# Seaweed potential in the Netherlands

**Hans Reith**

**Wouter Huijgen**

**Jaap van Hal**

**Jip Lenstra**

ECN-L--09-080 June 2009

Energy research Centre of the Netherlands

# Seaweed potential in the Netherlands

**Hans Reith, Wouter Huijgen, Jaap van Hal, Jip Lenstra**

**ECN Biomass, Coal and Environmental Research**

***Macroalgae - Bioenergy Research Forum, 2nd June 2009, Plymouth, UK.***

***Sponsored by SUPERGEN Bioenergy II***

ECN

## Contents

- Background
- Seaweed cultivation in the North Sea
- Potential integration with wind turbine parks
- Production costs
- Processing and biorefinery options

- Conclusions

*J.H. Reith, E.P. Deurwaarder, K. Hemmes, A.P.W.M. Curvers, P. Kamermans, W. Brandenburg, G. Zeeman. 2005. Report ECN-C--05-008 (in Dutch). http://www.ecn.nl/docs/library/report/2005/c05008.pdf*

# NL targets Transportation Biofuels

- 2007: Obligation 2% biofuels; no tax reduction: costs for user.
- Stimulation development "2nd generation" biofuels: 60 MEuro in 5 years

Revision of targets in Oct. 2008 (concern about effectiveness, sustainability)

- 2009: reduced from 4.5% to 3.75%
- 2010: reduced from 5.75% to 4%

# NL Biobased raw materials platform: target for 2030

- Substitute 30% fossil feedstock (ca. 850 PJ) with biomass to supply
  - 60% transport fuels
  - 25% chemicals and materials
  - 25% of the electricity demand
  - 17% of heating requirements

**Biomass demand: approx. 1200 PJth/yr = 80 Mton (60-80% from import)**

- Sustainable development and production of biomass in NL and abroad
  - **Aquatic biomass** (microalgae, seaweeds, other), use of agro-residues, crop development for biorefinery, certification of imported biomass
- Co-production of chemicals (C1-C6), transport fuels, electricity and heat
  - **Biorefining**, fermentation, enzymatic/chemical conversion
  - Gasification (SNG) /pyrolysis /co-firing/fermentation of residues

http://www.senternovem.nl/energytransition/themes/biobased_raw_material_platform/index.asp

ECN

# Current seaweed exploitation


Macrocystis pyrifera (giant kelp);Californie*

Laminaria digitata, Yorkshire,UK **

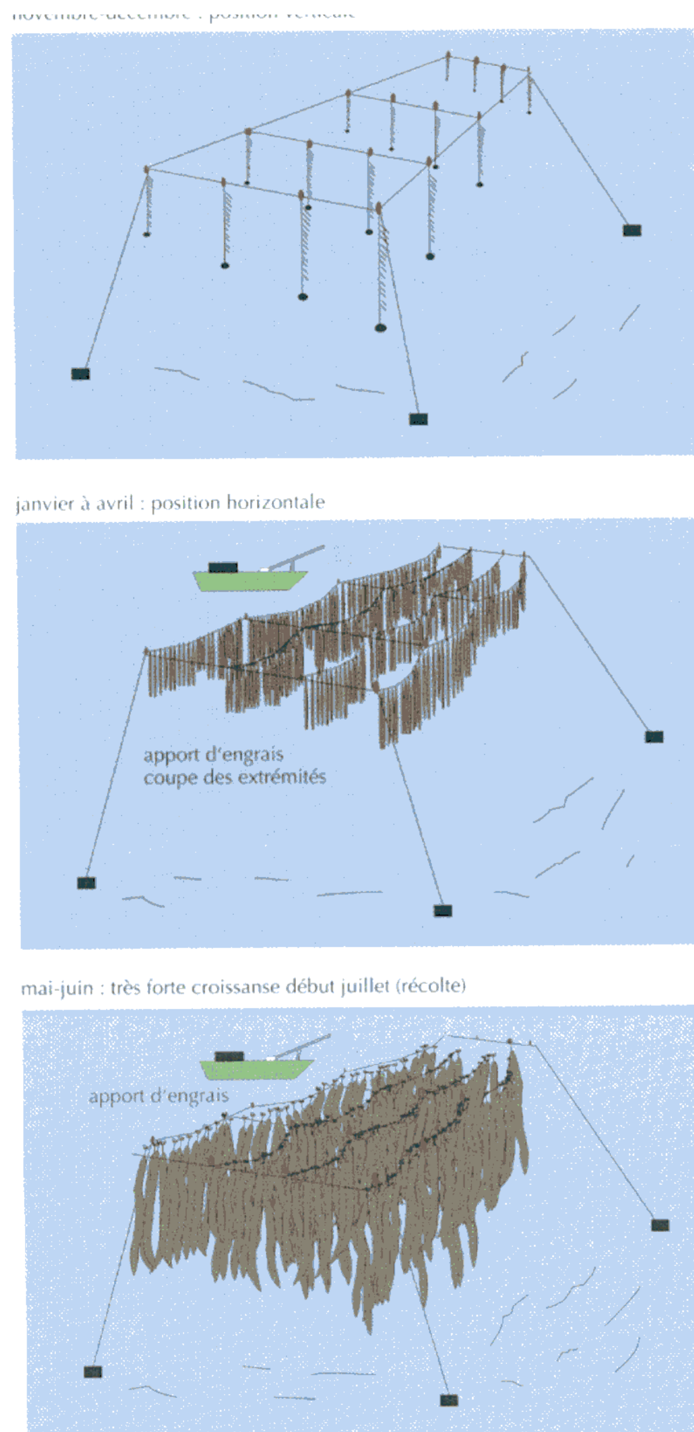
Gracillaria line cultivation



- 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

*Figure 84 - Culture de* Laminaria japonica *en Chine. La majeure partie de la récolte est utilisée pour l'alimentation humaine directe mais le tonnage destiné à l'extraction d'acide alginique augmente d'année en année.*

Photo's: © R. Perez,1997. Ces algues qui nous entourent. Ifremer.



Sea weed harvest in Asia (Photo Ifremer)


Harvest of Macrocystis (Kelco company)

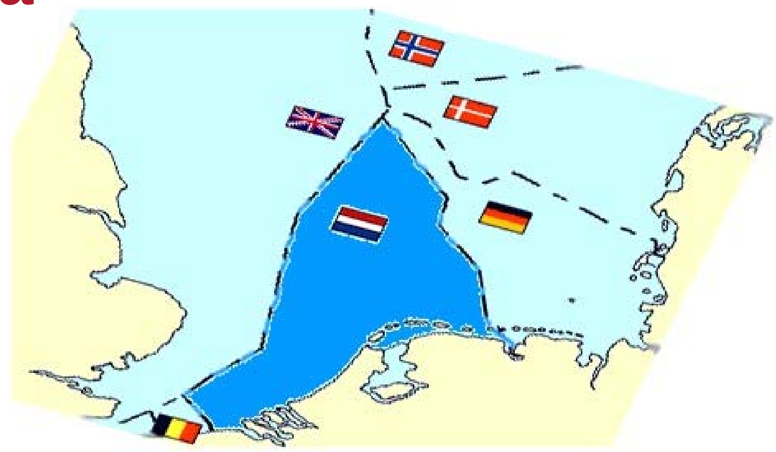
Experimental ring system for cultivation of Laminaria
in the German North Sea (AWI-Bremerhaven, B.H. Buck *et al*)

•Good stability in the North Sea
•Extrapolated biomass production ~ 20 tons d.w./ha.yr
• Scale-up potential ?

## BIO-OFFSHORE:

### Large scale Seaweed production integrated with offshore wind turbine parks in the North Sea

### - Assessment study 2005



## Projection for 2040

- Seaweed cultivation area 5.000 km2 (<10 % of the NL area of the North Sea @ 57.000 km2)
- Integration with off-shore wind parks & (other) aquaculture operations
- Energy potential up to 350 PJth (25 Mton dry biomass per year)

*J.H. Reith, E.P. Deurwaarder, K. Hemmes, A.P.W.M. Curvers, P. Kamermans, W. Brandenburg, G. Zeeman. 2005. Report ECN-C--05-008 (in Dutch).* http://www.ecn.nl/docs/library/report/2005/c05008.pdf

# Some results

- North Sea is an additional  area for biomass production
- Areal productivity ca. 20 tons d.w./ha.yr seems feasible without nutrient addition
- Productivity can possibly be increased up to 50 ton d.w./ha.yr via layered cultivation / controlled addition of nutrients

- Energy potential (5,000 $km^2$): up to 350 PJ. Net : 50 PJ green chemicals + 160 PJ fuels. Total estimated $CO_2$ emission reduction approx. 11 Mton/yr

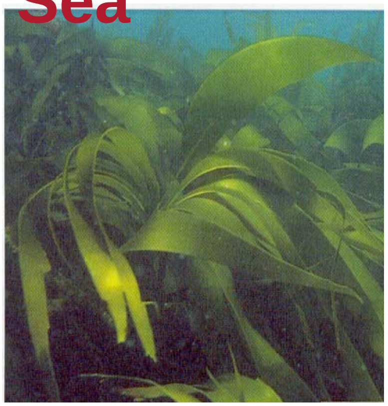
- Impact of large scale-seaweed cultivation on the North Sea ecosystem is a critical success factor (introduction of species, interference with marine mammals, eutrophication,..)

- Fast growing native seaweed species available

# Seaweed species native to the North Sea

Laminaria saccharina

Laminaria digitata



Laminaria hyperborea (Perez)

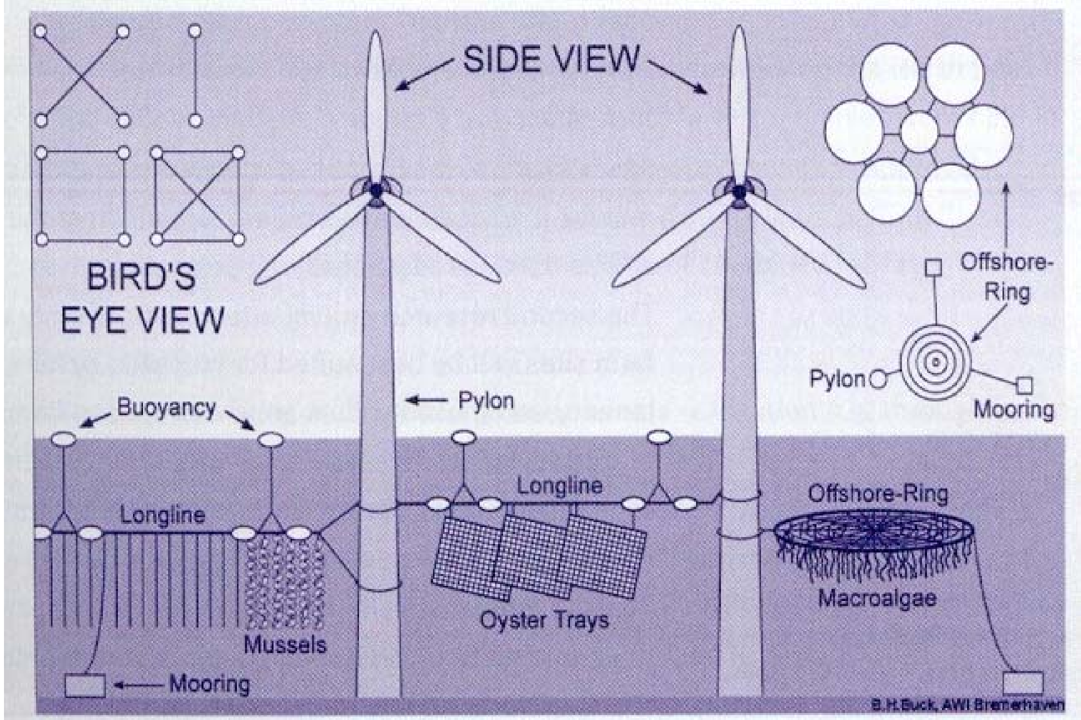
Ulva sp.

Alaria esculenta (Irish Seaweed Centre)

Palmaria palmata (AWI)

# 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

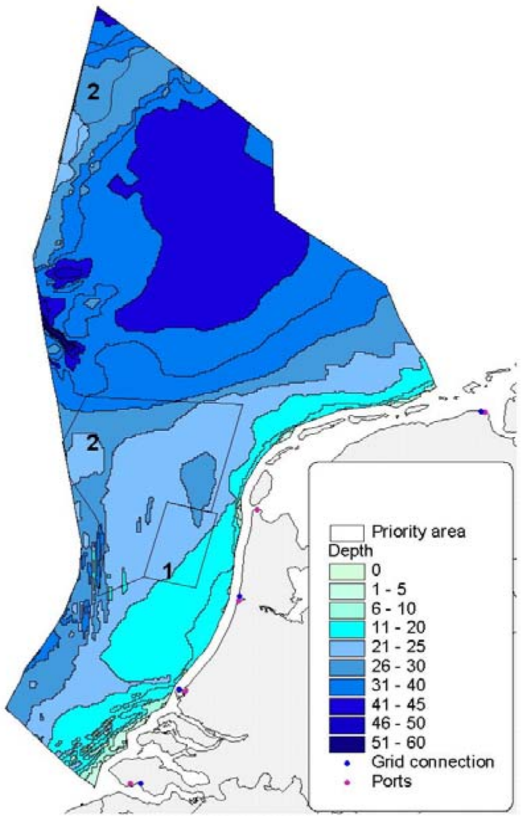


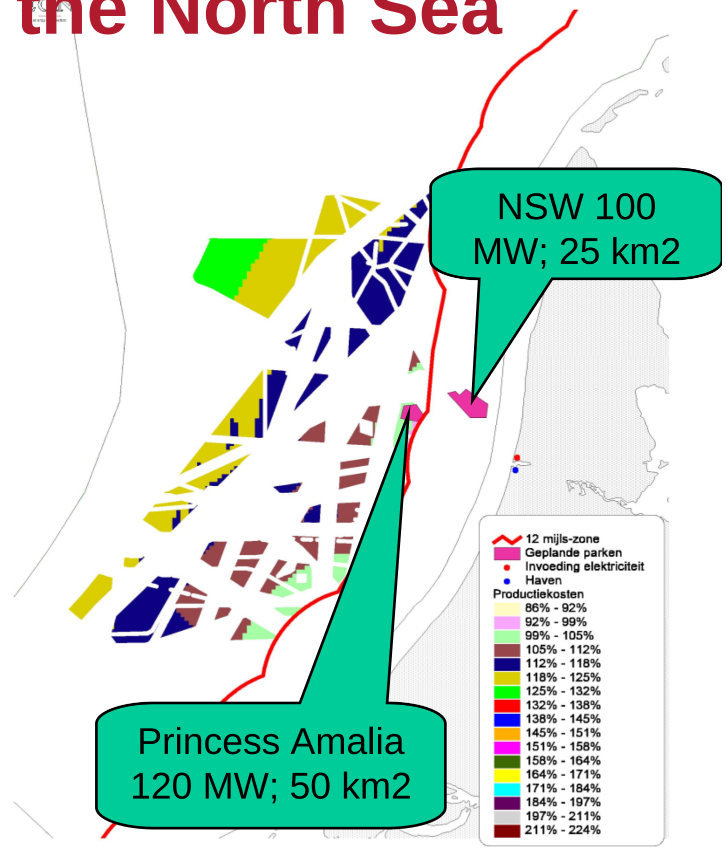

Source: Bela H. Buck, Alfred Wegener Institute, DE.

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

ECN

# Off-shore wind turbine parks in the North Sea




- NL Target 2020: 6000 MW (ca. 10% NL e-use)
- 10 parks @ 600 MW = 100 turbines 6 MW = 100 km2 per 600 MW park
- In 2020: 1000 km2 potentially available for seaweed cultivation
- Beyond 2020 ........



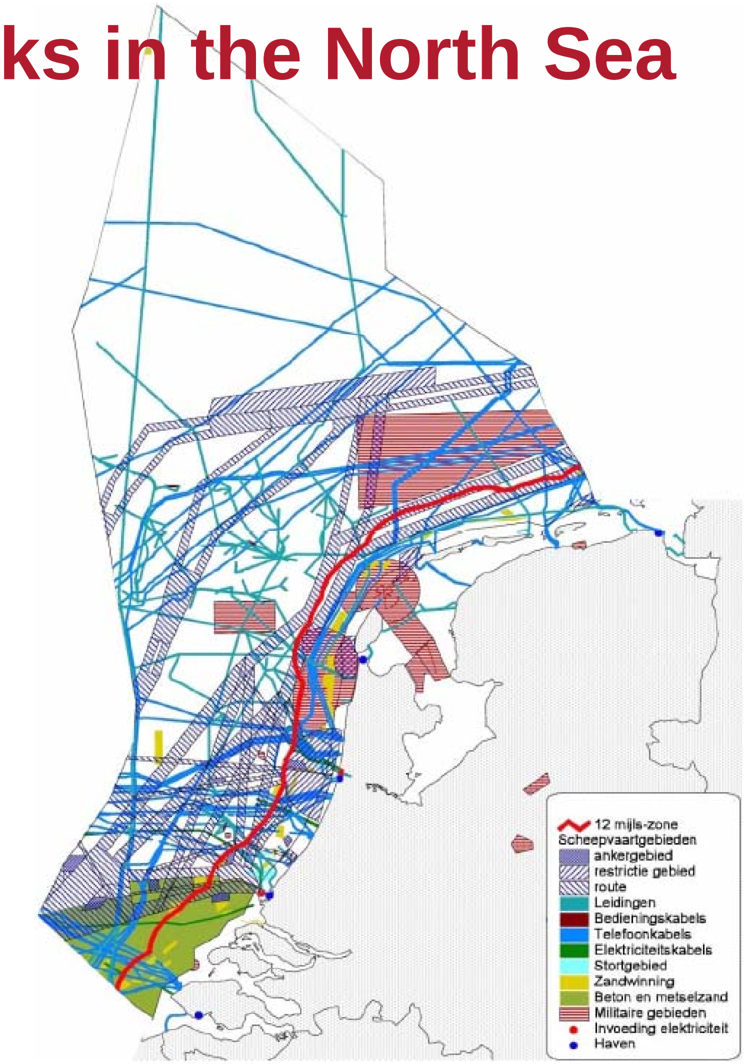
NSW: demopark; 2005/2006; 15 – 20 m
Q7: 20-25 m; exp. teelt mosselzaad

# Off-shore wind turbine parks in the North Sea

Spatial planning

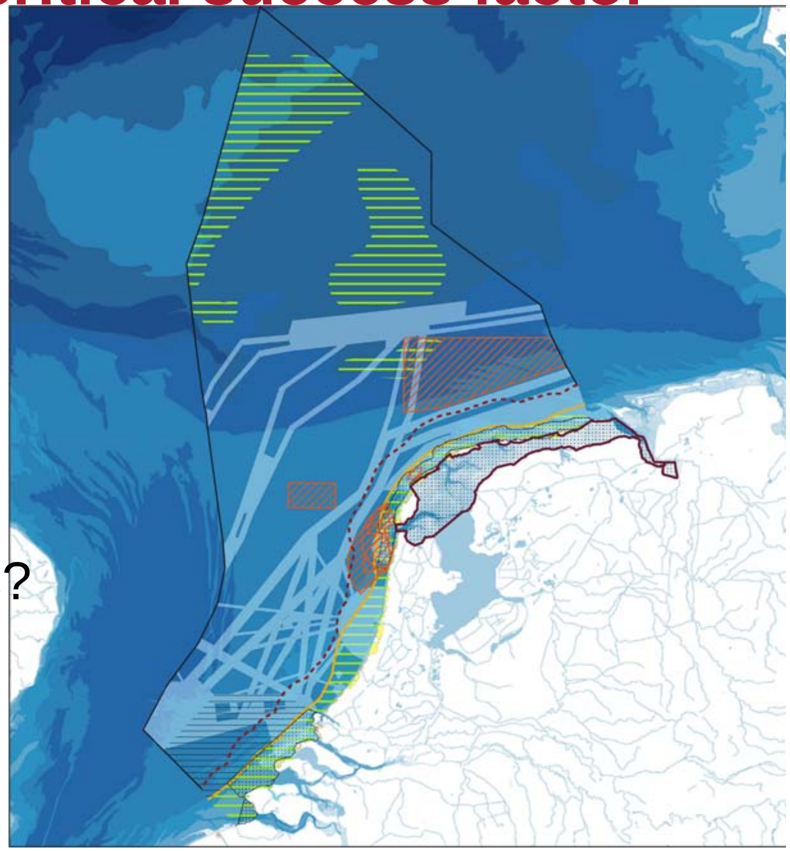
- Shipping routes
- Military areas
- Fishery
- Sand production
- …..

Location is a major factor for investment costs, logistics and operational costs




Figuur 7.1 *Beheers- en gebruiksfuncties in de Nederlandse Exclusieve Economische Zone (NEEZ) van de Noordzee. De gemarkeerde gebieden zijn uitgesloten voor offshore windenergie. Bron: Rijkswaterstaat*

# Effects on North Sea ecosystem “critical success factor”



- Introduction of species
- Effects on fish, marine mammals
- Effect on eutrophication
- ……..

- Seaweed cultivation can enhance biodiversity by offering shelter + feed for molluscs, fish. Restoring fish populations?

- Pilot scale test in North Sea required to assess impacts (-/+)
- Early involvement of stakeholders and public
- Communication, Address societal aspects

ECN

# 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<br>50 | 57<br>83 | 67<br>42 | 40<br>25 | [3] |
| Gracillaria/Laminaria line cultivation (offshore) | 11<br>45 | 14<br>59 | 538<br>147 | 409<br>112 | [3] |
| Tidal Flat farm Gracillaria/Ulva | 11<br>23 | 14<br>30 | 44<br>28 | 33<br>21 | [3] |
| Floating cultivation Sargassum | 22<br>45 | 32<br>66 | 73<br>37 | 50<br>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 dry weight.
Verification required!

# Seaweed production cost

Production costs depend mostly on :

- investment costs cultivation and harvesting systems
- biomass productivity per unit of area

Current cost offshore cultivation are too high for energy generation alone: combination of products and fuels via biorefinery may be economically feasible

**Definition of biorefinery cf. IEA Bioenergy Task 42 Biorefineries**

•Biorefinery is the sustainable procesing of biomass into a spectrum of marketable products and energy

Aims: optimize economics and reduction of environmental impacts

# Use of seaweed as bioenergy source at a scale of 500 kton /year (d.w. basis)

| **Bio-Energy option**<br><br>Assessment based on estimates of investments and operational costs conversion techn. | **Value of energy carrier** | **Maximum allowable (break even) cost seaweed**<br>**excluding profit**<br>**excluding subsidy for e-production**<br>**[Euro/ton d.w.]** | **Maximum allowable (break even) cost seaweed**<br>**excluding profit**<br>**INCLUDING subsidy for e-production**<br>**[Euro/ton d.w.]** |
|---|---|---|---|
| Methane via Anaerobic digestion (proven technology for seaweed) | Methane:<br>3.5 Euro/GJ | **8** | **8** |
| Electricity via Anaerobic digestion | 27 Euro/MWh | **10** | **76** |
| Ethanol + electricity | Ethanol: 0.4 Euro/L<br>Electr 27 Euro/MWh | **3** | **44** |
| Electricity via bio-crude (HTU) | Biocrude production cost 6.4 Euro/GJ<br>Electr 27 Euro/MWh | **-31** | **71** |

ECN

# 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 !

Specific composition: range of polysaccharides, proteins, minerals, no lignin

Highly suited feedstock for biorefinery to produce products and fuels

- higher value compounds (phycocolloids, colourants, mannitol, fucoidan, proteins)
- platform chemicals via fermentation (e.g. lactic acid) or chemical conversion
- fuels via fermentation (EtOH, CH4, H2) or thermochemical conversion (HTU, pyrolysis)

# Potential extraction products from Laminaria sp.

| Product | Markt waarde | Gehalte in Laminaria | Product 1) | Waarde zeewier |
|---|---|---|---|---|
| | $ /ton | gew. % ds | ton/ton | $ /ton droge stof |
| Alginaat | 6.000 | 23 | 0,184 | 1104 |
| Mannitol | 6.000 | 12 | 0,096 | 576 |
| Fucoidine | 6.000 | 5 | 0,04 | 240 |
| Jodium | 14.500 | 0,45 | 0,0036 | 52,2 |
| Potash | 60 | 9,5 | 0,076 | 4,56 |

- Product value ranges from 5 to 1100 $/ton seaweed
- Combinations possible
- Potential market volume unknown

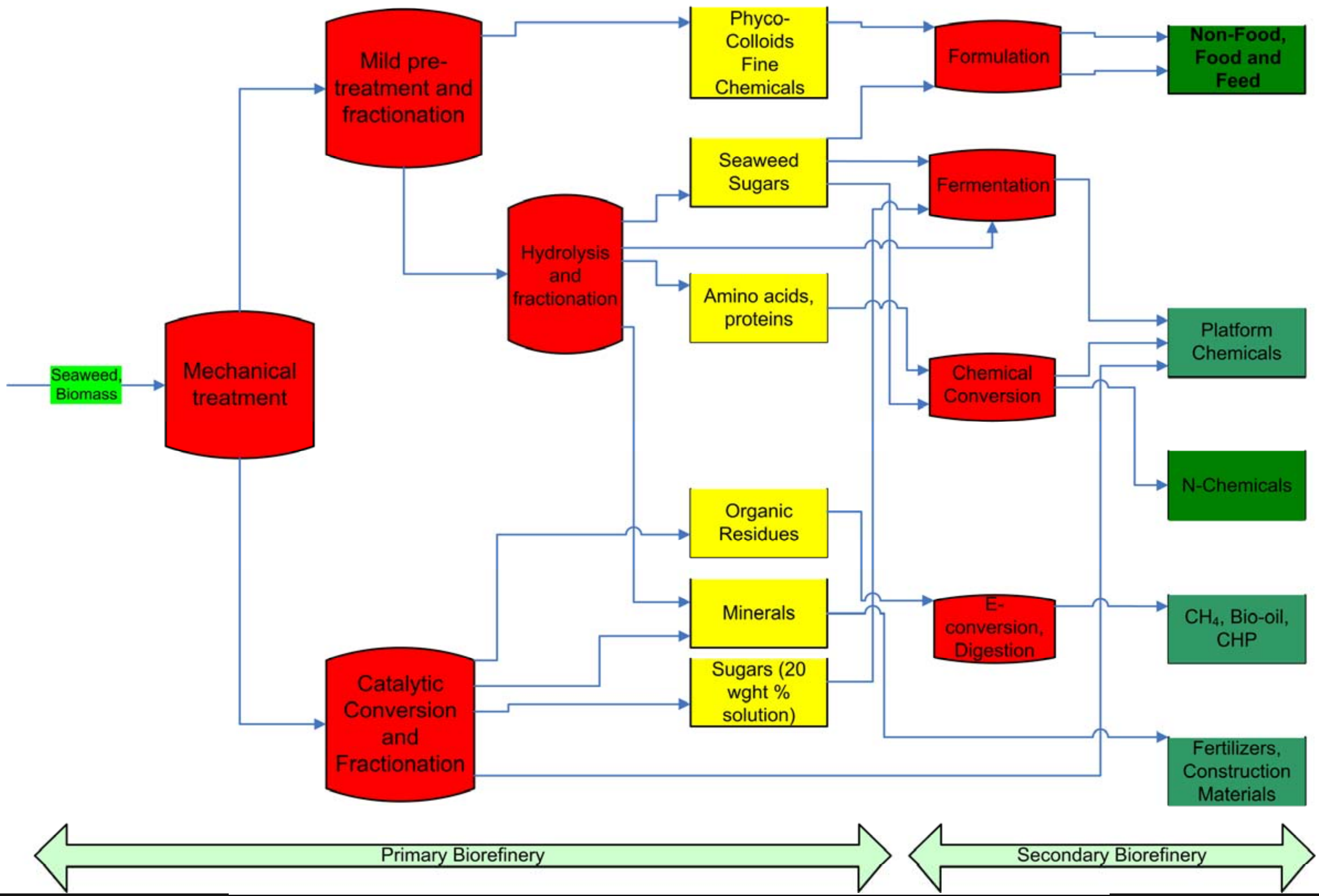
# Potential fermentation products from Laminaria

| Product | Markt-waarde | Produc-tie | Waarde | 100.000 ton/jaar (20 km2) | | 500.000 ton/jaar (100 km2) | |
|---|---|---|---|---|---|---|---|
| | ($/ton) | (kg/ton zeewier) | ($/ton zeewier) | (ton product) | Omzet (M$ /jr) | (ton product) | Omzet (M$ /jr) |
| | | | | | | | |
| Ethanol | 331 | 255 | 84 | 25.400 | 8,4 | 127.000 | 42,0 |
| Azijnzuur | 728 | 247 | 179 | 24.600 | 17,9 | 123.000 | 89,5 |
| Butyraldehyde | 948 | 123 | 117 | 12.300 | 11,7 | 61.500 | 58,3 |
| Adipine zuur | 1.433 | 370 | 530 | 36.900 | 52,9 | 184.500 | 264,4 |
| Butanol | 904 | 123 | 111 | 12.300 | 11,1 | 61.500 | 55,6 |
| Melkzuur | 300 | 486 | 146 | 48.600 | 14,6 | 243.000 | 72,9 |
| Succinic acid | 772 | 429 | 331 | 42.800 | 33,0 | 214.000 | 165,1 |
| Propylene glycol | 1.279 | 133 | 170 | 13.300 | 17,0 | 66.500 | 85,0 |
| Glycerol | 1.279 | 247 | 315 | 24.600 | 31,5 | 123.000 | 157,3 |
| Citroenzuur | 1.808 | 429 | 775 | 42.800 | 77,4 | 214.000 | 386,9 |
| Proprion zuur | 904 | 227 | 205 | 22.600 | 20,4 | 113.000 | 102,1 |
| 2-3 Butanediol | 1.984 | 163 | 323 | 16.200 | 32,1 | 81.000 | 160,7 |
| | | | | | | | |
| Gemiddelde waarde producten ($/ton) | | | 1.050 | | | | |
| Gemiddelde waarde zeewier ($/ton d.s) | | | 274 | | | | |

- large potential / Av. Product value per ton seaweed ca. 275 $
- technology for fractionation/hydrolysis and fermentation systems for seaweed sugars needs to be developed

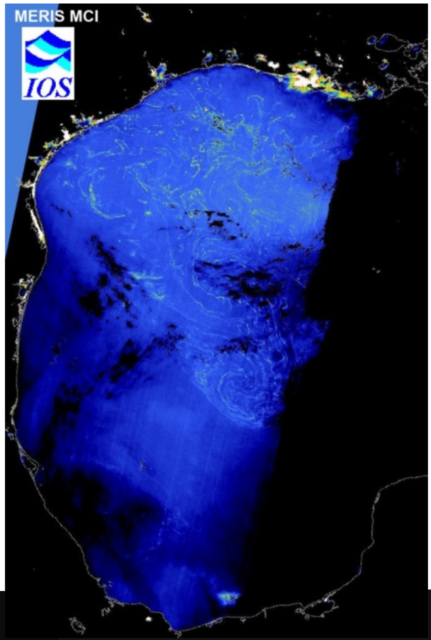
# Seaweed processing options

Focus EOS LT proposal Seaweed Biorefinery
• Platform chemicals and fuels via catalytic conversion and fermentation
•Full valorization



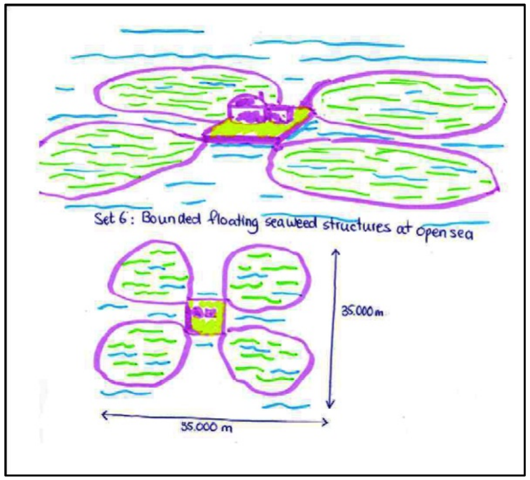
# Seaweed on ocean scale


- Focus on Sargassum sp. (fast growing, floating)
- The Sargasso Sea seems a good location
- Not much current, waves and storms
- Cost estimate floating cultivation ca. $50/ton d.w. (Chynoweth)
- Sargassum seaweed is now a pest
- But it forms also a good habitat for fish
- Monitoring with satellites feasible



# Seaweed on ocean scale

- Proposed concepts for farms
- Floating PE-pipe proposed as boundary circle
- Pre processing on sea to raw concentrate
- Biorefinery on shore
- Costs could be competitive to oil or natural gas if large scale production and conversion prove to be possible




ECN

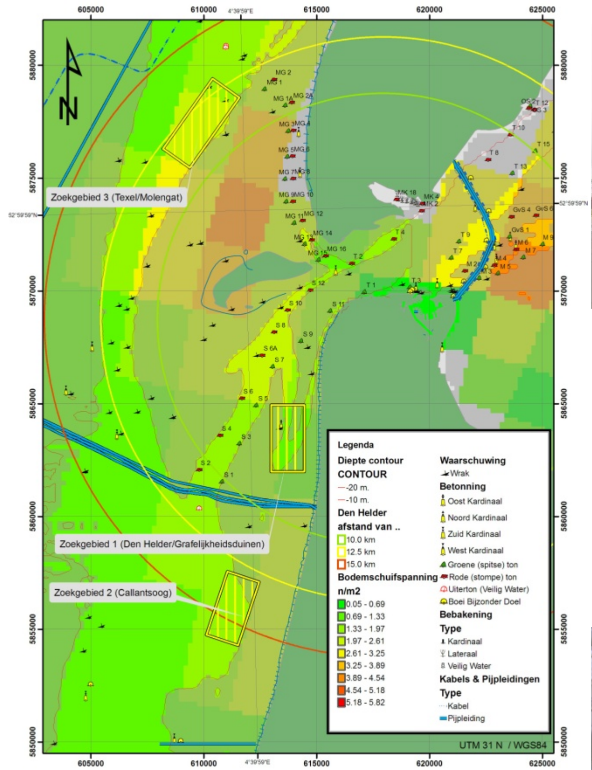
# Global aquatic biomass energy potential

| 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

## Nearshore Seaweed cultivation pilot (in preparation)

- Initiated by ATO Den Helder
- Cooperation with WUR, IMARES, TNO, ECN and others
- Hatchery at Den Helder (TNO)
- Grow out area at near shore location
- Experiments with several production techniques and North sea species
- EU-EFRO grant pending




## Seaweed biorefinery

EOS LT R&D project Submitted to SenterNovem

# R&D issues

**Technological**

- Offshore cultivation systems/ engineering
- Nutrient supply and recycle
- Harvesting  & logistics
- Processing (1st step at sea?)/
- Development of biorefinery systems
  - Hydrolysis and Fermentation systems
  - Chemical conversions
  - Energy conversion

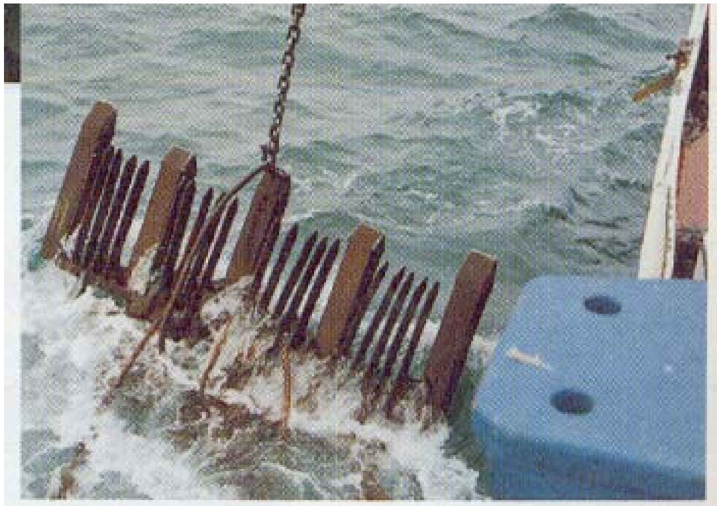


Photo: IFREMER, F.

**Non-technological**

- Ecological effects (-/+)
- Development of logistic chain
- Societal and Socio-economic aspects

ECN

# Conclusions

Seaweed biomass offers a vast potential as a source of biobased chemicals and bio-energy.

Seaweed cultivation combined with offshore wind turbine parks offers potential high productivity, multifunctional area use incl. potential combination with other aquaculture operations.

The production costs are uncertain. Offshore cultivation costs seem too high for energy production alone. Seaweed biomass is highly suited for production of combinations of renewable chemicals and energy via biorefinery to enhance economic feasibility and reduce environmental impacts.

R&D should focus on development of offshore cultivation systems, logistics and biorefinery and on environmental and socio-economic impacts. More insight in the feasibility of floating cultivation is required because of the potential low cost.

# Some key references

Energy supplies from Sea Farming, 1980. In: N.P. Cheremisinoff, P.N. Cheremisinoff and F. Ellerbusch (eds). Biomass: Applications, Technology and Production. Marcel Dekker Inc. New York and Basel.

Wilcox, H.A.1982. The ocean as a supplier of food and energy. In: Mischlin and Bachofen (eds). New trends in Research and Utilisation of Solar Energy through Biological Systems. Experientia Suppl. Vol. 43.

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.

Pérez, R. et al, 1997. Ces algues qui nous entourent. Conception actuelle, role dans la biosphere, utilizations, culture. Editions Ifremer. ISBN 2-905434-75-9.

K. Luning and S. Pang, 2003. Mass cultivation of seaweeds: current aspects and approaches. Journal of Applied Phycology 15: 115-119.

Buck, B.H. & C.M. Buchholz, 2004. The offshore ring: A new system design for the open ocean aquaculture of macroalgae. Journal of Applied Phycology 16: 355 - 368. 2004.

J.H. Reith, E.P. Deurwaarder, K. Hemmes, A.P.W.M. Curvers, P. Kamermans, W. Brandenburg, G. Zeeman. 2005. Report ECN-C--05-008 (in Dutch). http://www.ecn.nl/docs/library/report/2005/c05008.pdf

*http://www.awi-bremerhaven.de/*
*http://www.cbm.ulpgc.es/seapura/index.html*
*http://www.senternovem.nl/energytransition/*
*www.algaebase.org*


# Thank you for your attention

**Hans Reith, reith@ecn.nl**

**www.ecn.nl**
**www.biosynergy.eu**
**www.biorefinery.nl**