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Prospects of using microalgae for biofuels production: Results of a Delphi study

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ABSTRACT

Advanced biofuels, such as those obtained from microalgae, are widely accepted as better choices for achieving goals of incorporating renewables and non-food fuel sources into the transportation sector, and for overcoming land use issues due to biofuel crops. Main challenges are currently the feasibility of large-scale commercialization of microalgae biofuels, since there are still some technical problems to overcome (e.g. the high energy consumption associated with biomass processing) and the majority of economic and financial analyses are based on pilot-scale projects. Therefore, this article presents the results of a Delphi study aiming to identify the main obstacles and most critical issues affecting the potential of large-scale commercialization of microalgae biodiesel and its incorporation into the fuel market. According to the authors' knowledge, this is the first Delphi study with this objective. The respondents are worldwide market specialists in the survey themes that ranged from biofuels economics to their environmental sustainability. One of the key findings is that most of the experts believe that production of microalgae biofuels will achieve its full commercial scale until 2020, and that from 2021 till 2030 it could represent from 1% to 5% of the worldwide fuel consumption. The study results also showed that environmental issues are where expert opinion differs more.

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1. Introduction

It is consensual today that current production and consumption habits are unsustainable in the medium to long term. This is particularly true when considering energy production and consumption, a cornerstone of modern developed societies. We live in a world where fossil fuels, in particular oil and coal, are still the major source of energy to provide and meet the world needs. Besides that, they have a significant environmental impact, due to their exploration and, in particular, their utilization that contributes to pollution and climate change. Increasingly in future, cost and supply problems will lead to more significant economic, political and even social problems, as fossil fuels are very dependent on the geopolitical context, leading to oil price volatility. This is a big issue for most countries dependent on imports to meet energy needs, threatening their energy security. Due to these reasons much effort has being put on research and development of renewable energies, trying to find and develop good alternatives for fossil fuels with the long-term goal of providing reliable and cheap energy sources. The European Union (EU) has very ambitious targets till 2020, known as 20/20/20, which goals defined in the Directive 2009/28/CE [1] are to reduce the primary energy by 20%, increase the share of renewables in the final energy mix by 20%, and reduce the greenhouse gas emissions by 20% till 2020 compared to 1990.

Despite the challenges and depending on local conditions and practices, renewable energy sources are already a significant contribution to the energy mix. Two examples are wind and hydroelectric power that, in some European countries, represent more than fifty percent of the electricity consumed, and bioethanol in Brazil that currently represents 30% of fuel

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consumption in the transportation sector. However, from a global perspective, we are still far from the goal of producing most energy from renewable sources. Although all this condition is common to all activity sectors, the situation is even more delicate in the transportation sector, which has a global energy consumption share of about 30% [2] and the available options are limited and still have a modest impact. Other concerning aspect is that global energy use in transportation is increasing rapidly, especially in developing economies like China and Brazil, joining the fact that the transportation sector heavily relies on oil based products, where 95% of fuels are either gasoline or distillate fuels. Therefore, it is expected that CO_2 emissions from transportation will continue to rise. For that reason, there is a strong interest, both from companies and governments, to foster the development of renewable energy feedstocks.

Biodiesel and bioethanol are the two liquid biofuel options currently looked upon with more attention and under more vigorous development, since they can be used in today automobiles with little or no modifications of engines, for replacing diesel and gasoline respectively. The Directive 2009/28/CE also targets the transportation sector fuels; in particular each member state should reach a minimum 10% share of renewable energy by 2020. It is to mention that the pace that member states have been tracking is uneven among Europe, depending on their national specificities [3]. Complementarily, this Directive also states that this must be possible by using electricity and sustainable biofuels (i.e. based on a sustainable production). It also mentions that correct sustainability criteria should be adopted for biofuels, so that the rising world demand for biofuels does not destroy or damage land biodiversity, and establishes many others recommendations to ensure total sustainability of biofuels. An interesting point of this Directive is that, it recommends member states to incentive and support the use of biofuels that add supplementary diversifying benefits, such 2nd and 3rd generation biofuels (e.g. biodiesel from microalgae or bioethanol from lignocellulosic materials). Some changes were recently proposed to the Directive 2009/28/CE [4], in particular dealing with the calculation of carbon footprint, namely how to account for the ILUC (indirect land use changes), and setting new goals deemed more adequate to promote the growing European biofuels industry.

1.1. What is the potential of microalgae

Of the various potential biofuels' feedstocks much attention is being given to microalgae. This is a class of photosynthetic organisms with more than 30,000 known species that can grow in a wide variety of environments and conditions, including fresh, salty and brackish water. They have higher biomass and lipid productivity, requiring much less land area, of up to 49 or 132 times less, when compared to rapeseed or soybean crops, currently used as biodiesel feedstocks [5]. Also, they can be harvested either daily or every few days [6]. Generally, they are efficient CO_2 fixers, using solar energy to convert it to biomass, and can be considered almost carbon neutral, if the CO_2 released on combustion balances the saving from carbon capture during microalgae growth, and the energy needs for biomass processing are obtained from residues or other renewable energy sources, avoiding the usage of fossil fuels. Although open ponds' microalgae cultivation suffers from many limitations compared to closed cultivation systems, such as more susceptibility to invasions by other organisms and stronger temperature's variations [7], the essential cultivation requirements are small, as most species only need water, CO_2, and some essential nutrients such as nitrates and phosphates, without the need for fertilizers or even pesticides [8]. Besides that, biodiesel and other biofuels produced from microalgae have similar properties to petroleum diesel and to biodiesel produced from agricultural crops, currently named 1st generation. Extensive reviews dealing with the various aspects of microalgae cultivation and usage as feedstock for biodiesel production are available in literature [5,9–20]. A complete review of the main problems was done by Lam and Lee [21] and Januaun and Ellis [22], showing that many hurdles are directly linked with the process economics, due to its high energy requirements; in particular for processing microalgae biomass and for lipids extraction and refining.

1.2. Objectives

Currently, much experimental and even theoretical/simulation work is being done to ensure that biofuels from microalgae become a reality in the short to medium term. Some aspects were already identified as significant for the overall competitiveness, such as: the microalgae should have high biomass and lipid productivities [23–25]; the processing system should be highly efficient and integrated with other processes following the biorefinery concept [26]; there must be markets or valorization potential for the process byproducts or other high value products that may be obtained [27]; waste streams and/or remaining nutrients should be used to reduce operating costs and increase the process sustainability [25]; among others. Each of the previous possibilities has a positive impact on the competitiveness of using microalgae as a feedstock for biofuels, but there is a lot of discussion in which one should focus efforts of research and development.

To fulfill this gap, and building on previous work by the authors [28–30], this article presents a study based on the Delphi method to obtain more concrete information and predictions on how this area should be further developed. This way it will be possible to better define which lines of research should be supported, and what policy and funding instruments are more adequate. To the authors' awareness, no study can be found in the literature addressing these questions, involving the usage of microalgae as feedstock for biofuels.

A related work is the National Roadmap Algal Technology Roadmap [31], the result of a two day workshop that brought together specialists from various areas, including engineers, scientists, policy makers, financiers, and others, to discuss the present and future of microalgae as a feedstock for biofuel production. The final document was intended to serve as a revision of the current state of the art in the area, and to identify which are the key challenges that must be considered to achieve a commercial scale production, serving as a guide to ongoing efforts. The study is rather comprehensive and extensive but fails to highlight which are the areas and aspects that are considered to be more important and should be considered first, from a cost–benefit point of view.

Also related, the EurEnDel project was a European wide Delphi study on the future developments in the energy sector, with a time horizon of 2030 based on the situation up to 2003. Its main goal was to provide advice on energy R&D activities in this key area. Hundreds of responses from experts in a wide range of topics were gathered, several future scenarios were developed, and in which concerns biofuels, there is a short-term need for new production processes and an increase in their market share [32,33].

In 2009, a Delphi study was published dealing with the potential of biofuels in Alabama [34]. The information gathered supported the idea that there are no simple and unique technology answers for the commercial implementation, and that local questions and an array of technologies and feedstocks is the most adequate strategy. Similar conclusions were reached by Celitkas and Kocar [35] in their Delphi study of the renewable energy sector in Turkey, and by Lubieniechi and Smyth [36] in their work on the barriers to biofuels in Canada.

2. Research design

The Delphi method is a qualitative research aiming to support strategic future-oriented action, such as policy making in the areas of science and technology. It typically entails two or more survey rounds in which the participating experts are provided with the results of the previous rounds. The panel of experts is used as the source of information, and the questionnaires act as the medium of interaction. The key characteristics of a traditional Delphi study are iteration, participant and response anonymity, controlled feedback, and group statistical response. It is especially suitable in judgment and long-range forecasting (20–30 years) situations, when expert opinions are often the only source of information available, due to a lack of appropriate historical, economic or technical data [37–39].

2.1. Delphi process

The key objective of our Delphi study is to determine the prospects of using microalgae for biofuels production within a time scale extending to 2030. Before initiating the Delphi study, a brainstorming was organized by four microalgae specialists. In the brainstorming, the participants identified factors affecting production and competition of microalgae biofuels. Subsequently, the factors were categorized into sentences as presented in the Delphi study later on. The brainstorming's participants also suggested panelists for the Delphi survey. Based on this meeting, the statements for the first Delphi survey round were formed by the researchers. The questionnaires were sent to the Delphi experts via e-mail, enquiring about their willingness to participate in the study. In the first Delphi survey round, all statements were presented to the panelists at the same time. In the second survey round, the respondents similarly had the opportunity to comment on the critical factors voted on in the first round.

Our Delphi study included three survey rounds (the workshop and two Delphi rounds), which made it possible to understand the features that may develop or hold back this technology in the future. All three rounds were carried out during three months (from May 2012 to July 2012). There were 55 respondents in the first round, reaching a response rate of 36.7%, and, in the second round, when only were questioned those that answered the first round, the response rate was 54.5%. The Delphi participants were selected based on their expertise on the subject matter, as it is required in-depth knowledge about the microalgae biofuel markets and processes from all the experts.

Overall, the panelists represented 10 countries (USA, Portugal, the Netherlands, Italy, Norway, UK, Spain, Uruguay, Brazil and Australia). The experts can be categorized into three groups based on the field they represented: Academy (38.5%), Government (23.1%), Business (28.8%), Academy/Business (7.7%) and Academy/Business/Government (1.9%). The main focus of this Delphi study was to gather insights from specialists that symbolized distinctive fields, and not specifically the strategies of each country.

In the workshop, participants raised several factors that could affect competition in this particular market and they were categorized into four main themes. The first theme concerned microalgae biofuel economics as it plays a crucial role in establishing well-functioning and competitive market. The second theme studied some future trend hypothesis to be rejected or accepted by participants on the Delphi survey. The third key element in the study dealt with sustainability, which directly affects confidence-building in the development of the microalgae biofuel market. The final group of statements focused on policies and on forecast concerning the future.

The 1st round questionnaire consisted of 50 statements. Those that did not reach an overall consensus (more than 66% agree or disagree) shaped the basis of the second round, which included open-ended fields for further explanations or suggestions. The second round focused on clarifying the answers of the first round. All the questionnaires were pre-tested, and the panelists were given feedback after the first round with all the participants' answers from the first round. The participants in the study were likewise encouraged to provide arguments supporting their views and opinions.

3. Results and discussion

Once all the respondents had completed the first round, each answer was examined. The statements that, in the view of the experts, did not achieve an overall consensus formed the footing for the questions of the second round.

In Appendix 1, it is shown the statements of the first three themes asked in the survey. The question asked in Themes 1, 2 and 3 was "Please rate how strongly you agree or disagree with each of the following statements by placing a check mark in the appropriate box." The respondents could choose in a seven-level Likert scale from "Totally Disagree, Strongly Disagree, Disagree, Neither agree nor disagree, Agree, Strongly Agree and Totally Agree". After the first round of answers, the aggregated results Table 1 were achieved.

In the economics theme, expressive consensus were achieved on statements 1.1, 1.6 and 1.12 (above 90%), in a way that experts consider that there is plenty of room for innovative and more

Table 1
Aggregated results of themes 1, 2 and 3.

Statement number	Number of respondents	Agree (%)	Neither agree nor disagree (%)	Disagree (%)
1.1	55	94.5	3.6	1.8
1.2	54	68.5	24.1	7.4
1.3	55	63.6	20.0	16.4
1.4	54	42.6	22.2	35.2
1.5	54	85.2	9.3	5.6
1.6	55	94.5	3.6	1.8
1.7	54	66.7	14.8	18.5
1.8	55	81.8	10.9	7.3
1.9	55	78.2	16.4	5.5
1.10	53	83.0	9.4	7.5
1.11	54	79.6	7.4	13.0
1.12	52	94.5	3.8	1.9
1.13	54	83.3	9.3	7.4
1.14	53	67.9	22.6	9.4
1.15	53	84.9	7.5	7.5
2.1	52	78.8	15.4	5.8
2.2	52	73.1	11.5	15.4
2.3	51	47.1	25.5	27.5
2.4	52	84.6	7.7	7.7
2.5	52	75.0	15.4	9.6
2.6	50	70.0	14.0	16.0
2.7	50	66.0	18.0	16.0
2.8	51	92.2	7.8	0.0
2.9	49	40.8	24.5	34.7
2.10	51	82.4	13.7	3.9
2.11	51	82.4	9.8	7.8
3.1	50	38.0	28.0	34.0
3.2	50	60.0	18.0	22.0
3.3	46	15.2	41.3	43.5
3.4	47	27.7	42.6	29.8
3.5	48	72.9	12.5	14.6
3.6	48	47.9	29.2	22.9
3.7	49	59.2	10.2	30.6
3.8	49	79.6	18.4	2.0
3.9	48	79.2	14.6	6.3
3.10	46	32.6	32.6	34.8
3.11	49	61.2	22.4	16.3
3.12	49	81.6	12.2	6.1

effective production processes that could lead to economic feasibility, considered one of the main challenges facing large-scale deployment of biofuels from microalgae.

Statements 1.5, 1.8, 1.10, 1.13, 1.15 also revealed a high consensus level (above 80%). From those, it is important to highlight the awareness that R&D subsidies and supporting programmes will be needed to promote improvements in the technology in order to reduce the costs of algal biofuels and speed up development. Moreover, an interesting issue relates the perception that the increase in the overall consumption of biofuels, and the expected growing pressures on currently used feedstocks can be a key factor to the economic viability of microalgae.

The experts also reached an agreed consensus on statements 1.2, 1.7, 1.9, 1.11 and 1.14, but with less intensity (from 66% to 80% agree). Of which, it is important to highlight the interest in other co-products outside the transportation sector, such as nutraceuticals and compounds for the pharmaceutical and/or fine chemistry industries. The commercialization of theses co-products could assist industries to reach economic feasibility of microalgae biofuel.

Questions 1.3 and 1.4 did not reach a clear consensus and were asked again in the 2nd round for further analysis. From the results, 1.3 has a clear tendency on agreement; however, we could not conclude a clear overall consensus, since the sample that agreed now (69.0%) had already agreed on the 1st round (70.0%). Statement 1.4 did not reach any consensus (26.7% disagree/33.3% neither agree nor disagree/40.0% agree).

In Theme 2, expressive consensus was reached only on statement 2.8, which reached 92.2% of agreement. Therefore, experts strongly agree that no single microalgae strain will be the dominant one, and that different strains of microalgae will be used depending on the nutrients and/or waste streams available, and particular local climatic and water availability conditions.

High consensus was observed on declarations 2.4, 2.10 and 2.11. In this way, the reduction of oil imports dependence and the potential development of local and national economies is a relevant factor for the development of microalgae biofuels. Experts also believe that biofuels from microalgae will be produced commercially, but only in the mid to long term. This conviction was better described on Theme 5 of this study.

Mild agreement was reached on 2.1, 2.2. 2.5, 2.6, and 2.7 (from 66% to 80% agree). Two factors related to the economic feasibility of algae biofuels are noteworthy to point out. They relate to the sense that not only higher petro-oil prices, but also a more developed, globalized and comprehensive Carbon Market could foster microalgae biofuel to become more economically feasible.

Questions 2.3 and 2.9 did not reach a clear consensus and were asked again in the 2nd round for further enlightenment. Neither an achieved consensus was obtained on the 2nd round nor were some reasons clarified by the experts, for instance: “Hard to make predictions know. Depends on the evolution of other biofuels, technological advances, development of other biofuels… This is one is though…[sic]” (Comment on Statement 2.3).

The Sustainability theme was the most controversial one. In which, eight from twelve statements did not show consensus (3.1, 3.2, 3.3, 3.4, 3.6, 3.7, 3.10 and 3.11). All these were asked again in the 2nd round of the survey.

The highest consensus was achieved on 3.12 (82% agree) that said, “The potential to use waste streams and/or easily available renewable nutrients is a key factor in the overall system sustainability.”

Agreement was also reached on 3.5, 3.8 and 3.9, but with lower intensity (from 66% to 80% agree). All these statements had in common “carbon emissions”, where experts agree that the need to reduce world's CO_2 emissions is a key advantage for microalgae biofuels; and that the actual overall life cycle carbon balance is key aspect to consider in the microalgae biofuel production. They think that being carbon neutral is a key factor concerning microalgae biofuel production sustainability.

From the ones asked on the 2nd round, it is interesting to highlight that because biofuels of this origin do not have a well-known industrial process (there are different methods for producing them) and microalgae are not yet being cultivated commercially for this purpose, it was difficult for the experts to answer questions related to sustainability. Some of the comments to these questions were: “More information and practical data is needed to answer this one” (Statements 3.3 and 3.4); “All these statements are dependent on other factors, therefore difficult to respond with just a simple agree/disagree.” (Statement 3.6); “Depends on the processes utilized for product and co-products generation/use.” (Statement 3.10).

Theme 4 concerned “Policies”, where several prospects of policies were presented and the respondents were asked to choose “How important is each policy below to the success of microalgae biofuels?” The answers were presented in a seven-level Likert scale ranging from “Unimportant” to “Extremely Important”. The policies presented are displayed in Table 2.

All policies were seen by experts as important, in which the sum of “Important”, “Very Important” and “Extremely Important” in all items was above 80% of valid responses. In an attempt to rank which were the most important ones, values were set from 1 to 7 to “Unimportant” through “Extremely Important”. Consequently, it was possible to estimate the most important policies in the view of the experts interviewed. For that purpose, an overall mean was computed for each policy and is presented in Table 2. Analyzing this data, experts believe that “Public Investment in R&D” is the most important mechanism to develop microalgae biofuels. However, the other mechanisms were also important for this purpose and it is a sum of efforts that makes the development to go on.

In order to better specify which policies were the most important ones, in the 2nd round the same set of policies were given, but this time, the respondents were asked to rank them (from 1 − most important to 7 − least important) without repeating numbers. The results were similar to the ones from the first survey: public investment in R&D was elected as the most important one, with a statistic mode of 1 (most important) chosen by 34.5% of the respondents. This policy was followed by “developing strategies aimed to renewable resources, either research, utilization and integration in existing systems”; “tax incentives and subsidies”; and “mandatory country objectives”, subsequently.

Theme 5 was named “Future” where the question asked was “When do you think the following would happen in microalgae biofuels industry?” In some of the scenarios presented the

Table 2
Theme 4 statements and results.

Statement number	Theme 4: Policies	Mean
4.1	Mandatory country objectives	5.52
4.2	Sustainability standards (Emissions, production, etc.)	5.70
4.3	Public Investment in R&D	6.09
4.4	Tax incentives and subsidies	5.71
4.5	Certification schemes, in particular those concerning raw materials or the entire fuel life cycle	5.48
4.6	Specific legislation or international agreements (such as European Directives) aimed specifically to biofuels or to specific environmental questions (such as carbon emissions) where biofuels have a pivotal role	5.70
4.7	Development strategies aimed to renewable resources, either research, utilization and integration in existing systems	5.91

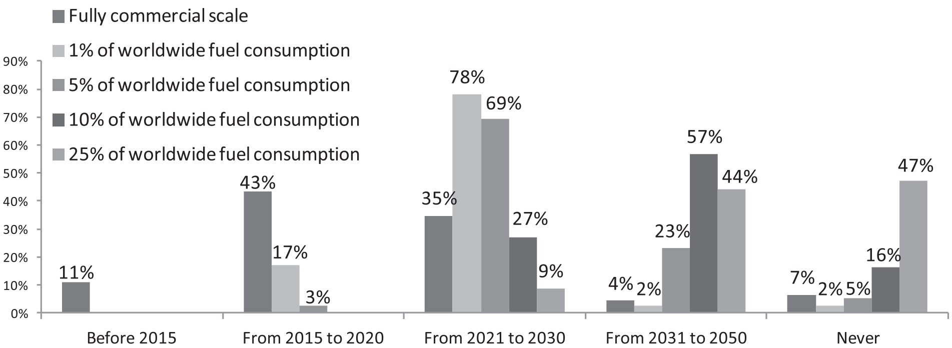

Fig. 1. Theme 5 overall results.

respondents could choose one option for each item. The outcomes are shown in Fig. 1.

The graph of Fig. 1 shows that most of the experts think that production of microalgae for biofuels will achieve full commercial scale until 2020. From 2021 to 2030 it is believed to represent from 1% to 5% of the total worldwide fuel consumption and from 2030 onwards it could reach figures of 10% to 25%. However, experts were divided regarding the possibility of microalgae biofuel reaching 25% of total worldwide consumption, whereas 47% of them doubt it could reach those numbers and 53% believe it could.

4. Conclusions

The Delphi method proved to be a successful research method when expert opinions are the main source of information available, due to a lack of appropriate historical, economic or technical data and the outcomes herein provided clearly outline the main issues of microalgae biofuels' market at present and in the future. In particular, the two-round survey revealed the most important issues affecting this emerging market and also, recommended ways to influence future policies and development of this biofuel.

One of the key findings is that most of the experts believe that the production of microalgae for biofuels will achieve full commercial scale until 2020 and from that period on, it could represent an important share of the total worldwide fuel consumption. On the other hand, environmental issues are most likely to reveal divergent opinions from experts. Conceivably because biofuels of this origin do not yet present a well-known industrial process and microalgae are not still being cultivated commercially for this purpose.

In order to boost development, experts agree that public investment in R&D is the most important policy to be adopted by countries. Developing strategies aimed to renewable resources; applying tax incentives and subsidies; and issuing mandatory country objectives were also encouraged.

Although this research has reached its aims, some challenges ahead still remain. First of all, the sample size could have been bigger and thus, more representative in statistical terms. The authors of this paper are aware that the outcomes might not represent the majority of the microalgae experts' opinion. In the same manner, after analyzing the results, some questions did not reach a consensus and could be further explored in a supplementary study or in a third round. Finally, more robust statistical calculations could have been done with the quality data obtained. However, to the best of these authors knowledge, this is the first Delphi study performed concerning the future of microalgae.

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Appendix A

The first three main themes asked in the survey (economics, future trends and sustainability) and their respective statements for the Delphi study are listed in Table A.1.

Table A.1
Statements of themes 1, 2 and 3.

Stat.	Theme 1: Economics
1.1	Achieving economic viability is considered one of the main challenges facing large-scale deployment of biofuels from microalgae.
1.2	The idea of a biorefinery is considered the business model more likely to ensure the economic viability of microalgae cultivation for biofuel production.
1.3	Microalgae biofuel will become a co-product of future large-scale facilities, where other high-value products are generated.
1.4	The price of competing fuels, especially biobased, will make it difficult for algal biofuels to achieve high growth on the cost only basis.
1.5	R&D subsidies and support programmes will be needed to promote improvements in the technology that reduce the costs of algal biofuels.
1.6	The potential of using waste streams from other processes, industries or systems, as for example waste flue gases or waste waters, can have a significant impact in the microalgae economic process viability.
1.7	Besides biofuels, the more relevant co products that will improve the economic viability of microalgae cultivation are nutraceuticals and compounds for the pharmaceutical and/or fine chemistry industries.
1.8	One of the key advantages of cultivating microalgae is the capacity of producing raw materials all year round, simplifying the process logistics and reducing costs.
1.9	The utilization of Genetic Engineering or more effective selection criteria may lead to more effective strains of microalgae, in particular in terms of overall productivity and/or cultivation robustness.
1.10	The economic feasibility is strongly affected by the amount of energy needed in the process, mainly due to the high water content of the original raw materials that has to be removed before the chemical reaction.
1.11	The limiting steps, in terms or processing costs, are the oil separation and water removal steps. Any improvements in these steps can have a profound impact in the economic feasibility of the microalgae biofuel production process.
1.12	There is still plenty of room for innovative and more effective production processes, from the cultivation, passing through the raw material processing, chemical reactions involved and purification steps.
1.13	The increase in the overall consumption of biofuels, and the expected growing pressures on currently used feedstocks can be a key factor to the economic viability of microalgae.
1.14	The economic viability of the microalgae production can be further enhanced if biofuels applications outside the transportation sector can be found and promoted.

(*continued on next page*)

Table A.1 (*continued*)

Stat.	Theme 1: Economics
1.15	Microalgae cultivation may become an important factor in the development of local economies and reduce the dependence on non-renewable energy sources.
	Theme 2: Future trends
2.1	Higher petro oil prices could make algae biofuel economically feasible.
2.2	A more developed, globalized and comprehensive Carbon Market could make algae biofuel more economically feasible.
2.3	Algal biofuels will be developed, but will play only a minor role in the future mix, in particular for the transportation sector.
2.4	Biofuels from microalgae will be produced commercially, but only in the mid to long term.
2.5	Advances in strain identification and process engineering are key factors in the development of the technology.
2.6	The nature of the cultivation system, closed or open, will depend on the production quantities, type of nutrients required, waste streams available and strains used.
2.7	The microalgae cultivation process will be increasingly used integrated in existing industrial processes, usually not related with energy production and for waste treatment and/or carbon capture purposes.
2.8	Different strains of microalgae will be used depending on the nutrients and/or waste streams available, and particular local climatic and water availability conditions. No single strain will be dominant one.
2.9	Open pond cultivation, or similar, will dominate the future production systems, although for small production involving the processing of waste streams the close cultivation systems will be also used.
2.10	The main aspects that have to be considered in the process development are improving its overall energy efficiency, the ability to produce other high value products, or the possibility to integrate it in other process under the biorefinery concept umbrella.
2.11	The reduction in the dependence in oil imports, and the potential development of local and national economies, is a relevant factor in the development of the area.
	Theme 3: Sustainability
3.1	The environmental sustainability of microalgal derived biofuels is a potential problem.
3.2	The utilization of genetic modified organisms may represent a potential problem in the diffusion of algal biofuels.
3.3	Open pond cultivation is more environmentally friendly than PBRs cultivation.
3.4	Closed PBRs cultivation is more environmentally friendly than open pond cultivation.
3.5	The need to reduce world's CO_2 emissions is a key advantage for algae biofuels.
3.6	The production of algae biofuels in large scale could generate potential impacts on local ecosystems from new algal species.
3.7	The production of algae biofuels in large scale could generate potential impacts on water reserves.
3.8	Although microalgae can be used to capture CO_2, the actual overall life cycle carbon balance is key aspect to consider.
3.9	The potential of biofuels from microalgae to be carbon neutral is a key factor concerning their sustainability.
3.10	Some potential undesired environmental aspects may arise from microalgae cultivation, as for example, increased emissions of NO_x and/or methane.
3.11	The environmental impacts of energy consumption is the key factor concerning the sustainability of the microalgae cultivation.
3.12	The potential to use waste streams and/or easily available renewable nutrients is a key factor in the overall system sustainability.

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