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MARICULTURE AS A NEW CHALLENGING RESOURCE

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Summary

In the last centuries, industrial development has caused a dramatic impact on the earth environment due to the high rate of use of natural resources. Oil reserves are being depleted in the next 30 years according to up to date information. At the same time, world's population will increase around. So, we face a big question: What are the available resources and technologies to support future society demands in a sustainable way? In this context, this paper intends initially to focus on the state of art of algae's use to supply modern society with food, feed, fiber, chemicals and energy. Secondly, it also intends to discuss the worldwide-proposed approaches to use renewable resources alternatively to oil in the near future. Science and technology skills seem to be the fundamental keys to guide policy-makers to formulate right policies and, of course, to direct entrepreneurs to use resources through safe process and friendly technologies. Physical and chemical devices present higher conversion rate to convert solar energy into other forms of energy. In spite of the low yield, only photosynthetic apparatus could be used to store matter as chemical energy. Unfortunately, arable land is a limiting factor and many species do not have potential and competitiveness. In spite of that, a lot of resources are being proposed to attend these needs such as planted forests, straws, crops (sugar cane, corn, oleaginous), as well as urban residues and effluents. In comparison with higher plants, algae have high productivity and an incomparably wider spectrum and high concentration of active components, which could be used to attend society needs such as food, chemicals and energy. Traditionally, macro-algae have been used as a source of minerals, proteins, vitamins, enzymes, pigments, fats and polysaccharides. Micro-algae are new powerful tools to attend the same purpose in a much more convenient way. So, it is urgent to start debating the real potential of mariculture in land and off shore. As technologists, the authors intend to address a message that mariculture deserves a fundamental role in this challenging situation, and IMBC 07 seems to be the right spot to focus, discuss, and spread out new ideas and proposals.

Introduction

Global oil production will probably reach a peak sometime during the next decades, and after that, the world's production of crude oil will fall and never rise again. In 1956, the geologist Hubbert [1] predicted that USA oil production would peak as early as 1970. Many analysts rejected this idea, but the fact was that the USA oil production started to drop at this time. Later on, several analysts reported at *Nature*, S*cience, and Scientific American* that the peak for the world's oil production will be between 2004 and 2008. Deffeyes [2] revised Hubbert´s studies and predicted that the peak in the world oil production might have occured around 2004. The important point is that crude oil reserves will deplete, moreover it must be recognized that oil is too valuable to be burned as fuel. Deffeyes believes, while long-term solutions exist in the form of conservation and alternative energy source, they probably cannot, and almost will not be driven in time to evade a short-term catastrophe of shortage, soaring prices, and global economic, agricultural, and possibly political disturbance. It means, it will be necessary to develop soon the use of alternative energy sources, to guarantee the future demand of the society, in special, alternative fuels, taking into consideration the green house effect caused by the tremendous use of fossil fuel nowadays. Certainly, the continuous use of fossil fuels is increasing the amount of CO_2 in atmosphere, and consequently warming earth surface and changing climate conditions [3]. Oil industry is nowadays facing big challenges and, certainly, important changes are taking place. According to Bajus [4], hydrocarbon technologies in the oil industry tend to be evolutionary rather than revolutionary. The technological development of the oil industry is really driven by economics, environment and safety, and hydrogen will play a basic role in tomorrow's oil industry. The future should bring a gradual change in the direction of using renewable resources for the production of biofuels. Besides these concerns, catalysts will continue to play a significant role in the production of higher quality fuel due to growing consciousness of human health and environment concerning existing products. International institutions like IUPAC and OCDE are encouraging the development of the Green Chemistry Program, as a real concern from international academia and private effort to minimize environmental impacts [5]. Inside this context, biofuels are already playing an important role in the future fuel market. In spite of the fact that they are renewable and decentralized produced, they should learn and apply the big experience related with fossil fuel production, performance and quality. Changes in the characteristics of this huge market are in progress, but unfortunately it will take a long time until biofuels achieve the recommended quality for the green label certificate. The experience we are facing with Brazilian alcohol program is a good example of that. Since

1921 Brazilian researchers from Instituto Nacional de Tecnologia (INT), National Regulations Agencies and the industry have been developing a big effort to guarantee the assured and desirable position now reached [6]. Unfortunately, the same can not be stated in relation to biodiesel type of alternative fuels. Not only in Brazil, but also all over the world an astonishing biodiesel fever is taking place. Due to the own nature of the triglycerides vegetable oils, biodiesel quality (transesterified oils) is far away from the position reached by ethanol in quality, as a distillate product. How can biodiesel be blended with a high standard fuel like diesel, produced by current oil processing technologies without a minimum guarantee of quality? Certainly, these mixtures are causing a lot of deposits in motors. The use of continuous reaction systems and purifying and standard separation processes must provide products of such desirable quality, thus preserving the environment. Barry Commoner and Paul Erlich were the earliest writers on environmental science, nearly thirty years ago [7]. They expressed their concern about the environmental impact through the quantitative equation (1), where the variable I means the total environmental impact, which can be evaluated through the product of three terms:

$$I = PCB \qquad (1)$$

The first is world population, P; the second is the per capita consumption, C; and the third is the environmental burden created by a unit of consumption, B. In this approach, it is taken into consideration that by 2030 the world population will increase 29% while the total primary energy consumption will be 59% higher than in 2004, resulting in a per capita consumption 19% higher [8]. Therefore B must decrease by 35% to maintain in 2030 the same total environmental impact I. Once it is taken into consideration the extreme negative impacts by the use of fossil fuels in this last century strong measures need to be taken to stabilize I replacing fossil energy by renewable energy. Among the renewable forms of energy in use today (14% of the total primary energy consumption) biomass stands out as the most utilized one (80% of renewable energy or 10.5% of total primary energy). Although the use of other forms of renewable energy, such as wind power and solar, are increasing very fast biomass will continue to play a significant role in the global energy matrix. The IPCC biomass intensive scenario [9] leads to 180 EJ/year in 2050, approximately 1/3 of the global primary energy demand; 2/3 will come from energy plantations requiring around 385 Mha (25% of today's cultivated land area), and the other 1/3 will come from residues. These figures show the importance of productivity of the feedstock's with respect to land use.

Photosynthetic Yield and Productivity of some species

A new green revolution is on the way since 1970. It promotes the intense use of advanced biotechnologies aiming at cell, protoplasts, tissue, and vegetable organs cultures through the use of genetic engineering to multiply plants and to create new ones rapidly [10]. This experience together with the increase in the photosynthetic efficiency could be applied to increase biomass productivity. Certainly, the appropriated choice of the right cultures in terms of its photosynthetic yields is of primary importance for the success of the productive systems. The photosynthetic capacity of each vegetal culture depends on the quantity of CO_2 absorbed per unit of time of the vegetal organism, their foliar surface, and also, of the type of mechanisms, (C3 or C4) involved in this process. Of course, it depends on the radiation intensity, temperature, and CO_2 concentration, as well as on the amount of nutrients used. The conversion of radiant energy into chemical energy can be represented by the following equation, in which, the chemical term (CH_2O) represents one-sixth part of a glucose molecule [11].

$$CO_2 + H_20 \xrightarrow{\text{8 photons}} CH_2O + O_2 \qquad (2)$$

In general, the maximum theoretical yield of the photosynthetic process is about 6.5% but the practical yield is no more than 2.5% for sugar cane as well as algae, the best species of the vegetal kingdom in terms of photosynthesis yield, which depends on the strain and place where the plants are being cultivated [10]. The yield of the photosynthetic process depends on the difference between the biochemical mechanism of assimilation and fixation of CO_2 and also on the genetic selection of the cultivar. It is important to notice that the photosynthetic efficiency depends yet on the cultivation method employed. In the photosynthesis process of chlorophyll containing vegetables, oxygen is normally liberated due to the reduction and assimilation of CO_2 through the reduction cycle of the pentose phosphate. Basically, the efficiency of the photosynthetic process depends on the way the plants capture the radiant energy and assimilate it to incorporate carbonic gas (CO_2). In general, several factors contribute to the C4 plants to have a larger photosynthetic efficiency than C3 plants: their leaves stand in a more vertical position, resulting in small hatching of the leaves, so, contributing to a high photosynthetic saturation point, and consequently, having a higher net photosynthetic yield. Also, they possess an enzyme, PEP- carboxylase, located into its cells whose attraction for CO_2 is extremely high, increasing the carboxilase activity of Ribulose - 1,5 - Bisphosphate Carboxylase, that is located in the cells of the mesophilic to foliate excessively. Besides that, C4 plants do not photo-respire,

which contributes for the fact that their net photosynthesis yields are larger than C3 plants. So, it is a well known fact in tropical countries, where the temperatures are high, the productivity of the C4 plants are significantly superior to C3 plants, exactly as observed in the **Table I**, which presents the theoretical values of the maximum productivity, photosynthetic efficiency and maximum yields of some plants cultivated in the United Sates of America. Values estimated are shown in parenthesis [12].
Concerning to sugar cane, it should be observed that today in Brazil the average sugar cane productivity and sugar content result in an ethanol production around 6,000 liters per hectare-year (l/ha/yr), considering the 6 year cycle with 5 harvests before planting again. This productivity has been improving at a rate of 1.6% in ton of cane/ha and 1.4 kg of sugar /ton of cane per year in the past 2-3 decades [13]; the breeding specialists consider that this improvement will continue for many years, as far as the present research efforts are maintained or increased. Projecting the rate of improvement in productivity to 2025, we can expect ethanol productivity around 10,800 l/ha/yr, including a small increase in the cane processing efficiency also. In terms of energy, this represents an increase from 138 GJ/ha/yr to 248 GJ/ha/yr. So far, no other crop can produce such energetic performance.
Aquatic plants grow in different streams utilizing areas not yet committed to other purposes. Floating species offer advantages for easy harvesting. *Hydrila* ducked and various algae show promise, and water hyacinth is very productive in hot climate [14]. Some of those aquatic plants can convert nitrogen from atmosphere to organic nitrogenous compounds, which greatly reduce the need for fertilizer. Compared with higher plants, algae have an incomparably more variable spectrum and higher concentration of potential components and active principles. Marine plants have high growth rates and in the open oceans there is an offer of vast areas in spite of the fact that ocean surfaces are very low in nutrients. There are skills to anchor giant kelp (algae) in the oceans using wave action to pump nutrient-laden water from the depths [14].

Table I - Values of maximum productivity, photosynthetic efficiency and maximum yields of some plants cultivated in the United States

Region and plant	Productivity		Efficiency (%)
	$g/m_2/day$	ton/ha/yr	
I - Theoretical maximum			
United States-Average (annual)	61	224	
SW United States (year)	72	263	
SW United States (Summer)	106	387	
II - Maximum measured			
Plants C - 4			
Sugar cane	38	(138)	2.4
Pennisetum purpureum	39	(139)	2.4
Sorghum	51	(186)	3.2
Corn	52	(190)	3.2
Plants C - 3			
Sugar beet	31	(113)	1.9
Alfalfa	23	(84)	1.4
III - Annual Production			
Plants C – 4			
Sugar cane	31	112	2.8
Sorghum	10	36	0.9
Plants C – 3			
Alfalfa	08	29	0.7
Eucalyptus sp.	15	54	1.3
Sugar beet	09	33	0.8
Algae	24	87	2.2

Source: Sasson, A. (1993).

A floating marine plant with great potential is *Sargassum* that holds nutritious sediments that would settle in open oceans, and might be harvested by wind action. Other algae excrete oils or waxes when the nitrogen supply is limited. Micro-algae are microscopic plants with a size range of one micrometer to one millimeter. In the sea, as well as other natural environments, they would be uneconomic; however, they could grow in shallow ponds supplied with seawater and nutrients, particularly nitrogen and phosphorus, to achieve the concentrations and productivities necessary to make their cultivation economic. Carbon dioxide is also

essential for growth and this may come naturally from the atmosphere or to be supplied artificially from other sources [15], [16]. *Chlorella*, *Spirulina* and *Dunaliella* are actually the micro-algae species that present the best potential, due to the fact that they are the most efficient species that convert solar energy into valuables chemical compounds through photosynthesis [17]. Differently from other vegetal species, algae contain polysaccharides, protein, pigments, and a large amount of minerals. Depending on the species, the specific strain and the growth conditions, algae have a wide range of components which are used in food and feedstuffs, but which more and more gain in attractiveness to health, pharmacy and cosmetics.
Considering the qualitative and quantitative composition of the photosynthetic active pigments, they differ among red, green and blue algae, thereby subdividing according to morphology into macro-algae and microscopically small micro-algae, also called phytoplankton [18]. The application of many marine macro-algae in cosmetics has a long tradition, whereas the use of micro-algae products is gaining in importance only recently and in connection with the rapid developments in the field of biotechnology. So they could supply society with food, fibers, nutrients and fuels [19], as shown in **Figure 1**. In the beginning of the eighties it was developed a bilateral cooperation program between Sea Laboratory-LABOMAR from Federal University of Ceará (Brazil) and University of Aachen (Germany) to start developing the cultivation of micro-algae in Fortaleza, Brazil [20], aiming at methane production, taking into consideration the high potential of algae in comparison with other agricultural species as shown in the **Table II**.

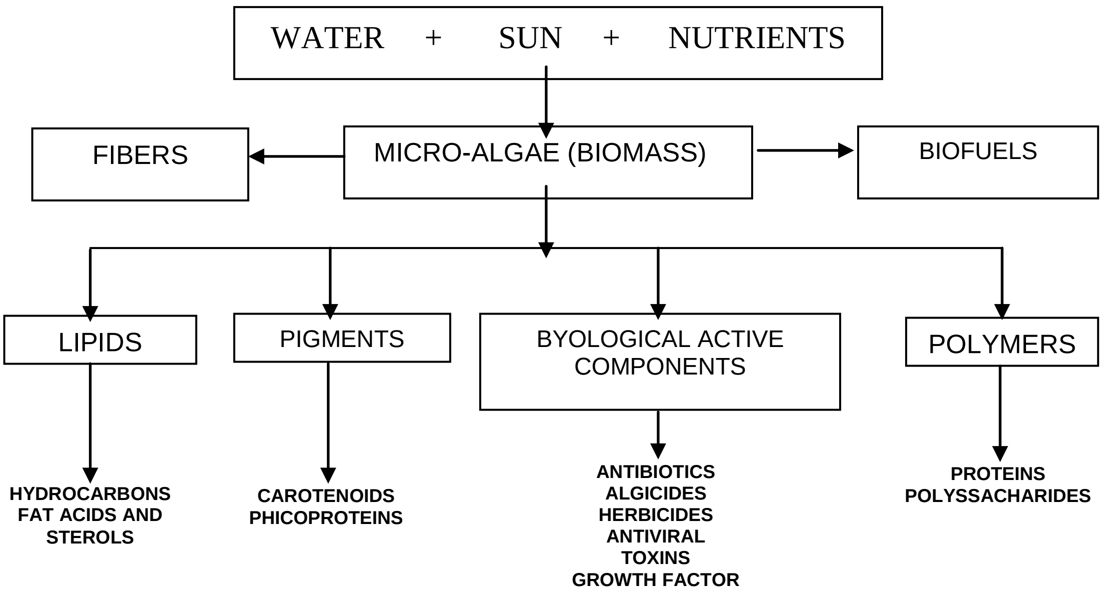

Figure 1: Types of products obtained from micro-algae

With the same purpose, some efforts are in progress to cultivate micro-algae in the tropics with relative success [21], [22], [23]. Recently, a scientific cooperation project is being developed between Carioca and Ben-Amotz [24] to introduce *Dunaliella* algae in the Northeast of Brazil, near Fortaleza, to supply Pharmaceutical industry with β-carotene powder as food supplement. The biflagellate unicellular alga *Dunaliella bardawil* thrives in media with extreme concentrations of salt in desert lands exposed to high solar radiation, and also produces and accumulates large amounts of intracellular glycerol to counter high extracellular osmotic concentration in the surrounding medium, and high content of a mixture of β-carotene stereoisomers to defend cell from the damaging effect of excessive radiation [24]. In these decades β-carotene has been used as food ingredient, as pro-vitamin A (retinol) in food and animal feed, as additive to cosmetics, multivitamin preparations, and as a health food product under the “antioxidant” claim. Many epidemiological and oncological studies suggest that humans fed on diet high in carotenoids-rich vegetables and fruits, who maintain higher than average levels of serum carotenoids, have a lower incidence of several types of cancer and cardiovascular disease [24], [25].

Table II: Some annual yields of dry matter production

Type of Crop	Yields (Tons / ha /yr)	
	Average	High short term
Sugar cane	54	113
Cassava	14.5	65
Corn (sillage)	35	150
Grassland	5	22
Forest (Temperate)	13	
Silviculture (short rotation)	20	
Water hyacinth	150	
Freshwater swamp	30	
Algae (ocean beds)	25	
Ocean upwelling	10 – 20	
Kelp	9	90
Algae (cultured)	60 - 90	>150

Source: Wagner, K. (1980)

Woody plants, firewood, were the fuels for primitive humans, and still is the most familiar energy crop. Practically a century ago trees were the most important source of energy worldwide. It was observed a deficit in wood production for house and ship constructions [26]. Nowadays, only poor people in developing countries use wood to cook food and warm homes. In spite of that, a large variety of chemicals can be derived from wood as shown in **Table III**, and also, fuel boilers to produce steam, electricity or both. Institutions like FAO [27] have recommended setting up forest plantations not only to supply chemicals and energy, but also to reduce CO_2 concentration in the atmosphere, avoid erosion problems and so on. Globally, according FRA - 2000, Forest Resource Assessment, planted forests accounted for only 5% of the forest area, but up to 35% of round wood supply. This is anticipated to rise 40-44% by 2020. Planted forests reflect a higher social, environmental and economic importance than their area would suggest. Woody biomass exists in highly concentrated form. Harvesting and collection using modern whole-tree harvesting equipment can supply industrial needs. Wood can be stored on the stump until needed and, even in the form of ship piles as at pulp mills, and it is less susceptible to microbial deterioration than non-woody biomass [28].

Table IIII: Main Processes and Products from Wood

Type of process	Main product	Byproducts
Pyrolysis	Charcoal	Liquids: Methanol, acetic acid, ketones, phenol derivatives; Gases: CO, CO_2, H_2, CH_4;
Liquefaction (Hydrogenation)	Phenols and Cycle hexane derivatives	Hydrocarbons
Hydrolysis	Hexoses	Alcohols, Polyols, Ketones, Acids, Hydroxymethylfurfural, Glucose;
	Pentoses	Furfural, Polyols, Xylose
	Lignin	Phenols derivatives, Vanillin, Catechols , hydrocarbons.

Source: Goldstein, I. (1978)

Oleaginous data published in the literature [29] reveal that the oil productivity, expressed in liters/ha, is strongly larger for palm, practically, 5,950 liters /ha in comparison with other oleaginous species according to **Table IV**. In this case, the net photosynthetic yield depends on another factor, the length for maximum cycle efficiency, which for palm is 8 years in comparison with the other C3 plants period, almost annual, with three months of crop length. That is the case of the other C3 plants, leguminous or other botanical families like soy, sunflower, colza, peanuts, cotton and castor oil plant. According to this data, it does not make sense to use vegetable oils to energy purpose [30].

Table IV – Potential of Some Vegetable Oleaginous Species

Species	Origin of the oil	Oil content (%)	Cycle for maximum efficiency	Crop length (months)	Oil productivity (t/ha)
African palm oil (*Elacis guineensis*)	Almond	20	8 years	12	3.0-6.0
Avocado (*Persia americana*)	Fruit	7-35	7 years	12	1.3-5.0
Coconut (*Cocus nucifera*)	Fruit	55-60	7 years	12	1.3-1.9
Babassu (*Orbinya martiana*)	Almond	66	7 years	12	0.1-0.3
Sunflower (*Helianthus annus*)	Grain	38-48	Annual	3	0.5-1.9
Rapeseed (*Brassica campestris*)	Grain	40-48	Annual	3	0.5-0.9
Castor oil (*Ricinus comunis*)	Grain	43-45	Annual	3	0.5-0.9
Peanuts (*Orachis hypogeae*)	Grain	40-43	Annual	3	0.6-0.8
Soya (*Glyine max*)	Grain	17	Annual	3	0.2-0.4
Cotton (*Gossypium hirsut*)	Grain	15	Annual	3	0.1-0.2

Source: http://www.biodieselbr.com.

Besides these oleaginous plants it is possible to consider those shrubs, *Euphorbia lathyrus* and *Euphorbia tirucalli*, which contains a sap, an emulsion of hydrocarbons in water according to Melvin Calvin [32]. They represent a future promise that might produce the equivalent of 20 to 125 barrels of oil per hectare. Still there are other energy crops which can be used to produce biofuels. Among them, it can be mentioned: manioc, sunflower, sorghum, kenaf, grasses and residues from agricultural and silviculture.

3. Biomass Farming Systems (BFS)

Traditionally, biomass has been utilized for food, fiber and fire-wood production elsewhere since ancient times. Vegetable oils represent an important source of raw material for the food and chemical sector [26]. Oil depletion is pressing in short term the substitution of oil-derived fuels by biofuels, as well as, the substitution of petrochemicals by biomass-derived products, in a feasible way. That means, in technical, economical and environmental terms. It must be considered that even in the case of partial replacement, it will be necessary to deal with large-scale production systems of renewable raw materials, which are not well developed yet. Fortunately, many countries that are not self-sufficient in oil have potential to produce biomass. Certainly, the productive systems in these countries need to attend several requirements, among them: they could not compete with food production, they require large arable areas and consume large amount of water and fertilizer. At this moment, several Biomass Refining Systems (BRS) are in development in different countries, as summarized in the **Figure 2**. In Brazil, for example, sugar cane farming and processing system seems to be well developed concerning the production of ethanol to replace gasoline. Technological development has been achieved in the whole chain, from field until the industry. They have important social aspects for developing countries. Similar program is on the way in the United States of America using corn. Small-scale biogas production from manure also seems to be running in a reasonable way in India and China. Planted forests do exist for the production of pulp and paper, and today the planted area is increasing as part of the incentives to reduce the CO_2 concentration in the atmosphere. Differently from this concept, planted forests are being used for the production of charcoal in small oven to support metal shaping Brazilian industry in the state of Minas Gerais. Unfortunately this is not an environmental friendly process [33]. Large amounts of gases are released in the atmosphere by these ovens, and the liquids effluents disposed on the earth are polluting drastically the environment. Concerning urban residues, more than 3,000 power plants [34] are operating all over the world to process this type of residue to generate electricity. After this short overview on Biomass farming and refining systems, it is important to consider now the farming and refining systems based on algae. According to Barowitzka [35] over the last fifty years, the main products of these systems are still focusing on the production of phycocolloids, mainly, agar and carrageenans. Many macro-algal species such as *Laminaria*, *Undaria*, *Chondrus*, *Porphyra*, and *Caulerpa* continue to be used for human food. Micro-algae such as *Spirulina* has also had a long history in human nutrition. Since the 1950´s the micro-algae have been focus of attention as potential sources of protein, liquid fuels and fine chemicals. There are now well-established micro-algae production plants in Taiwan (*Chlorella*), Thailand (*Spirulina*), USA (*Spirulina, Dunaliella*), Australia (*Dunaliella*, *Chlorella*), Israel (*Dunaliella*) and Mexico (*Spirulina*), as well as smaller facilities in other countries like India, China, Vietnam, Chile, France, Spain and South Africa. During the eighties, some of the feasibility studies were made aiming at growing micro-algae for the production of methane [15], [16] [36]. Practically, at the same time [37] developed the technology, which is based on large scale production of micro-algal biomass for anaerobic digestion to methane associated with wastewater treatment. It was concluded at that time that the production of fuels from sewage-grown algae should present in a near-term practical potential. Another important feasibility study on ocean farming has been developed on the production of SNG, "Synthetic Natural Gas" using "giant California kelp, *Macrocytis pyrifera*, which grows along the coasts of California, Mexico and New Zealand. This specie is considered to be one the world's fastest growing plants [38]. **Figure 3** shows the proposed process analyzed. This process is considered an advantageous technique for harnessing solar energy since many desirable materials and forms of energy are produced and stored, unlike some other solar energy conversion process. Recent data shows an amazing increase in quality and quantity of products from algae [39], [40]. Based on these data, and also on the real fact that in the tropics algae presents a high productivity, the authors together Prof. Ben-Amotz are developing a plant for growing 60 ton/year of *Dunaliella* near Fortaleza [24] in order to evaluate the profitability of the systems to supply food supplement, as well as to analyze the potential for methane production, as a real technological route to produce SNG, an important intermediate to the production of hydrocarbons, through Fischer-Tropsch process, specially diesel, an important fuel for trucks and heavy cars. A primary parameter to be considered relevant in order to evaluate what is the most appropriated technology to aim these goals is through the parameter, Net Energy Ratio (NER), as defined below [16]:

NER = Total energy of the outputs / Total energy from the inputs (3)

Inside this context, **Table V** shows the NER for different biomass production systems.

Table V: NER Parameter for Biomass Production Systems

Biomass systems	NER	Reference
Alcohol	8.3	30
Biodiesel	1.42	30
Algae		
For methane	18	16
For Methanol	8.8	16

A secondary factor nowadays is becoming environmentally impeditive to be used, that is the amount of polluting components involved in the different raw materials. **Table VI** shows some of these components in the various types of biomass systems.

Table VI: Types of Pollutants in Various Biomass Systems

Type of biomass	Pollutants
Urban sludge	Toxic heavy metals, organisms
Urban refuge	Toxic heavy metals, organic compounds
Animal manure	Toxic organic compounds
Agricultural crops	Pesticides
Industrial wastes	Toxic heavy metals
Forestry, wood	None if fresh, putrefaction agents on aging
Wood Processing	Toxic inorganic chemicals

Source: Klass, D.L. (1976).

From the above, it can be seen that algae will play an important role as a future resource when energy balance and environmental impacts are taken into account. This is true for food, fiber, chemicals and energy use.

5. Conclusions

Traditionally, biomass systems have been utilized for the production of food, fiber, fire-wood and chemicals from specific species. The oil depletion is challenging and consequently driving research institutions and industry to start analyzing the production of biofuels and fine chemicals from biomass farming and refining systems. Several important points needed to be considered in this analysis. In spite of the fact that sun energy is available elsewhere in the globe, few countries have soil and climate conditions to grow biomass all year around for biofuels production. Land, water and fertilizer are critical production factors. Residues in general are actually used as a source of energy for the productionof chemicals and SNG (thermochemical) and, naturally, hydrocarbons and electricity. These types of products when produced from lignocelluloses materials demand high investments and are subject to environmental considerations. Today, ethanol is the leading biofuel with respect to energy balance and land use. However, methane bioconversion from micro or macro-algae represents day after day a new promising and a challenging technological path-way to biofuels, especially to convert methane into hydrocarbons through Fischer-Tropsch process with a very high net energy ratio. Countries like Brazil, Africa and Australia present high potential to utilize coastal and arid land to grow micro-algae in an environmentally friendly way. The experience developed to grow micro-algae during these last seventy years assures us that mariculture deserves a distinguished place in biofuels scenarios for the next years. In summary, arable land is a limiting resource considering the future demands for food, fiber, chemicals and energy. More than 70% of the earth surface is covered with water; therefore, mariculture can be an alternative for raw materials production to relieve the pressure on the land, mainly in coastal area and desert land.

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FIGURE 2: POSSIBLE ROUTES AND PROCESSES FOR BIOMASS REFINING

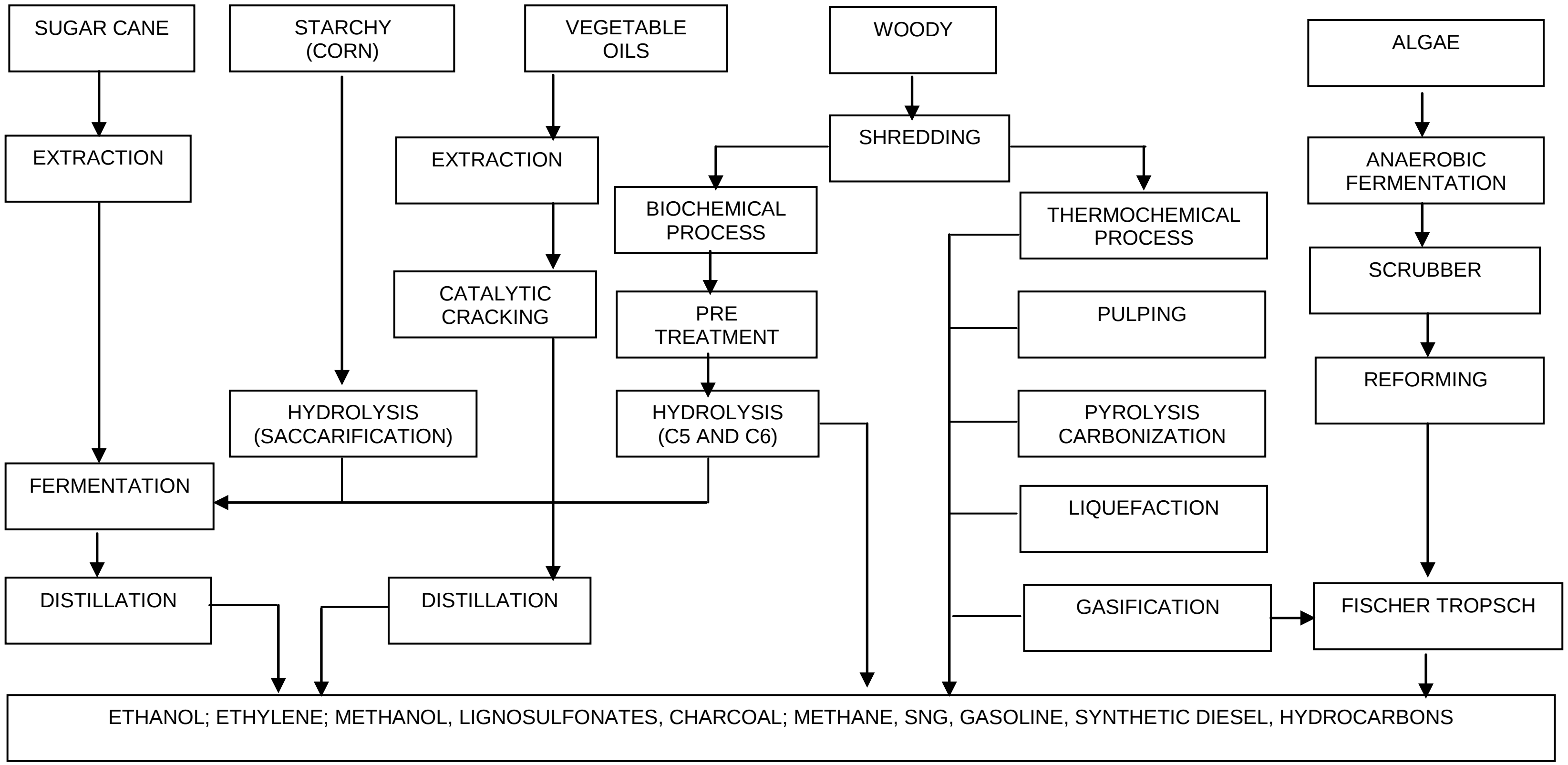

FIGURE 3: MICRO AND MACRO-ALGAE PROCESSING ALTERNATIVES