Proposal full title:

Algae and aquatic biomass for a sustainable production of 2nd generation biofuels

Proposal acronym:

AquaFUELs

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Recommendations for decision-makers

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Rev 0	24/06/2011	Raffaello Garofalo, Pierre-Antoine Vernon	EBB	EBB	PU
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Rev2	08/07/2011	F. Gabriel Acien Fernandez	UAL	UAL	PU
FINAL	08/07/2011	Raffaello Garofalo, Pierre-Antoine Vernon	EBB	EBB	PU

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1. Introduction

The recommendations for decision-makers are intended for private and public decision-makers, with a view to allow informed decisions on algae as a potential feedstock for biofuels.

These recommendations have four dimensions:

1. National and international research development and demonstration incentives for rapid deployment
1. Inclusion of algae and aquatic biomass based biofuels in European legislative text on renewable energy and biofuels (especially in the RED Directive and 10% biofuels mandate)
1. Start-up of CEN working group aimed at preparing draft European fuel standards for definition of CEN fuel standards for algae and aquatic biomass derived biofuels and for their inclusion (in blends) in conventional diesel (eventual addenda to CEN EN590 diesel)
1. REACH Registration of algae and aquatic biomass derived biofuels

These recommendations build on the reports on the state of the art of algae biofuels, their overall sustainability assessment and the coordination with relevant research activities carried out outside the AquaFUELs Consortium. These recommendations summarise the operative conclusions of the AquaFUELs deliverables, comments from Consortium members and the Expert Group.

The contributions from the presentations and discussions at the AquaFUELs Roundtable, held on October 20th-21st, 2011 in Brussels, Belgium, also formed a significant input to these recommendations. The concise summary of the AquaFUELs Roundtable forms the Annex 1 to these recommendations.

In order to ensure the greatest scientific credibility, this report was refined according to the discussions held during the AquaFUELs Final Conference, held on June 30th, 2011 in Brussels, Belgium and further circulated to the participants. The authors wish to thank Dr. Wilmotte (University of Liege), Dr. Wilhelm (university of Leipzig), Mr. Duvauchelle (Eco-Solution) and Mr. Flammini (FAO) for their direct input to these recommendations.

2. Research, Development and Deployment

Technological bottlenecks could be found at all steps of the algae biofuels production pathway. The high costs of algae production could be decreased by scaling up and overcoming the bottleneck of harvesting, extraction and dewatering. However, increased productivity through improved biology and biotechnology could also balance the high costs of algae production. The identification of one specific pathway and strategic planning to address each of its bottlenecks are necessary to unlock the

potential of algae for biofuels production. One of the main findings of the project is that macro-algae for biogas or bioethanol production would show the greatest potential.

Progress on the biology of algae could be achieved by sequencing and annotating algae strains of relevance to algae biofuels, including their relevant metabolic pathways, photosynthetic properties or ability to grow with a high growth rate to high biomass densities. The consortium identified 53 species: *Alaria esculenta, Amphiprora hyalina, Amphora sp., Anabaena sp., Ascophyllum nodosum, Botryococcus braunii, Caulerpa racemosa, C. taxifolia, Chaetoceros muelleri, Chlamydomonas Reinhardtii, Chlorella sp., Chlorococcum sp., Chondrus crispus, Cryptechodinium cohnii (heterotrophic), Cyclotella cryptica, Cylindrotheca sp., Cystoseira baccata, C. tamariscifolia, Desmodesmus sp., Dunaliella sp., Fucus serratus, F. spiralis, F. vesiculosus, Grateloupia turturu, Haematococcus pluvialis, Halidrys siliquosa, Himanthalia elongata, Isochrysis sp., Laminaria digitata, L. hyperborea, L. ochroleuca, Mastocarpus stellatus, Monodus sp., Nannochloropsis sp., Navicula acceptata, N. saprophila, Nitzschia dissipata, Odontella aurita, Ostreococcus lucimarinus, O. taurii, Palmaria palmata, Parietochloris incisa, Pavlova sp., Phaeodactylum tricornutum, Phormidium sp., Porphyridium cruentum, Prototheca sp. (heterotrophic), Saccharina latissima, Saccorhiza polyschides, Sargassum muticum, Scenedesmus sp., Schyzochytrium sp., Skeletonema sp., Spirulina sp. (Arthrospira sp.), Synechococcus sp. (or Synechocystis sp.), Tetraselmis sp.,Thalassiosira pseudonana, Tharustochytrium sp., Ulkenia sp., Ulva lactuca,U. rigida, Undaria pinnatifida.* These strains reflect the parameters needed for an algae to be suitable for biofuels production: productivity, robustness, harvestability, an appropriate composition and easy accessibility of components, the possibility to valorise co-products and local origin.

The interaction of large scale algal cultivation on its immediate surrounding area should be assessed, both from the point of view of possible environmental contamination and concerning possible contamination from unwanted organisms decreasing productivity. This is particularly true for macro-algae, which has both the greatest potential for cultivation in seawater and could also be harvested from the wild, provided that harvesting takes place in a sustainable way.

On the technological level, the biggest challenge for micro-algae remains scaling up production to the size of a commercial algal biofuel plant, as all parameters of algae cultivation represent a challenge when applied at a large scale. Mixing, gassing, water management, cleaning, logistics, control of cultivation parameters, etc are all challenges when deployed at a large scale. For macro-algae, the development of algae farms at sea represents the main technological bottleneck. Pilot plants reflecting the conditions of commercial production, including siting, could allow confirming the scaling-up potential of algae cultivation.

Harvesting, extraction and dewatering represent both a technological challenge and an energy-intensive step likely to hamper the economic viability and the greenhouse gas intensity of algae biofuels, making them a priority for further research. On the opposite, the price gap between open and closed systems has been reduced and further research in photobioreactor design would need to take due account of the existing research before engaging into further developments. Further technological breakthroughs are essential to improve the economic viability of algae biofuels, e.g. “milking” the algae to avoid the energy-intensive harvesting, extraction and dewatering.

The currently low net energy ratio of algae cultivation should be improved, as it is the key factor to improve both the economic and environmental sustainability of algae biofuels. Neither economic sustainability nor environmental sustainability are optional, as the market for biofuels is driven by both prices and environmental benefits and because algae biofuels would be legally required to meet the mandatory sustainability criteria applicable to biofuels in the EU.

Most studies on algae focus on the production of algae until extraction, while conversion into biofuels and the quality of the final biofuel have been less investigated. Fuel quality is a major parameter for the marketability of fuels and has an impact on biodiesel quality, since the characteristics of the initial feedstock affect the quality of the final biofuel. On the opposite, the conversion to biogas or bioethanol offers greater flexibility in therms of feedstock type.

None of the presented pathways currently qualifies as a biofuel production process allowing the economically viable production of renewable fuels. Macro-algae conversion to biofuels appeared the most realistic perspective. Indeed, bioethanol and biogas productions are compatible with a wet feedstock and macro-algae are easy to harvest.

The need for European LCAs reflecting operations in largest pilot plants to replace the currently available LCAs was stressed. These LCAs would need to be based on the methology of the Renewable Energy Directive, including achieving 50% GHG savings compared to fossil fuels, because meeting the sustainability requirements would be a prerequisite to algae biofuels production. The need for LCAs taking into account the positive sustainability characteristics of algae was also stressed, e.g. the potential negative pressure on land, water and soil from algae cultivation and the extra protein produced.

Many uncertainties still remain on the economic viability of algae biofuels, for which costs are often hypothetical and reflecting future aspirations than practical experience. It appears that very significant cost reductions need to be achieved to allow algae to compete with other potential biofuels feedstocks. A 50% cost reduction can be obtained when using waste CO2 and nutrients, restricting the possible locations. It would be desirable to develop data on the performance of large scale systems designed specifically to produce biofuels.

The general opinion that algae co-products are essential to the economic viability of algae biofuels is not matched with sufficient data. Algae production for biofuels needs to be integrated with other production pathway in a bio-refinery approach. In this respect, further steps towards the viability of algae biofuels could be the development of large algae production plants for value-added applications (food, feed, cosmetics), where the co-products would be valorised as biofuels. Moreover the treatment of waste efluents (liquids or gases) from other activities (population, industrial, agricultural) not only improved the economic feasibility of the biofuel production process but also enhances its sustainability.

Future funding opportunities should take due account that macro-algae received considerably less funding than micro-algae for research towards biofuels production, despite their greater potential as a biofuels feedstock.

3. European legislation on biofuels

1. Renewable Energy Directive (2009/28/EC)

The Renewable Energy Directive 2009/28/EC sets a binding target for 10% renewable energy in transport. Member States have to implement National Action Plans detailing how they will progressively increase renewable energies in transport and finally meet the 10% target, which becomes binding on January 1st, 2020. After releasing their National Action Plan next June 30th, 2010, Member States needed to transpose the Renewable Energy Directive into national law by December 5th, 2010. Hoewever, the transposition process was still ongoing in June 2011.

The Renewable Energy Directive made the targets for renewable energy in transport binding and set sustainability requirements increasing over time. The mandatory greenhouse gas savings are 35% compared to fossil fuels until January 1st, 2017, when 50% will be required. On January 1st, 2018, new plants commissioned after January 1st, 2017 will need to achieve 60% greenhouse gas savings. In addition, the EU is now contemplating further requirements on indirect land-use change. The increase in greenhouse gas emissions savings and the commercial availability of advanced biofuels is the ultimate objective of these requirements. EABA members are committed to reaching commercial availability for algae biofuels, but this goal will only be achieved if Member States grant the necessary support to R&D, in particular to initiatives aiming to reach commercial scale production.

a) Double-Counting

Double counting applies to biofuels produced based on raw materials allowing a diversification of biofuels feedstocks, which is the case for algae according to the Renewable Energy Directive. As already observed for other double-counting feedstocks, the higher price and demand for double-counting biofuels would be a strong incentive for the development of algae biofuels, which are still more costly to produce than biofuels currently on the market.

b) Greenhouse Gas Savings

Member States are free to define waste and residues, provided that they are not the intended product of a production process. Classifying all algae materials left after the extraction of certain substances could help valorising these materials as biofuels feedstock. This aspect is essential, because algae will only become economically viable if all algae materials can find a potential end market. As waste and residues automatically receive a zero life-cycle emission value, classifying algae after extraction as residues would allow producing advanced biofuels with high greenhouse gas savings.

c) Support to biofuels with additional environmental benefits

Member States can not only support both the research and development towards advanced biofuels, but also compensate the price difference between these biofuels and competing products. This support proved instrumental in creating the first biofuels market in the EU and the same actions must be introduced for algae biofuels. This is all the more relevant that algae biofuels have been estimated to be 10 times more expensive than the target price for commercial production.

d) Land use

The distinctive advantage of algae is their potential to provide an efficient and high quality feedstock with limited competition with food, feed or arable land surface. In the event that the European Union adopts legal requirements for biofuels regarding indirect land use change, the limited land use for the production of algae biofuels must be properly reflected.

e) Default value

A number of biofuels pathways have received conservative default values which can be used by producers not willing to assess specifically the greenhouse gas emissions from their fuels. In this respect, the inclusion of a default value for algae biofuels, once commercial production materialises, would be essential to allow a level-playing field with current biofuels.

2. Revision of the Energy Taxation Directive

Directive 2003/96 has been one of the major pieces of legislation for biofuels, because of the possibility for Member States to grant detaxation to biofuels. In the EU, taxation is decided by Member States, but the Energy Taxation Directive 2003/96 sets the framework for national taxation, e.g. minimum taxation levels, different taxation between end-uses, possibility to exempt certain energy products from taxation, etc.

The European Commission proposal to revise the Energy Taxation Directive has set taxation levels for fossil fuels, which would also apply to all fuels used to substitute them. It would be essential to maintain this undiscriminatory approach in order to allow for algae biofuels, when they are commercialised, to have full legal certainty on the levels of taxation.

The proposal also exempts biofuels from the CO_2 tax and allows Member States to grant detaxation for biofuels until December 31st, 2022. Detaxation would be essential in the emergence of algae biofuels and it would be important that the final revision on the Energy Taxation Directive reflects the initial provisions on these aspects.

4. Standardisation

Algae biofuels, when technologically feasible, will need to fit into current markets and standardisation could allow their smooth introduction. Technical standards are widely accepted, making them de facto binding in many instances despite their voluntary nature. Standards improved confidence in new technologies from established industry players and more generally, clients.

During the standardisation work, experts from authorities, industry, consumer organisations and other stakeholders participated in the standardisation process, which is kept open and transparent and

consensus-driven. European standards published by CEN officially supersede national standards, implying that national standards covering the same aspects have to be withdrawn.

There are currently technical standards on the quality of biofuels, as EN 14214 for biodiesel and EN15326 for bioethanol. In addition, biofuels are also covered by the standards for fossil fuels (EN 590 for biodiesel and EN228 for unleaded petrol), because biofuels are commercially available in a blends with fossil fuels. In addition, the interest shown by the aviation sector for algae fuels indicate that algae biofuels will also need to meet the specifications for jet fuel, which are chiefly set by the US standard ASTM D1655.

A CEN Workshop Agreement could help summarising the situation on the new market of algae biofuels, before proper standardisation work can be undertaken. CEN Workshop Agreements are agreed between stakeholders and often used by innovative industry sectors, as it had been the case for biofuels. Currently, CEN work towards a Workshop Agreement on “paraffinic diesel from synthesis or hydrotreatment” is going on to address the emerging market for hydro-treated vegetable oils. The standard for biodiesel released in 2003 had supported the important increase in production and sales in this emerging sector, which has now reached commercial scale.

It would be essential for the emergence of algae fuels to launch CEN work towards a Workshop Agreement.

5. REACH

The Regulation of the European Commission for the Registration, Evaluation and Authorisation and restriction of CHemicals (REACH) introduced a fundamental reform of the European chemicals legislation and came into force on June 1st, 2007. REACH is the main instrument of the EU legal framework for chemicals safety.

Annexes IV and V of the REACH Regulation exempt from registration specific substances, considering that sufficient information is available to prove that their intrinsic properties cause minimum risk. Annex V paragraph V(9) exempts natural substances from registration, including vegetable oils, animal fats, fatty acids from C6 to C24 and their potassium, sodium, calcium and magnesium salts. However, biofuels are covered.

Prior to commercialisation, algae biofuels would be subjected to registration. This registration would need to take place through the consortia for the respective biofuels produced from algae, except in the case of algae directly yielding substances potentially used as fuels.

It would be essential that algae biofuels are provided a level-playing field with existing biofuels and that a smooth REACH registration can take place.

Annex 1 – Concise Summary of the Proceedings of the AquaFUELs Roundtable

Introduction – the AquaFUELs project

Algae has been in the spotlight for its promising perspectives as a biofuel feedstock, in particular since the EU adopted an ambitious climate-energy package including a target for 20% greenhouse gas (GHG) reduction by 2020, including a 10% target for renewable energy in transport. The addition of the aviation sector to the industrial sectors obliged to reduce their greenhouse gas emissions also led this sector to look for algae biofuels with greater emphasis. For the sake of simplicity, AquaFUELs uses the term "algae" within the meaning of the "macro-, micro-algae and other aquatic biomass".

In this context, algae appeared to represent the future of biofuels production, among other feedstock types and technological pathways. With the increased attention paid to biofuels sustainability, the assets of algae appeared with greater clarity, in particular their yields significantly higher than terrestrial crops, allowing for low greenhouse gas emissions per ton of biofuel, reduced pressure on land and water, thus decreasing the competition with food production. Similarly to other renewable technologies, the emergence of algae biofuels attracted praises from various commentators due to the many options available to increase biofuels sustainability. In addition to being sustainable fuels, algae biofuels attracted much attention for their capacity to capture undesirable compounds from the air or water, thus offering de-pollution options in addition to their achievements in sustainability.

AquaFUELs gathers a select consortium of researchers and producers focused on looking into the potential of algae biofuels regardless of the current public attention focused on them, in order to provide a realistic assessment of the state of the art on research, technological development and demonstration activities in the field of algae biofuels. Partners: Università degli Studi di Firenze, Diester Industrie International, Wageningen Universiteit, Ben-Gurion University, Almeria University, Roquette Frères, Irish Seaweed Center, University of Gent, Necton-Algafuel, Imperial College, Czech Institute of Microbiology ASCRe; co-ordination: European Biodiesel Board.

The project objectives are to:

1. report on the actual **status quo of algae biofuels**
1. draw up **technological, economic, environmental and social assessments**
1. identify **future research needs** in biology, biotechnology and production pathways
1. contribute to **structuring the algae community** by:
    a. networking with more than 30 ongoing projects covering related issues
    a. creating the European Algae Biomass Association (EABA)
    a. building consensus among major stakeholders

The AquaFUELs Roundtable

The Roundtable is a milestone in the AquaFUELs project. In addition to the scientific significance of gathering international experts to assess the state of the art of algae technologies for biofuels production, the objective of the Roundtable is to analyse the findings of the first half of the AquaFUELs project and to define the great orientations for the further activities until June 2011. Indeed, the state of the art identified during the first half of the project will be instrumental in assessing the sustainability of algae-to-biofuels pathways and identifying the need for further scientific and industrial developments, which will constitute the second half of the project.

The AquaFUELs Roundtable was a great success and 68 participants instead of the expected 40 attended the event. The event brought together prominent researchers and PhD students, start-up companies from the algae sector and biofuels producers, technology providers specialised in specific parts of the processing and public decision-makers for the various end-markets, etc. Meeting in Brussels allowed the participation of representatives from the European Commission and European associations relevant to algae. The recently published FAO report on the potential of Aquatic Biofuels was presented, as well as the International Energy Agency report on the same issue. The AquaFUELs Roundtable also attracted representatives from other projects interested in liaising with AquaFUELs – a direct contribution to the coordination with other research projects, which is one of the project objectives. The AquaFUELs Roundtable was the project's mid-term milestone and succeeded in fostering critical thinking on the state of the art and future perspectives for algae biofuels.

Summary of debates and discussions

The AquaFUELs Roundtable succeeded in stirring critical thinking and reasoning on the state of the art of research, development, and industrial initiatives. A consensus emerged on a number of issues, while on some others diverging views were still observed.

Price

The cost of algae biofuels was generally estimated to be close to 4-5€/kg, while the target price was estimated as 0.4-0.5€/kg. A decrease in price by ten to fifty times was therefore needed to reach commercial viability. Large pilot plants producing *Scenedesmus* and *Dunaliella* reported respectively 8.1€/kg and 17USD/kg (12.4€/kg). It was estimated that the most efficient production facilities for *Chlorella* and Spirulina were located in China, while Philippines, Tanzania and Malaysia achieved production at 1USD/kg. Algae biofuels could not be the only end market due to the low estimated price and that co-products valorisation was necessary. Industry participants questioned the target price usually given for algae biofuels, stressing that the price and market size of biofuels were different from that of crude oil and its derived products. However, the mass production of algae for biofuels, once economically viable, could decrease the prices for products currently sold at high prices.

Algae strains of interest

Among the algae and other aquatic biomass produced for biofuels, the following genera were mentioned: *Scenedesmus, Dunaliella, Phaeodactylum, Nannochloropsis, Haemotococcus,*

Porphyridium, Isochrysis, Pavlova, Chaetoceros, Neochloris, Odontella and Botryococcus, Ulva, Lemna, Schizochytrium.

Production

Optimal conditions for cultivation could be found in Africa and South-East Asia, while Europe and the US were the most active players for research and development. Europe was not regarded as appropriate for algae biofuels production despite its CO2 and wastewater resources due to the competition for land in areas with high sun irradiation. Many announcements exceeded what was theoretically achievable or represented lab scale extrapolations and realistic yields were estimated between 5.5 ton per hectare per year and 80 tons per hectare per year of dry biomass. However, the composition of algae varied greatly between algae and culture conditions, making it difficult to draw clear prospects for biofuels production, whereas the IEA Task 39 report forecasted that in the best case scenario, algae biofuels could replace 5% of global transport fuels by 2030, which would require producing over 66,000 tons of algae biofuels per year. In comparison, the current global algae production was estimated around 5,000 tons for micro-algae. On the opposite, macro-algae production and blooms constituted a biomass sources of several hundred thousands of tons, representing a potential feedstock for biogas production.

Technological bottlenecks

Technological bottlenecks could be found at all steps of the algae biofuels production pathway. The high costs of algae production could be decreased by scaling up and overcoming the bottleneck of harvesting, extraction and dewatering. However, increased productivity through improved biology and biotechnology could also balance the high costs of algae production. In this respect, scientist strongly supported increased use of genetic modification in algae, while public decision-makers and industry representatives deemed it opposed to the legal obligation to produce sustainable biofuels. The price gap between open ponds a and photobioreactors was considered to represent a smaller issue due to the improvements achieved and some photobioreactors were even close to competing with open ponds. Photobioreactors were considered mainly as a way to produce the inoculum.

Legislation

Although algae have been included in the Catalogue of feed materials, Commission called for increased contacts with the algae community and more information on the new feed materials produced from algae, e.g. Schizochytrium. It was suggested to contact the European Food Safety Authority (EFSA) for a scientific opinion of the risks of algae in animal feed. By contrast, it was confirmed that the inclusion of a default value for algae biofuels could not be included in the Renewable Energy Directive on the short term. CEN showed interest in fuel standardisation for algae biofuels, suggesting a workshop agreement if a proper standard was regarded as premature. Available Life-Cycle Assessments (LCAs) for algae biofuels were considered as inadequate and scientifically perfectible, yet often quoted. More generally, the sustainability criteria in the Renewable Energy Directive were considered as disregarding the main sustainability assets of algae: low pressure on water resources and land use and also bio-remediation.

Conclusions and future perspectives

Integrated approaches with other industrial applications

The integrated algae production facilities or bio-refineries were regarded as the best way forward towards economic viability of a wide range of algae products. Several synergies with other industrial applications could be explored, including integrated aqua-agrobiotech approaches or integrated wastewater plants and algae production facilities. Energy-environmental incentives would allow advancing towards algae biofuels production. 2.1€ per kg biomass (dry weight) was deemed achievable by reducing power consumption and scaling up to reduce manpower costs. In this respect, drying algae by using waste heat from the large emitter providing the CO2 was suggested.

Hybrid technologies to combine respective assets

Hybrid solutions were considered likely to bridge economic gaps and to overcome technological hurdles, e.g. filamentous micro-algae combining the biology of micro-algae with the easy harvestability of macro-algae, semi-closed production technologies allowing inexpensive production under controlled conditions, or the coupling of membrane filtration with centrifugation for efficient and low-cost harvesting and water recycling.

Realistic European Life-Cycle Analyses

The need for European LCAs reflecting operations in largest pilot plants to replace the currently available LCAs was stressed. These LCAs would need to be based on the methology of the Renewable Energy Directive, including achieving 50% GHG savings compared to fossil fuels, because meeting the sustainability requirements would be a prerequisite to algae biofuels production. The need for LCAs taking into account the positive sustainability characteristics of algae was also stressed, e.g. the potential negative pressure on land, water and soil from algae cultivation and the extra protein produced.

Refocusing on macro-algae

Macro-algae may have more potential for biofuels than microalgae, with Aresta having performed LCAs and the findings of Alejandro Bushman. Important quantities of macro-algae landing on the coasts of Europe would make it appropriate to produce bio-methane, provided that they come in sufficient quantities.

Improving photobioreactor cost and sustainability

It was deemed unfair to compare photobioreactors developed for 20 years specifically for biofuels with photobioreactors developed for high value components more recently, without regards to costs and sustainability. However, photobioreactor design proliferation was also noted, even without

proper knowledge of material science. As photobioreactors contribute to the energy balance and sustainability of algae, their design is capital and it was recognised that photobioreactors had the greatest prospects for improvement.

Projects relevant to AquaFUELs

The AquaFUELs Roundtable also provided a significant input to the Coordination of Research under Work Package 4 thanks to the information received on the following projects: ALCHEMIS (2010-2012), Photosynthetic Cell Factories, Solar-H and Solar-H2, SUNBIOPATH, Sealand Sole, SUNLIGHT, CO2 fixation, Reactor design, Food and Nutrition Delta, AlgiCoat, Wetsus and AlgaePARC. EnAlgae (2011-2015), BioAlgaeSorb (2010-2013), GIAVAP (2011-2014), BIOFAT, BIOMAP, MAMBO and ALGADISK.

The full presentations are publicly available online: www.aquafuels.eu/meetings

Annex 2 – Summary of the AquaFUELs Final Conference

1. Presentation of the structure of the EC VII Framework Programme AquaFUELs project - organization of the day

Mr. Garofalo welcomed the participants and presented the AquaFUELs project as intended to provide a realistic assessment of the potential of algae as a feedstock for advanced biofuels. Prof. Tredici added that the European Algae Biomass Association would follow-up on the AquaFUELs project.

2. Session 1: Algae to biofuels production technologies

Speaker : Prof. René Wijffels, University of Wageningen

- many barriers to biofuels production from algae still remain
- applied science, e.g. the project algaePARC, is key to break them
- « milking » algae would allow breaking several bottlenecks

Speaker : Dr. Natascia Biondi, University of Florence

- 63 algae strains relevant to biofuels have been identified, either because of their potential or because of their commercial availability
- Integrated fact sheets grouping taxonomy, biology and biotechnology were produced
- The value of co-products can change significantly the economics of algae biofuels
- productivity and robustness are the main criteria for strain selection, in particular photo-inhibition

Speaker : Prof. Sammy Boussiba, Ben-Gurion University

- Growing an inoculum in a photobioreactor and further cultivating in an open pond proves optimal ; 50% production increase can be reached by improving the culture medium
- Stimulating TCA cycles is the key to lipid accumulation, while starvation does not always work
- GMOs could make algae produce lipids continuously, e.g. by continuous Actin OGP-1 production
- EU support to research is key to unlock the potential of algae for all applications

3. Session 2: Micro and Macro algae-to biofuels potential and ongoing activities

Speaker : Dr. Benoit Queguineur, Irish Seaweed Centre

- Algae cultivation at large scale could supply a sudden demand created by sudden shortages on certain markets, e.g. oil schocks in the 1970s, algae shortage due to nuclear contamination
- Large scale algae seaweed cultivation is taking place in Asia today (10 million tons/year in China)
- Seaweed cultivation is already taking place in Europe at smaller scale
- The potential of macro-algae (seaweed) for biofuels/biogas needs to be recognised
- Political and financial support is needed to advance to large scale cultivation

Speaker : Dr. Annick Verween, University of Ghent

- Altough using algae blooms for biofuels would have a positive environmental effect, algae blooms are an unreliable source of feedstock
- Europe has enough CO2 and nutrient sources, but not enough sunlight and coastal land availability, making it a sub-optimal location for biofuels compared to South America /South Asia
- The best location is also dependent on what algae are grown

Speaker : Mr. Pierre-Antoine Vernon, European Biodiesel Board

- Algae stakeholder mapping started with the questionnaire (111), then through the report on main stakeholders (419), to be finally taken over by EABA (1042)
- Refining of the database possibly needed to come up with a genuine Who's Who
- Full detail will be presented at the EABA Conference in November 2011

Discussion: GMO modification can allow modifying 1 to 10 genes, but not to change complex parameters such as resistance to high temperature, which can however be changed through selection of specific algae strains in the wild or selection of mutants showing these parameters from a given strain. The state of knowledge on algae biology can be compared to that of bacteria 20 years ago and much remain to be investigated. Genetically modified macro-algae is used allows better yields. More research is needed for macro-algae, as little research has been done while macro-algae seems to be the most suitable feedstock for biofuels and biogas production. Macro-algae also have better sustainability characteristics because it can be grown at sea. However, the priority is to demonstrate the potential of algae and all options must be pursued to unlock it.

4. Session 3: Overall sustainability and economic assessment of algae biofuels

Speaker : Dr. Raphael Slade, Imperial College

- No efficient conclusion can be drawn from the existing LCA of algae biofuels
- Open ponds show better economic and environmental sustainability than photobioreactors
- Harvesting seaweed from the wild in large quantities could have negative environmental effects

- Economic viability could perhaps be reached if nutrient and CO2 were free and with open ponds
- Under current conditions, producing biofuels from micro-algae seems unrealistic

Speaker : Mr. Vitor Verdelho Vieira, Necton / Algafuel

- Research needs are related to a given application, hence the need for further demonstration
- Controlling heat, carbonation and light is essential
- Most valuable compounds identified in algae do not have an end market
- The greatest potential among energy applications is biogas

Mr. Garofalo announced that all AquaFUELs deliverables would be uploaded on the AquaFUELs website and that the final recommendations would be circulated to all participants. The EABA annual conference on November 29th, 2011 will be followed by a parliamentary evening on November 30th, 2011, where members of the European Parliament will debate on the potential of algae in a low-carbon economy.

5. Session 4: How to co-ordinate future and ongoing European research on algae, what role for EU decision makers, what tasks for the EABA?

Speaker : Dr. Natascia Biondi, University of Florence

- AquaFUELs created ties with many other research projects
- 7 barter agreements were signed formally, but many more are expected
- EABA will take over the cooperation with research projects on algae

Speaker : Dr. Hans Reith, ECN (projects SBIR – EOS LT)

- 2 pilot plants for macro-algae (*laminaria*) currently exist, to be connected to wind farms
- *Laminaria*, containing 60% fermentable sugars, is well suited to biogas and bioethanol production
- a bio-refinery approach could allow valorising valuable co-products
- seaweed could allow unlock the potential of the sea and thus solve a great share of energy needs

Speaker : Ing. Svenja Bierbaum, PTS (project ALBAQUA)

- algae are used jointly with bacteria to degrade paper industry effluents
- using algae makes aeration unnecessary and improves degradation
- algae settling is not stable, sometimes « eaten » by the bacteria

Speaker : Raffaello Garofalo, European Biodiesel Board

- producing algae biofuels requires valorising co-products in large quantities
- A proper LCA is required to eventually have a default value in the Renewable Energy Directive
- The potential of specific strains should be tackled, not algae as a whole
- Standardisation and REACH registration of algae biofuels should start
- Algae biofuels are particularly relevant to aviation

Discussion: many conclusions of AquaFUELs are consistent with the FAO report on algae biofuels regarding the need for valorisation and the need for field data instead of lab scale extrapolation. Algae can both help producing the protein to address the forecasted increase in demand for meat and for energy at global level. There is a need for more pilot plants producing algae biofuels at an affordable rice and sustainably, which means that the net energy ratio must be improved. Avoiding to dry the algae and "milking" the algae could help improving the net energy ratio. More focus should be given to macro-algae.

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