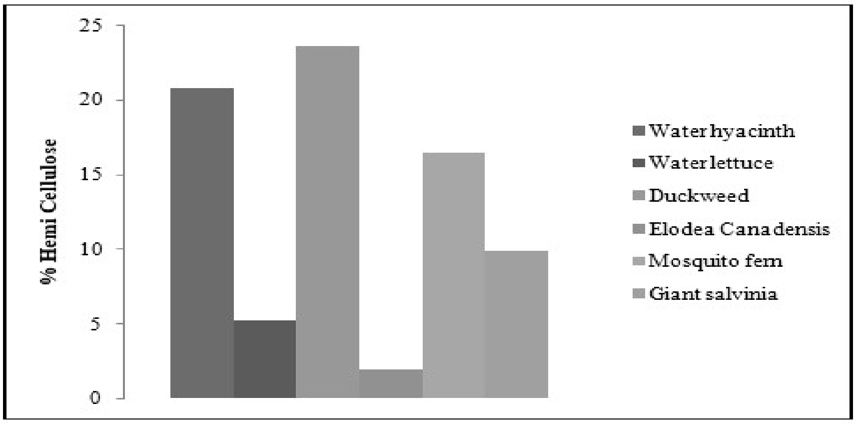

Figure 3: Comparison of Hemicellulose content in variety of Aquatic weeds

- **Lignin:** Lignin is a complex polymer that gives some aquatic weed species' cell walls rigidity and strength. It aids the plant in keeping its form and warding off deterioration. Aquatic weeds don't generally contain lignin. Lignin, a sophisticated organic polymer, gives vascular plants like trees and terrestrial plants' cell walls structural support. It is not frequently seen in the cell walls of aquatic plants.

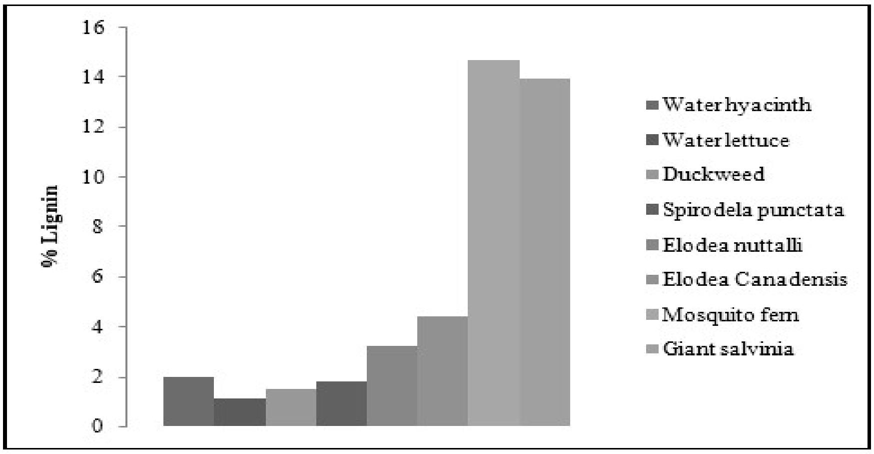

Figure 4: Comparison of Lignin content in variety of Aquatic weeds

- **Pigments:** Aquatic weeds have a variety of pigments, including carotenoids (yellow, orange, and red pigments) and chlorophylls (green pigments). During photosynthesis, these pigments are involved in light absorption.

- **Minerals:** The minerals in the water and sediment that aquatic weeds grow in are absorbed and accumulated by them. Potassium, phosphorus, calcium, magnesium, and sulfur are typical minerals present in their tissues.

- **Secondary Metabolites:** Alkaloids, phenolics, and terpenoids are examples of the secondary metabolites that some aquatic weeds generate. These substances frequently have anti-herbivore or anti-pathogen properties.

- **Trace Elements:** Heavy metals or trace elements may also be present in aquatic weeds, which they pick up from their surroundings.

3. **Impact of Aquatic Weeds on Environment:** To keep aquatic ecosystems healthy and in balance, aquatic weeds must be managed and controlled. Aquatic invasive weeds can have a negative effect on recreational activities, native plant and animal species, and water quality. Their management and spread in impacted water bodies is controlled using a variety of techniques, including mechanical removal, biological control, and the use of herbicides. To avoid additional ecological disruptions, it is essential to carry out these management actions in an environmentally appropriate way.

IV. PRODUCTION OF BIOETHANOL FROM AQUATIC WEEDS

Aquatic weeds possesses many special features over other feedstocks as they are considered as waste product with unwanted growth phenomena. Generation of value added products and energy from these unutilized weeds can serve many purposes like protecting water bodies and addressing the world’s energy demand with out efecting the food chain. Their presence in abundance is drawing interest due to the damage caused by them if left unattended. The consequences caused by aquatic weeds can be reduced by converting them as feedstock for biorefineries. Their rapid growth has been a great advantage as it avoids the usage of resources like arable land, water bodies etc. Fertiliser production from aquatic weeds is another way of converting these waste weeds into valuable products. Thier availability through global distribution is another special feature to treat them as an alternative resource for biofuel production apart from other sources such as fungi, lignocellulose waste, microalgae, and muncipal waste etc. Other areas of applications include extraction of medicinal compounds, enzyme production, etc,.

There have been a number of developments in bioethanol production technology in recent years. Aquatic weed biomass is typically processed using straightforward hydrolysis procedures, much like any other bioethanol feedstock, and the resulting sugars are then fermented to make bioethanol[17]. The production of bioethanol may vary depending upon the composition of fermentable sugars like glucose and xylose present in aquatic weeds. There is a need to thoroughly investigate the potential of various aquatic weed as bioethanol feedstock and determine its sugar composition for employing effective conversion technologies.

Aquatic weed is a viable feedstock for the synthesis of bioethanol since it has high levels of cellulose and hemicellulose and little lignin. Aquatic weeds including duckweed, water lettuce, water hyacinth, and other weeds are a very new topic of research, and there are just a few scattered research reports available.

Zhang et al. studied simultaneous saccharification and fermentation (SSF) ofWater hyacinth for optimized bioethanol production of 1.289 g/L[18]

K. Whangchai et al. reported bioethanol production of 15. 385 g/L from water lettuce. They also compared the production rates from fresh biomass and pretreated dry biomass[19].

Faizal et al. applied SSF process to four types of duckweed species and obtained ethanol in the range of 0.16-0.19 g/L[20].

Miranda et al.discussed the suitability of Mosquito fern in considering feedstock for bioethanol[21]

Kityo et al. mentioned the improved ethanol yield of 15.9 g/L from Salviniamolesta with sonication[22]

V. BARRIERS TO BE CONSIDERED

There are still research gaps in areas like maximizing process efficiency, discovering appropriate feedstock organisms and transformation technology, improving the performance of the end product, as well as rendering the overall process costeffective, despite recent resea rch on applications like the production of bioethanol, biomethane, and fertilizer.

Aquatic weeds have a rapid rate of growth and are highly invasive. When growing aquatic weeds for potential use in the manufacture of biofuel and other goods, it is important to pay close attention to these features [23]. Aquatic weeds should be produced in quarantine facilities and occasionally harvested for use in order to prevent invasion in natural water bodies. It takes time to collect aquatic weed from a contaminated body of water or a cultivation facility. Manual harvesting on a modest scale can be used to gather aquatic weed. For large-scale operations, mechanized harvesting is necessary. Up to 90% of the water content in aquatic weed biomass can have an impact on how well it converts to biofuel.. To facilitate the downstream process of producing biofuel from aquatic weed, efficient and affordable dewatering technologies need to be assessed. The cost of production may increase due to the transportation of aquatic weed biomass and ensuring a consistent supply for downstream processing. It is advised to construct the processing plant close to the locations of the harvest.

Aquatic weed biofuel production on a big scale may face difficulties with harvesting, drying, transportation, and costeffective conversion methods.These problems require addressi ng.Studies on the techno-economics and life cycle analysis of biofuel production from aquatic weed biomass are quite few. However, before it can be successfully implemented to benefit the environment and humankind, there are still issues that need to be resolved. Aquatic weed has demonstrated significant potential for the generation of biofuel and other purposes. Some of the aforementioned issues are the subject of recent studies.

VI. TECHNOLOGIES FOR PROCESS INTENSIFICATION

Enzymatic hydrolysis processes that convert lignocellulose to ethanol involve four biological processes: the formation of saccharolytic enzyme (cellulases and hemicellulases), the hydrolysis of polysaccharides that exist in pretreated biomass, the microbial fermentation of hexose sugars, as well as the fermenting of pentose sugars. In simultaneous saccharification and cofermentation (SSCF) of both hexoses and pentoses, as well as simultaneous saccharification and fermentation (SSF) of hexoses, the hydrolysis and fermentation processes have been combined. The ultimate goal would be a one-step "consolidated" bioprocessing (CBP) of lignocellulose to bioethanol, where all four of these steps take place in one reactor and are mediated by a single microbial consortium or microorganism that is capable of fermenting pretreated biomass without the addition of saccharolytic enzymes. CBP is becoming more widely acknowledged as a potential innovation in low-cost biomass processing. When a mature CBP process is used instead of an advanced SSCF process, a fourfold decrease in the cost of biological processing and a twofold reduction in the cost of processing as a whole are predicted[24].

Zhang et al looked into the prospect of increasing water hyacinth's ability to produce bioethanol through a combination of pretreatment techniques. The destruction of water hyacinth was examined using three different pretreatment techniques: microbial pretreatment, microbial combined dilute acid pretreatment, and microbial combined dilute alkaline pretreatment. The findings demonstrated that the most efficient method for producing the maximum amount of cellulose and reducing sugars was microbial combination dilute acid pretreatment. The water hyacinth's basic tissue has been extensively degraded, according to analyses using scanning electron microscopy and a Fourier Transform Infrared Spectrometer. [25].

The efficiency of microwave-assisted alkaline pretreatment of algal waste was examined by Maceiras et al. [14]. The product was hydrolyzed with sulfuric acid following pretreatment. They looked at the impacts of the NaOH concentration, microwave power, irradiating period, and solid-liquid ratio. In the ideal circumstances, Saccharomyces Cerevisiae was used to convert the fermentable sugars into cellulosic bioethanol, with a bioethanol output of 1.93 0.01 g/g and a fermentation efficiency of 40.4%. The concentration of reducing sugars was 30% more than what would have been achieved with regular hydrolysis without pretreatment. The results show that compared to methods without the microwave impact, microwave assisted alkaline pretreatment is successful in enhancing the production of cellulosic bioethanol from algal waste. Low microwave power and a brief microwave irradiation time are advantageous for this procedure in terms of energy consumption.The impact of microwave technology on the water hyacinth structure for the manufacturing of pyrolysis product was examined in another study[26]. They came to the conclusion that microwave pretreatment was very successful at altering and destroying the water hyacinth's smooth outer structure, which in turn had a good impact on the pyrolysis performance of the weed biomass and increased the yield of pyrolysis products.

Ulva rigida, a common green seaweed, was employed as a feedstock for a simultaneous saccharification and fermentation (SSF) process that was conducted under sonication to produce bioethanol. Korzena et al. [27] observed that Ulva rigida's simultaneous release of glucose and its conversion to bioethanol was sped up by sonication. In addition to being quick, the procedure required no chemical preparation and only one round of sonication for the simultaneous fermentation of glucose into ethanol using Saccharomyces cerevisiae and the release of glucose from algae by the action of enzymes.

VII. FUTURE SCOPE

Aquatic weed is becoming more popular as a useful resource for the creation of biofuels and other products with added value. Aquatic weed has an advantage over several commonly used terrestrial biofuel feedstocks due to its quick growth rate, appropriate composition, and low land demand. Aquatic weed has demonstrated promising potential for biomethane, bioethanol, and oil production. The scientific community should pay attention to how aquatic weed can be used to produce biodiesel and biohydrogen. Aquatic weed-based biorefinery is a sustainable method for producing biofuels and other crucial chemicals for industry, but there are a few issues that require the scientific community's attention. To create effective pre-treatment and conversion technologies, research is required.

- There are difficulties, including the requirement to extract biomass, poor hydrolysis and conversion, scaling up, and high processing costs.
- To increase biofuel yields, biological and other hybrid pretreatment techniques as well as process intensification can be used. Aquatic weed biomass must be used to its fullest extent in order to be commercially viable. Under an integrated biorefinery system, residual biomass after biofuel production could be used for various industrial applications.
- To develop and scale up the aquatic weed-based biorefineries for a sustainable future, extensive life cycle analyses and risk assessment studies are needed..

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