Energy research Centre of the Netherlands

Perspectives of seaweed cultivation and seaweed biorefinery

Jip Lenstra, Groningen, May15, 2012

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


Lembongan, Bali Indonesia
Image © 2007 DigitalGlobe
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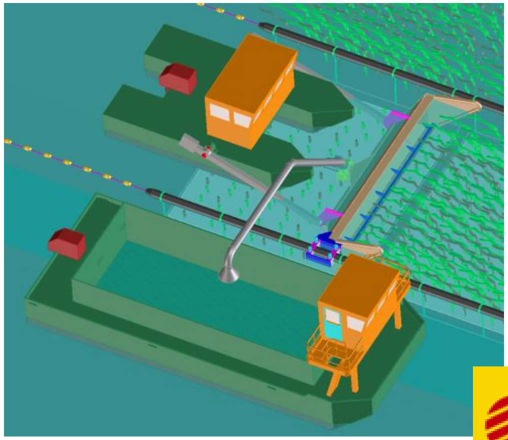
Seaweed in our daily live

- E400 – E407 are seaweed derived texturizers, gelling agents, emulsifiers and stabilizers
- Carrageenan is now seen in many custards and yoghurt
- Mold making material for dentistry

ECN

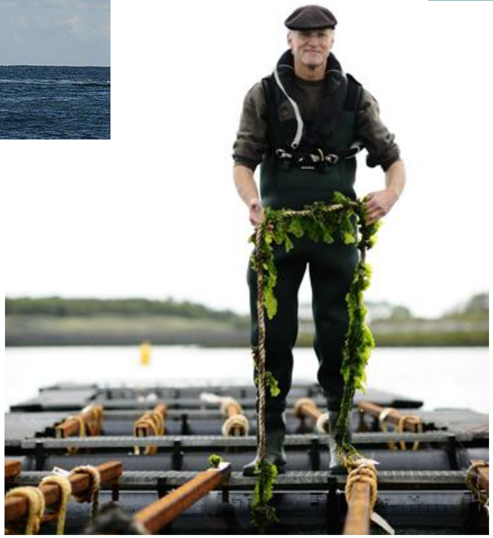
Dutch seaweed work



ECN

ECOFYS

sustainable energy for everyone



Hortimare

propagating seaweed for a sustainable future

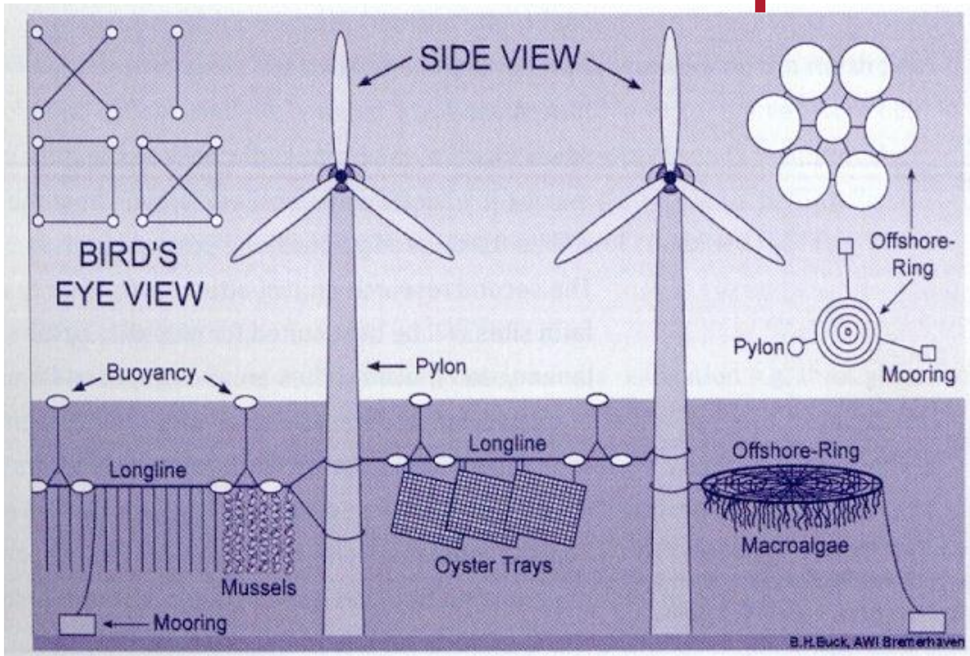
Eneco

WAGENINGEN UR

For quality of life

Seaweed cultivation in offshore wind turbine parks

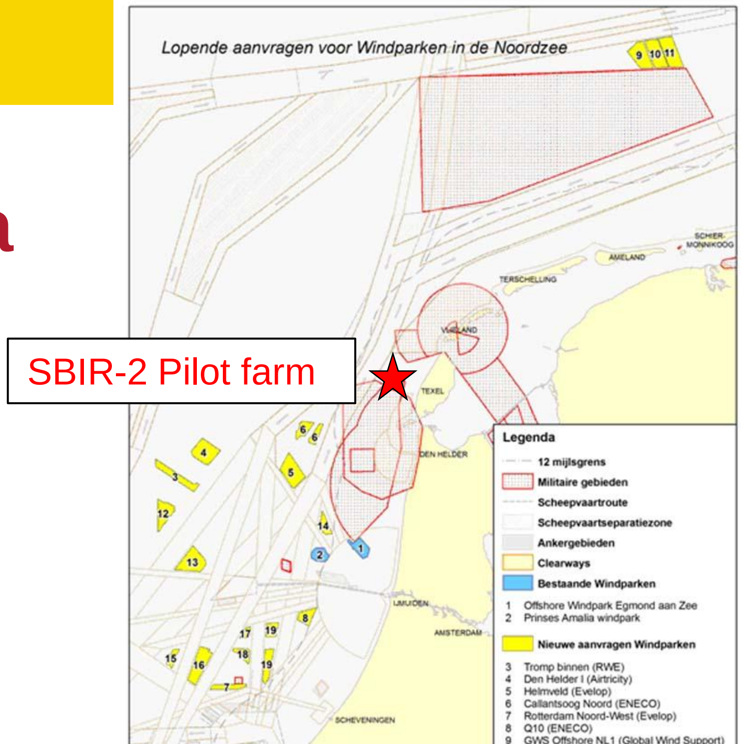
- Area closed for shipping
- Multifunctional use of area and offshore constructions
- Potential combination with other aquaculture e.g. mussel cultivation
- Joint O&M: personnel, vessels, equipment
- Synergy and cost benefits

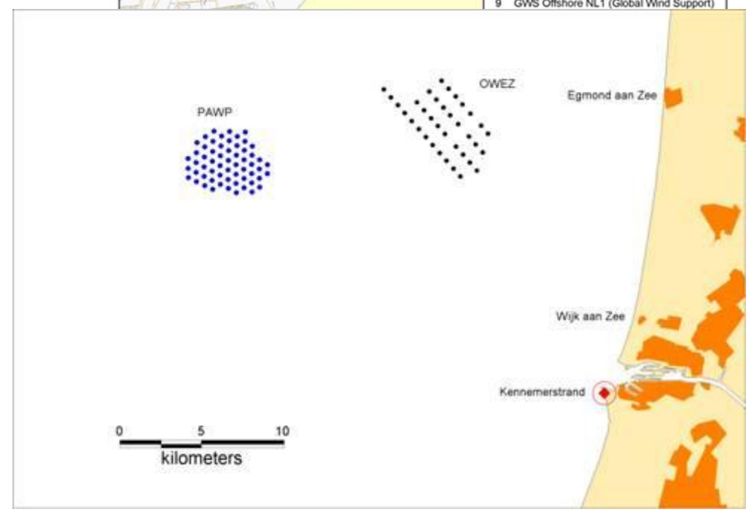


Source: Bela H. Buck, Alfred Wegener Institute, DE.

Seaweed at the North Sea

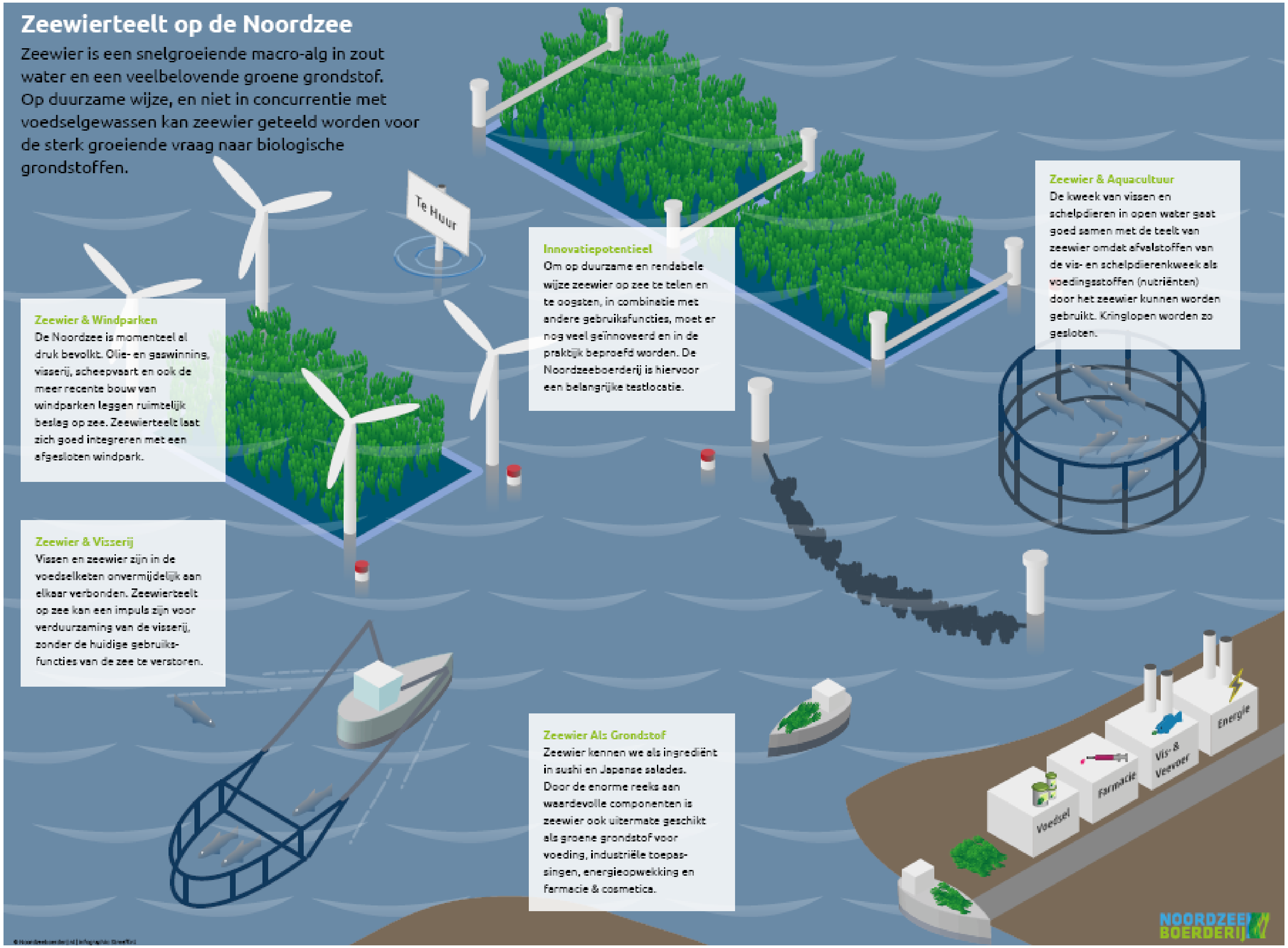
- 2 wind parks operational, 3 more planned/under construction.
- Ca. 100 KM2; Target: 6000 MW = 1000 km2
- Plans for combination seaweed in wind parks (Ecofys/Eneco/ECN)
- Construction must be stable in storms, high waves, current,..
- 0.5 Hectare experimental farms (Texel, Zeeland)
  - Test cultivation concepts
  - Test harvesting concepts
  - Product quality
  - Cultivate test quantities of native seaweeds



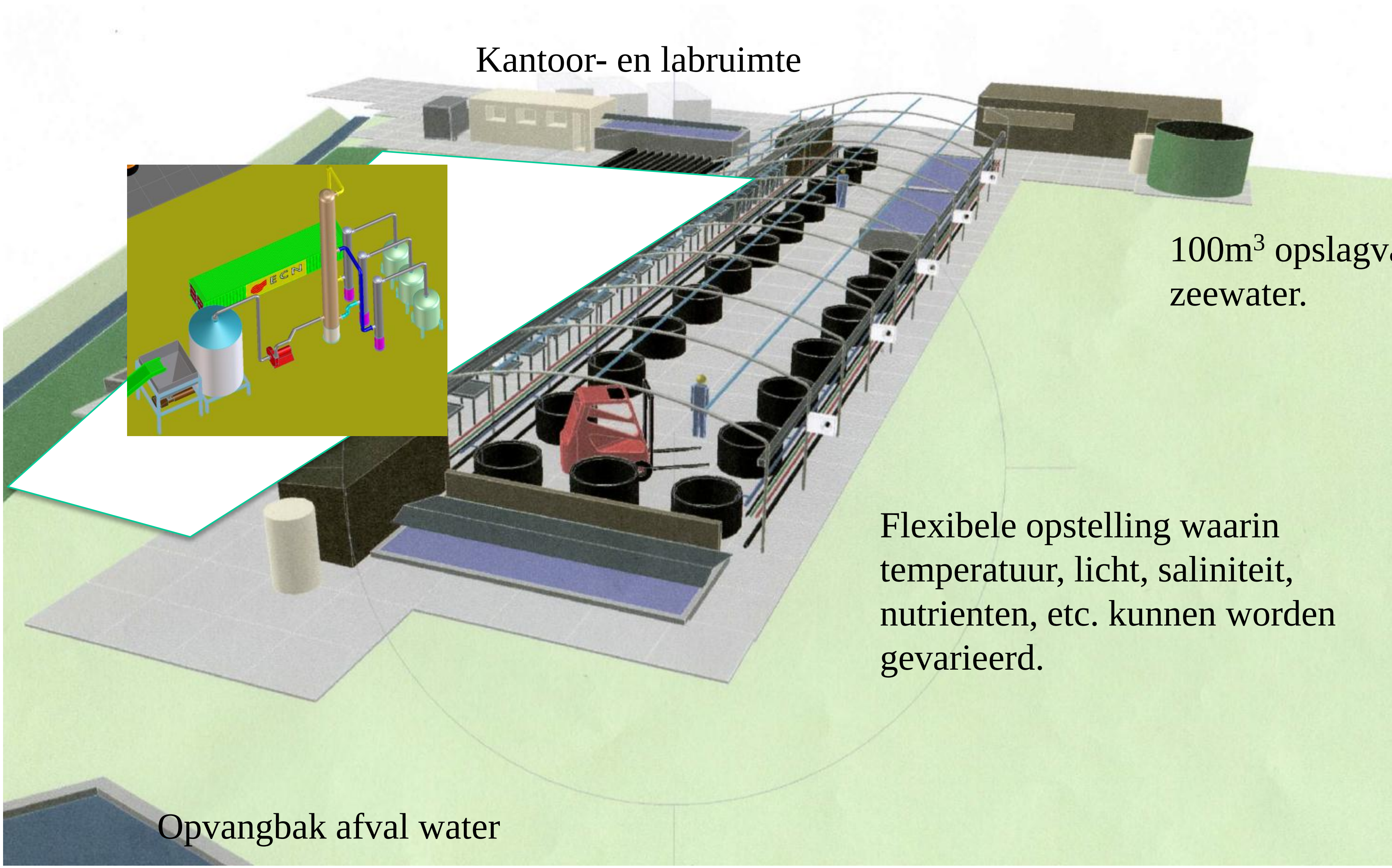


ECN

Ecofys/ECN seaweed pilot (SBIR)


Zeewierteelt op de Noordzee
Zeewier is een snelgroeiende macro-alg in zout water en een veelbelovende groene grondstof. Op duurzame wijze, en niet in concurrentie met voedselgewassen kan zeewier geteeld worden voor de sterk groeiende vraag naar biologische grondstoffen.
Te Huur
Zeewier & Windparken
De Noordzee is momenteel al druk bevolkt. Olie- en gaswinning, visserij, scheepvaart en ook de meer recente bouw van windparken leggen ruimtelijk beslag op zee. Zeewierteelt laat zich goed integreren met een afgesloten windpark.
Innovatiepotentieel
Om op duurzame en rendabele wijze zeewier op zee te telen en te oogsten, in combinatie met andere gebruiksfuncties, moet er nog veel geïnnoveerd en in de praktijk beproefd worden. De Noordzeeboerderij is hiervoor een belangrijke testlocatie.
Zeewier & Aquacultuur
De kweek van vissen en schelpdieren in open water gaat goed samen met de teelt van zeewier omdat afvalstoffen van de vis- en schelpdierenkweek als voedingsstoffen (nutriënten) door het zeewier kunnen worden gebruikt. Kringlopen worden zo gesloten.
Zeewier & Visserij
Vissen en zeewier zijn in de voedselketen onvermijdelijk aan elkaar verbonden. Zeewierteelt op zee kan een impuls zijn voor verduurzaming van de visserij, zonder de huidige gebruiksfuncties van de zee te verstoren.
Zeewier Als Grondstof
Zeewier kennen we als ingrediënt in sushi en Japanse salades. Door de enorme reeks aan waardevolle componenten is zeewier ook uitermate geschikt als groene grondstof voor voeding, industriële toepassingen, energieopwekking en farmacie & cosmetica.
Voedsel
Farmacie
Vis- & Veevoer
Energie
NOORDZEE BOERDERIJ

TESTFACILITEIT VOOR ZEEWIER ONDERZOEK
Netherlands Seaweed Science & Technology Center



Seaweed species native to the North Sea

Lattissima saccharina

Laminaria digitata

Laminaria hyperborea (Perez)

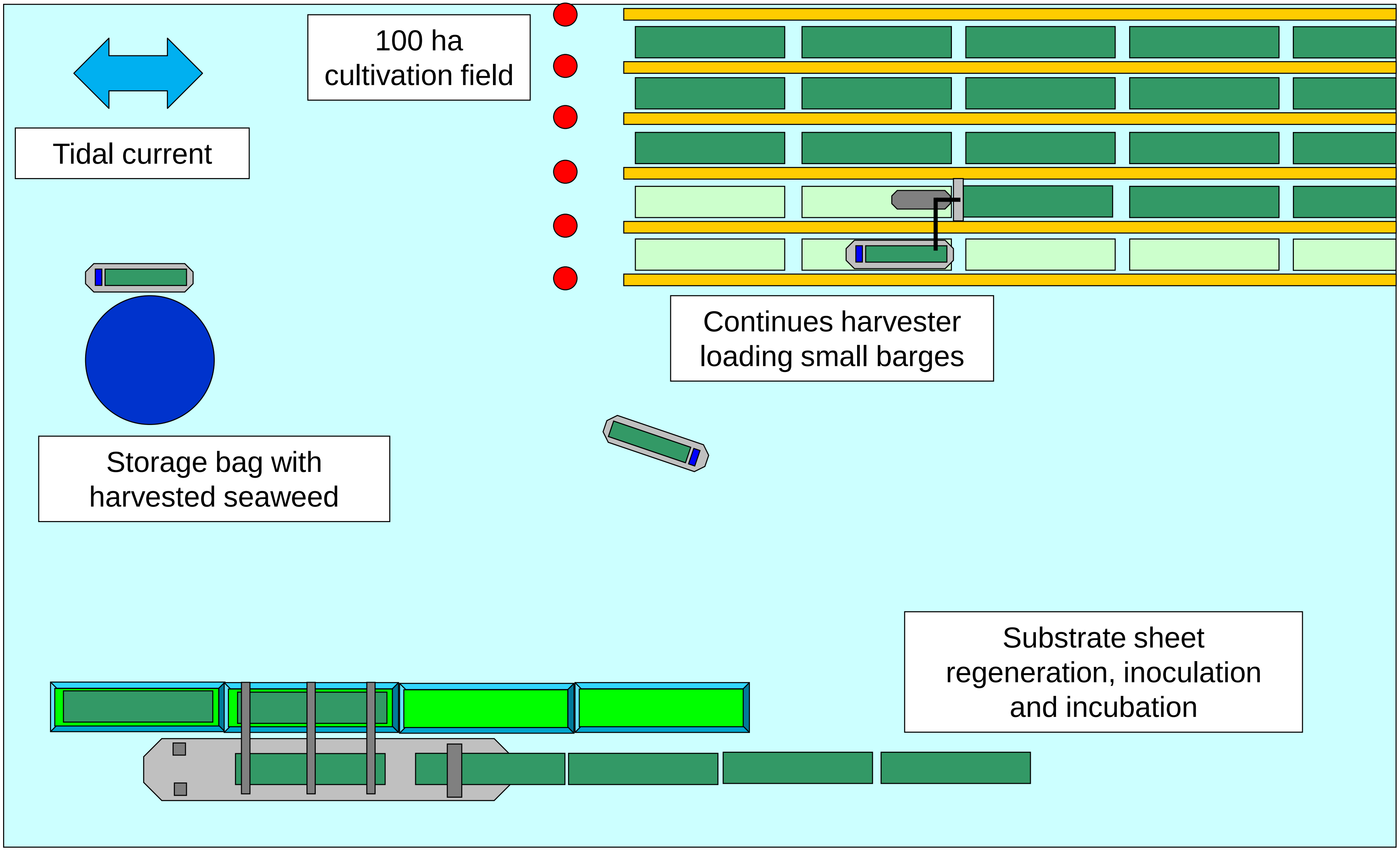
Ulva sp.

Alaria esculenta (Irish Seaweed Centre)

Palmaria palmata (AWI)

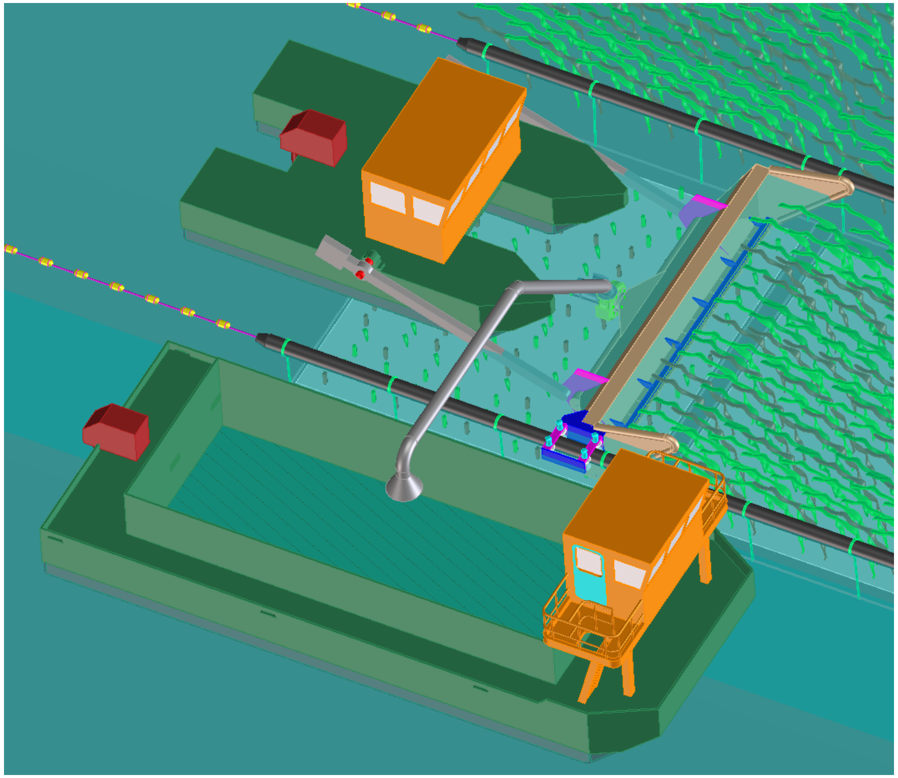
European projects with ECN

- Mermaid
  - Integration of aquaculture with seaweed cultivation
  - Integration with wind farms and tidal energy
- AT~SEA
  - Development of cultivation systems from textile
  - Inflatable structures
  - Semi closed systems


100 ha
cultivation field
Tidal current
Continues harvester
loading small barges
Storage bag with
harvested seaweed
Substrate sheet
regeneration, inoculation
and incubation

Large scale harvester (proposed)

- System can work continuously
- Separate barge for transport to storage barge
- Seaweed is pumped with water to barge
- Excess water is flowing off from barge



Seaweed production cost

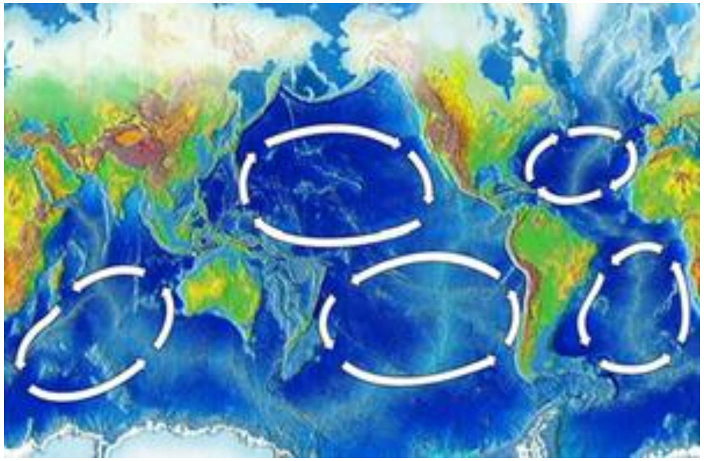
Type of cultvation system	Productivity		Costs		Reference:
	ton daf/ ha.yrr	ton d.w./ ha.yr	\$ ton daf	\$ (or €) / ton d.w.	
Chili: harvest of natural populations	-	-	-	250	Internet
Philippines: coastal cultivation; ‘off-farm’ price	-	-	-	80 - 160	Internet
Nearshore cultivation Macrocystis	34 50	57 83	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]

Ref [3]: Chynoweth, D.P. 2002. Review of biomethane from Marine Biomass. History, results and conclusions of the “US Marine Biomass Energy Program” (1968-1990). 194 pp.

Indication large scale production cost (mostly from published design studies): **50 € (nearshore/floating) - 400 € (offshore) per ton dw.** **Verification required!**

Ocean farm concept ECN

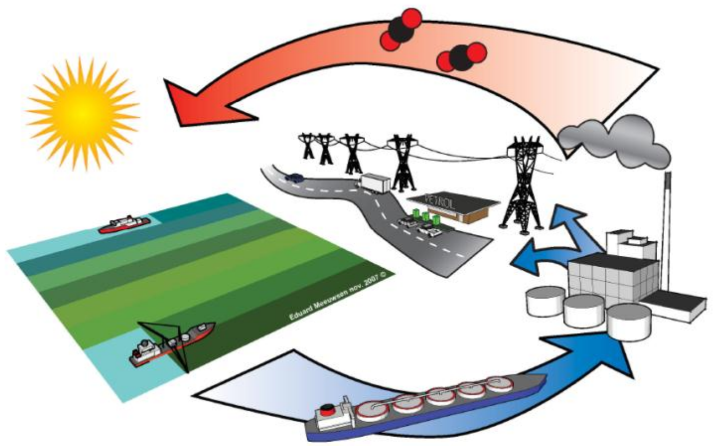
- Location: ocean gyres/ low current
- Sargasso seaweed *Sargassum natans* has attractive properties: (fast growing, floating, global occurrence; uses nitrogen fixation by an associated epiphyte or cyanobacteria (Philips et al, 1986)
- Large potential: >25.000.000 km2



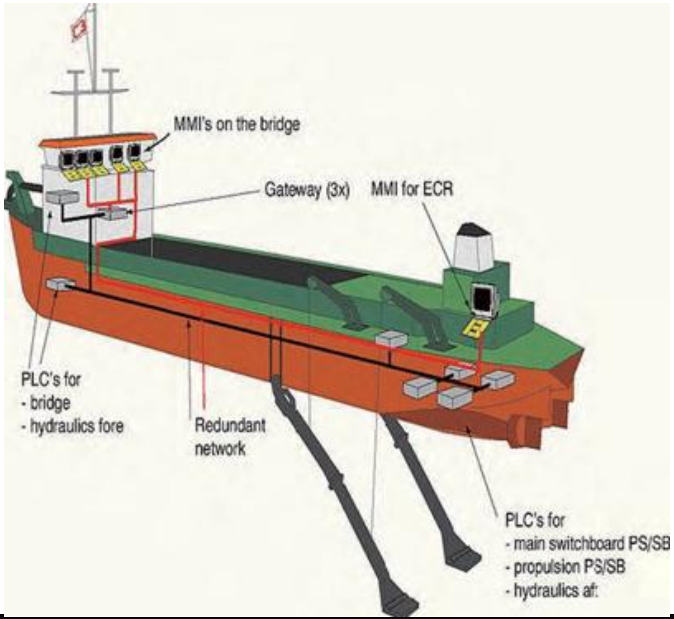
A **spiral oceanic surface current** driven primarily by the global wind system and constrained by the continents surrounding the three ocean basins (Indian, Pacific, Atlantic).

Ocean farm concept ECN

- Farm location in gyre areas marked with buoys (ownership)
- Seeding with small fragments of *S. natans* combined with harvesting
- Selective fertilizer supply (no nitrogen), slow release
- Selective harvesting (no fish or turtles)
- Processing on shore (biorefinery)
- Ecological uncertainties: effects on marine ecosystem
- Much more research is needed



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



Cost estimate (preliminary)

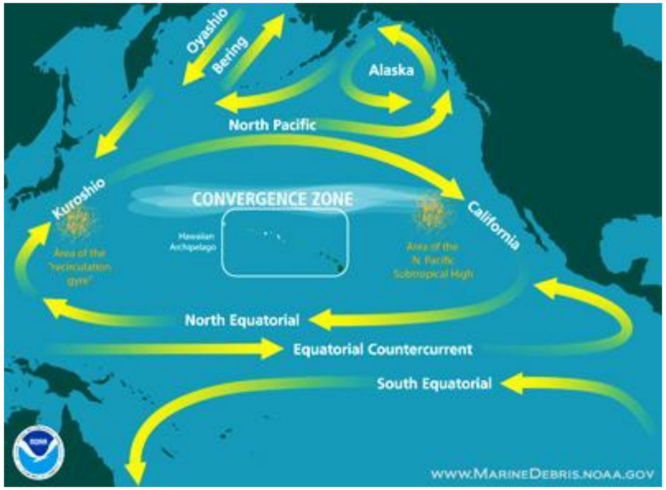
- Scale: one harvester\transporter Aframax size (80.000 ton)
- Assumed seaweed density: 10 ton/ha (dw)
- Harvesting capacity 3000 ton/hr (wet)
- Ship rent and fuel costs: 0,3 €/ton/day

	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
- Approx. 0.25% of dry mass would be garbage



S. natans proteins compared with soy beans

Sargassum natans

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

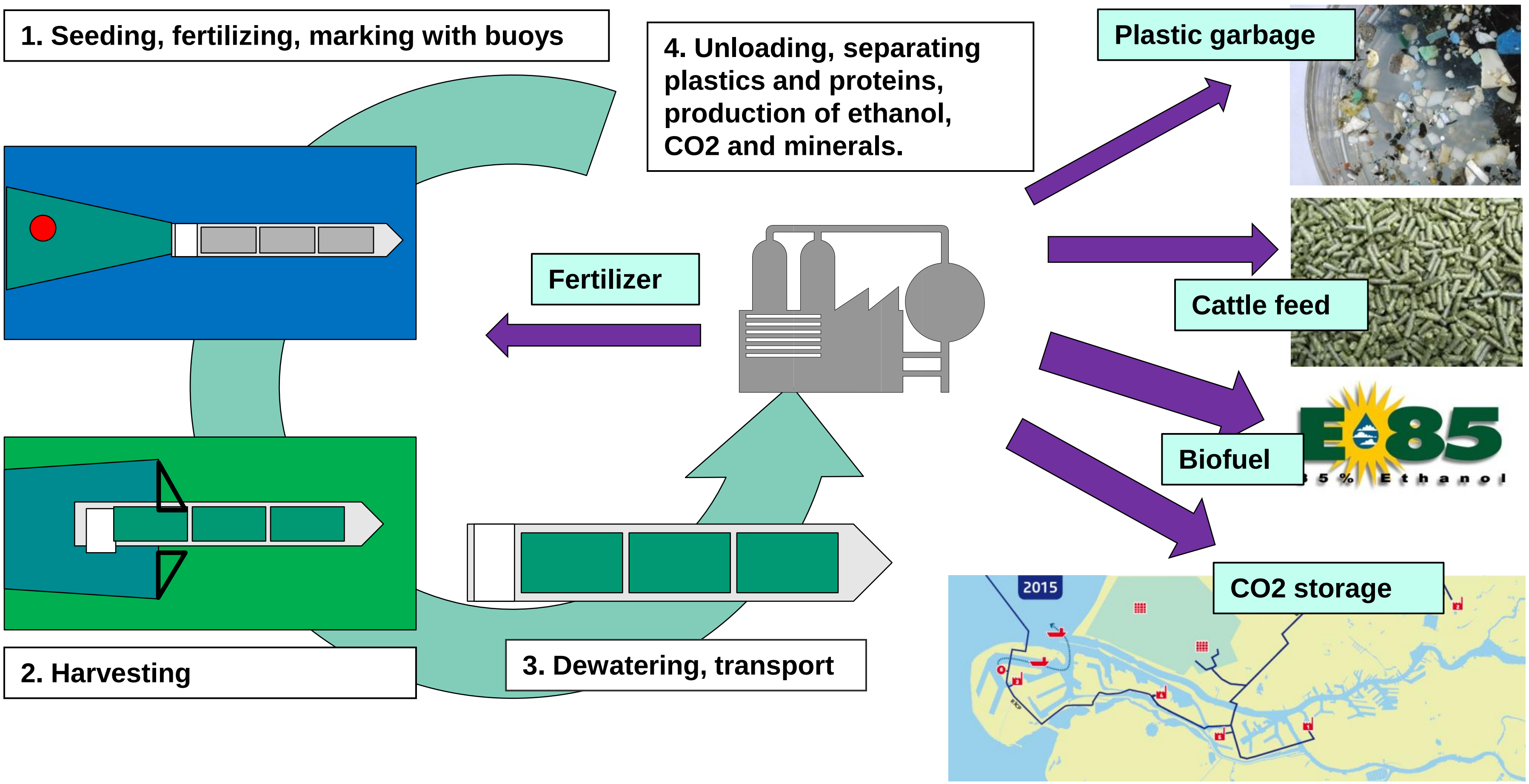
Source: Basil S. Kamel (1980)

Soy beans

- 36,5% proteins o.w.:
  - Methionine 1,4%
  - Lysine 7,4%
  - Threonine 4,9%

Ca. 5 ton dry *S. natans* could replace 1 ton soy beans for feed

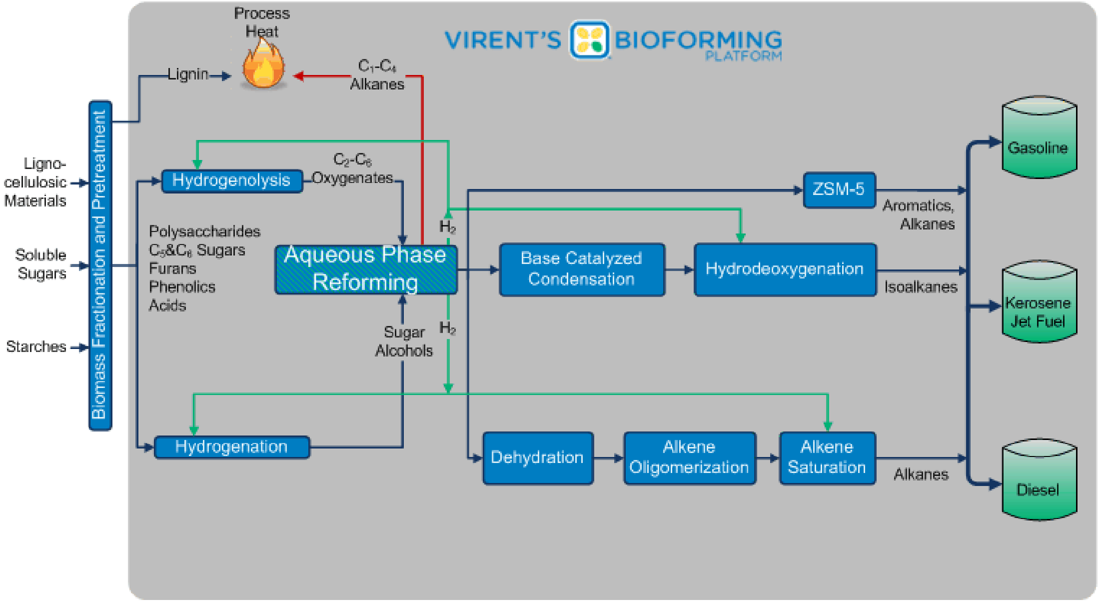
Ocean seaweed to fuel chain

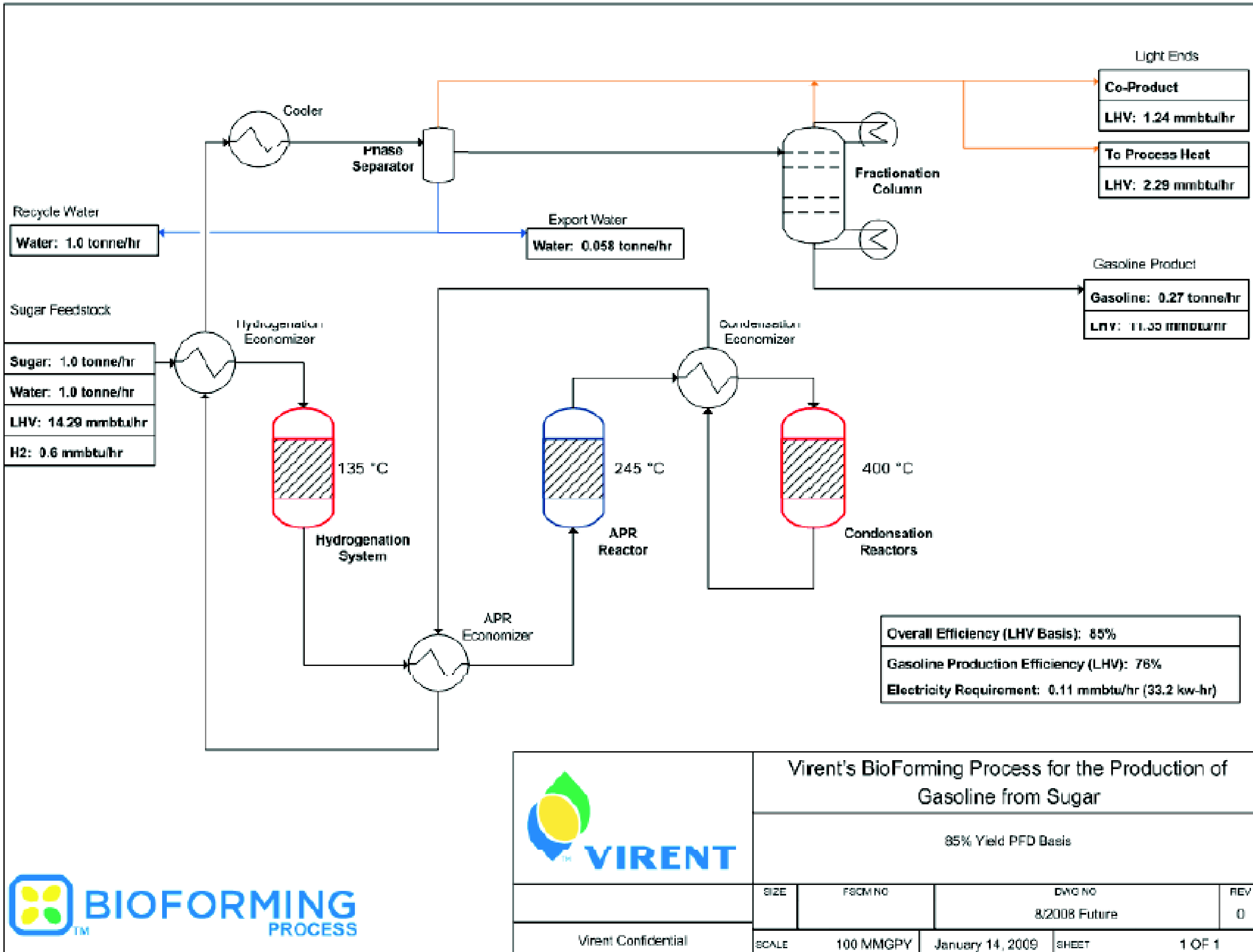


Shell, AB Rotterdam deliver CO2 to OCAP > horticulture

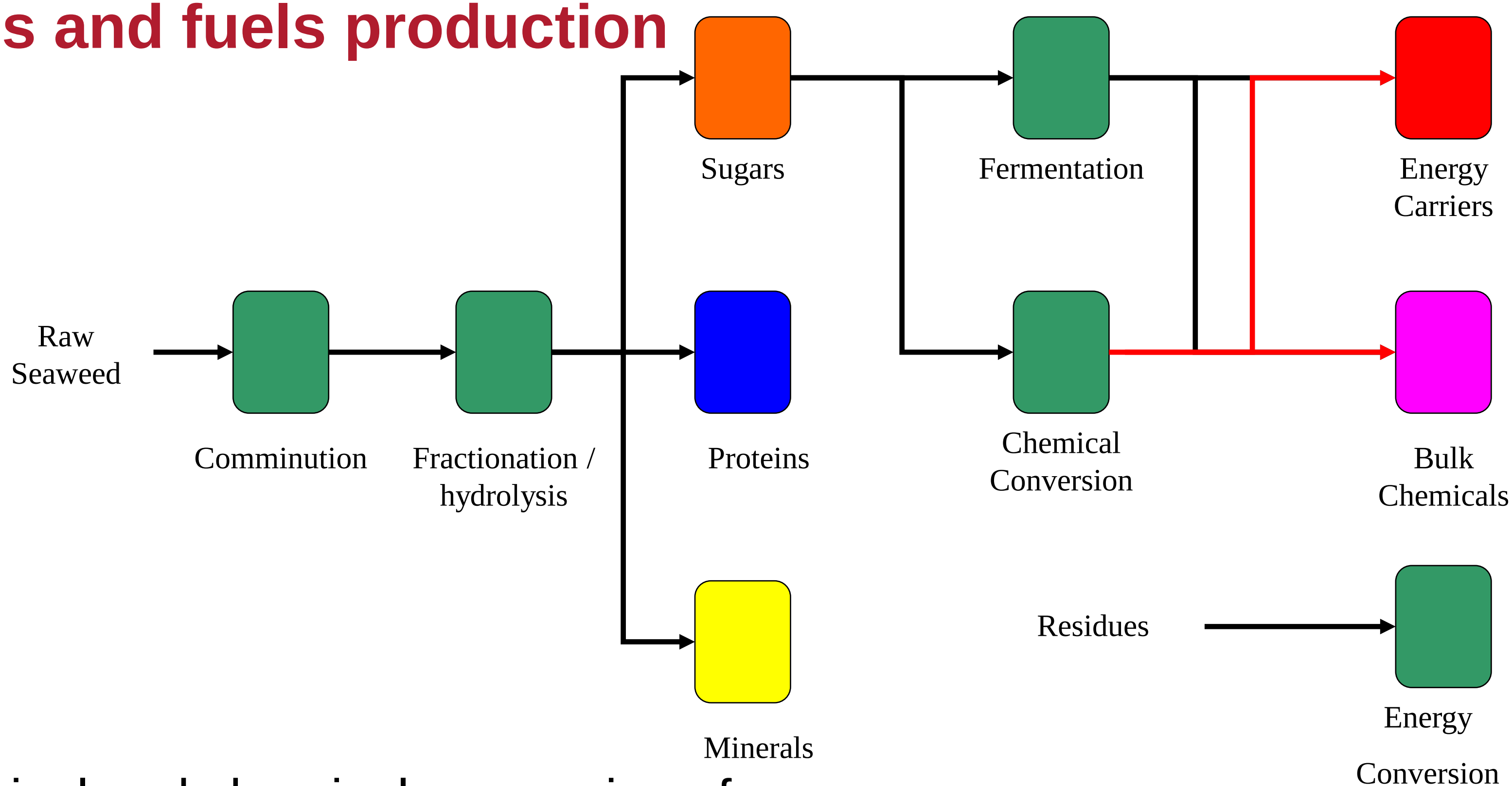
Potential energy carriers from seaweed

- Ethanol, butanol from sugars (≥ 60 wt%) via fermentation
- Diesel and jet fuel via Aqueous Phase Reforming technology
- Methane via anaerobic digestion




Light Ends
Co-Product
LHV: 1.24 mmbtu/hr
To Process Heat
LHV: 2.29 mmbtu/hr
Cooler
Phase Separator
Fractionation Column
Recycle Water
Water: 1.0 tonne/hr
Export Water
Water: 0.058 tonne/hr
Gasoline Product
Gasoline: 0.27 tonne/hr
Sugar Feedstock
Economizer
Economizer
Sugar: 1.0 tonne/hr
Water: 1.0 tonne/hr
LHV: 14.29 mmbtu/hr
H2: 0.6 mmbtu/hr
135 °C
245 °C
400 °C
Hydrogenation System
APR Reactor
Condensation Reactors
APR Economizer
Overall Efficiency (LHV Basis): 85%
Gasoline Production Efficiency (LHV): 76%
Electricity Requirement: 0.11 mmbtu/hr (33.2 kw-hr)
VIRENT
Virent's BioForming Process for the Production of Gasoline from Sugar
85% Yield PFD Basis
SIZE
FSCM NO
DWG NO
8/2008 Future
REV
0
Virent Confidential
SCALE
100 MMGPY
January 14, 2009
SHEET
1 OF 1
BIOFORMING PROCESS

Aim: Development of biorefinery technologies for chemicals and fuels production



- Biochemical and chemical conversion of sugars
- Valorization remaining fractions: proteins, minerals, biogas
- Extraction of bio-actives, alginates, fucoidan,.. Not the focus
- Design, economic evaluation, LCA

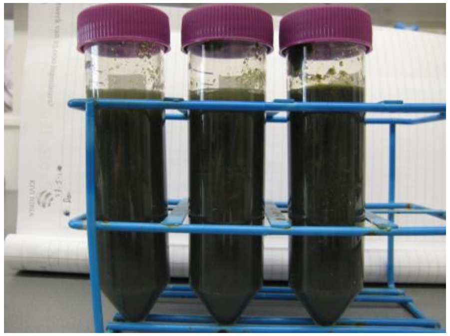
Biomass characterization

basis for process development and selection of products/applications

	Laminaria digitata	*Sargassum muticum*	*Saccharina latissima*	*Palmaria palmata*	*Ulva lactuca*
Harvest month	June	June	July	March	February
Sugars					
Total sugars, % d.m.	**14.5**	**7.8**	**17.6**	**40.5**	**11.3**
Glucose	5.9	2.2	6.6	3.8	5.4
Xylose	0.4	0.3	0.2	31.1	1.3
Fucose	1.9	1.1	1.6	0.0	0.0
Mannose	1.9	0.4	0.3	0.0	0.0
Arabinose	0.0	0.0	0.0	0.0	0.0
Galactose	0.7	1.0	0.8	5.5	0.5
Rhamnose	0.1	0.1	0.1	0.0	4.1
Mannitol	3.6	2.7	8.1	0.0	0.0
Total water extrac. % d.m.	25.2 (no mono-)	32.8 (mannitol)	47.9 (mannitol)	32.2(no mono-)	38.3 (no mono-)
EtOH/Toluene extract. % d.m.	3.4	7.9	6.3	6.3	2.6
EtOH extrac. % d.m.	1.3	2.5	3.3	2.0	0.2
Ash (900°C) % d.m.	22.8	22.9	25.0	9.9	18.2
Protein, % d.m. (Kjeldahl)	10.8	16.0	12.4	17.8	23.5

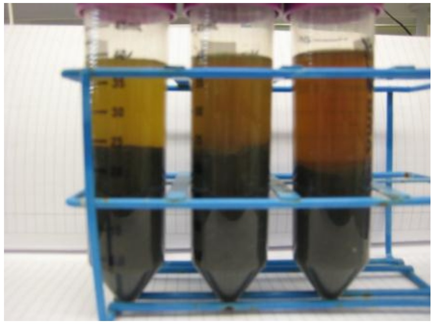
Fractionation of Laminaria

Optional Catalyst



Water + Seaweed

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



Liquid

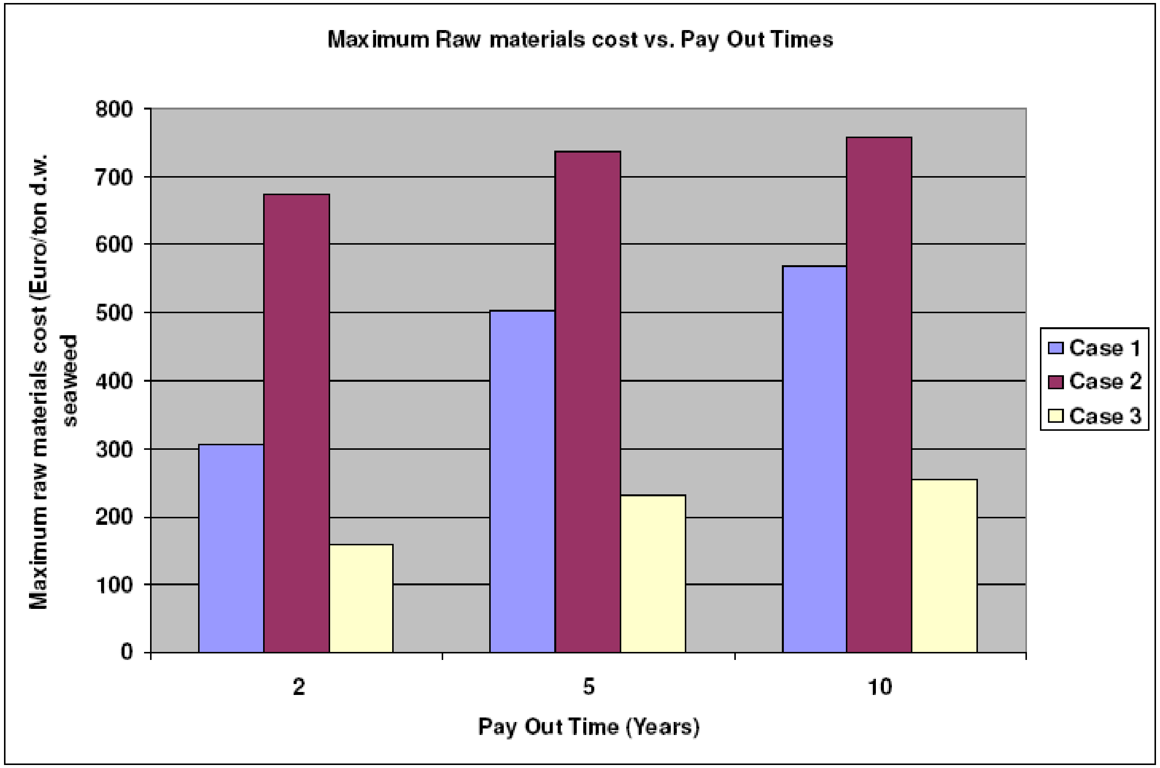
Solid

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

Economics: 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 Pay Out Time 2, 5, 10 yrs



Scale biorefinery 330 kt/yr

= 110 km2 @ 30 ton/ha/yr

1: Full Biorefinery: mannitol, fucoidan, furanics, fumaric acid, protein, K-"ore": 300-600 €

2: Extraction of (too much) alginate, fertilizer (K,P) and energy (AD + CHP): 650- 750 €

3: Simplified Biorefinery producing butanol and fertilizer: 150 - 250 € /ton d.w