Economic aspects of open ocean seaweed cultivation

Jip Lenstra, Jaap van Hal, Hans Reith,

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Alg’n’ Chem 2011, 7-10 November 2011, Montpellier, France
Aquatic biomass energy potential

<table>
<thead>
<tr>
<th>Most feasible technical concepts</th>
<th>Area</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1: Land based open ponds for microalgae</td>
<td>Arid land in (sub) tropical zones (deserts) and close to coast (max 100 km)</td>
<td>90 EJ</td>
</tr>
<tr>
<td>Set 3: Horizontal lines for macroalgae</td>
<td>At existing infrastructure – f.e. offshore wind farms (up to 100 km offshore)</td>
<td>110 EJ</td>
</tr>
<tr>
<td>Set 5: Vertical lines for macroalgae</td>
<td>Near coast (max 25 km) in nutrient rich water</td>
<td>35 EJ</td>
</tr>
<tr>
<td>Set 6: Macroalgae colony</td>
<td>At open sea (biological deserts), up to 2000 km offshore</td>
<td>~6000 EJ</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>~ 6235 EJ</td>
</tr>
</tbody>
</table>

Source: Ecofys. World energy consumption: 480 EJ/yr
The role of aquatic biomass for energy production

• Large scale & low costs required

• Micro algae are probably too valuable

• Seaweed in wind farms (North Sea) could be feasible combined with extraction of alginates

• Seaweed from ocean farms seems most promising for large scale biofuel production

<table>
<thead>
<tr>
<th>Value in $/ton dry seaweed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
</tr>
<tr>
<td>Pharmaceuticals, phycocolloids</td>
</tr>
<tr>
<td>Chemicals</td>
</tr>
<tr>
<td>Ethanol</td>
</tr>
</tbody>
</table>

Market volume
Many ocean farm concepts proposed

Figure 3: Conceptual design of a 405 ha (1,000 acre) ocean food and energy farm unit. (Leese, 1976)

Leese, 1976

TU Delft, 2008. Without enclosures, nutrient upwelling

Ecofys, 2008

ECN, 2009, PE enclosure

Kaare Baekgaard, Dk, 2010

http://www.idesign.li/Welcome/Services/Public.htm
http://www.youtube.com/watch?v=xwV1sciDDUA
ECN proposal

- The ocean gyres as location
- Not much current
- Sargasso seaweed has attractive properties (fast growing, floating, global occurrence)
- *Sargassum natans* uses nitrogen fixation by an associated epiphyte or cyanobacteria (Philips et al, 1986)

A spiral oceanic surface current driven primarily by the global wind system and constrained by the continents surrounding the three ocean basins (Indian, Pacific, Atlantic).
Ocean potential: >25,000,000 km²

Current global agricultural crop area: 15,000,000 km² (FAO, 2006)
Sargassum natans

- Sargassum seaweed is now a pest (on shores)
- It forms also a good habitat for fish and many other species
- It can be monitored by satellite (MERIS)
Ocean farm concept ECN

- Open farm seems most promising
- Farm location in gyre areas marked with buoys (ownership)
- Seeding with small fragments of *Sargassum natans*
- Selective fertilizer (no nitrogen) for *Sargassum natans*, slow release
- Selective harvesting (no fish or turtles)

Concept for offshore open ocean farming (Herfst, TU-Delft, 2008)
Harvesting and logistics

- Mass flows comparable to dredging ships
- (Partial) dewatering at sea (pressing)
- Further processing on shore (biorefinery)
- Ecological uncertainties: effects on marine ecosystem
- Much more research is needed
Advantages

- No road transport involved until after refinery
- Large scale shipping and harvesting possible
- No costs for surface use
- No fresh water use
- No land owners
- Fast growing species
- Abundant CO2 available

Disadvantages

- Ecological constraints
- International conventions
- No protected ownership
- Harsh conditions
- Long distances
- Very wet biomass
Cost estimate (preliminary)

- Scale: one harvester\transporter Aframax size (80.000 ton)
- Assumed seaweed density: 10 ton/ha (dw)
- Harvesting capacity 3000 ton/hr (wet)
- Ship rent and fuel costs: 0,3 €/ton/day

<table>
<thead>
<tr>
<th></th>
<th>US-harbor (500 km)</th>
<th>Rotterdam (6000 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass in harbor (dw)</td>
<td>12 €/ton</td>
<td>35 €/ton</td>
</tr>
<tr>
<td>Ethanol plant (on shore)</td>
<td>0,15 €/ltr</td>
<td>0,15 €/ltr</td>
</tr>
<tr>
<td><strong>Total ethanol costs</strong></td>
<td><strong>0,20 €/ltr</strong></td>
<td><strong>0,27 €/ltr</strong></td>
</tr>
<tr>
<td>Market value ethanol*</td>
<td>0,60 €/ltr</td>
<td>0,60 €/lr</td>
</tr>
<tr>
<td><strong>Total per liter petrol eq</strong></td>
<td><strong>0,29 €/ltr</strong></td>
<td><strong>0,40 €/ltr</strong></td>
</tr>
<tr>
<td>Market value petrol</td>
<td>0,50 €/ltr</td>
<td>0,50 €/lr</td>
</tr>
</tbody>
</table>

* 750 Euro/tonne ethanol
Seaweed to reduce the garbage patches

• Low density and small particles (density 5 ton/km$^2$, 5 gram/m$^2$)
• Methods to collect the garbage are expensive
• Collection together with seaweed could be possible with little extra costs
• App. 0.25% of dry mass would be garbage
Composition of *Sargassum natans* as reported by some studies.

**Sargassum fluitans** and *S. natans*

Photo: [http://www.tamug.edu/rooker/coastal.html](http://www.tamug.edu/rooker/coastal.html)

<table>
<thead>
<tr>
<th>Composition</th>
<th>S. natans + S. fluitans, Arabian Gulf (Kamel, 1980)</th>
<th>S. natans, Guangdong, China (Wang et al, 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Protein (% dry matter)</strong></td>
<td>6.59</td>
<td>9.6</td>
</tr>
<tr>
<td><strong>Lipid (%)</strong></td>
<td>0.54</td>
<td>1.39</td>
</tr>
<tr>
<td><strong>Carbohydrate (%)</strong></td>
<td>76.43</td>
<td>63.97</td>
</tr>
<tr>
<td><strong>Phosphorus (%)</strong></td>
<td>0.0818</td>
<td></td>
</tr>
<tr>
<td><strong>Potassium (%)</strong></td>
<td>19.56</td>
<td></td>
</tr>
<tr>
<td><strong>Energy (MJ/kg dry matter)</strong></td>
<td>14.1</td>
<td>8.68</td>
</tr>
</tbody>
</table>
**S. natans** proteins compared with soy beans

**Sargassum natans**
- 6.6% (dw) proteins o.w.:
  - Methionine 2.3%
  - Lysine 4.5%
  - Threonine 3.8%

Source: Basil S. Kamel (1980)

**Soy beans**
- 36.5% proteins o.w.:
  - Methionine 1.4%
  - Lysine 7.4%
  - Threonine 4.9%

App. 5 ton dry *S. natans* could replace 1 ton soy beans for feed
Ocean seaweed to fuel chain

1. Seeding, fertilizing, marking with buoys

2. Harvesting

3. Dewatering, transport

4. Unloading, separating plastics and proteins, production of ethanol, CO2 and minerals.

Plastic garbage

Shell, AB Rotterdam deliver CO2 to OCAP > horticulture

Fertilizer

Cattle feed

Biofuel

CO2 storage

E85 85% Ethanol
Conclusions

• Seaweed from ocean farming is a promising source for biofuel production with low costs and a large potential.
• Seaweed could be a large source of proteins for cattle and fish feed.
• Seaweed could help reduce ocean garbage and acidification.
• Ecological benefits and risks need to be balanced.
• Independent ecological assessment required.
Thank you for your attention

Contact
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Potential energy carriers from seaweed

- Ethanol, butanol from sugars ($\geq 60$ wt%) via fermentation
- Diesel and jet fuel via Aqueous Phase Reforming technology
- Bio crude via HTU
- Methane via anaerobic digestion
ECN activities on seaweed

- Bio Offshore 2005
- EOS-LT seaweed biorefinery
- SBIR-1 feasibility study
- SBIR-2 pilot cultivation
- At~Sea Advanced textiles (FP7)
- Mermaid (Multi-use offshore platforms, FP7)
- Main interest of ECN is conversion to energy!
Scale similarity agriculture/aquaculture

- greenhouse horticulture
- open field horticulture
- farming
- large scale farming
- photo bioreactor
- open pond aquaculture
- seaweed farming
- ocean farming
Seaweed to reduce ocean acidification?

- Ocean CO2 uptake 2.4 GtC (8.8 GtCO2) per year
- Production of app.15% of world energy consumption with ocean biomass would be needed to compensate
- High yields (ton/ha) and large area will be needed (10 dm t/ha, 20 mln km\(^2\))
- Ocean biomass could help but not enough to solve the problem