Biofuels from microalgae - current status and way forward

Jukka Seppälä
Finnish Environment Institute, SYKE
Marine Research Centre
jukka.seppala@environment.fi
**Microalgae**

**Phytoplankton algae**
- Unicellular or filamentous
- Size: 0.5-100 µm
- Aquatic
- Photosynthetic
- >50000 species
- Genetic & physiological diversity

**Growth requirements**
- CO₂, N, P, (Si), micronutrients
- Light

**Compared to higher plants**
- Minimal amount of structural components
- Fast growing
Why biofuels?

**History of the Age of Oil**

- Biofuels? *With conventional techniques, to replace all fossil fuels with biofuels, we need altogether 5 Planet Earths.*
- Origin of fossil fuels: Oil and natural gas mainly from plankton organisms (algae, zooplankton)
- Storage of sun energy, stored for 50-350 million years. Can we speed up? Is it realistic?
Microalgae for biofuels

- High production potential of algae (up to 20-70 g Dry weight m$^{-2}$ day$^{-1}$).
- High lipid content of algae (30-50% (-80%) of Dry weight).
Microalgae cultivation

- For commercial use microalgae must be cultivated.
- Harvesting of natural microalgae is not economically viable.
- Cultivation in open ponds or in photobioreactors.

[Images of microalgae cultivation facilities]
Economics of microalgae cultivation

- Microalgae cultivated worldwide >5,000 tonnes of dry weight
- Approx. commercial value of € 1250 million (= 250 € / kg)
- Main products: carotenoids, ω-3-fatty acids, aquaculture feed
- Costs are too high for bulk products like biofuels

- No large scale production, no true estimates of production costs
- Estimate of the minimum price with current technology 5 € / kg
- Significant decrease in price if CO₂ and nutrients are free (use of waste stream)

Data: Norsker et al. 2011
Decreasing costs of cultivation

Decreasing major costs

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Means of Decreasing Costs</th>
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<tbody>
<tr>
<td>Labour</td>
<td>Automation of cultivation, scaling-up of processes, location of cultivation site</td>
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<tr>
<td>Cultivation equipment</td>
<td>New technical solutions for photobioreactors, finding robust algae strains</td>
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<tr>
<td>Mixing</td>
<td>Finding new energy saving methods for mixing</td>
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<td>( \text{CO}_2 )</td>
<td>Use of flue gases, recycling ( \text{CO}_2 ) (e.g. in algae biogas plants)</td>
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<td>Fertilizer</td>
<td>Recycling of major nutrients, use of waste streams</td>
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<td>Light</td>
<td>New innovations for distributing light in culture vessels</td>
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<td>Water</td>
<td>Recycling of water</td>
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<td>Photosynthesis efficiency</td>
<td>Increase of efficiency by strain selection or engineering</td>
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<tr>
<td>Content of end-product</td>
<td>Increase of efficiency by strain selection or engineering</td>
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<td>Harvesting</td>
<td>New low-cost technology innovations</td>
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<td>Extraction</td>
<td>New solutions to extract end products</td>
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<td>Side products</td>
<td>Optimising algae production in biorefineries</td>
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<td>Ecosystem services</td>
<td>Finding correct prices for nutrient and ( \text{CO}_2 ) recycling</td>
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Biorefinery concept
State of the art

- Algae is on political wish list, considered as a part of the solution on our way towards sustainable bioeconomics
- Support for research at various levels
- No holistic view in EU, or roadmap, available
- Various stakeholders, partly competing & overlapping actions (industry lead projects)
- Hype and greenwashing existing

- Pilot scale activities existing
- New technical solutions emerge
- Biological engineering
- LCA, techno-economical models
Major gaps in knowledge

- Availability of nutrients, CO₂ and water while upscaling the production.
- Technical solutions in cultivation, harvesting and processing of microalgae biomass.
- Uncertainties in economic analyses.
- How to integrate with other commercial activities
- Sustainability and constrains of biomass productivity in large production units is unknown.
- How the prices of other energy forms and fertilizers affect the profitability of microalgae production.
- Environmental impacts not fully resolved as fullscale units not yet planned.
Regional aspects

- Solar irradiance
- Temperature
- Precipitation/evaporation
- Severe weather conditions
- Water availability
- CO₂ availability
- Nutrient availability
- Land availability
- Availability of skilled personnel
- Cost of labour and other services
- Transport facilities
- Downstream processing of biomass
- Markets for main products
- Socioeconomic stability
- Legal aspects

Figure 8. World map of algae biomass productivity (tonnes/ha/year) at 5% photosynthetic efficiency considering an energy content of 20 MJ/kg dry biomass.
Actions in Baltic Sea Region

- Funding of high quality research
- Networking & support for public-private partnerships
- International cooperation
- Pilot sites
- Algae cultivation R&D for high value compounds
When algae biofuels enter market?

1900

2000

2000

2???