International Workshop
"Aquatic Biomass: Sustainable Bioenergy from Algae?"

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Report on the Workshop Outcomes

prepared by

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This report on the outcome of the workshop draws from the notes taken by the session and working group chairs, and the respective rapporteurs[1].

All discussions were held under the Chatham House Rules[2]. The workshop report is a summary from the organizers' point of view, and does not necessarily express the views of each individual participant.

Presentations made during the plenary sessions of the workshop are available at http://www.bioenergywiki.net/Sus_BioAlgae

Acknowledgements

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We especially thank the German government for sponsoring this event though the two research projects "bio-global" and "conCISEnet".

1 see Workshop Agenda for details

2 When a meeting, or part thereof, is held under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed (http://www.chathamhouse.org.uk/about/chathamhouserule)

Session 1: Introduction

Welcome and Overview of Workshop Objectives

Almuth Jering (German Federal Environment Agency, UBA)

Almuth Jering opened the workshop by welcoming the participants. Then she introduced the objectives of the workshop, i.e. to identify technical opportunities and potentials of bioenergy production from algae biomass as well as related environmental opportunities, risks and their mitigation needs.

Furthermore, she gave a short overview on the background of the Bio-Global project[3].

Aquatic Biomass – Promises and Open Issues: Key Questions for the Workshop

Klaus Hennenberg (Öko-Institut)

Klaus Hennenberg gave a short overview on

- cultivation techniques of algae (open and closed ponds, offshore cultivation),
- world production of algae (about 16 Mio t of macroalgae per year, about 0.01 Mio t microalgae per year) and
- productivity of algae (range from 0.5 to more than 150 t/ha/yr).

Then he drew up four blocks of questions:

- What is technically possible (cultivation, yields, harvest, etc.)?
- What is economically feasible?
- What are related environmental risks (cultivation + down streaming)?
- How to achieve sustainable production?

At the end of his presentation, he summarized the sustainability standards for biofuels at the EU level[4] and related those to algal production, i.e. "no-go" areas for land-based systems (primary forests, highly biodiverse grassland, protection areas, wetlands, forested areas, and peatlands).

For offshore cultivation of macroalgae, protected areas are especially relevant. Furthermore, residues from aquaculture (including land-based systems?) need to fulfill the sustainability criteria.

3 see details in "Sustainable Bioenergy: Current Status and Outlook" http://www.umweltdaten.de/publikationen/fpdf-l/3741.pdf and overall project info: www.oeko.de/service/bio

4 Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC; Official Journal of the EU, June 5, 2009 L 140 pages 16-62 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

Session 2: Status of Algae Research, Activities and Practical Experiences

– 2.1: Microalgae –

Microalgae Biomass for Biodiesel: Reality and Prospects

Prof. Avigad Vonshak (Director, Jacob Blaustein Institute for Desert Research, Ben Gurion University of the Negev, Israel)

Prof. Vonshak started his algae work with Prof. Soeder in Germany. Since the topics in the Agenda of the Workshop stated that most people will present the prospects of microalgae for biofuel, he will talk about problems. He is optimistic but thinks that research and development need to solve the right problems. For example, the design of new photobioreactors (PBRs) is not a priority, because there are already many good ones. Key problems are mainly related to the biology of algae, and the right organisms and the right cultivation procedures are needed. Once it is known which algae to use for a specific task, then the right PBR should be chosen or designed.

Main problems are: nutrient utilization and deficiency.

With the use of wastewater, the problem is that a reduction of the amount of nutrients induces a stress for the cultivated algae. The need to add nutrients to the culture may not fit with the idea of wastewater treatment.

Avigad also pointed out that pond/culture management is critical and that the development of systems with multiple products is needed.

Regarding fact and fictions, Avigad stated:

- Algae are the fast growing organism on the planet, but some bacteria can even grow faster.
- It is true that some algae species have a very fast specific growth rate.
  BUT: The **highest growth rate** is achieved at the **lowest algae concentration**. This is contrary to the aim of high biomass production per area unit.

Further critical points are:

- All / most existing projections are extrapolations, and thus, they are fictional. Most estimates are done with ideal results (e.g. use laboratory scale result for extrapolation; use short term experiment results etc.). Avigad showed the comparison of productivity variation when algae were grown at different concentration and season.
- It is not necessarily true the algae convert sunlight into biomass more efficiently than any other life form. Algae are not necessarily designed to use all of the available light.
- Studies showed that you can have too much light (photoinhibition). Too much light actually reduces productivity. In the desert it gets very cold at night and very hot during the day. Photoinhibition occurs from the morning when temperature is still low and light is already high. Studies showed that productivity of the shaded cultures was higher. Algae with smaller attenna will be useful.
- Cultures cannot be grown at high densities due to the effect of shading. But algae can be selected or modified so that they can be cultivated at higher densities. The knowledge about photosynthetic characteristics of algae needed to be further developed (light saturation curve etc.)
- It is not necessarily true that in extreme environments contamination does not occur. Contamination can be a problem even in *Spirulina* grown at pH of 9-10.

Finally Prof. Vonshak concluded:

- We have to be careful about the huge promises that are being made. Someday we'll have to deliver, won't be able to, and will damage the reputation of algal biotechnology.
- We can't break the laws of thermodynamics.
- We need to learn from the mistakes. Currently we are repeating some of them.

Three years of active research on microalgal biofuel in Europe: Achievements and hurdles

Bruno Sialve (Naskeo Environnement S.A., France)

Bruno Sialve addressed four points in his presentation: (1) projects in Europe; (2) overview of French projects; (3) "Shamash" and "Symbiose" project: objectives and results; (4) conclusion: achievements and hurdles.

Projects in Europe. Based on an investigation of information on studies available on the Internet (project website and reports), Bruno and colleagues identified 104 projects in the world working on microalgae. Most projects are located in the U.S. (about 50%) and in Europe (about 30%). The main differences have been found in the systems to produce energy, and the main difference between the U.S. and Europe is that in Europe projects showed a more academic orientation whereas in the U.S. a focus on is patents and commercialization.

Projects in France. In France, the following projects on microalgae have been recognised: Shamash (INRIA), Symbiose (Naskeo), Algomics (CEA), Biosolis (GEPEA), and Fermentalg (SA). Only the project Winseafuel (Biocar) worked on macroalgae.

Objectives and results from the Shamash project. The Shamash program aims to select adopted species and to understand metabolic and physiological processes. Further objectives are the cultivation of selected microalgae, the optimisation of extraction processes and the characterisation of lipids for fuel. Results of the project are, .e.g., for *Isochrysis affinis galbana*:

- The selection mutation process leads to a 300% increase in total fatty acids produced
- Nitrogen starvation improved lipid production
- If you use natural light cycles under starvation, the lipids are consumed by the cells at night, so you have to harvest the algae before it uses up it's oil

Objectives and results from the Symbiose project

The objective of the Symbiose project was the selection of adapted species/ecosystems to system constraints, the enhancement of biomass conversion into methane, the modelisation and control of the system, and the integration of LCA in pilot scale design and process management. Main results of the project are as follows:

- The use flue gas and organic waste is suitable for algae production (already shown in other studies).
- It is possible to produce methane from any type of algae. Methane production from algal sludge of selected strains range from 0.2 to 0.5 l CH_4/g VS.
- Main recognized limitations for methane production are: high protein content, cell wall resistance and cell survival, and sodium toxicity for marine species.
- Proposed solutions are: selection of adapted species, increase of the C/N ratio (co-digestion or metabolic strategy), and biomass pretreatments (attack the cell wall first).

Finally, he concluded that a main technical challenge is the harvesting of microalgae and the extraction of lipids (high energetic costs). Furthermore, the management of fluxes of nutrient including phosphorus are challenging as well as carrying out studies under more realistic conditions. Future project strategies shall address life cycle analysis (LCA) to guide research and orient towards sustainability, and cultivation under industrial scale. However, lack of investments and qualified experts are main constraints.

Recent developments on microalgae cultivation in Brazil to produce biofuels

Sergio Lourenco (Universidade Federal Fluminense, Brazil)

At the beginning of his talk, Sergio Lourenco gave an overview on global and Brazilian energy demands as well as information on renewable energy production in Brazil in general (sugar cane, soya). However, though Brazil has a long tradition in biofuels, microalgae are just recently being considered for biofuel production. Because the Government is looking for ways to diversify bioenergy production, e.g. by making use of new crops, microalgae are of interest for biofuel production. However, algae for energy is not commercial in Brazil today, but is supposed to be used in the future, and several companies are investing significantly in projects and initiatives to utilize microalgae.

However, Sergio pointed out the following main constraints:

- High cost of production
- Low efficiency of harvesting
- Drying
- Losses in the conversion of biomass into biofuels
- Diseases and contamination
- Water
- Lack of scientific knowledge
- Heavy investments for a higher biotechnological production

Nevertheless, Brazil is one of the favourable regions for microalgae cultivation. And because of the levels of poverty in some areas, algae could help to develop some underdeveloped areas of the country. However, Brazil is not ready for the up-scaling of microalgal production. One point is the lack of national culture collections, but the work has started.

Sergio summarised the current progress in Brazil as follows:

- government is investing in microalgae
- Brazilian teams are networking
- 80 research groups on microalgae are working to produce fuel from algae from the north to the south of the country
- working on PBRs and open systems
- investment in science in Brazil overall is increasing
- next year Brazil wants to invest 2% of internal gross product in science

Finally, he highlighted in his concluding remarks that it is mandatory to diversify the matrix of biofuel production and that bio-kerosen needs to be put on the agenda. Here, microalgae are the most promising source for biodiesel and bio-kerosen. In terms of research, probably no team will get full control of all steps of biofuel production from microalgae, and a focus is needed.

Algae Redux: The return of a US algae R&D effort

John Sheehan (Institute on the Environment, University of Minnesota, USA)

The program of microalgae at the Department of Energy (DOE) goes back more than 20 years, and research already started in the 50's at a university. Researchers looked at algae that produced high amounts of lipids, but they also use the other components of the algae. Furthermore, the idea was to use CO_2 from power plants. The first genetic transformation of algae with potential for biodiesel production was achieved in 1994.

However, in 1996 the U.S. program was ended. In 1998 they produced a close-out report that helped generate a lot of the current interest in algae in the US. It was ended under Clinton during budget cuts when oil prices were extremely low. Their strategic mistake was being honest about needing 10 years to get ready. Meanwhile the cellulosic ethanol producers said they could have 60 cent/gallon cellulosic ethanol by 2000 – which obviously hasn't happened.

In 2007 the US congress increased the mandate for renewable fuel. The great land use debate got started in 2008, which sparked even more interest in microalgae because it may need less land. There are more than 150 companies worldwide investing in microalgae. However, some companies overstate the potentials ("snake oil" salesmen – selling fake promises/technologies) and these companies will hurt the industry.

In 2009 the American Recovery Act was passed and we entered the "too big to fail era." $800 million was allocated for the DOE Biomass Program. $50-70 million was allocated to algae to be disbursed in January 2010 to a research consortium. The US congress also earmarked $35 million of the current biomass budget for work on algae.

John has been working on a "reality check process model" looking at material balances such as water. Evaporative losses are huge and can reach 1,600 kg per kg of algae oil produced. This could be the most important reason for going to a closed system.

Regarding economical aspects, currently a barrel costs more than $1000. This value may get down to several hundred if the productivity is really pushed. However, up to 80% of the costs in Johns calculations are capital costs making cost reductions difficult.

A long timeline is needed to develop biofuels from microalgae, is also concluded in the DOE Algae Roadmap. Nevertheless, several companies are interested in this sector like Exxon and Solix.

Finally, he pointed out that combined systems focusing on at least two different purposes (e.g. fish and algae; waste water treatment and algae) are most promising, especially when high value products are produced for existing markets.

Question: How much evaporation occurs per day?

Answer: John thinks that it's less than one centimeter per day, but he needs to look it up. However, the water use of algae is 2-3 times higher than, e.g., for rape seed.

Microalgae research in Thailand and Southeast Asia

Boosya Bunnag (King Mongkut's University of Technology, Thonburi, Thailand)

In her presentation, Boosya Bunnag focused on the following points: (1) Researches at King Mongkut's University of Technology Thonburi (KMUTT), Thailand; (2) Commercial plants in Thailand; (3) Researches in Thailand; (4) Researches in other South Asian countries.

At *King Mongkut's University*, they are starting to use *Spirulina* because due to its good growth performance, and they are sequencing the genome of *Spirulina*. Work on cultivation management and strain selection is also taking place and workshops with farmers have been carried out. Furthermore they want to use *Spirulina* as "factories" for chemicals.

Regarding other research in Thailand, culture collection of microalgae is underway in Thailand (taxonomy; collecting fresh and marine strains of green algae and cyano-bacteria)

Wastewater Utilization. Took/takes place at:

- Utilization of Tapioca Wastewater-Funded by the National Center for Biotechnology and Genetic Engineering (1986); ran for a few years, but it was decided that it wasn't the core business of the company and the algae required a lot of time, so they shut it down.
- Wastewater from pig farm (KMUTT-Funded by the World Bank, 2007-2008 under the project 'Management of Pig Farm Wastes'). In this project, pig manure is digested, methane is burned for energy, and then the effluent is used for growing *Spirulina*.
- Wastewater from palm oil industry, tuna canning industry
- Microalgae cultivation for shrimp business. It is lucrative to sell microalgae (*Chaetocoeros*, *Skeletonema*) to shrimp farmers for their hatcheries.

Furthermore, there is a small commercial plant near Bangkok. The large scale production plant is located in Chiangmai which is in the north. The capacity of the plant is 60 tons/y but currently it produces only 20 tons/year. The market is health food.

Other ongoing projects are more focused on basic science.

Research in South-East Asia. Most of the research topics are similar to the researches in Thailand (diversity, taxonomy, wastewater utilization). There are not many commercial plants in the region. Most of the commercial plants are located in China, Taiwan and India.

Recently, the Philippines government (Department of Science and Technology, Philippines Council for Aquatic and Marine Resources) granted funding to the University of Philippines Los Banos to study microalgal oil, and in Indonesia, the Bogor Institute of Technology also studies the potential of using microalgae oil and mentioned that Indonesia could be the 'Middle East' of algae oil.

Questions and Discussion of Session 2.1

Moderated by Olaf Kruse (University of Bielefeld, Germany); Rapporteur: Suzanne Hunt (HuntGreen LLC, USA)

First the discussion focused on the need to develop new Photobioreactors (PBR). The developments to control the biological is more challenging and time consuming than developing the needed reactor. Thus, first activities should focus on the biology of microalgae. Nevertheless, there is still the need to make PBR small, smart and cheap.

During the presentations, life-cycle analysis (LCA) was underrepresented, especially comparing algae-based biofuels with fossil fuels. However, it was indicated that bioenergy form microalgae has been shown to reduce greenhouse gas (GHG) emissions up to 50 or 60% compared to fossil fuels.

Regarding sequestration of carbon, microalgae systems capture and utilize CO_2, but this cannot be used for CO_2 sequestration for power plants because there are strong physical and biochemical restrictions (e.g. the need of high amounts of water to clean emissions from coal plants). This topic is more seen as PR and marketing.

It was concluded that microalgae can make a meaningful contribution to the energy mix but cannot do it all by itself.

It was emphasized that we should look at complete systems and to integrate multiple products and services (not only two) to increase market access and economic feasibility of installations.

Session 2: Status of Algae Research, Activities and Practical Experiences

– 2.2: Macroalgae –

Overview on European experiences and projects on mass cultivation of sea-weeds (marine macroalgae) as a renewable energy biomass

Klaus Lüning (Sylter Algenfarm GmbH & Co.KG, Germnay)

First, Klaus gave a comprehensive overview on mass cultivation of macroalgae worldwide. For example, in Brittany, 70.000 t_{FW} are harvested for alginate production and other purposes (wellness products, etc.); Norway harvests 150.000 t_{FW} from the wild for alginate production; in Ireland, this value amounts to 25.000 t_{FW}; and in California, 150.000 t_{FW} are used. In total, worldwide up to 10 Mio t_{FW} are harvested, almost from aquacultures. The capture from natural stands, however, is already restricted in many regions due to ecological problems.

Sushi red algae require quite difficult cultivation techniques and cultivation is labor intensive (4 Mio tons are produced in Japan; 3 Mio tons produced now in China in artificial conditions).

Klaus presented an overview on offshore cultivation practices (rope cultivation, ring systems, systems within wind parks, etc.) as well as for land-based cultivation systems (mainly open ponds). His conclusion was, that both offshore and land-based systems are needed.

Furthermore, Klaus highlighted several studies and reports on the cultivation of macroalgae.

Regarding productivity of cultivation systems, he a calculation that 2.3 kg C m^{-2} $year^{-1}$ is a realistic range that is similar for natural and many microalgae systems. These yields are also comparable to yields from crop production.

Potential and challenges for biofuels production in Latin America (experiences form Chile and Mexico)

Renato Morchio (Sur Solutions, Chile), Carlos Caceres (CELA, Chile)

First, Renato gave an overview on macroalgae-species used (*Lessonia, Gracilaria, Gigartina, Sarcothalia, Mazzaella, Macrocystis, Chondrus, Porphyra, Callophyllis, Durvillaea*, etc.) and on their production in South America. In total, annual production of macroalgae is highest in Chile (400.000 t), followed by Peru (14.000 t), Mexico (10.400 t) and Argentina (2.320 t).

Then, Renato showed slides regarding cultivation and harvesting techniques. Though there have been improvements during the last years (e.g. production of 1.500 m of *Gracilaria* rope per hour with tow workers; 20.000 m needed for one ha), he pointed out the need of further development.

In Latin America, macroalgae are used for various products like food, vitamins, fertilizers, stimulants and animal feed.

In Chile, the fuel market depends 98% on imports, and the government is looking for alternatives that don't require large tracks of land. The meadows of macroalgae such as *Macocystis* currently represent a resource with high development potential.

In Mexico, a project aims at producing biodiesel from *Salicornia* (a freshwater macroalgae which can tolerate salt). Cultivation is planed to take place in a desert area where seawater is available (investment of US $35 Mio).

Renato highlighted the potential along South American coastlines to produce macroalgae for bioenergy production. The most suitable conversion techniques are alcoholic fermentation or biogas production. For example, 1000 kg of wet macroalgae (about 100 kg DW) can be converted to 15 l of ethanol.

With a price of $1.1 per l, 15 l of ethanol (produced from 1.000kg) would reveal an income of $16.5. For animal food, from 1.000 kg, an income of about $127, and for alginates one of about $400 can be generated. Thus, the lack of economic feasibility is a major barrier for bioenergy from macroalgae.

Pulp and Paper - Bio-ethanol made from Red Algae (Korea)

Hack-Churl You (1Pegasus International Inc., Korea)

1Pegasus has established the use of red macroalgae to produce paper at a business scale. The advantages of red algae are:

- Comparable high amount of fiber and carbohydrate.
- The processing of red algae requires 20% of the process energy compared to wood, and GHG emissions are reduced, respectively.
- Replacing wood cutting with the algae for pulp for paper.

The process of paper production compromises cleaning, then boiling, agar extraction, 1st and 2nd bleaching.

Cultivation carried out in Indonesia since 2006 based on an agreement with the Indonesian government. Because they were not able to achieve expected / required yields in Korea, they moved cultivation to Indonesia in regions with warm water (doubling time of 30 days). They only cultivate species that contain fiber, and currently, they are developing better strains for the red algae.

For cultivation, they use anchored structures in shallow water and lines in deeper water. The cultivated macroalgae can grow year round in tropical waters. Once the algae are established, harvest takes place about every 70 days when mass accumulations gets saturated, and then the algae regenerate from remaining material.

Bioproducts from red algae also include different sugars, and they started to produce ethanol from this resource as a new field of their company.

Questions and Discussion of Session 2.2

Moderated by Olaf Kruse (University of Bielefeld, Germany); Rapporteur: Suzanne Hunt (HuntGreen LLC, USA)

The short discussion focused on environmental risks on coastal areas. Also technical problems that can occur under rough wind and wave conditions have been addressed. In consequence, potential areas for offshore cultivation may be limited.

In addition, for the near future it appears hard to achieve a cost effective way to produce energy from algae at the large scale.

Furthermore, the potential to obtain macroalgae as a by-product of aquaculture was highlighted. Aquacultures release millions of gallons of wastewater. The controls are tightening in some places like Denmark. In future, the fish farmers will be forced to keep the nutrients out of the sea and macroalgae cultivation may be a solution for this problem.

Environmental challenges of algae biofuels

Catherine Ryan (Terrapin Bright Green, USA)

Catherine presented the main results of their study "Cultivating clean energy: The promise of algae biofuels." The aim of the study is to identify those environmental issues that should be considered when developing algae projects.

Within the study, the production chain was divided in five steps: (1) algae cultivation; (2) biomass harvesting; (3) oil extraction; (4) oil and residue conversion; and (5) bi-product distribution. For each step of the production chain the relevance of the following three points was analysed:

- Core environmental areas (water, land, air, soil, biodiversity, and energy)
- Environmental impacts (benefits, concerns, unknowns)
- Environmental relationships (process, input, output, scale)

The study mainly outlines systems and potential problems that may occur. However, today sufficient data are not available to calculate, e.g. energy- or water-balances. Nevertheless, producers should use this framework to incorporate environmental aspects into their projects.

WORKING GROUP 1: MICROALGAE (SESSION 3 & 4)

WG Chair: Christian Wilhelm (University of Leipzig, Germany); WG Rapporteur: Boosya Bunnag (King Mongkut's University of Technology, Thailand) and Suzanne Hunt (HuntGreen LLC, USA)

Session 3: Potentials, Economics and Perspectives (WG 1)

Input statement: Energy Efficiency and Potential

Anja Eggert (Leibniz Institute for Baltic Sea Research Warnemünde, Germany)

Anja explained on the basis of an energy flow chart for *Phaeodactylum tricornutum* where and how different losses of light energy occur along the biomass production process. She pointed out that:

- Based on incident light (QPAR), potential photosynthetic efficiency of microalgae is typically not higher than 5%.
- All information with higher values must be evaluated very critically!

Furthermore, Anja stressed the point that in algal culture, additional loss of light due to light absorption (shading) is common. Turbulent flow, e.g., in closed systems, however, creates high energy costs.

Regarding estimations on potential yields, Anja highlighted the problems of extrapolation for up-scaling. Extrapolations / calculations are often based on achieved biomass yields during a short time period (e.g. a few weeks during midsummer), and extrapolation from small-scale laboratory systems or pilot plants to large-scale commercial plants is critical.

Nevertheless, there the high phylogenetic diversity of algae offers many opportunities, and one change is to improve the communication between all partners (phycology-experts, technical engineers, bioenergy-producers, etc.) to improve systems.

Input statement: Technical and Economic Restrictions

Otto Pulz (Insti-tut for Cereal Processing IGV, Germany)

Otto focused his input statement on technical and economic restriction. Today, tubular photobioreactors are not economically feasible for biodiesel. Cheaper-mobile reactors are under development and in the test phase to use flue gas of different origin.

Than he gave a short overview on yields reported in the literature, that need to be evaluated very critically, and showed estimates for possible increases in solar radiation conversion efficiency that would result in yield increases.

Finally he stated that still a lot of research is needed regarding efficiency, processes, fluxes, harvesting, refinement (e.g. oil), integrated concepts as well as scalability.

Session 4: Environment and Sustainable Use (WG 1)

Input statement: Example of combined production of materials and energy

Jorge Kaloustian (Oil Fox, Argentina)

Jorge gave an overview on algae production carried out by Oil Fox. The main point of this presentation was that Oil Fox combines the production of high value algal materials (e.g. dietary supplements) with biofuel production. By doing so, they are able to achieve strong improvements for environmental aspects (nutrient cycles, reduced GHG emissions, waste water treatment, etc.). Furthermore, Jorge showed that their production system is economically feasible.

Working Group 1: Results and Discussion (Session 3 and 4)

During the discussion in the Working Group 1, topics of Session 3 and 4 were combined and the results of both Sessions presented together. The following topics were addressed:

Possibilities for optimization

Optimization is especially needed to achieve maximum productivity and maximum utilization of light. Central points are:

- The biology (cell physiology-small attenna, resistance to daily variation of light and temperature); these point are mainly a matter of improvements of photosynthesis (see below).
- Pond management (when to harvest, nutrient flow, etc.). Optimum conditions in the laboratory only exist for a short amount of time during the day. The concentration of maximum light utilization may not be the same as the concentration of maximum productivity.

Are smaller units of PBR more flexible?

Many small modular systems are working better than huge ones. This can be especially of interest because several available land areas are relatively small and distributed across the landscape. Processes like conversion to fuel may still be centralized.

However, for smaller units scalability may be problem, especially due to higher cost caused by additional technical infrastructure for harvest and refinement and operating problem (e.g. instead of analyzing nutrients in a one large reactor, you will have to analyze them 10 different times).

Furthermore, PBRs should be build up rather than build across the surface. But, due to shading, it may not be possible to put each reactor close to the others.

How to improve photosynthesis?

The improvement of photosynthesis could be achieved via genetic modification of organisms (GMO) or via the selection of strains of algae.

Regarding GMO, it was stated that it is difficult to control metabolic-flux without using GMO. But most genetically transformed algae are not stable (the Cyanobacteria (*Anabaena*) is OK), and more study is needed in this area of research. However, even in the US there is agreement that transgenic algae in open systems are a problem. In addition, also closed systems are not closed hermetically, so from a GMO standpoint they are as good/bad as open systems.

Regarding stain selection, the huge diversity of algae is not yet used. Already available strains in culture collections need to be screened with modern technologies, and a focus on cultures from extreme environments may especially be promising. The need to develop a data sheet as platform for screening algae was mentioned.

Refining

Refining could focus on lipids or on carbohydrates. The accumulation of lipids always slows down growth. Thus focusing on carbohydrates (e.g. ethanol production from sugar) promises better energy balances.

In case of biogas production from algae cleaning of biogas is needed (e.g. hydrogen sulfide).

Water management

Improvement of water management practices is a central issue when producing microalgae. Water management can be hugely energy intensive. Criteria for optimization may be the optimization of processes, optimization of costs, and the scalability.

Where do you get the land/space?

The land issue is important. In Europe, bare land or poor quality lands are difficult to find. The desert may be ideal. In the US, displays of solar panels is already causing concerns and they are more efficient at producing energy than algae. The area for algae cultivation will be much larger. However, apart from energy, algae production may also provide other products and services like food and CO_2 absorption.

CO_2 and other Greenhouse Gas Emissions (GHG)

In general, CO_2 is recycled in algae, not sequestered. CO_2 from flue gases can be an additional source for required CO_2, but the transport of flue gas is not economically feasible. Brazil has experimented with the use of CO_2 locally (close to the site of emission, e.g., brewery, winery, cement production). This may be feasible.

However, an additional CO_2 source is often not needed. A significant amount of biomass production can already be achieved just by mixing CO_2 from the atmosphere, depending on species and pH of the culture medium. Often light and biomass are the limiting factors. In addition, the growth rate is limited by enzymatic up-take.

Regarding GHG, balances have not been developed yet and will be an important challenge. Depending on the conditions in ponds, especially nitrous oxide may be significant.

Economics

Today, energy production from microalgae alone is not economically feasible. This is mainly due to capital of up to 80%. However, if the capital costs are paid off, e.g. due to the production of high value products, the costs for energy will be much lower.

WORKING GROUP 2: MACROALGAE (SESSION 3 & 4)

WG Chair: Klaus Lüning (Sylter Algenfarm GmbH & Co.KG, Germany); WG Rapporteur: Renato Morchio (Sur Solutions, Chile)

Session 3: Potentials, Economics and Perspectives (WG 2)

Input statement: New uses and potentials: Macro-Algae as Bioproducts & Bioenergy
Roberto Marcos (Consultora Los Lagos, LTD / Algamar, S.A., Mexico)

Roberto gave information about the use of macroalgae as bio-products like bio stimulants and grow promoters (agricultural use), inmuno-stimulants, natural binder and additive for animal feed and inmuno-products for human consumption. He spoke about the techniques used in Mexico to harvest macroalgae (especially *Macrocystis* and giant kelp) and to transform algae to bioproducts. Furthermore, he gave information on experiments on the production of bioenergy. One of the interesting points was the use of big harvester boats to harvest kelp, cutting only the canopy of them, obtaining big quantities of biomass without damaging the environment (sustainable harvest) and the use of technology to produce spores of *Macrocystis* cultured in laboratory for offshore cultivation.

Input statement: Perspectives in developing countries
Alessandro Flammini (GBEP Secretariat, FAO, Italy)

Alessandro summarized the points of view of FAO to achieve a sustainable biofuel development. He spoke about ensuring environmental sustainability, investing in rural development and innovative production, protecting poor people against food insecurity, adjusting current biofuel policies and coordinating domestic bioenergy policies/strategies. Alessandro gave an overview about key problems and challenges regarding the cultivation of macroalgae for biofuels (e.g., use of algae as a food product; natural harvest is unsustainable to produce biofuels in a large scale; cultivation is labor intensive often resulting in low incomes; use of offshore infrastructure; use the anaerobic digestion to produce biofuels).

Finally he spoke about the outcomes of the algae based biofuels. It seems that the production of algae for biofuels can be promising for developing countries, but not in the short or medium term. Furthermore investments and technology capacity are required (not suitable for lower income countries). Alessandro pointed out the importance of developing more knowledge regarding production and technology. Due to limited industrial scale experiments, productivity data are often extrapolated form experiments and analysis. In addition, energy and GHG balances as well as further sustainability assessments need to be carried out.

Session 4: Environment and Sustainable Use (WG 2)

Off-shore cultivation of macroalgae – risk for eco-systems and biodiversity
Ariane Breucker (Federal Agency for Nature Protection BfN, Germany)

Ariane informed about the importance of macroalgae in limited and sensitive ecosystems, as a nursery for diverse aquatic organisms, habitat for sensible species, and fragility of this systems. She mentioned the significance of carry out an Environmental Impact Assessment (EIA) to know the expected impact of the activity in the environment and to carry out the project only if the EIA result is positive (no damage to the ecosystems, no introducing alien species, no changes in the cultivation area, etc).

She spoke about the importance of not developing projects in protected areas (should not be allowed) and some results for certain institutes who find that the cultivation can bring some problems in sensitive marine habitats. In a case study of the Institute Biofino they described that the characteristics of the habitat changed drastically, reducing species, nitrification of the systems and the habitat finally complete changed.

Working Group 2: Results and Discussion (Session 3 and 4)

Natural resources of algae can, in principle, be managed sustainably. In Baja California, sustainable harvests of algae were carried out for many years employing big harvest ships cutting up to 800 t/hour of kelp. During the past few years, aerial prospection and evaluation determined no overexploitation of the natural kelp resources, the production was based on the sustainable management plans.

It is very important to take into account economical, social and environmental evaluations before using natural resources such as offshore kelp stocks and to implement sustainable exploitation of these natural resources.

The procedures of macroalgae production can be improved using low cost systems considering especially the seeding and the harvest of macroalgae. For example, to plant one hectare of macroalgae regularly, 15 persons and two days of work are required. In the case of an effective low cost system (e.g. harvesting machines instead of manual labor) the seeding can be carried out within one day by only two persons.

Macroalgae can be used to reduce the sea waters` nutrient loads. To reduce waters` nutrient loads algae can be used as biofilters in aquaculture systems or considering effluents` treatments in regard to high load of nitrogen and phosphates.

The culture, harvest and economical feasibility of an operation depend strongly on the applied production procedures.

In countries such as Mexico that provide great natural resources of kelp, developing additional kelp aquaculture systems is not necessary.

In countries such as China that provides cheap manual labor there is no need to implement the use of mechanical harvest systems due to increased production costs. Every producer should analyze the overall situation referring to the advantages and disadvantages of the local conditions to manage the operation in a sustainable and competitive way from the economic and environmental point of view.

Sustainability of natural resource exploitation should be an obligatory basic condition due to the fact that in some countries the lack of regulation and control caused overexploitation of macroalgae stocks resulting in social, economic and environmental damages and problems.

Biofuels should be considered as by-product of the process. In case that the process does only involve the production of one single product it is very difficult to produce in an economically feasible way (maximal potential of the production process is not reached). For this reason some companies focused on the production of multiple products (biodiesel, bioethanol, biogas, feed supplements, fertilizers, carbon bonus).

Future perspectives:

At the moment, there is no development in the EU to use macroalgae, neither in offshore wind systems nor for the use as biofilters (reduction of N and P) in aquaculture systems.

In general, there is no macroalgae producer so far that used genetically modified organisms (GMO). However, in some countries there is no restriction for the use of this technology and possibly the production of GMO macroalgae could become more prevalent. Until now, genetic manipulation has not been necessary, because the natural stocks provide good genetic pools. In Korea, for example, macroalgae can be imported from other regions to improve the genetic characteristics and the production yields.

The biogas (methane) obtained from macroalgae seems to be a very good option to produce energy due its simplicity, low production costs and gas yield. Biomethane can be sold or used as power supply in the own processing plant. Moreover, the by-products of fermentation can be further processed to obtain products with higher economic value.

Still, the overall energy and GHG balances of macroalgae energy systems are not yet known, and the recycling of the fermentation residues are an open question as well.

Session 5: Next Steps / Future Challenges

A number of key concerns and future challenges were discussed including:

- Interference in natural ecosystems. With harvesting macroalgae for example, we'll invade some environments. So we need to understand how they will be changed. And we need to bring in the social/job creation aspects. CBD highlights coastal areas as critical areas.
- Energy Balance. To what extent can we use the energy in the algae? What is the energy balance? The concern was raised that the LCA energy balance of existing algae to fuel production systems is negative. The point was made that energy balance is one of many metrics to evaluate, especially if the systems are providing other, non-energetic benefits, such as nutrient reduction in waste waters, and by-products.
- Excess nutrients in seawater. The concern was raised that extracting nutrients from seawater using algae is a concern, because the priority should be on preventing excess nutrients from reaching the sea in the first place.
- Promise vs. potential. What is the promise vs. what is the potential? The potential can be proved.
- Dramatic improvements needed. The point was made that algae to fuel yields need to improve by a factor of 10 or 20.

Uwe R. Fritsche (Öko-Institut) summarized the outcome of the workshop, noting that UNEP is working to develop sustainability criteria for investments in bioenergy for the Global Environment Facility.

He included comments about potential next steps, especially to make the workshop results known to a broader audience bioenergy Wiki, (e.g. in publish articles in journals, etc.).

Key next steps:

- Start LCA for algae, following the Terrapin Bright Green/NRDC initiative.
- Identify where the key losses in efficiency are.
- Look more at hybrid systems.
- We have different systems that we're trying to optimize. If you look at the whole system from the photon to the products, it all must be higher efficiency than other systems that achieve CO_2 reductions. We should identify the important bottlenecks. We should not just optimize what we know, but rethink and invent new systems. We need at least an improvement factor of 10.
- Develop criteria for optimization. We should weigh different parameters.
- As we look at sustainability issues, we need to do it on a "what if" basis. We should look at best available scenarios for small and large systems. Allow policymakers to develop a framework for this.
- There is a need for more interactions like this workshop.
- The upcoming call of the EU's 7th Framework Programme was mentioned, and respective info made available[5].

5 Renewable Fuels 2010 FP7 ENERGY Call Topic Energy.2010. 3.4-1: Biofuels from algae. For additional information please contact Mr Kyriakos Maniatis kyriakos.maniatis@ec.europa.eu