ENVIRONMENTALLY INNOVATION IN THE FUEL SECTOR: THE ROLE OF BIOFUEL FROM ALGAE[1]

GIOVANNI LAGIOIA (*) - VERA AMICARELLI (*)
GRAZIA CALABRÒ (**) - FILIPPO ALBERTO TRESCA (*)

Abstract

Today, as it is commonly recognized, energy patterns lead to an unsustainable future, that concerns not only natural energy resources narrowness and scarcity but is strictly linked to greenhouse gas emissions (GHGs), mainly CO_2 ones. Burning fossil fuels is one of the main causes of energy natural resources depletion and climate changes.

After power generation one, transportation is the second sector that considerably generates these phenomena. As per the above, policy makers efforts are more and more focused on how to effectively harmonize growing energy demand and climate change mitigation. In these scenarios, a valuable option is the increase of renewable energy sources utilization. Among these sources a relevant role is held by biofuels intending any fuel derived from biomass, living organisms (algae) or their metabolic byproducts (bovine manure). Biofuels of so called "third generation" seem to be a promising possibility to convert a low-input and high-yield no food feedstock into biofuels, mitigating the transportation sector influence on energy demand and climate changes. The objective of this paper is to investigate the role of the third generation biofuels, their impact on existing transportation sustainability and linked emergent markets.

Keywords: Biofuels, sustainability, microalgae, environmental critical innovation.

[1] This work is the result of the authors' commitment, starting from the idea and ending in its accomplishment. Particularly: the references collection and the conclusion are the result of the same authors contribution; the introduction can be ascribed to F. A. Tresca, first and second paragraphs to G Calabrò, paragraphs n. 2 and n. 3 to V. Amicarelli and paragraph n. 4 to G. Lagioia.

(*) University of Bari Aldo Moro, Italy. g.lagioia@dgm.uniba.it; v.amicarelli@dgm.uniba.it; pippotresca@gmail.com
(**) University of Messina, Italy. grazia.calabro@unime.it.

J. COMMODITY SCI. TECHNOL. QUALITY *2011, 50* (II) 119-140

Introduction

As it is commonly recognized today energy patterns lead to an unsustainable future, that concerns not only natural energy resources narrowness and scarcity but is strictly linked to greenhouse gas emissions (GHGs), mainly CO_2 ones. It is not possible to encourage further fossil resources increment because consequent climate changes lead to local and/or global environmental disasters. It is estimated that exceeding the CO_2 atmospheric concentration limit of 450 ppm means to overpass the point of no return towards global warming and non-reversible environmental changes (1-2). This means that the use of fossil fuels must stop prior to deposits depletion.

According to the previous concerns and considering that burning fossil fuels causes approximately 60% (18 million metric tons, Gt) of total CO_2 emissions (30 Gt), their contribution to energy demand is equal to more than 80% (9.8 billion tons oil equivalent - Gtoe), models of low fossil fuels energy or low carbon economy must be realized (3-4).

Among energy sector issues, the fuels production has significant criticisms because it highly depends on fossil sources. This awareness makes policy makers more and more engaged to find the right way to effectively harmonize the growing energy demand and climate change mitigation.

In this paper fuel sector means the economical activities finalized to producing and delivering "energy" for transportation, that is all those systems for moving people or goods (family cars, trucks, airplanes, boats).

In order to achieve the goal of low carbon economy, the innovations or the options explored for the energy sector looked upon: energy saving, energy systems efficiency improvement, switching to less carbon-intensive fossil fuels, capture and storage of CO_2 emissions and a wider use of renewable energy sources.

The latter is a strategic option because it improves domestic energy self-sufficiency and security (particularly for countries importing many energy carriers), the economic stability and sustainability of energy needs and above all their use decrease the CO_2 atmospheric emissions.

A renewable energy source with a relevant role is biomass because it suitable to producing biofuels, intending any fuel derived from biomass, included living organisms (algae) or their metabolic byproducts (bovine manure).

It is interesting to note that biomass was at the origin of fossil fuel origins and today is one of the best promising options to solve their crisis.

It is a matter of fact, that using biomass for biofuels production is not a novelty but the interest in its development is directly proportional to oil price, oil availability and environmental protection. Biofuels can be grouped in 'generation', according to the type of biomass feedstocks and technology used. Up today there are three biofuels generations.

The first refers to biofuels, which are produced from food crops treated with technologies, today well established, including transesterification (biodiesel form oil crop), fermentation (bioethanol from sugar or starch crops) and anaerobic fermentation (biogas from organic residues).

Second generation relates to biofuels produced from a wider range of no-food lignocellulosic crops feedstocks. Utilized technologies include different options such as enzymatic production of lignocellulosic ethanol and pyrolysis-oil and syngas gas based fuels. Second generation technologies are not yet economically and technical aspects are still under development.

Third generation, also called oilgae or algae fuel, refers to the possibility to convert a low-input and high-yield no food feedstock, like algae are, into biofuels. Also in this case the technical aspects affect the diffusion and the convenience of this last generation.

These preliminary considerations summarize the principal reasons why the currently energy patterns, and particularly fuel sector, are unsustainable.

It is commonly argued that environmentally technical innovations stimulate the change toward environmentally friendly and sustainable patterns. The innovation is environmentally critical if it causes large reduction in environmental risks, represents a significant technical advances and involves favorable ratio of social and private returns.

In particular, the reductions in environmental risks have to consider a large populations and significant categories of risks as human health and natural ecosystems modifications. It is beyond question the importance of human health but also the modification of natural assets is imperative because we do not have any alternatives to the services provided from the Nature (for instance the service of waste neutralization, freshwater generation, clean air, new soil). Among the critical concerns of natural ecosystems, the biodiversity losses are the most important risks. Furthermore, the technical advances should introduce a method of production absolutely new and we cannot consider as a significant advance the simple increasing of efficiency of the current technology.

The objective of this paper is to investigate the role of the third generation biofuels, their impact on existing transportation sustainability and linked emergent markets.

The paper is split in different sections. After a brief introduction, a first part presents an overview on first and second biofuels strengths and weaknesses which make necessary to consider the third generation.

A second section regards the state of technology in the different phases of third generation biofuels production chain. In the last part and based on the results obtained, the authors illustrate the related effects of the applied technologies, if they will be able to modify fuel generation patterns, if they will be environmentally critical technology related to CO_2 emissions and if they will represent a chance for the emergent markets of bio-chemicals.

The Current Scenario of Biofuels Production

The renewable energy sources, as above, have to play a relevant role in the near future and among them the role of biomass will be significant because it gives the possibility to produce biofuels intending any fuel (combustible materials) derived, directly or indirectly, from biomass such as living organisms (algae) or their metabolic byproducts (bovine manure).

A wide range of biomass (energy crops, food, short-rotation crops, agricultural waste, etc.) sources can be used to produce bioenergy and the type of biomass used influence the energy yield.

The use of biomass to produce biofuels is not a novelty and several reasons, such as concerns about the adverse effects of increase greenhouse gases, the dependence on fossil fuels, the continuous increasing of oil price and instability in political situation, justify the expansion of biofuel markets and the interest related to it.

In fact, biofuel can be a good opportunity to government worried about the stability of their fuel imports or the long-term future of global oil production.

It is estimates that the world energy demand will increase of 36% up to 2035, from the current 12,300 Mtoe to 16,700 Mtoe; we know that about 30% of total energy consumption is related to transport sector and we can estimate that this consumption is going to expand in parallel with the enlargement of transport demand (5).

Over the 2006-2030 period, transportation accounts for nearly 80% of the total increase in world liquids consumption (6).

All these reason s show that it is necessary to re-organize transport sector and that it is important to free it from dependence on fossil fuels and on the continuing increases in oil prices which will make it untenable in the long run. That is why in these last years great attention has been paid on liquid biofuels for transportation, mostly produced using agriculture and food commodities as feedstock.

Biofuels can be classified according to source and type. They may be solid (fuelwood, charcoal, wood pellets), liquid (ethanol, biodiesel, pyrolysis oils) or gaseous (biogas). They also can be divided in: primary biofuels that are used directly in their natural form and secondary biofuels (charcoal, ethanol, biodiesel, bio-oil, biogas) that have a great application also for transport sector. Table 1 illustrates the different methods of biofu-els generations.

TABLE 1

METHODS OF BIOFUELS GENERATIONS

First generation biofuels	- Vegetable oils - Ethanol - Biodiesel
Second generation biofuels	- Lignocelluloses ethanol - Enzymatic bioconversion of vegetable oils - Hydrogenation Biodiesel - Synthetic fuels
Third generation biofuels	- Energy crops for bio-alcohol - Hydrogen from algae - Oil from algae

Source: personal elaboration by the authors.

The major liquid biofuels currently produced are ethanol, with approximately 76 billion liters in 2009 obtained by feedstocks containing significant amount of sugar or materials that can be converted into sugar, and biodiesel (16 billion of liters in 2009), generated by vegetable oils, with ethanol production being far greater at the global scale (7-9). In fact, actually, biodiesel production is dwarfed by that of ethanol. The first generation biofuels are based on a well-established technology, which is widespread in the world. In Brazil, for example, ethanol from sugarcane replaces about 50% of gasoline for transportation.

Brazil and United State of America (USA) are the most important producer of ethanol respectively by sugarcane and corn, but in European Union (EU) it is estimated a future ethanol production approximately equal to 12 billion liters/year by 2012 (7-9).

Brazil and USA accounted for 88% of global ethanol production in 2009. Ethanol production in USA was about 41 billion liters in 2009 (about 54% of global production) and corn-based USA ethanol displaced more than 360 million barrels of imported oil for gasoline production. Owing to the increase in sugar prizes and the adverse weather conditions, ethanol production in Brazil has decreased from over 27 billion liters in 2008 to 26.3 billion liters in 2009 (8-9).

Almost 80% of the world's production of biodiesel occurs in Europe where biodiesel plays an important role among biofuels consumption.

France has increased its production by 34% in 2009 to surpass Germany, that was the leading country in manufacturing biodiesel from rapeseed in EU thanks also to a strict cooperation with automobile industry (9).

The production of biodiesel has increased in percentage terms in countries such as Argentina, Austria, Colombia, Indonesia, Spain and United Kingdom while has decreased in other top countries such as USA, Italy and Belgium.

In order to incentive the use of renewable resources, in early 2008, EU has set a legal minimum of 10% renewable fuel share for all transportation fuels by 2020, which would amount about to 34 Mtoe or roughly 60 billion liters if all biofuels are ethanol. In addition to the target of 10%, in the EU for share of transport energy from renewable includes Belgium and Croatia (5.75% by 2010), France (10% by 2015) and Portugal (7% biodiesel by 2010).

Furthermore, only alternative fuels that meet established GHG savings and limits on biodiversity impacts will count towards the legal quota, thus limiting the import of biofuel blends not conformed to European quality standards.

Pros and Cons of Biofuels Production

One of the parameter used to judge the opportunity to produce biofuel is the fossil energy balance, i.e. the ratio between the energy content of the biofuel and the fossil energy consumed in its life cycle.

A fossil energy balance of 1.0 means that it requires as much energy to produce a litre of biofuel as it contains (no net energy is gained or lost); a fossil fuel energy balance of 2.0 means that a litre of biofuel contains twice the amount of energy as that required in its production.

Conventional gasoline and diesel have a fossil energy balance of around 0.8-0.9, because some energy is consumed in refining crude oil into usable fuel and transporting it to the markets. So, we can consider the efficiency in biofuels and the reduction in the dependence from fossil fuels if the energy balance exceeds that numbers.

Just as different crops have different yields in terms of biofuel per hectare, wide variations also occur in terms of energy balance and greenhouse gas emission reductions across feedstock, locations and technologies. For example sugar-cane ethanol from Brazil has a much more favorable energy balance; for each ton of sugarcane, the fossil fuel energy input is equivalent to 210 MJ and the energy output close to 2,190 MJ, yielding an energy output ratio around 9; this depends on the fact that in that country ethanol is processed using biomass residues (bagasse) from sugar cane as energy input.

The net energy balance is an important consideration with regard to determining the net greenhouse gas emissions from the use of a biofuel, even if studies have not totally demonstrate that there is a point to point relationship between net energy balance and net greenhouse gas emissions. Lots of the considerations depend on system boundaries; for example, most recent analyses (10-11-12) show a positive benefit on net greenhouse gas emissions from using liquid biofuels, especially for producing ethanol from sugarcane or biodiesel from palm oil, if peat soil conversion and indirect land use changes are not considered.

The production of biofuels have shown, during the years, some limits that have changed the optimistic first impression that they could have been the perfect response to increasing demand of energy and the perfect candidate to replace gasoline and diesel fuels.

Production of biofuels may have lots of environmental consequences: changes in the land use, expansion in agriculture, changes in agriculture practices, transportation of biomass used to make biofuels, conversion of the biomass into fuels and disposal of the remain waste materials after fuels are made. Not less important is the effect, from an economical and social point of view, of the conversion of land on no-food agriculture.

Environmental concerns related to the production of biofuels have been discussed in lots of studies (12-14) and now they represent the most controversial factors of biofuel production.

First of all, the reduction of greenhouse gas emission was the first and prominent objective of biofuel policies. All over the world ambitious reduction goals have been stated; for example UE had first fixed an objective of 45-60% by 2015 that it is now changed into 50% by 2017.

The basic question is whether the use of biofuels and thus the use of land for feedstock production saves more GHG emissions by displacing fossil fuel than that saved by leaving land in its existing use even while continuing to use fossil fuels. In particular this affect the forest land modification (12).

As we mentioned before, GHG emissions are driving the production of biofuels and they are the major problem on which the most efficient refining technologies are based. The impact of biofuels on greenhouse gas emissions varies widely, depending on where and how the various feedstocks are produced, the logistics concerns, the technology and the type of energy used.

In any case, we might think that as biofuels are produced from biomass they should be carbon neutral as their combustion only returns to the atmosphere the carbon fixed by the plant during its growth.

But, in reality, different biofuels can vary in the GHG balances when compared with fossil fuels and, sometimes, they can determinate more GHG than fossil fuels do.

The agricultural practices, such as fertilizing, pesticide use, irrigation technology and soil treatment, influence net GHG emissions and can determine a balance that may not necessarily be positive or as positive as it is often initially assumed. For example a problem is the nitrous oxide (N_2O) that is realized by nitrogenous fertilizer as land conversion. A full consideration of N_2O emissions can transform the net GHG emissions of biofuels from positive to negative. Moreover, the land conversion itself can have some negative effects on GHG emissions that sometimes can double the GHG emissions respect to fossil fuels because of deforestation.

Secondly, large areas of land are necessary to produce adequate amount of biofuels to substitute a significant quantity of fossil fuels.

For example, it is estimated that the 10% substitution of gasoline and diesel fuel requires 43% and 38% of current cropland area in USA and Europe respectively (15). As even this low substitution level cannot be met from existing arable land, forests and grasslands would need to be cleared to enable production of the energy crops and this may place additional strains on the environment. Moreover, if we stress the opportunity to use sustainable practices for crops cultivation, needed area is larger.

Enlargement of land use can have immediately and direct environmental and social consequences: FAO report (2008) stated that while biofuels will offset only a modest share of fossil energy use in the future, they will have much bigger impacts on agriculture and food security.

The use of some food crops (maize, sugar, oilseeds, palm oil) for the production of biofuels has as consequence the increase of food prices. Between 2006 and early 2008, corn prices rose from $87 USD per ton to $217 USD per ton (14).

The growth of some agricultural products, as new and significant source of demand for biofuels, contributes, with other factors, to higher prices in agricultural commodities. So, we can say that there is a strong competition between food and biofuels for raw materials appropriation and probably it is going to grow in parallel with the growth of biofuel production in lands suitable of food-agricultural production.

This is one of the most controversial points to be analyzed when we want to weigh the pros and cons of no-food agriculture. In fact, from one side biofuel is viewed as an opportunity of promoting access to energy in rural areas and supporting developing countries agriculture sector and this is shown for example by the important role that ethanol production from sugarcane has for Brazilian economy. From another side there is the risk that higher food prices could threaten the food security of the world's poorest people that paid more the adverse effect in terms of lack access to energy, food, land and water.

Risks for biodiversity and environmental problems related to an intensive form of agriculture (water consumption due to irrigation, use of pesticide, no set aside) need to be discussed if we want to evaluate whether the benefits of devoting land to biofuel exceeds those of leaving that land in its existing use or potentially improving its existing use in other ways.

To preserve biodiversity, EU provisions prohibit conversion of wetland to no-wetland and forest to other biofuels uses, but would permit harvest of forest or conversion of those unmanaged forests that do not meet standards for native vegetation to tree plantations.

It is estimated that, in the short term, the introduction of good agricultural practices and the conversion of large areas of land back to secondary forest provide other environmental services (such as prevention of desertification, provision of forest products, maintenance of biological diversity, regional climate regulation), whereas conversion of large areas of land to biofuel crops might place additional strains on the environment.

Also the irrigation is an adverse effect of no-food agriculture, as the oil problems can be translated into the water problems (16). All these problems show that we need to pay attention on cost-benefit analysis.

Infact the efficiency of biofuels depends mainly on two factors: the net reduction in fossil carbon emissions arising from use of agricultural derived biofuels and the effect of alternative land-use strategies on carbon stores in the biosphere.

Some studies showed that in a short term (30 years or so) it could be better to improve the efficiency of fossil fuel use, to conserve the existing forests and to restore natural forest and grasslands habitat on cropland that is no needed for food. Forestation of an equivalent area of land would sequester two to nine times more carbon over 30 year period than the emissions avoided by the use of biofuel (15). According to this consideration, the emissions cost of liquid biofuels would exceeds than of fossil fuels and, sometimes, it is better to convert large areas of land back to secondary forest in order to provide other environmental services, such as prevention of desertification, provision of forest products, maintenance of biological diversity, regional climate regulation.

Together with the above-mentioned problems, the production of biofuels shows some other defects. One is related to the intrinsic characteristics of ethanol; ethanol is in fact corrosive and hygroscopic and these characteristics make difficult its storage and transport.

Also biodiesel shows some problems. For example, the presence of some fatty acid methyl esters tends to give it poor cold flow properties.

Moving to non-oxygenated biofuels can overcome many of the issues of corrosion and cold-flow inherent in oxygenated biofuels.

Another important consideration concerns the small role of biofuel in the context of total energy consumption as they supplied only for 0.4% in 2006 (5). In terms of liquid fuels used for transportation, biofuel contributed 1.8% globally, with fossil fuels making up 92% of global use. In the 2030 scenario, it is forecast an increasing in the coal share at the expense of the oil while, for the some period, biofuels are projected to represent the still modest share of 3.0-3.5 % of global transport energy consumption (14).

According to these considerations, biofuels feasibility and economical convenience mainly depends on the political impulse towards this sector also in terms of incentives and subsidies and technological innovations, in order to eliminate critical states previous analyzed.

Actually, biofuel tax exemptions exist in ten EU Countries at last (Belgium, France, Greece, Ireland, Italy, Lithuania, Slovenia, Spain, Sweden, UK), in the OECD Countries Australia and Argentina and in several developing Countries (Argentina, Bolivia, Colombia, South Africa) (8).

The OECD has estimated that the elimination of all biofuel subsidies and mandates would reduce US ethanol production by roughly 20% on average compared to the level that ethanol would otherwise average in 2013-2017.

Technological innovation can lower the costs of agricultural production and biofuel processing. Investment in Research and Development (R&D) is critical for the future of biofuels as economically and environmentally sustainable source of energy.

In this sense, the tendency is towards new generation of biofuels able to balance economy and ecology. Since these fuels can be produced from biomass with much greater efficiency than for ethanol, less land is needed to produce an equivalent amount of energy.

Greenhouse gas emissions and other environmental consequences associated with land conversions and intensive agriculture are reduced accordingly, as is the potential competition with food production.

The second generation biofuels use biomass not used for food production and, in this sense, represent a great opportunity to overcame lots of debates on pros and cons the use of first generation biofuels. In fact, lignocellulosic biomass is more resistant and it can be used completely as the entire crop is available as feedstock for conversion to fuel. On the other side, they have some problems related to the lack of highly efficient enzymes for converting cellulose.

Moreover, lots of the species developed (jatropha curcas and switchgrass), although the advantage of not competing with the food market, are considered invasive or potentially ones and may have negative impacts on water resources. In any case, investments are direct to the development of this biofuels; in particular international investors are rushing to establish large areas of jatropha cultivation in developing countries because of its great adaptability and potentiality.

In any case, as we mentioned above, the new tendency is towards third generation biofuels that refers to the possibility to convert a low-input and high-yield no-food feedstock into biofuels. Algae offer the potential for higher energy yield from lipids that would be cultivated using salt and/or fresh water in areas not currently used for food agricultural production so their use can reduce or eliminate food-fuel competition.

Algae Biofuels Outlook

The term algae include macroalgae - seaweed- and a vastly diversified group of microorganisms known as microalgae.

Algae can be aquatic or subaerial when instead to be immerged in the water they are exposed to the atmosphere. They show a good tolerance for a broad range of environmental conditions such as pH, temperature, turbidity, oxygen and carbon dioxide concentration.

Due to these attitudes and to their carbohydrate (8-64% on dry matter), protein (6-71% on dry matter) and lipid (15-75 on dry matter) content algae are minor sources of foods, feeds and high-value nutraceuticals, pharmaceutical and other bioactive compounds (17-19).

The growing interest in algae is, as just mentioned before, their potentiality to provide different types of biofuels including biohydrogen, methane from thermal gasification or anaerobic digestion of algae biomass; bioethanol by fermentation; bio-oil by pyrolysis and biodiesel by trasbesterifications of algae oil fraction (Fig. 1).

Biodiesel and bioethanol are the main promising options for the future sustainability of transportation sector but considering that fossil diesel is the fraction most used in transportation sector in this paper the authors focus their analysis on biodiesel.

This choice is based on worldwide diesel and gasoline consumption figures in 2009 equal respectively to more than 30 and 27 million of barrels per day, and because of the most commonly argued approach of algae exploitation is to obtained biodiesel rather than others biofuels (19-22).

Furthermore because of oil yield from macroalgae up today is less profitable than microalgae the authors in their analysis refer to microalgae (17).

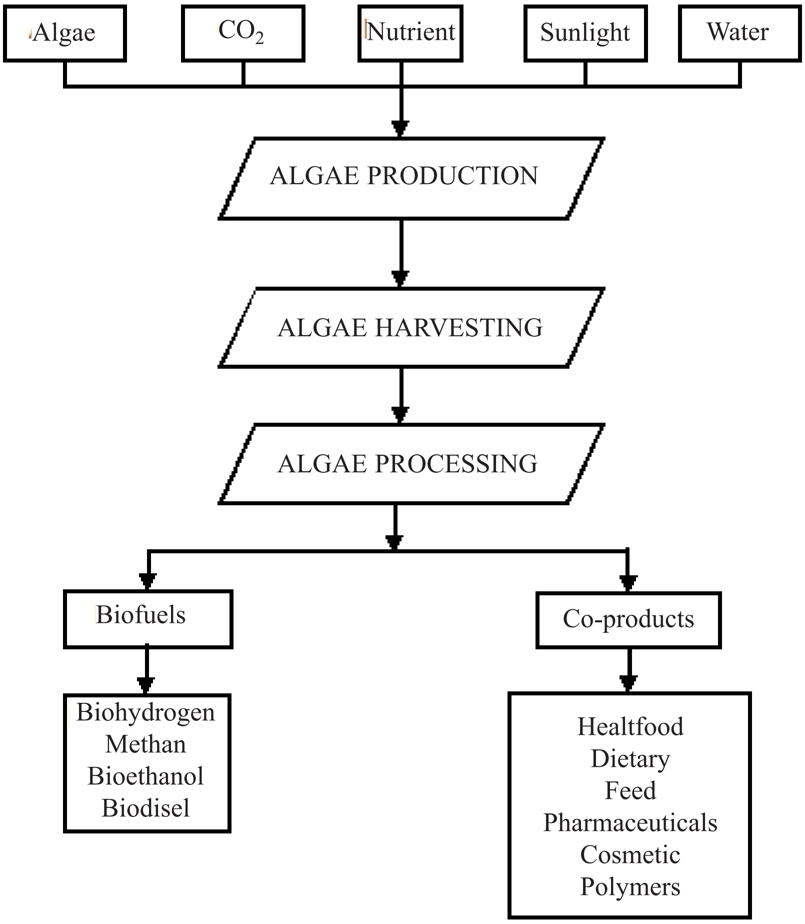

Fig. 1 - Integrated algae biomass processing (personal elaboration by the authors).

Microalgae are microscopic organisms that grow in fresh, salt or wastewater. The three most important classes of microalgae in terms of abundance are the diatoms (Bacillariophyceae), the green algae (Chlorophyceae), and the golden algae (Chrysophyceae).

Microalgae seems to be a miniature biochemical factories, they are more photosynthetically efficient than terrestrial plants and they are efficient CO_2 fixers alike from atmosphere, from discharges gases (power plants) and soluble carbonates (Na_2CO_3 and $NaHCO_3$).

To produce one ton of microalgae biomass approximately 1.8 t of CO_2 are required.

Microalgae are able to double their biomass within 24 hours, so they show a very short harvesting cycle (1-10 days) allowing a higher oil yield compared with the best oil crops (Table 2) (17-23). Due to their just mentioned adaptability to a wide range of climate conditions, including wasteland and/or wastewater, they can be cultivated also in desert areas without competing with agriculture land use and food crops.

TABLE 2

OIL CROP PRODUCTIVITIES

Plant	Oil kg/ha	Oil L/ha
Corn	143	172
Soybean	374	446
Jatropha	1,730	1,892
Coconut	2,260	2,689
Oil palm	5,000	5,950
Microalgae[a]	136,900	157,435
Microalgae[b]	58,700	67,505

a) 70% oil (by wt) in biomass. b) 30% oil (by wt) in biomass.
Source: (17-19).

All these characteristics and considering that since 2007 the biodiesel demand has exceeded the vegetable and animal oil supply, the potentiality of microalgae has to be investigated despite technical and economic problems still affecting oilgae production and its costs.

Oilgae production chain is composed by several phases such as microalgae cultivation, harvesting, oil extraction and subsequent transformation in biodiesel. It is important to underline that up today the microalgae biomass production useful for biodiesel is obtained in pilot scale plants (from 10 meter to 2 hectares).

This does not mean that there is no algae production, quite the contrary, worldwide algae production (few thousand tons of algae per year) are used in niche but profitable markets (up to 800,000 USD/t) such as health food, dietary, pharmaceutical or cosmetic ones (17-22).

Sunlight, CO_2, water and nutrients such as nitrogen (N), phosphorus (P), and potassium (K) are the principal inputs needed to make microalgae growth. Silica and iron, as well as several trace elements, may also be considered important nutrients as the lack of one can limit their growth.

Different important factors influence the productivity of microalgae biomass first of all microalgae species (fatter and faster), light and insolation conditions (to improve the photosynthetic process) and the amount nutrients (determinant growth rate and chemical composition) (24).

The key factors determining the growth algae rate are summarized in Table 3.

TABLE 3

FACTORS INFLUENCING GROWTH ALGAE RATE

Algae species	Algae species depend on the type of products you want to produce. "Fatter and faster" approach is at the base of the choice of high oil content algae with the faster growth rate.
Aeration and CO_2	The algae need aeration to fix CO_2 and to grow. To improve growth rate it is necessary a secondary CO_2 source for instance flue gas from power plant.
Medium and Nutrients	The composition of land and/or water determine growth algae rate. If water from farm-run off or waste water effluent are used, their high level of nitrogen stimulate the algae growth.
Light	Normally sunlight is needed for photosynthesis process. Artificial light sources are introduced to stimulate algae growth in same demonstrative pounds.
pH level	To grow optimally algae need a pH ranging between 7 and 9. This range could be influenced by CO_2 and nutrients inputs.
Mixing	Mixing is necessary to ensure that all algae cells are equally expose to light and to prevent sedimentation
Temperature	Warm temperature ranges are often required by several algae species to grow

Source: personal elaboration by the authors on data by (22).

They are cultivated in various types of ponds (such as closed or open raceway-ponds) and photobioreactors. Raceway open pond is the cheaper system, microalgae oil estimated production costs in open raceway ponds ranges between 2.4-4.5 $/L.

Critics points of these systems are the vulnerability to contamination by other microorganisms (bacteria and/or other algae species) and the difficulty to control biocultural conditions (pH, light, carbon dioxide, temperature).

Closed-ponds system is preferable but researches and studies show the difficulty of producing large amount of algal biomass in such a plant and above all costs increase too much losing competitiveness with the photobioreactos.

They, an enclosed and light culture vessel, are much more expensive systems than raceway open ones. Estimated oil production costs ranges between 5.2 -10 $/L (22).

The principal technological goals during this phase are the improvement of microalgal biomass growth with high oil percentage and the development of the best and cheaper microalgae growing system able to achieve commercial success in sufficient quality and quantity to meet commercial scale viability in biofuels markets in the next 3-5 years.

The subsequent phase in oilgae production chain is harvesting and dewatering. Several options are available with different efficiency and cost level.

Sedimentation, filtration, froth floatation, flocculation and centrifuges are commonly cited algae harvesting methods.

Sedimentation is often the first step used in harvesting utilizing gravity to operate a preliminary separation of algae from water.

Filtration due to dimensions of microalgae does not work well as froth floatation.

Centrifuges systems are today the most used despite their capital and operating high costs (0.6 $/L) especially for energy inputs (3 kWh/L) (22-25).

The main problem of this method is the efficiency because algae are small portion of the total mixture centrifuged (1-4 g/L of mixture).

When algae are harvested and dewatered oil extraction can be made by different methods such as traditional mechanical crushing, solvent extraction (with hexane and benzene), supercritical CO_2, microwave, ultrasonic cavitation and cellular decompression.

Also in this case they differ for efficiency and costs.

Hexane extraction system is the most used even if ultrasonic cavitation is the emerging trend in oilgae industry as it can accelerate the extraction processes.

Microwave technologies are also considered a good option but its high capital and energy costs make it too much expensive to use. Like other vegetable oil, algae oil cannot be directly used in diesel engines above all because of its high viscosity.

The algae oil obtained has to be transesterified to achieve the right standards parameters required in USA and/or EU for fossil diesel (26).

Final Remarks

The sustainability of energy system represents one of the most important problems in the next future above all in transportation sector characterized by a high dependence from fossil fuels.

To achieve this sustainability means to make compatible during the time, energy demand with energy supply without compromise natural equilibrium. Unfortunately there is not one solution rather than a mix of solutions by which to solve this kind of problem.

Moreover, the mix has to be contextualized according to the realty, possibility and potentialities of specific situation.

In this general context biofuels represent an innovative good options and in order to understand their role, in the first part of this paper, the authors have briefly described the evolution of biofuels of first and second generation highlighting pros and cons.

Subsequently they focus on third generation with particularly attention on algae biodiesel. At the end of this review, authors have analyzed the contribution of biofuels innovation with the aim to verify if they represent environmental critical innovations able to get transportation sector towards sustainability.

Based on the definition of environmentally critical innovation that is a type of innovation able to cause large reduction in environmental risks, to represent a significant technical advances and to involve favorable ratio of social and private returns, the authors have been compared the three biofuels generations (Table 4).

TABLE 4

THE ROLE OF ENVIRONMENTAL CRITICAL INNOVATION IN THE BIOFUELS PRODUCTION

	Reduction in environmental risks	Technical advances	Social effects	Market developments
First generation	Low	High	Negative	Low
Second generation	Low	High	Medium/low	Low
Third generation	High	High	Medium/high	High

Source: personal elaboration by the authors.

Environmental critical innovation boosts shifting from the first to the third biofuels generation. The main limit of first generation biofuels is the social effects (food and cropland competition) followed by a low reduction in environmental risks.

In fact several first generation biofuels input/output analysis are available and, despite the difficulties to compare final results, they often show that CO_2 fixed by the energy crop are equal or exceed CO_2 emitted during production and consume phases or in the same way energy inputs during all phases (agricultural, production and consume) are higher than energy value of biofuels produced.

Second biofuels generation overpass the social effects but the feedstock logistic difficulties; high production costs mainly due to the investment and moderate reduction in environmental impacts still limit them.

As concerning algae biodiesel (third generation) it seems to be the promising environmentally critical innovation.

The state of the art and the medium term scenario available show that algae exploitation can accomplish two environmental problems such as CO_2 sequestration and wastewater reduction.

Algae need CO_2 to grow and can be grown in wastewater reducing two important environmental risks.

They show high yield rates, high oil content and they are not in competition with food production, cropland and freshwater sources. Quite the opposite algae cultivation in arid and deserted land could contribute to the social and economic development of those areas.

Moreover, algae biodiesel is accompanied by joint production of several profitable co-products (Fig. 1) already present on existing value added markets.

As just mentioned in previous paragraphs, today algae production is finalized to obtain profitable products such as omega3, carotenoids and other useful bio-chemicals.

Up today, in terms of values the much more profitable algae commodities are those at the top of a pyramidal scheme at the base of which there are low value products such as algae oil useful in biodiesel production. The paradox is that the by-products of these emergent markets are source for biodiesel industry and market, which are suffering a supply feedstock crisis.

The role of these emergent markets is also important because bigger are their return bigger will be the capacity to invest in R&D in algae biofuels field improving their techniques of production and making lower their production costs. These markets could be the bridge to include algae biodiesel in the mix of options useful to transportation sustainability.

Conclusion

At the end of this analysis, the authors believe that in third generation biofuels field, innovations still present a large margin of action.

The main challenger to exploit algae biomass could be summarized in these words fatter, faster, cheaper and better. Fatter and faster because it is necessary to identify and/or modify genetically the algae species with high oil content able to be harvested daily rather than few time a week.

Cheaper and better because costs and efficiency in algae biomass production have to be progressed in order to became profitable for companies and so available on fuels markets.

In any case, it is necessary to remember that joint to environmental critical innovations, such as algae biomass, a concrete contribution to make sustainable the global energy problem arrives faster and cheaper from energy saving actions.

Received May 26, 2011
Accepted July 20, 2011

REFERENCES

(1) J. Hansen et al., "Target Atmospheric CO_2: Where Should Humanity Aim?", *The Open Atmospheric Science Journal 2008*, 2, 217-231. Available on line in web site: http://www.benthamscience.com/open/toascj/articles/V002/217TOASCJ.pdf, last access January 2011.

(2) J. Rockström et al., "Planetary boundaries: exploring the safe operating space for humanity", *Ecol. Soc. 2009*, 14/2, art. 32. Available on line in website: http://www.ecologyandsociety.org/vol14/iss2/art32/, last access January 2011.

(3) ITF, International Transport Forum, *Reducing transport greenhouse gas emissions: trends & Data 2010*, 2010. Available on line in website: http://www.interna-tionaltransportforum.org/Pub/pdf/10GHGTrends.pdf, last access January 2011.

(4) IEA, International Energy Agency, Key *World Energy Statistics*, IEA, Paris,2010, Available on line in website: http://www.iea.org/textbase/nppdf/free/2010/key_sta-ts_2010.pdf, last access March 2011.

(5) IEA, International Energy Agency, *World Energy Outlook 2010*, IEA, Paris, 2011. Available on line in website: http://www.worldenergyoutlook.org/, last access March 2011.

(6) EIA, Energy Information Administration, *International Energy Outlook 2010*, EIA, Washington, 2010. Available on line in website: http://www.eia.doe.gov/oiaf/ieo/in-dex.html, last access February 2011.

(7) A. Eisentraut, "Sustainable Production of Second Generation Biofuels: Potential and Perspectives" in *Major Economies and Developing Countries,* IEA, Paris, 2010. Available on line in website: http://dx.doi.org/10.1787/5kmh3njpt6r0-en, last access February 2011.

(8) REN21, Renewable Energy Policy Network for the 21st Century, *Renewables 2010 global status report*, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, 2010. Available on line in website: http://www.ren21.net/Portals/97/documents/GSR/REN-21_GSR_2010_full_revised%20Sept2010.pdf, last access March, 2011.

(9) RFA, Renewable Fuels Association, *Industry Statistics*, RFA, Washington, 2011. Available on line in website: http://www.ethanolrfa.org/pages/statistics, last access February 2011.

(10) J. Hill, E. Nelson, D. Tilman, S. Polansky, D. Tiffany, “Environmental, economic and energetic costs and benefits of biodiesel and ethanol biofuels”, *Proceeding of National Academy of Science 2006*, 103/30, 11206-11210.

(11) E. Ghallagher, *The Ghallagher Review of the indirect effects of biofuels production*, Renewable Fuels Agency, London, 2008. Available on line in website: http://www.renewablefuelsagency.gov.uk/sites/renewablefuelsagency.gov.uk/files/_documents/Report_of_the_Gallagher_review.pdf, last access February 2011.

(12) R.W. Howarth, S. Bringezu, Biofuels: Environmental Consequences and Interactions with Changing Land Use. Gummersbach, Germany: SCOPE (Scientific Committee on Problems of the Environment), 2009. Available on line in website: http://cip.cornell.edu/biofuels/, last access February 2011.

(13) C. Azar, E.D. Larson, “Bioenergy and land use competition in Northes Brazil”, Energy for sustainable development 2000, IV/3, 64-71.

(14) FAO, Food and Agriculture Organization of the United Nations, The state of food and agriculture – Biofules: prospects, risks and opportunities, Roma, 2008, FAO.

(15) R. Righelato, D.V. Spracklen, “Carbon mitigation by biofuels or by saving and restoring forest?”, *Science 2007*, 317/5840, 902.

(16) R.F. Service, “Another Biofuels drawback: the demand for irrigation”, *Science 2009*, 326/5952, 516-517.

(17) J.C.J. Bart, N. Palmieri, S. Cavallaro, Biodiesel science and technology, Woodhead Publishing Series in Energy and CRC Press LLC, Cambridge, 2010.

(18) E.W. Becker, “Micro-algae as a source of protein”, *Biotechnol. Adv 2007*, 25/2, 207-210.

(19) Y. Chisti, “Biodiesel from microalgae”, *Biotechnol. Adv 2007*, 25/3, 294-306.

(20) BP, Beyond Petroleum, BP Statistical Review of World Energy 2010, Beacon Press, London, 2010. Available on line in website: http://www.bp.com/liveassets/bp_inter-net/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/statistical_review_of_world_energy_full_report_2010.pdf, last access May 2011.

(21) L. Lardon, A. Hélias, B. Sialve, P. Steyer, O. Bernard, "Life-cycle Assessment of biodiesel production from microalgae", *Policy Anal. 2009*, 43/17, 6475-6481.

(22) W. Thurmond, *Algae 2020*: Vol. 2: Global Biofuels, Drop-In Fuels, Biochems Market and Forecasts, Emerging Markets Online, Houston (US), 2011.

(23) J.E. Andrate, A. Perez, P.J. Sebastian, D. Eapen, "A review of bio-diesel production process", *Biomass Bioenerg. 2011*, 35/3, 1008-1020.

(24) P.H., Pfromm, V. Amanor-Boadu, R. Nelson, "Sustainability of algae derived biodiesel: A mass balance approach", *Bioresuor. Technol. 2011*, 102/2, 1185-1193.

(25) P.M. Schenk, S.R. Thomas, E. Stephens, U.C. Marx, J.H. Mussgnug, C. Posten, O. Kruse, B. Hankamer, "Second generation biofuels: High-efficiency Microalgae for biodiesel production", *BioEnergy Res 2008*, 1/1, 20-43.

(26) M. Aveni, R. Rana, La produzione di biodiesel da microalghe, *La Rivista dei Combustibili e dell'Industria Chimica 2008*, 62/4, 231-248.