Economic aspects of open ocean seaweed cultivation

Jip Lenstra, Jaap van Hal, Hans Reith,

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Energy research Centre of the Netherlands

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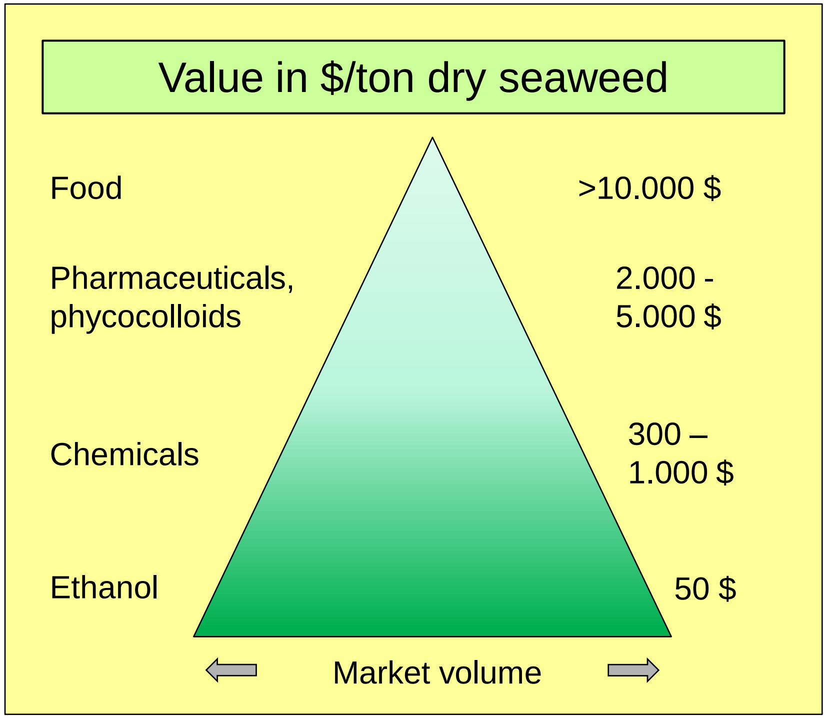
Aquatic biomass energy potential

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

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



Many ocean farm concepts proposed

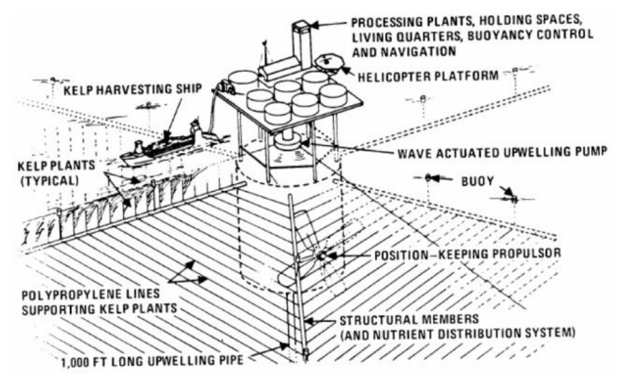
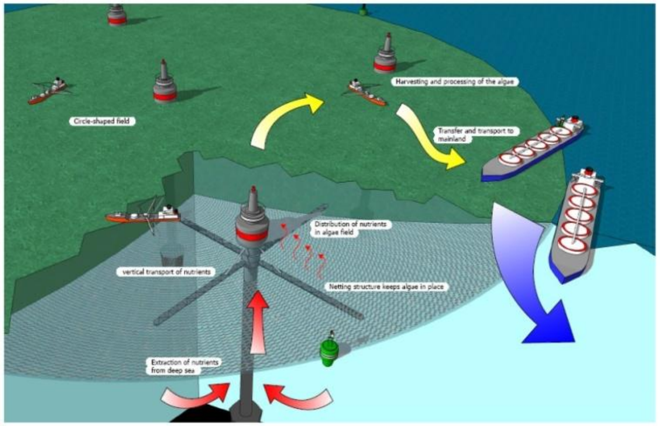
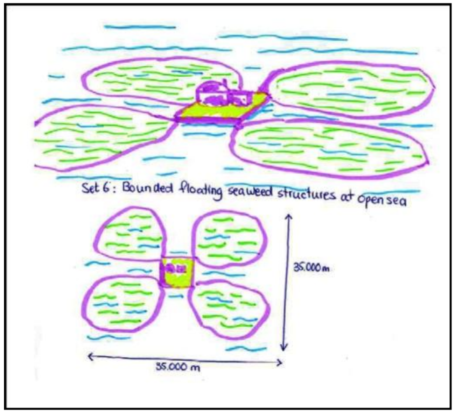


Figure 3: Conceptual design of a 405 ha (1,000 acre) ocean food and energy farm unit. (Leese, 1976)

Leese, 1976

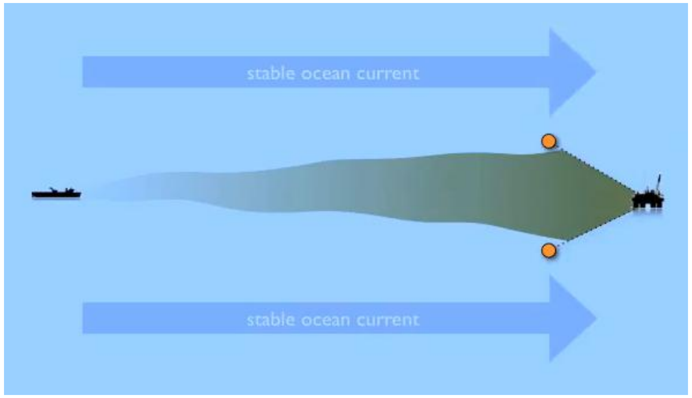


TU Delft, 2008. Without enclosures, nutrient upwelling



Ecofys, 2008

ECN, 2009, PE enclosure



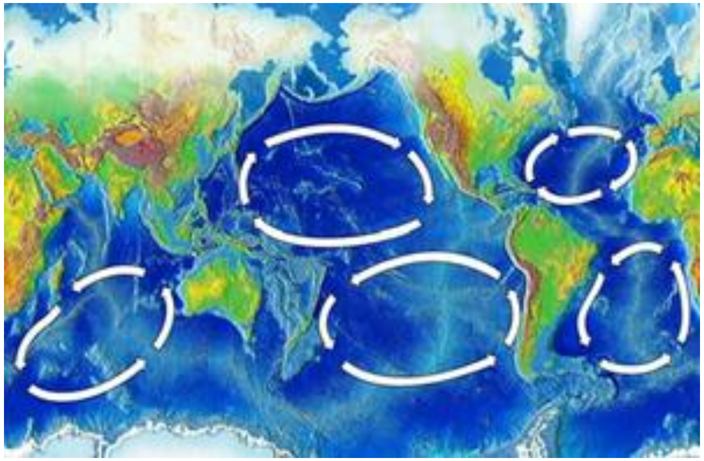
Kaare Baekgaard, Dk, 2010

http://www.idesign.li/Welcome/Services/Public.htm

http://www.youtube.com/watch?v=xwV1sciDDUA

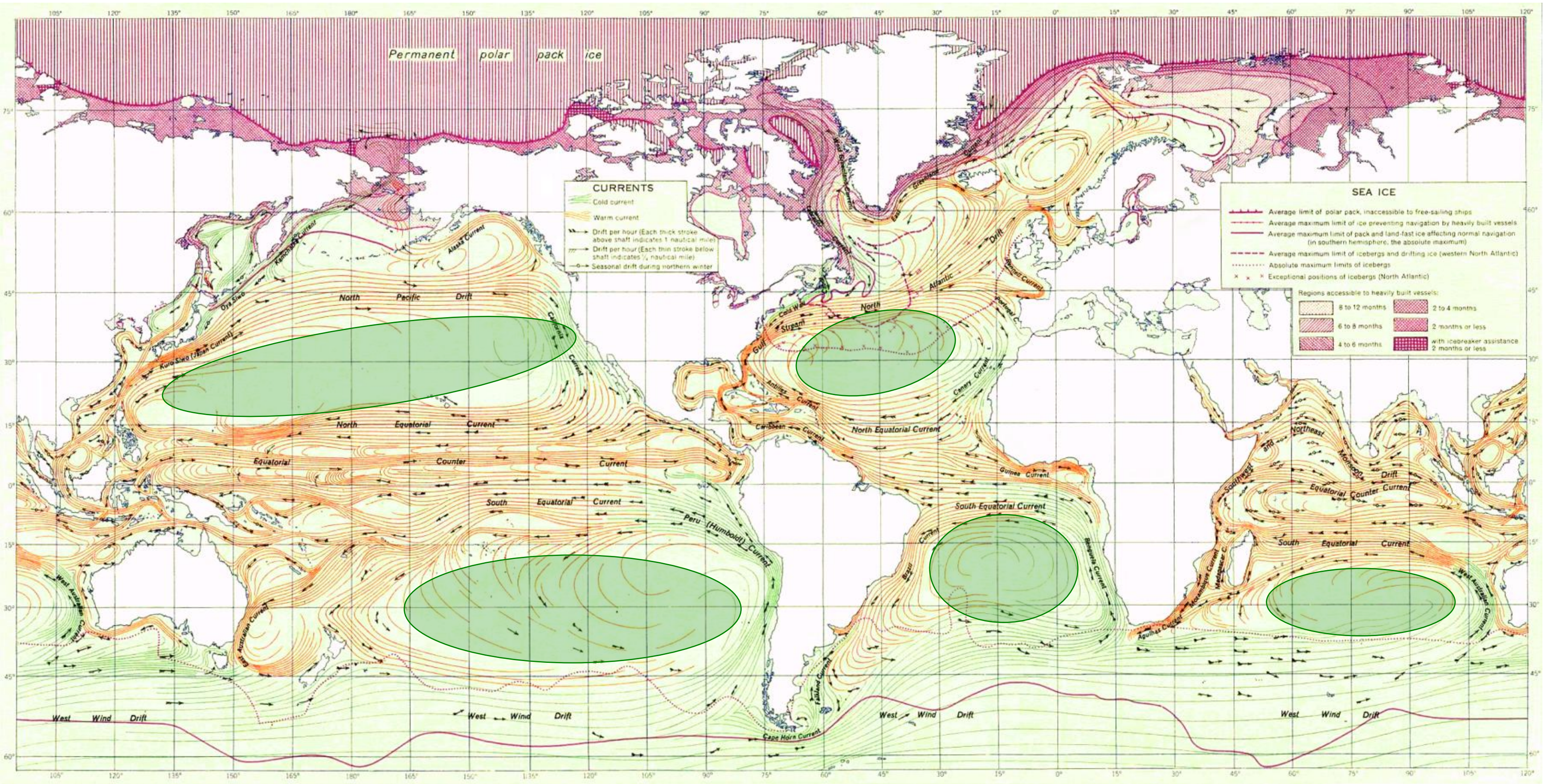
ECN proposal

- 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).

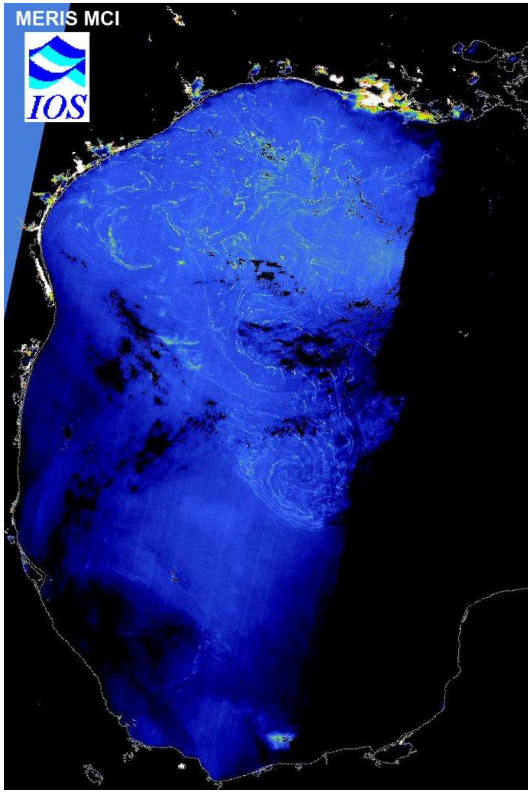
Ocean potential: >25.000.000 km^2



Current global agricultural crop area: 15.000.000 km^2 (FAO, 2006)

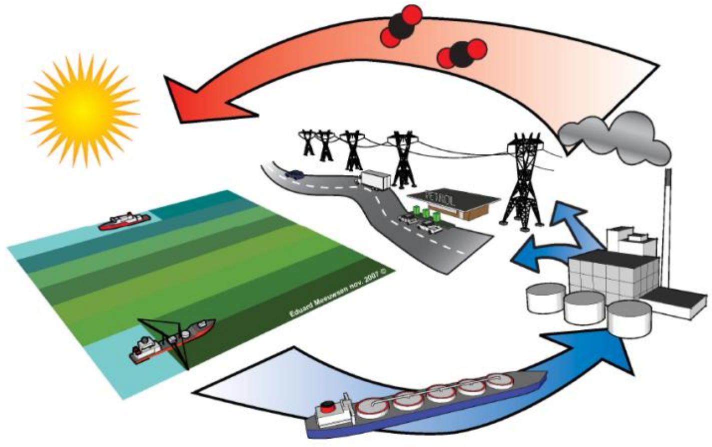
Sargassum natans

- 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

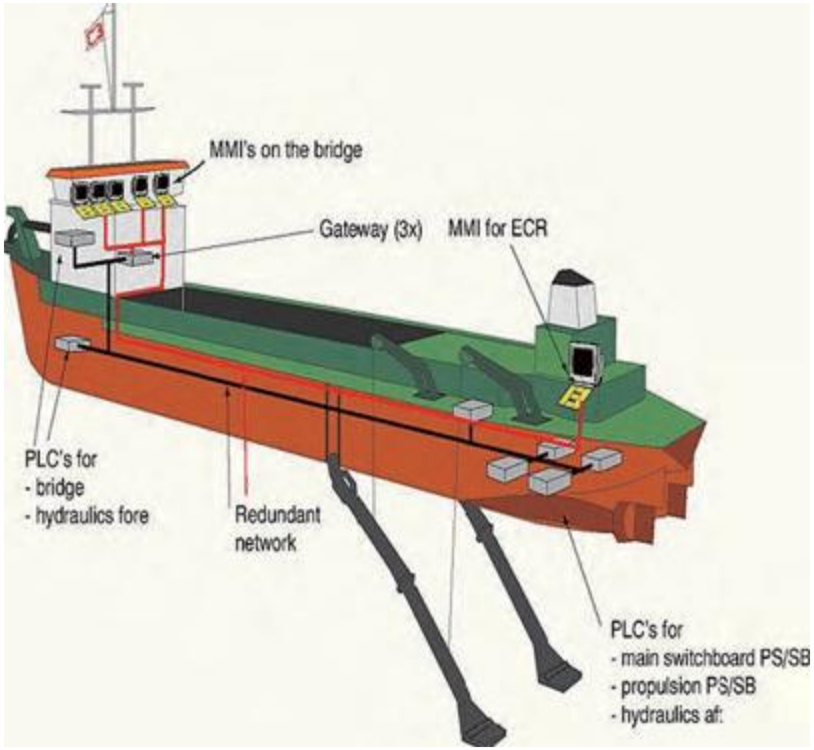
- Open farm seems most promising
- Farm location in gyre areas marked with buoys (ownership)
- Seeding with small fragments of *Sargassum natans*
- Selective fertilizer (no nitrogen) for *Sargassum natans,* slow release
- Selective harvesting (no fish or turtles)



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



Economics

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 CO_2 available

Disadvantages

- Ecological constraints
- International conventions
- No protected ownership
- Harsh conditions
- Long distances
- Very wet biomass

Cost estimate (preliminary)

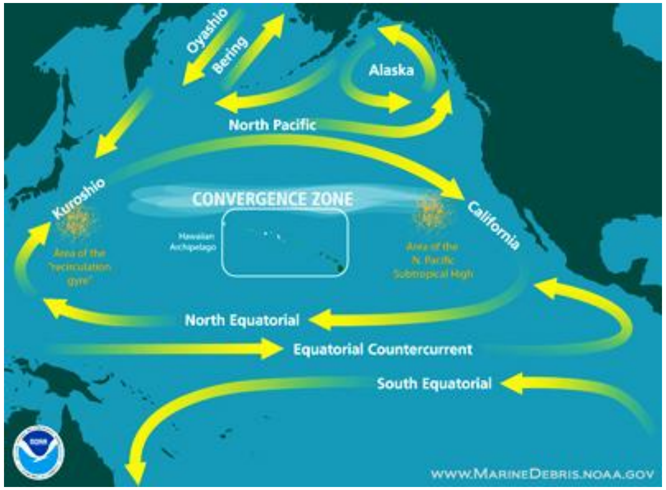
- Scale: one harvester\transporter Aframax size (80.000 ton)
- Assumed seaweed density: 10 ton/ha (dw)
- Harvesting capacity 3000 ton/hr (wet)
- Ship rent and fuel costs: 0,3 €/ton/day

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

* 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*

Composition of *Sargassum natans* as reported by some studies.

Sargassum fluitans and S. *natans*

Photo: http://www.tamug.edu/rooker/coastal.html

Sargassum	S. natans + S. fluitans, Arabian Gulf (Kamel, 1980)	S. natans, Guangdong, China (Wang et al, 2008)
Protein (% dry matter)	**6.59**	**9.6**
Lipid (%)	0.54	1.39
Carbohydrate (%)	**76.43**	**63.97**
Phosphorus (%)	0.0818	
Potassium (%)	**19.56**	
Energy (MJ/kg dry matter)	14.1	8.68

S. natans proteins compared with soy beans

Sargassum natans

- 6,6% (dw) proteins o.w.:
  - Methionine 2,3%
  - Lysine 4,5%
  - Threonine 3,8%

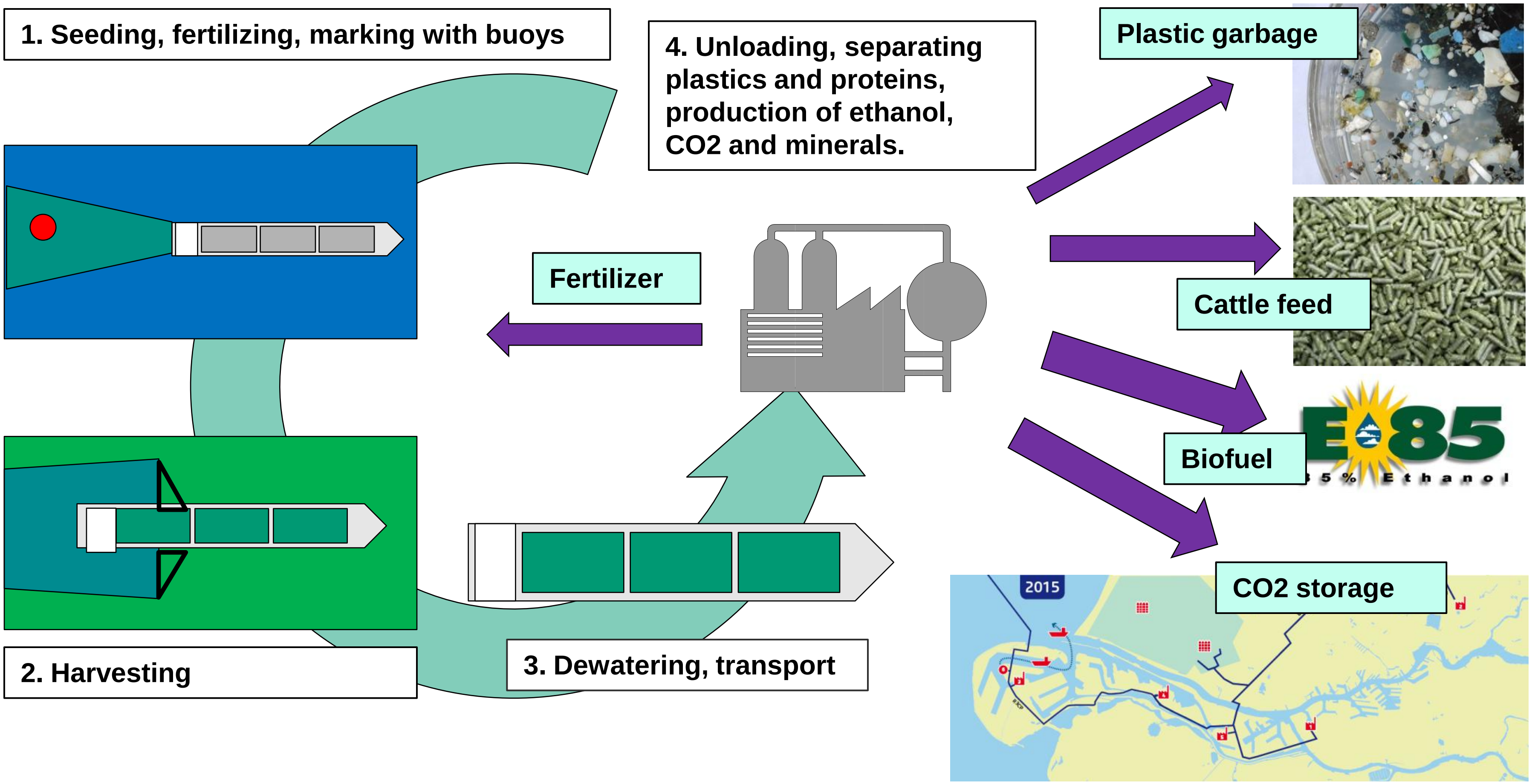
Source: Basil S. Kamel (1980)

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



Shell, AB Rotterdam deliver CO2 to OCAP > horticulture

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 balanced
- Independent ecological assessment required

Thank you for your attention

Contact

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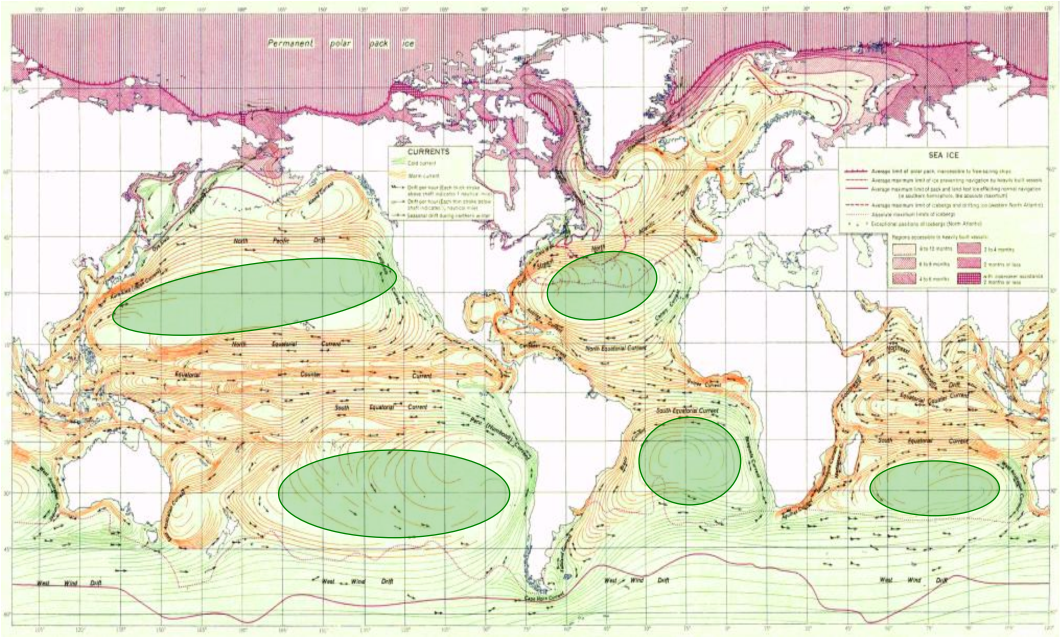
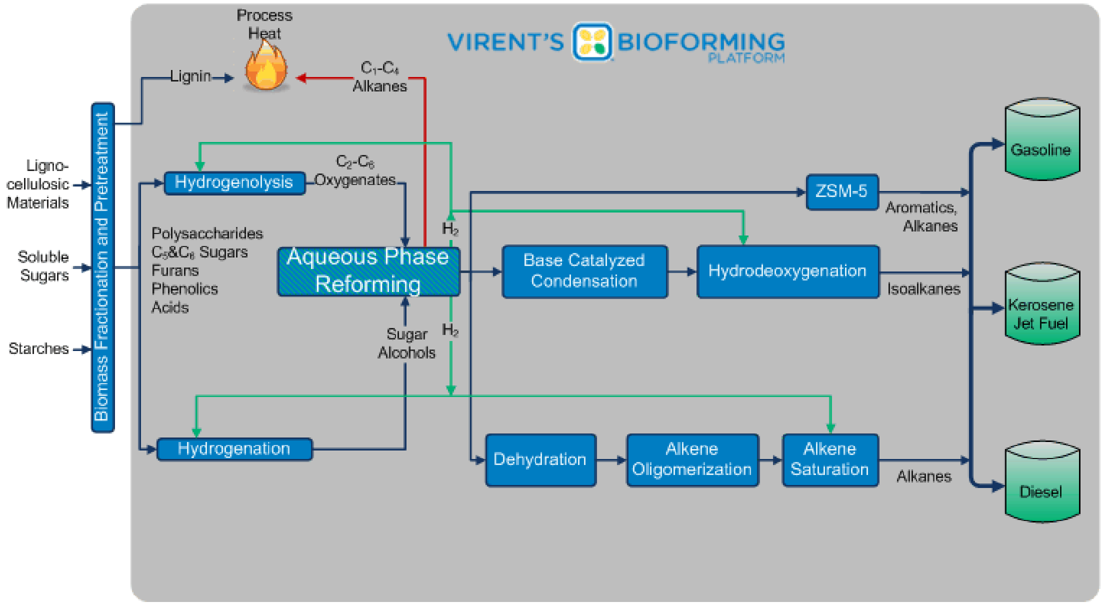


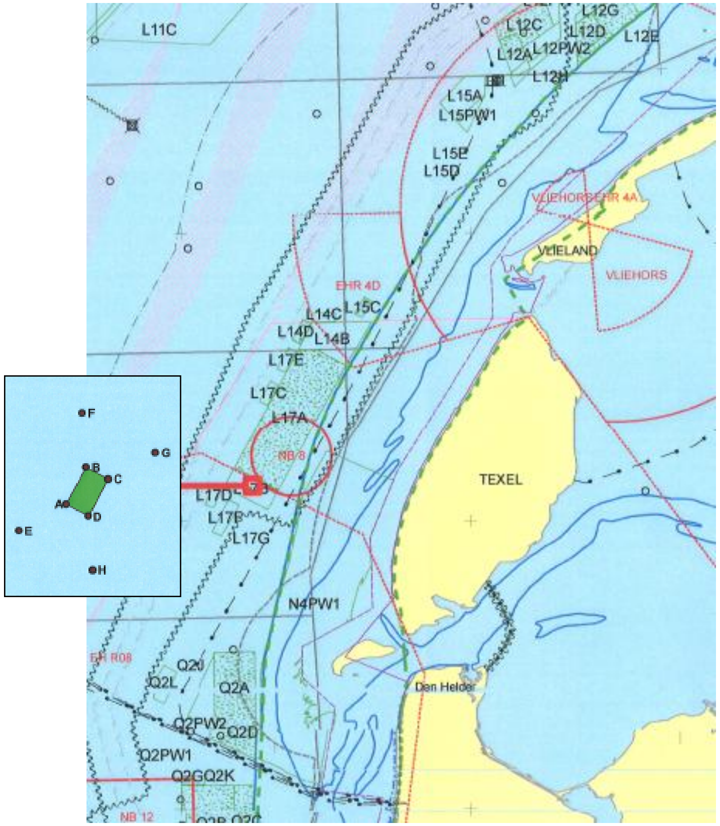
Potential energy carriers from seaweed

- Ethanol, butanol from sugars (≥ 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