ECN

Energy research Centre of the Netherlands

From seaweed to chemicals and fuels

Current activities in the Netherlands on seaweed cultivation and biorefinery

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Aquatic biomass energy potential

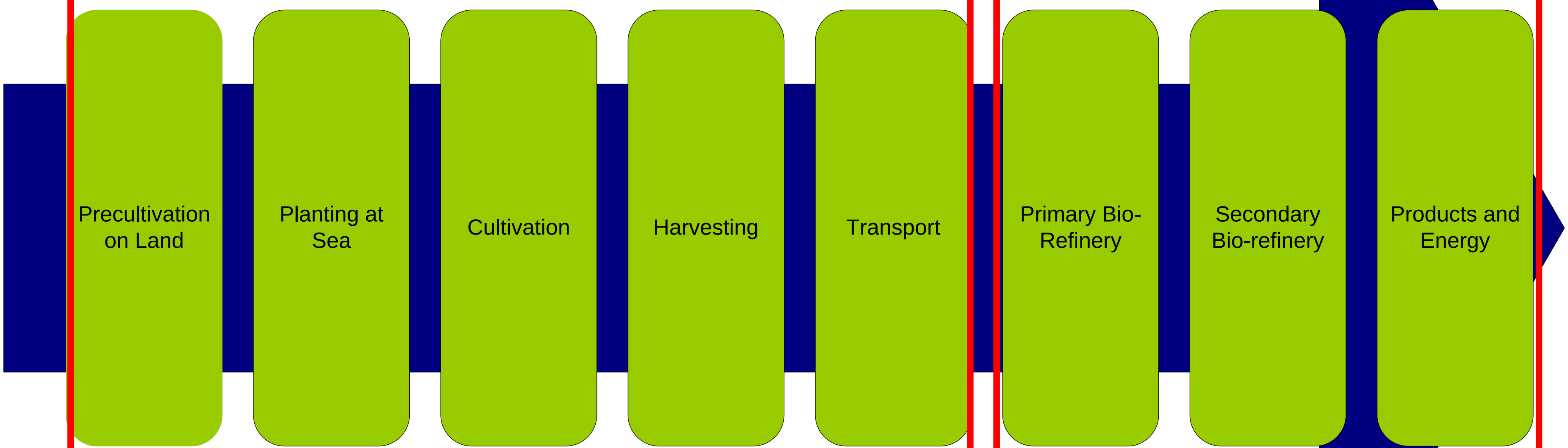
Most feasible technical concepts	Area	Potential
Set 1: Land based open ponds for microalgae	Arid land in (sub) tropical zones (deserts) and close to coast (max 100 km)	90 EJ
Set 3: Horizontal lines for macroalgae	At existing infrastructure – f.e. offshore wind farms (up to 100 km offshore)	110 EJ
Set 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

Seaweed projects in the Netherlands

SBIR

EOS LT



Partners: Ecofys, Eneco, ECN, OceanFuel, Van Beelen, PipeLife, De Vries & Van de Wiel

Partners: ECN WUR, ISC, ATO, Process Groningen

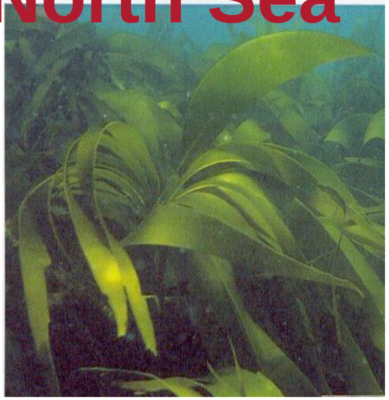
SBIR II status

- ½ Hectare experimental farms (Texel, Zeeland)
  - Test cultivation concepts
  - Test harvesting concepts
  - Product quality
  - Cultivate test quantities of native seaweeds
- Vision; 1 km^2 test farm for potential users
  - Foundation to start it
  - LLC (BV) for exploitation
  - Large batches for production runs

Seaweed species native to the North Sea

Lattissima saccharina

Laminaria digitata



Laminaria hyperborea (Perez)

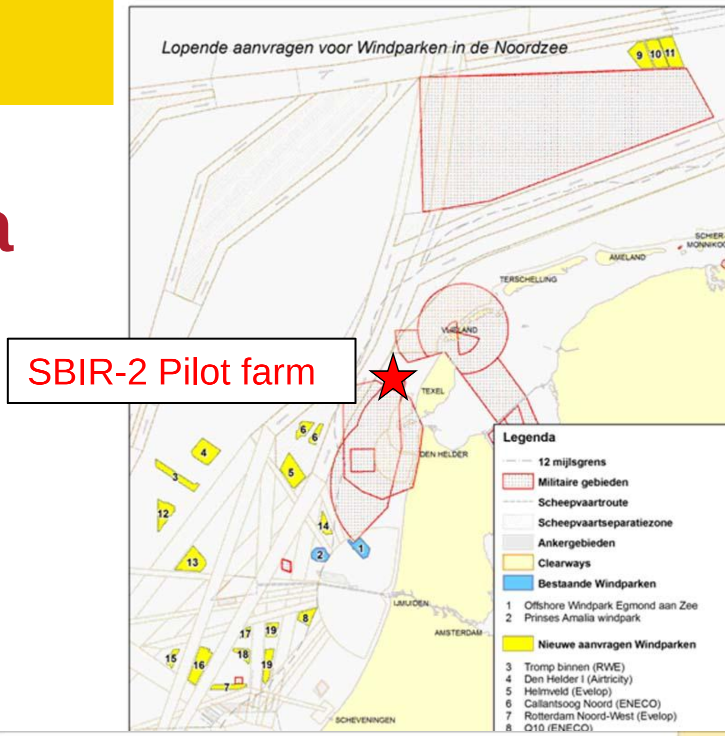
Ulva sp.

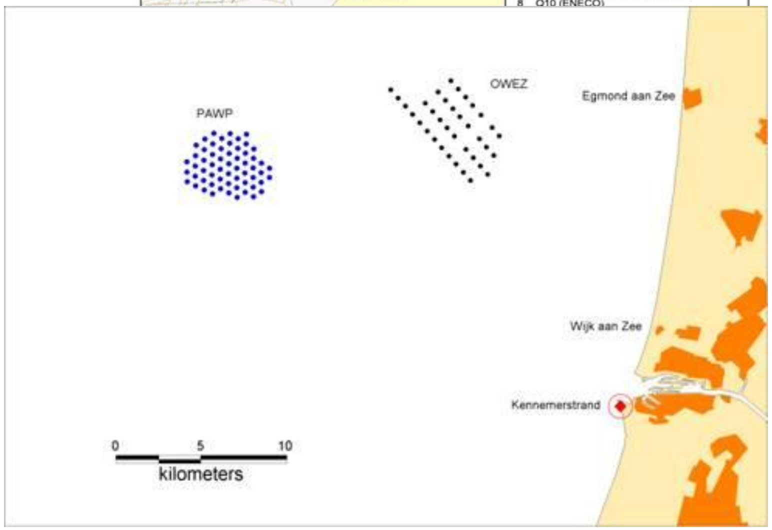
Alaria esculenta (Irish Seaweed Centre)

Palmaria palmata (AWI)

Seaweed at the North Sea

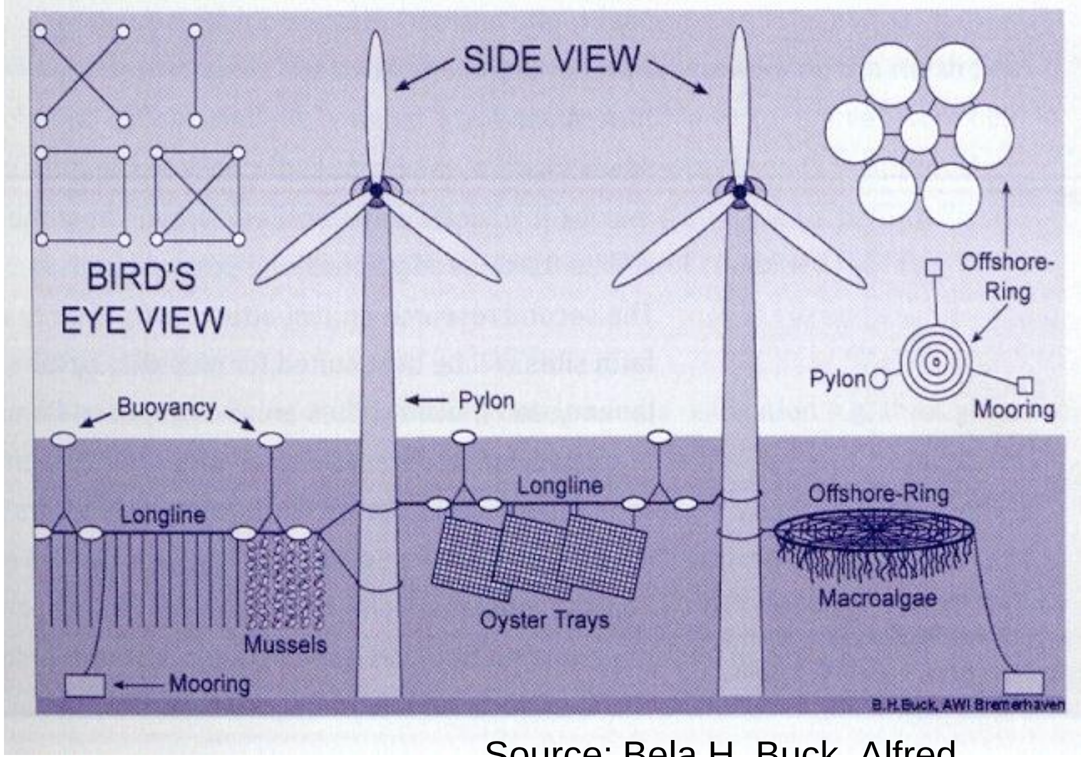
- Plans for combination with wind parks (Ecofys/Eneco/ECN)
- High yield per hectare necessary
- Construction must be stable in storms and high waves
- Biorefinery on shore
- No extra nutrition to avoid eutrophication
- Area is closed for all navigation





Synergy with offshore wind turbine parks

- Parks closed for shipping
- Multifunctional use of area and offshore constructions
- Potential combination with other aquaculture operations, e.g. mussel cultivation
- Joint O&M: personnel, vessels, equipment



Source: Bela H. Buck, Alfred Wegener Institute, DE.

Result: Cost reduction for both activities
Challenges: construction, additional facilities,……….

Feedstock composition

Representative composition *Laminaria* sp.

Component	Contents in w% d.w.
Cellulose	6
Hemicellulose	0
Lignin	0
Lipids	2
Proteïns	12
Starch	0
Alginates	23
Laminaran	14
Fucoidan	5
Mannitol	12
Total fermentable sugars	60
Ash contents	26

Assumed

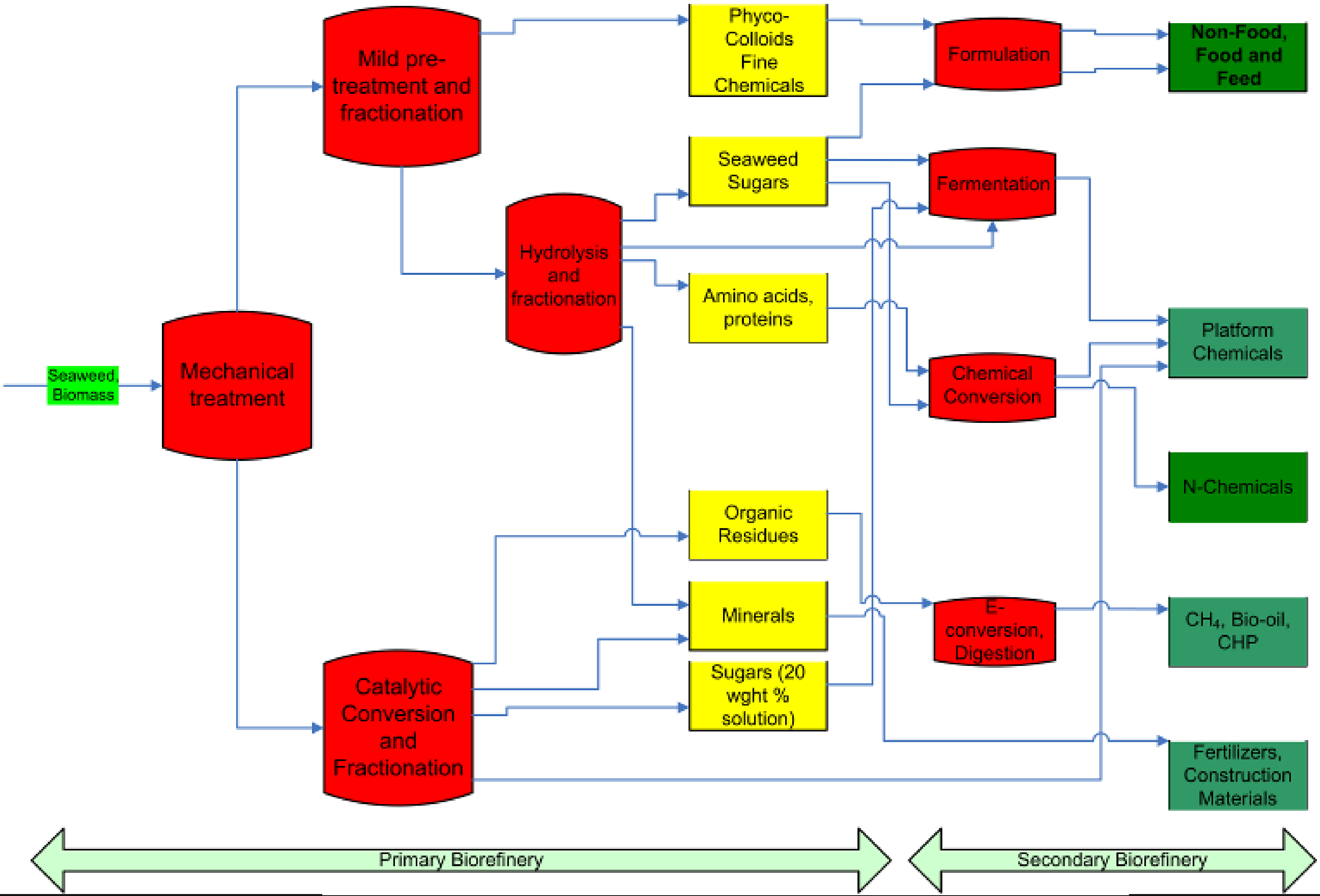
Macroalgae

- polysaccharides, proteins, minerals, no lignin
- highly suited for biorefinery to co-produce food, feed, chemicals and fuels
- higher value compounds (phycocolloids, colorants, mannitol, fucoidan, proteins)
- platform chemicals via fermentation (e.g. lactic acid) or chemical conversion
- fuels via fermentation (EtOH, CH4, H2) or thermochemical conversion (HTU, furanics)

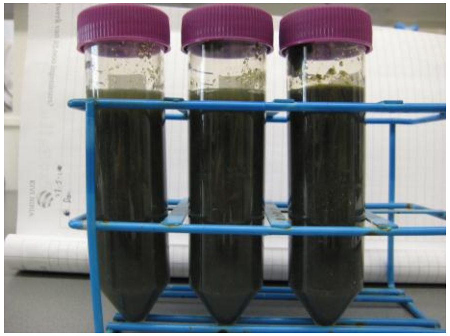
Microalgae

- suited for biorefinery/ numerous higher value products incl. omega f.a., antioxidants etc.
- proteins + **oils > biodiesel**
- proteins + **carbohydrates > fermentation**

Development of seaweed biorefinery



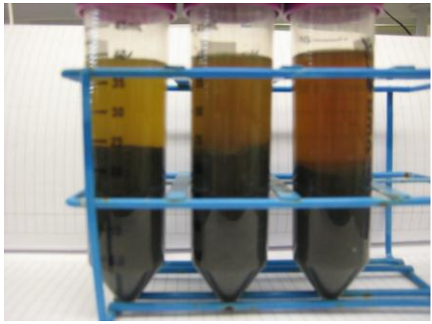
Fractionation R&D at ECN



Optional Catalyst

Water + Seaweed

T: 120-160 °C
t: 1-4 h
Liquid:Solid=1:10
Cat: 0-1 M H_2SO_4



Liquid

Solid

- After reaction, separation by centrifugation (10 min, 4000 rpm) and separation of the phases.

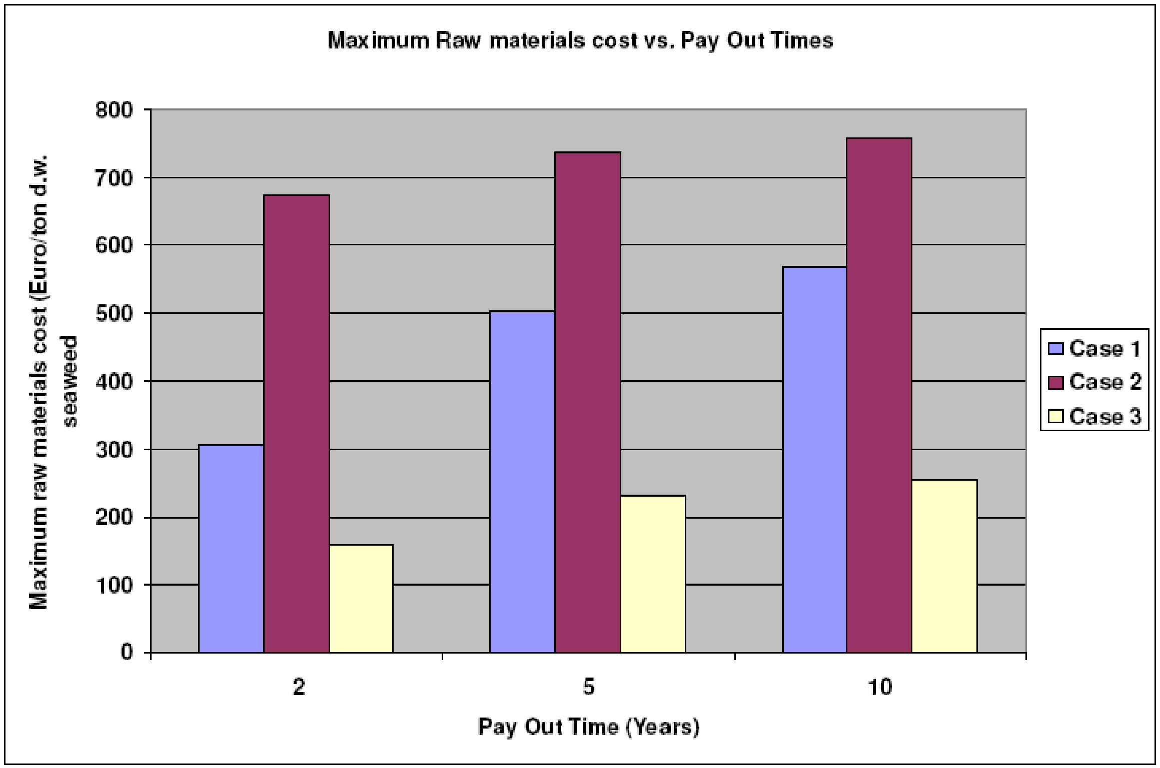
Preliminary results for *Laminaria*

- Mannitol extraction possible under mild conditions
- Total liquefaction possible under relatively mild conditions
- Biochemical conversion to ABE possible
- Seaweed specific conversion routes needed
- Monetizing of all fractions is needed for viable biorefinery

Product spectrum

Product	Estimated Value (Euro/ton)
Mannitol (valued as sorbitol)	1,500
Fumaric acid (as adipic acid)	1,600
Fucoidan (as detergent)	2,900
1-Butanol (chemical grade)	1,200
Ethanol (fuel grade)	600
Protein	1,000
Fertilizer (as ore)	350
Furanics	800
Alginates	3,000

Max. allowable seaweed costs based on projected sales revenues for a specified P.O.T.



Scale biorefinery 300 kt/yr

100 km2 @ 30 ton/ha/yr

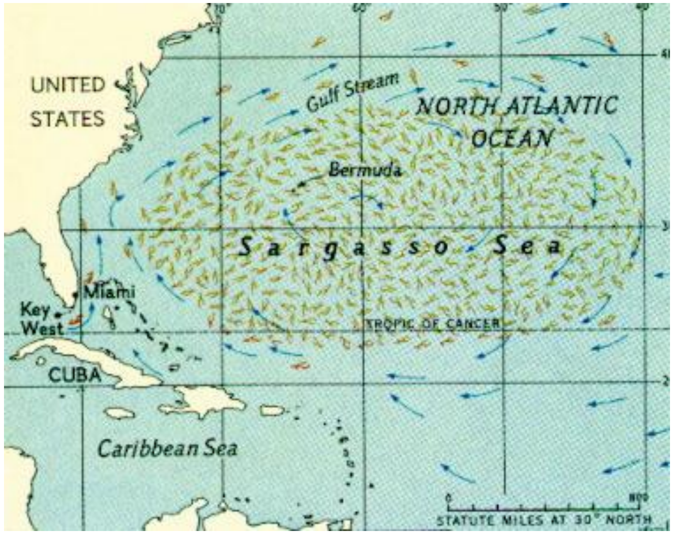
Case 1: Full Biorefinery: mannitol, fucoidan, furanics, fumaric acid, protein, K-”ore”

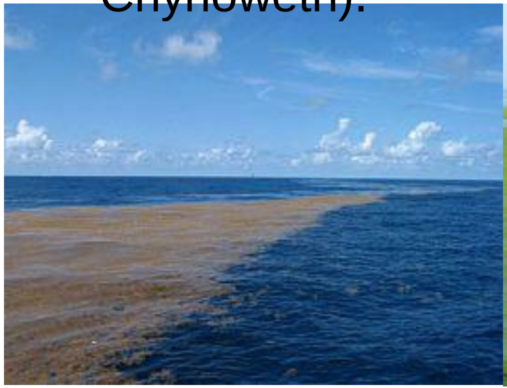
Case 2: Extraction of (too much) alginate, fertilizer (K,P) and energy (AD + CHP)

Case 3: Simplified Biorefinery producing butanol and fertilizer

Seaweed on ocean scale

- The Sargasso Sea seems a good location
- Sargasso seaweed has attractive properties (fast growing, floating)
- *Sargassum*: symbiosis with cyanobacteria to fix N2
- Large energy potential. Cost estimate floating cultivation ca. $50/ton d.w. (cf. Chynoweth).





Thank you for your attention

More information:

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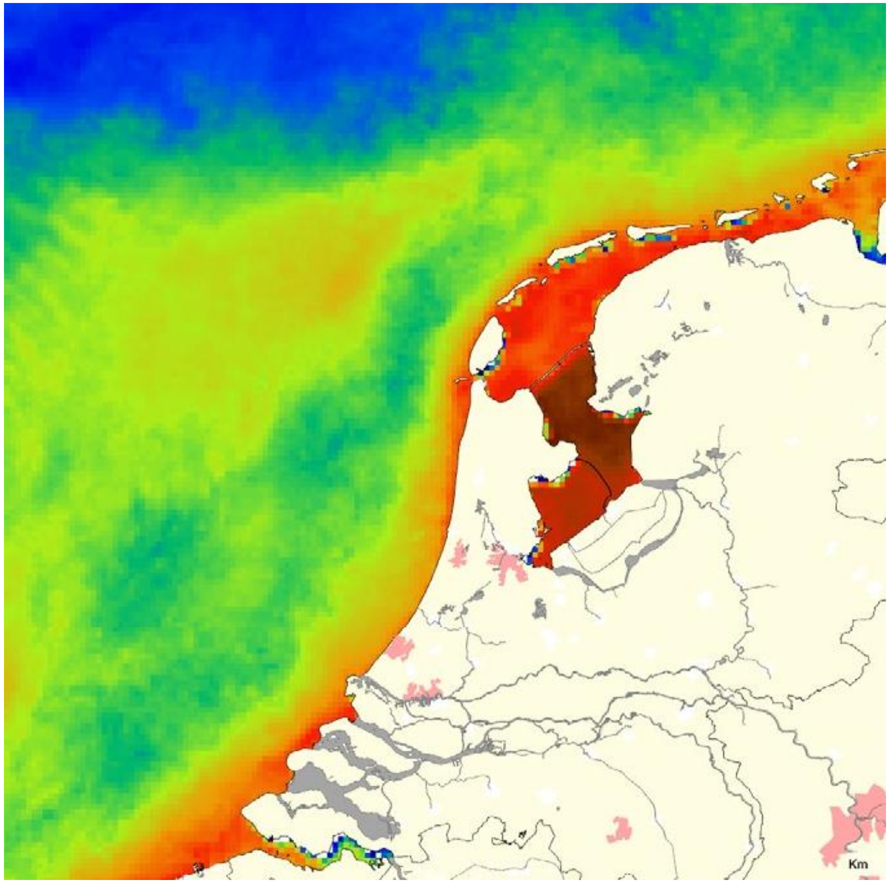
Seaweed production cost

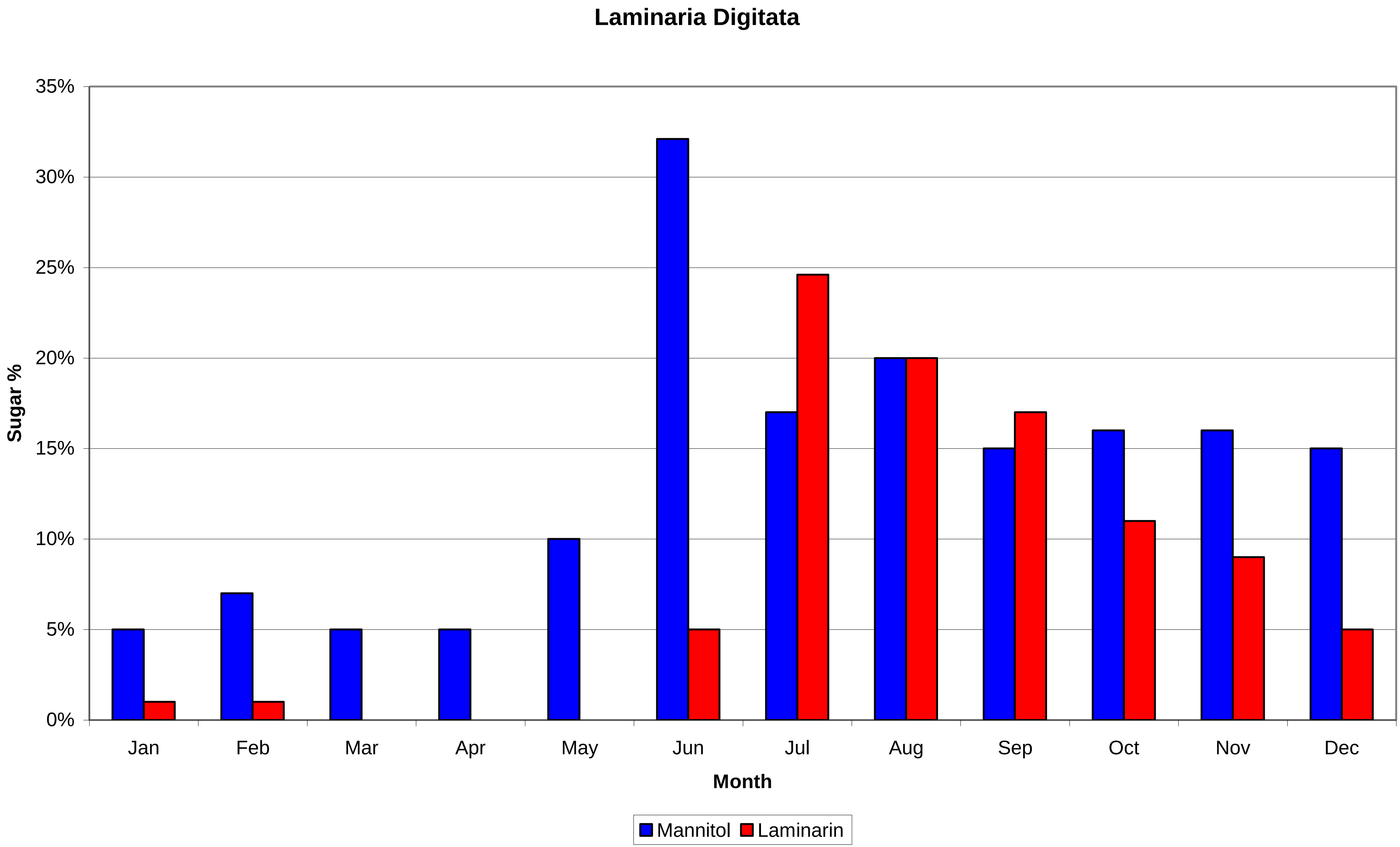
Type of cultvation system	Productivity		Costs		Reference:
	ton daf/ ha.yrr	ton d.w./ ha.yr	$ ton daf	$ (or €) / ton d.w.	
Chili: harvest of natural populations	-	-	-	250	Internet
Philippines: coastal cultivation; ‘off-farm’ price	-	-	-	80 - 160	Internet
Nearshore cultivation Macrocystis	34 50	57 83	67 42	40 25	[3]
Gracillaria/Laminaria line cultivation (offshore)	11 45	14 59	538 147	409 112	[3]
Tidal Flat farm Gracillaria/Ulva	11 23	14 30	44 28	33 21	[3]
Floating cultivation Sargassum	22 45	32 66	73 37	50 25	[3]
Experimental, ring system offshore Laminaria cultivation in the North sea	-	20	-	2500 €	[4]

Indication production costs (mostly from published design studies):
50 € (nearshore/floating) - 400 € (offshore) per ton dw. Verification required!
Biomass production costs depend mostly on 1) investment cultivation and harvesting system 2) achieved productivity

Seaweed at the North Sea

- Seaweed production without extra nutrients
- Dependant on present phosphates and nitrogen
- Map shows eutrophication, chlorophyll as indicator

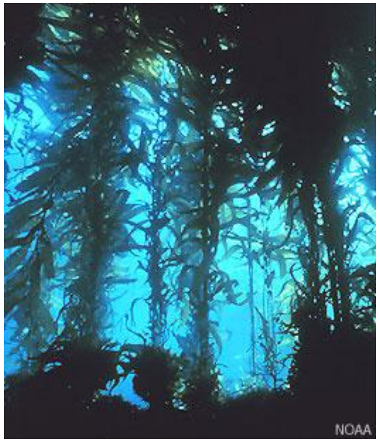



Laminaria Digitata
35%
30%
25%
20%
15%
10%
5%
0%
Sugar %
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Mannitol
Laminarin

ECN

Current seaweed exploitation

* © C.J. Dawes
** © M.D. Guiry



Macrocystis pyrifera (giant kelp);California

Laminaria digitata, Yorkshire,UK

Gracillaria line cultivation

- Current world production: ca. 10 Mton yr, > 40 species exploited (China, Philippines, Indonesia, USA, France, Ireland, Norway, …)
- Market size ca. 6 Billion US$ / year; 2 a 3% growth per year
- Major applications: food, phycocolloids as thickeners/gellings agents, extracts for cosmetics, animal feed/aquaculture, fertilizer…. No major energy applications
- Cultivation: line systems or floating