ALGAE – ENERGY SOURCE OF THE FUTURE IN THE AUTOMOTIVE SECTOR

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ABSTRACT - There is a general consensus that in order to reduce gaseous emissions, climatic changes and global warming effects, while also responding to the ever increasing demand for energy in the recent years, finding alternative energy resources is a pressing mission. For environmental and economic sustainability, transport fuels need to be renewable and carbon neutral. Based on current knowledge and technology projections, third generation biofuels, particularly those derived from algae, are considered to be a technically viable alternative energy source.

This paper focuses on algae and how they can be used for biofuel production. Like plants, algae use sunlight to produce oils, but they do so more efficiently than crop plants. Oil productivity of many algae species exceeds the oil productivity of the best oil producing crops. Therefore, a comparison between microalgae and macroalgae is discussed in detail, along with energy production pathways and the possibilities of combining these steps with pollution control, considering specific species of algae that are found in the Black Sea area, especially at the Romanian shore.

INTRODUCTION

The availability of secure, reliable and affordable energy is fundamental to economic stability and development. There is an increasingly urgent need to mitigate greenhouse gas (GHG) emissions, including those related to energy production and consumption. Approximately 69% of all CO_2 emissions are energy related, and about 60% of all GHG emissions can be attributed to energy supply and energy use. The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that 50% to 80% cuts in global CO_2 emissions by 2050 compared to the 2000 level will be needed to limit the long-term global mean temperature rise to 2.0°C to 2.4°C. For 2030, GHG emission projections (Kyoto gases) consistently show a 25–90% increase compared to 2000, with more recent projections being higher than earlier ones [1, 2]. Table 1 illustrates the relation between emissions and climate change according to the IPCC 2007 Assessment Report.

Table 1 The relation between emissions and climate change according to the IPCC 2007 Assessment Report [1].

Temperature increase	**All GHGs**	**CO_2**	**CO2 emissions 2050 (% of 2000 emissions)**
[°C]	[ppm CO_2 equivalent]	[ppm CO_2]	[%]
2.0 – 2.4	445 – 490	350 – 400	-85 to -50
2.4 – 2.8	490 – 535	400 – 440	-60 to -30
2.8 – 3.2	535 – 590	440 – 485	-30 to +5
3.2 – 4.0	590 – 710	485 – 570	+10 to +60

In these conditions, biomass, terrestrial or aquatic, comes as an alternative energy feedstock, since it is renewable and it fixes the CO_2 in the atmosphere through photosynthesis and it has zero or almost zero emissions of both air pollutants and greenhouse gases. Among biomass, algae are emerging as a fuel feedstock with higher photosynthetic efficiency and yield [3]. The photosynthetic efficiency of aquatic biomass is much higher (6-8%, average) than that of terrestrial biomass (1.8-2.2%, average). Aquatic biomass has the adaptability to grow in different conditions, fresh or marine environments, and in a wide enough range of pH [4].

MACROALGAE vs. MICROALGAE

Like all organisms, algae provide biogeochemical cycles as well as ecological services: they function to link metabolic sequences and properties to form a continuous, self-perpetuating network of chemical element fluxes. Algae played an important role in shaping Earth's biogeochemistry. Earth's initial atmosphere was composed of 80% N_2, 10% CO/CO_2, 10% H_2 (by volume), no free O_2 appeared until the development of oxygenic photosynthesis by cyanobacteria, transforming the atmosphere composition in the actual 78% N_2, 21% O_2, 0.036% CO_2 and other minor gases (by volume). The fossilized hydrocarbons that we now consume in forms of fuels, plastics, dyes, etc. are mostly formed by decomposition of organic matter consisting of the remains of several freshwater marine microalgae. Once again, these small organisms are about to save us from the threat of global warning [5].

The terms "microalgae" and "macroalgae" are often used to distinguish microscopic organisms such as phytoplankton from larger organisms such as seaweed or kelp. The biomass can be derived from both macroalgae and microalgae sources and may represent an economically and environmentally sustainable renewable energy/fuel source.

TYPES AND COMPOSITION

The term *algae* has no formal taxonomic standing [6]. Algal organisms are photosynthetic organisms growing in aquatic environments. Photosynthesis is the key to making solar energy available in useable forms. These organisms use energy from the sun to combine water with carbon dioxide to create biomass [7]. Algae range from small, single-celled organisms to multicellular organisms, some with fairly complex and differentiated forms [5].

Types of microalgae

Microalgae are microscopic photosynthetic organisms, found in both marine and freshwater environments, that produce lipids as the primary storage molecule. Biologists have categorized microalgae in a variety of classes, mainly distinguished by their pigment composition, biochemical constituents, ultrastructure and life-cycle. The four most important in terms of abundance are the diatoms (*Bacillariophyceae*), the green algae (*Chlorophyceae*), the red-green algae (*Cyanophyceae*) and the golden algae (*Chrysophyceae*). Microalgae reproduction occurs primarily by vegetative cell division, but under appropriate growth conditions, sexual reproduction may occur in many species [7].

Oil content of microalgae

Many microalgae species can be induced to accumulate substantial quantities of lipids thus contributing to a high oil yield. The average lipid content varies between 1 and 70%, but it can reach 90% under certain conditions [8].

Table 2 Oil and productivity yield of two species of microalgae [8, 9]

Microalga	**Oil content (% dw)**	**Yield (g/m2/day)**
Nannochloris sp.	20-35	20
Tetraselmis suecica	15-23	19

The selection of the most adequate species needs to take into account other factors like the ability of microalgae to grow using the nutrients available or under specific environmental conditions. Different nutritional and environmental factors, cultivation conditions and growth phases can affect the fatty acid composition.

Types of macroalgae

Macroalgae, commonly known as seaweeds, belong to lower plants. They do not have roots, stems or leaves. Instead, they are composed of a thallus (leaf-like) and sometimes a stem and a foot. Seaweed is a loose, colloquial term encompassing macroscopic, multicellular, benthic marine algae. A seaweed may belong to one of several groups of multicellular algae: the red algae (*Rhodophyceae*), green algae (*Clorophyceae*), and brown algae (*Phaeophyceae*). As these three groups are not thought to have a common multicellular ancestor, the seaweeds are a polyphyletic group. The prokaryotic cyanobacteria (the red-green algae *Cyanophyceae*) have frequently been included with the algae.

Composition of macroalgae

Algae distribution is directly influenced by a number of factors: substrat, climate (temperature), light penetration, water chemistry (salinity); modifying each of these factors (water quality) induces changes in the algal culture.

Green algae (*Ulva. Enteromopha, Cladophora, and Ulothrix and Urospora during spring time*) are the dominant species at the Romanian Black Sea shore. Red algae biomass consists primarily of species of *Ceranium*; other types of algae are found in quantities that play a minor role in this matter. The large quantities of green and red algae biomass confirms that, in eutrophicated coastal environments, like Romanian Black Sea shore, species of these groups of algae grow well, the excess of nutrients allowing a mass growth. From the species found in the Romanian Black Sea shore, two species of green algae were studied *Enteromorpha instestinalis* and *Ulva lactuca*. The composition of these species is presented in Table 3.

Table 3 Composition of Macroalgae found in the Romanian Black Sea area

Macroalga	**Dry matter (on wet weight)**	**Mineral residue (on D.M.)**	**Carbohydrates (on D.M.)**	**Proteins (on D.M.)**	**Lipids (on D.M.)**
Enteromorpha intestinalis	10-15%	6-32%	30-45%	7-20%	1-3%
Ulva lactuca	20-30%	17-35%	41-62%	7-30%	1-3%

CULTIVATION

Microalgae cultivation parameters

A culture can be defined as an artificial environment in which the algae grow. Culture conditions should resemble the alga’s natural conditions, in reality many significant differences exists.

Culture parameters: a culture has three distinct components: a culture medium, the algal cells growing in the medium, and air to allow exchange of carbon dioxide between medium and atmosphere. An entirely autotrophic alga needs for its growth: light, CO_2, water, nutrients, and trace elements. Through photosynthesis the alga will be able to synthesize all the biochemical compounds necessary for growth. The most important parameters regulating algal growth are nutrient quality and quantity, light, pH, turbulence, salinity, and temperature.

Temperature: most commonly cultured species of microalgae tolerate temperatures between 16 and 27 °C, but an intermediate value of 18-20 °C is most often employed. Temperatures lower than 16 °C will slow down growth, and temperatures higher than 35 °C are lethal for a number of species.

Light: is the source of energy which conducts photosynthetic reactions in algae and the most important parameters are intensity, spectral quality and photoperiod. Light intensity must be increased at higher depths and cell concentration to penetrate through culture. A higher light intensity may result in photoinhibition. Most commonly used light intensities varies between 100 and 200 µE sec^{-1} m^{-2}, which corresponds to about 5-10% of full daylight (2000 µE sec^{-1} m^{-2}). Light source may be natural or fluorescent tubes emitting in blue or red light spectrum. A light/dark cycle may be used as many microalgae species do not grow well under constant illumination (maximum 16:8 LD, but normally used 14:10 or 12:12 LD).

pH: varies for most cultured microalgae species between 7 and 9, and an optimum range is considered to be 8.2-8.7. A failure in maintaining an acceptable pH may cause complete culture collapse. The addition of carbon dioxide allows to correct increased values of pH, which may reach limiting values of up to pH 9 during algal growth.

Salinity: marine algae are extremely tolerant to changes in salinity. Salinities of 20-24 g l^{-1} are found to be optimal.

Mixing: is necessary to ensure that all cells of the population are equally exposed to the light and nutrients, to avoid thermal stratification, to prevent sedimentation of algae, and to improve gas exchange between medium and air.

Marine medium: marine species generally have wide tolerances. Seawater is an ideal medium for growth of marine species, but it is a complex medium which contains over 50 known elements in addition to a large number of organic compounds. Nutrients are often needed to enrich seawater (nitrogen, phosphorus, and iron) [6].

Microalgae cultivation methods

To minimize expenses, algal biomass must be produced using freely available sunlight, and this is affected by day/night cycles and seasonal variations in light levels [10]. Microalgae cultivation using sunlight energy can be done in open or closed ponds or closed photobioreactors, based on tubular, flat plane, or other designs. Indoor culture allows control over illumination, temperature, nutrient level, possible contamination The most common culture system is the batch culture, due to its simplicity and low cost. It is a closed system, volume limited, and there is no input or output of materials. It is done by subculturing, meaning transferring a small volume of existing culture to a large volume of fresh culture medium at regular intervals [6]. Closed systems are usually most expensive than ponds, they present more operating challenges (overheating, fouling), and, due to, among other things, gas exchange limitations, cannot be scaled up to much beyond approx. 100 m^2 per individual growth unit [5].

Large outdoor ponds can be unlined, with a natural bottom, or lined with materials like clay, brick, cement, plastics such as polyethylene, PVC sheets, glass fiber, or polyurethane. Ulined ponds suffer from silt suspension, percolation, and heavy contamination, and their use is limited to a few algal species [6]

Photobioreators are types of tanks or closed systems in which algae are cultivated, and have the ability to produce algae while performing other beneficial tasks like scrubbing power plant flue gases or removing nutrients from wastewater. Photobioreactors have higher efficiency and biomass concentration (2 to 5 g/L), shorter harvest time (2 to 4 weeks), and higher surface-to-volume ratio (25 to 125/m) than open ponds. Generally, photobioreactors provide better control over cultivation conditions, yield higher productivity and reproducibility, reduce contamination risk, and allow greater selection of algal species used for cultivation [5].

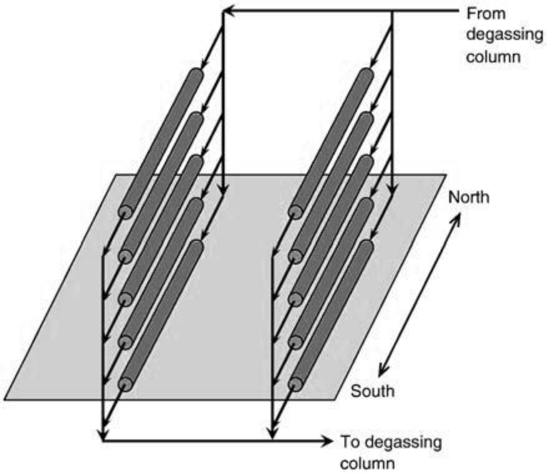

Figure 1. Photobioreactor (fence-like type)

A tubular photobioreactor () consists of an array of straight transparent tubes that are usually made of plastic or glass. The solar collector tubes are usually 0.1 m in diameter because light does not penetrate too deeply in the dense culture broth that is necessary for ensuring a high biomass productivity of the photobioreactor.

In a typical arrangement, the solar tubes are placed parallel to each other and flat above the ground (Figure 2). Horizontal, parallel straight tubes are sometimes arranged like a fence to increase the number of tubes that can be accommodated in a given area [9].

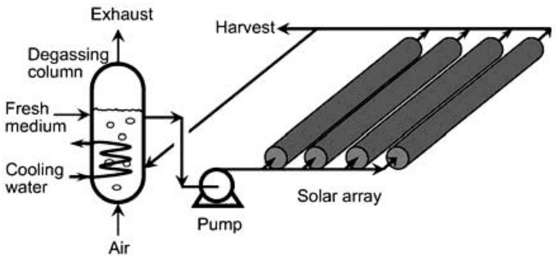

Figure 2. Tubular fotobioreactor

A racewaypond is made up of a close-loop recirculation channel that is typically about 0.3 m deep. Mixing and circulation are produced by a paddlewheel. Raceway channels are built in concrete or compacted earth and may be lined with white plastic. The culture is fed continuously during daylight, in front of the paddlewheel where the flow begins () [5].

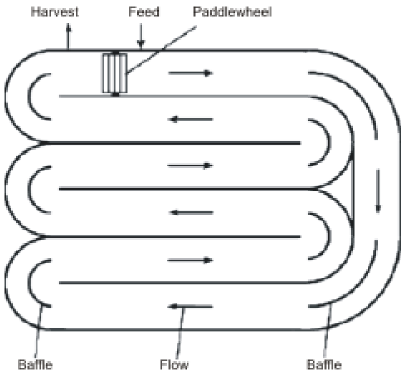

Figure 3. Raceway pond

Seaweed cultivation

Seaweed can be cultured either in sea or in open ponds or tanks. A wide range of techniques is used to cultivate seaweed, depending on a number of factors such as: species being farmed, life cycle and biogeographic factors. In general, fragments of adult plants, juvenile plants, sporelings or spores are seeded onto either ropes or other substrates in nurseries and the plants are on-grown to maturity at sea.

Land-based cultivation systems include tanks and ponds. Tanks use seaweeds that receive a steady stream of aeration and seawater. Efficiency of these systems is very much dependent on the input of various types of energy and nutrients. Carbon supply can be improved by either pumping more seawater or by adding CO2. Temperature and salinity can also be manipulated by the same method. The pH of the tanks should be managed in the range of 7.9-8.3 and the nutrient conditions should be constantly monitored. Tank systems may be used for the processing of polluted water, the removal of extra nutrients from waste water, or for energy production.

Macroalgae are mostly grown in the sea, where the cultivation occurs along coastal areas. Seaweed cultivation in the sea includes the following systems that hold the seaweeds in place: long-line cultivation systems, net-style farm systems, line and rope farm systems and offshore or deep-water seaweed cultivation. The operating costs for these types of macroalgal culture systems vary as a function of harvest frequency and lifetime of materials in a site-specific environment. For some macroalgae like the drift seaweeds, location and seasonal availability are unpredictable. Land based cultivation is usually preferred for the better control on growing conditions. The use of tanks may provide the greatest productivity per unit area per day and is more efficient than any other type of farming as they can provide the necessary aeration and nutrients to the growing algae under controlled conditions.

HARVESTING

Conventional processes used to harvest microalgae include concentration through centrifugation, foam fractionation, flocculation, membrane filtration, and ultrasonic separation. Two processes are involved in harvesting: bulk harvesting and thickening. Algae typical cell density achieved in the industrial application is between 0.3 and 0.5 dry cell/L or 5 g dry cell/L at best [11]. Algae pressing is very similar to the techniques used to press flowers and it is used widely as means of preserving algae. Alum and ferric chloride are used as chemical flocculants to harvest algae. Flocculation can happen on its own if the dioxide carbon supply is interrupted, and it’s called “autoflocculation”. Flocculation reduces/neutralizes the negative surface charge of micro algal cells, allowing them to aggregate into larger lumps with an efficiency of >80. Centrifugation uses centrifugal force generated by the spinning of a suspension to separate and harvest algal cells.

Macroalgae grow either attached to a solid substrate or free-floating in water, and can be harvested either manually or using some special equipments. The common procedure for the majority of targeted species is to harvest the total biomass of each plant; the thallus is removed either by hand grabbing or cut using a cutting implement. Some species will be cut above the holdfast to enable regeneration. The processing of harvested seaweeds vary according to the desired end product, but it usually involves washing, with fresh water, sorting, drying (using in-house drying apparatus, or outside drying in suitable weather) and final packaging [12]. Some macroalgae are attached to rocks by holdfast. Holdfasts are just like tree’s roots which hold on the kelp. Such macroalgae are harvested by tearing off top portions and leaving the holdfast to allow re growth.

ENERGY PRODUCTS FROM ALGAE

The biomass can be derived from both macroalgae and microalgae sources, and that can represent an economically and environmentally sustainable fuel source. Until now, seaweed has been valued mainly as food, fertilizer, animal feed and recently for producing algin, agar and carrageenan. If we consider the amounts of waste seaweeds, macroalgae may be considered a potential source of fuel. Wild seaweeds that grow along the coastal line due to heavy nutrient discharge, many times wash up on the sea shores. These large quantities of seaweeds will rot and begin to smell if left as such in the coastal area. Collecting and disposal of these seaweeds represents a major problem for local administrations.

Microalgae are being widely researched as a biodiesel source because their oil content is very high and they can grow rapidly. On the other hand, macroalgae are taken into account for their natural sugar and other carbohydrates they contain, which makes them suitable for fermentation to produce biogas or alcohol-based fuels. Macroalgae generally do not contain lipids, though they are preferred due to their ease of harvesting and culturing in natural environments compared to microalgae [11].

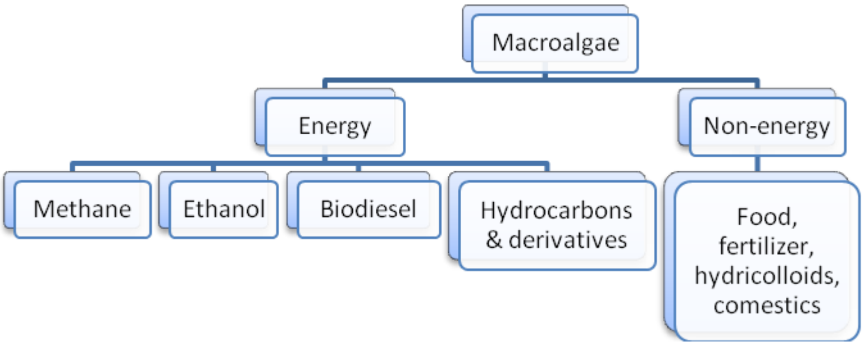

Figure 4 End-products from macroalgae

There are several advantages of macroalgae versus microalgae and their use as a source of energy: high biomass productivity, no need for fresh water, harvesting and cultivation costs are less when compared to microalgae, minor need for fertilizers. Wild seaweeds are in fact an untapped source of energy and macroalgae can produce a combination of end products, as shown in Figure 4. Energy/fuel can be obtained from macroalgae through various sources, which are listed in Table 4.

Table 4 Pathways for fuels from macroalgae

Source	**Process**	**Fuel**
Macroalgae	Anaerobic digestion	Methane
	Fermentation	Ethanol
	Transesterification	Biodiesel
	Pyrolysis/Gasification	Hydrocarbons and derivatives

The oil content of macroalgae is lesser than that of microalgae and it was reported to vary between 1.3 and 8.7%. Macroalgae can be also gasified to produce syngas.

CONCLUSIONS

A major outbreak in growing macroalgae on a large scale is that they are found to grow in wastewater, where they not only grow extensively, but also clean up the wastes. Seaweed can be cultivated to extract energy from them as they can quickly yield large amounts of carbon-neutral biomass, which can be burnt to generate electricity and other high-value compounds.

Near Romania coastal line, turbidity, salinity and temperature appears to play an important role in structure, distribution and growth of green algae. Species like *Enteromorpha intestinalis* are resistant to changes in water salinity, and *Ulva lactuca* grows in areas where the salinity is not affected by the Danube floods. The turbidity and constant wastewater discharge leads to water pollution, and in these conditions, algal biomass decreases. Yet, some species of green algae are not affected of this situation, moreover, they tend to develop and to replace species of red and brown algae. In these conditions, we can observe the importance of green algae species in the process or coastal waters purification by providing the necessary oxygen and through the power of retention of pollutant substances that are present near Constanta or Mangalia harbors. ANAR (*National Agency "Apele Române"*) reported in 2007 a quantity of 39,000 m3 of waste seaweeds collected along Romanian coastal line. It is to be noted that this biomass is in a state of degradation that make it impossible to extract any active substances. Yet, in terms of energy, this waste biomass can be processed (by anaerobic digestion or fermentation) to provide renewable energy.

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