Seaweed Biorefinery in the Netherlands

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Energy research Centre of the Netherlands (ECN)

- What do we do:
  - ECN develops market driven technology and know-how to enable a transition to sustainable energy society

- Business units:
  - Biomass & energy efficiency
  - Solar energy
  - Wind energy
  - Policy studies
  - Environment & energy engineering

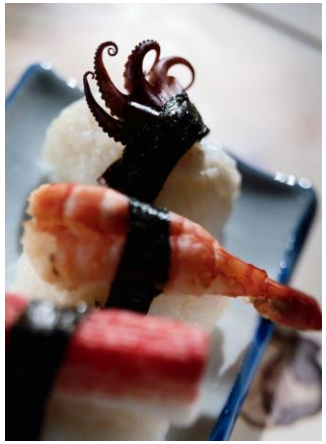
ECN

- Independent research institute
- ~600 employees
- Locations:
  - Petten (HQ)
  - Amsterdam
  - Eindhoven
  - Brussels
  - Beijing

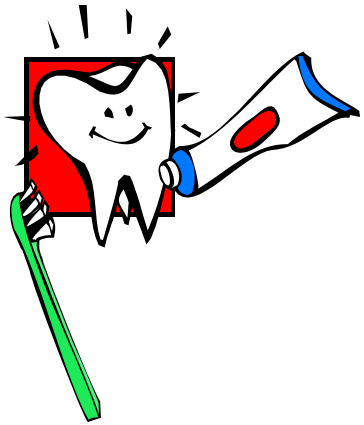
(Biorefining of) Seaweeds

Have you had your seaweed today?

- Food (sushi)



- Thickener (agar)

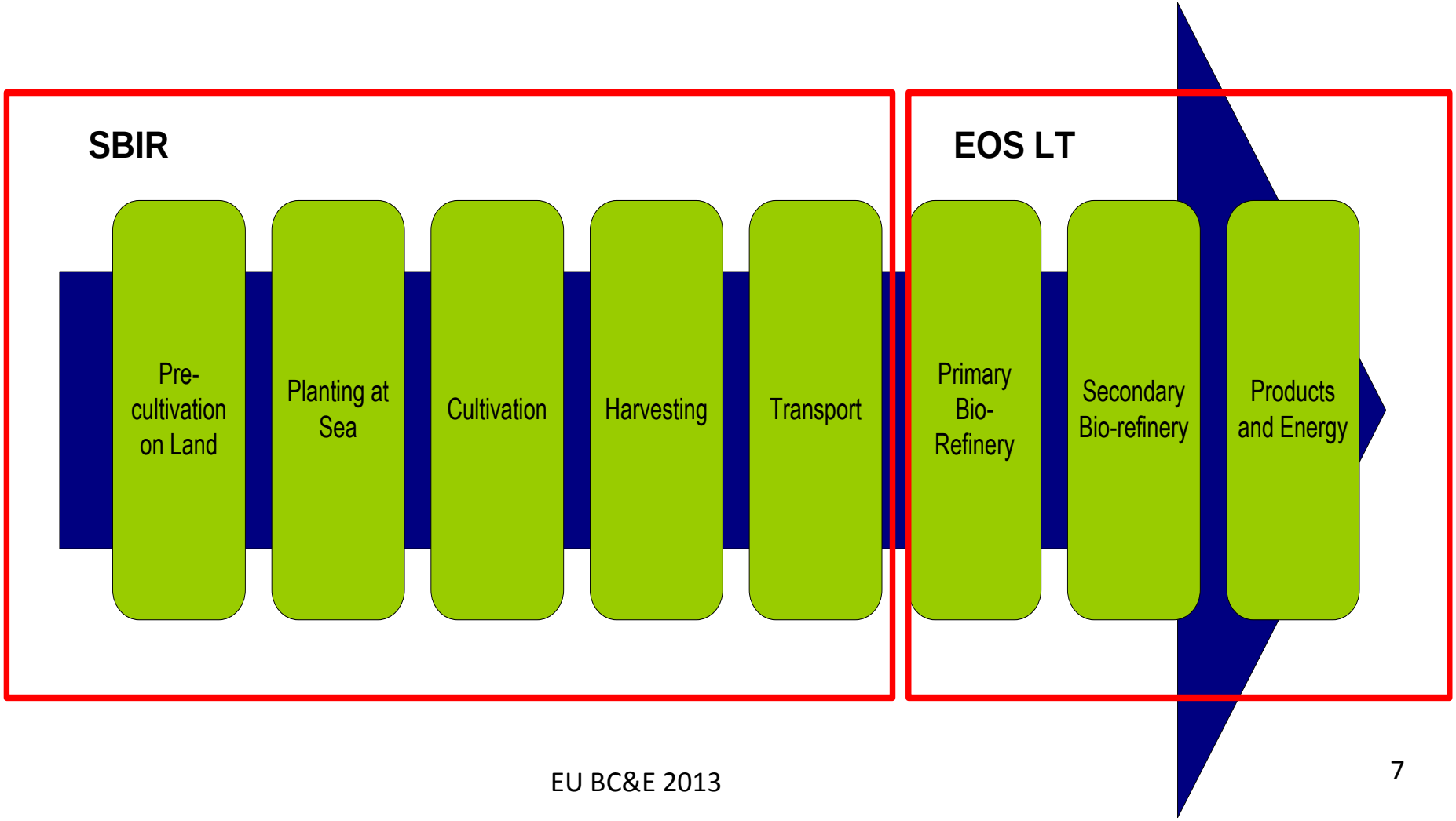


Why seaweeds for biorefining?

- Large potential availability
  - Earth's surface ~70% water.
  - Fastest growing biomass at the latitude of The Netherlands.
- No competition for land use
- Opportunity for simultaneous food and chemicals production
- Chemical composition
  - Comprised of (specialty) carbohydrates, proteins and ash.

    → Source for glutamic acid, aspartic acid, xylose, rhamnose, mannitol, uronic acids (alginate), fucoidan, ...
  - Complementary to micro-algae and lignocellulose.
- Various potential applications of biorefinery products

Dutch Seaweed Biorefinery Program



Seaweeds native to the North Sea

Saccharina latissima

Laminaria digitata

Laminaria hyperborea

Ulva sp.

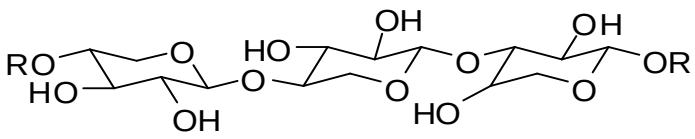
Alaria esculenta

Palmaria palmata

Example: *Palmaria palmata*

Palmaria palmata

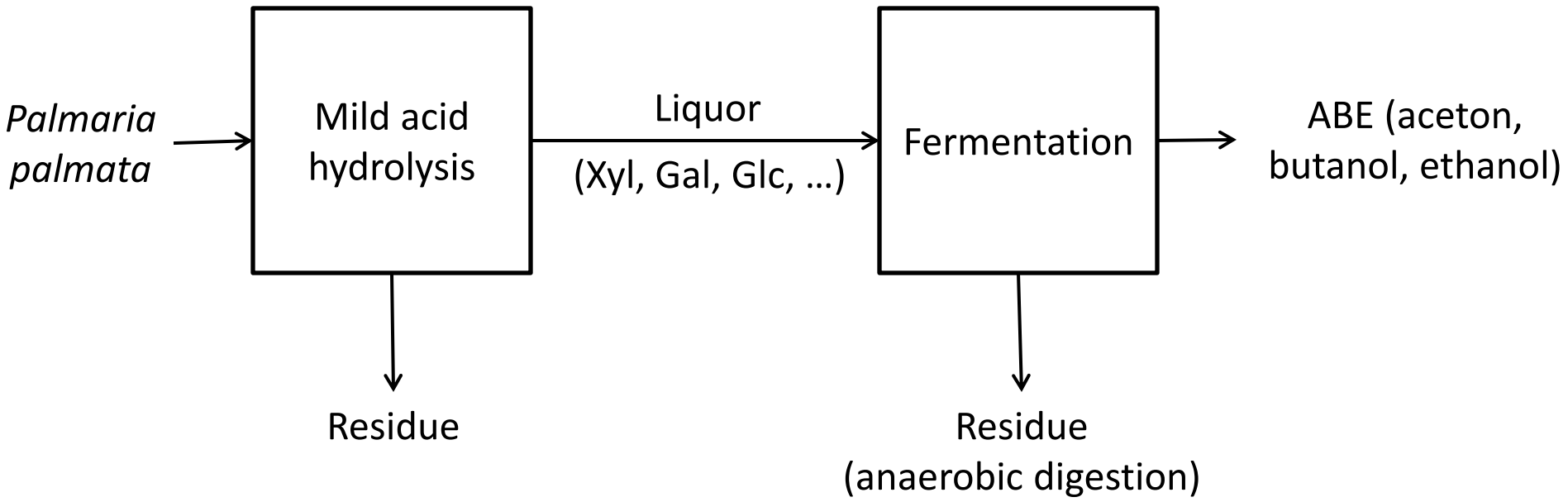
- Red seaweed.
- Rich in carbohydrates xylose, galactose and glucose.
- Shape: seaweed plant with holdfast (stem) and blades.
- Size: decimeters.



Xylan (1,3 and 1,4 linkage)

	Arabinose	Fucose	Galactose	Glucose	Xylose	Glycerol	Ash	Sum
Composition specific batch (dw%)	0.2	0.1	11.5	10.7	30.2	6.9	12.8	72.2

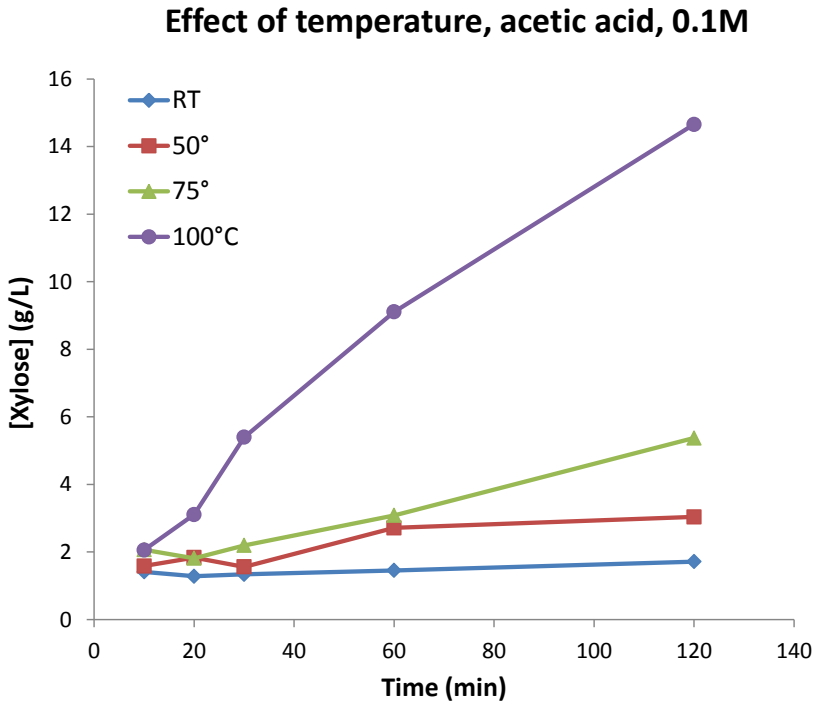
Palmaria Biorefinery Scheme



Hydrolysis of freeze-dried *Palmaria*

- Tests with freeze-dried *Palmaria*.
- Various acids and conditions tested.
- Hydrolysis of Palmaria to (oligomeric) xylose proven.
- Xylose concentration is dependent on the $[H]^+$, not on type of acid.
- Selected conditions: 0.1M acetic acid, 100 °C, 2hrs.

→ Scale up using fresh seaweeds.



Hydrolysis of fresh *Palmaria*

- *Palmaria* harvested in Ireland in July 2012 and processed within one week (no mechanical treatment).
- Input (20L autoclave):
  - 5 kg Palmaria (~1 kg d.w.)
  - 1:1 HOAc solution.
- Red seaweed turned into green 'soup'.
  - Solids recovery 51.6% dw.
  - Yield xylose ~45% & galactose ~60%.
  - Process liquor used for ABE fermentation.
- Future work:
  - Improvement separation solid residue – liquor (potential increase Xyl yield to ~70% & Gal to ~90%).

Fermentation Hydrolysates to ABE

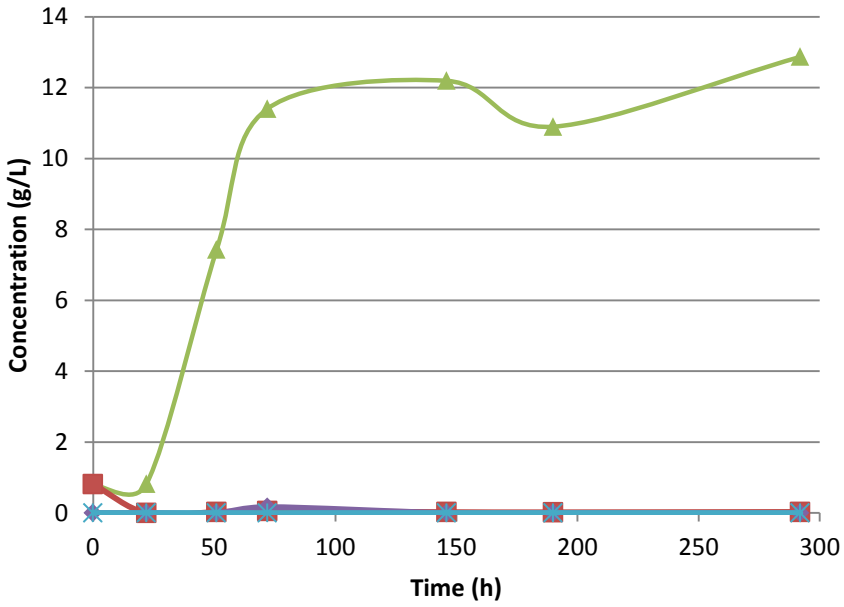
- Microorganism: *Clostridium beijerinckii*
- Fermentation conditions:
  - Anaerobic, 37°C, 50mL serum flasks.
- Cultures:
  - *Palmaria palmata* extract (~0.1 M HOAc).
  - *Palmaria* extract pre-incubated with enzyme GC220 to hydrolyze oligomers (50°C, 24 h).

Monosugars and products concentrations (g/L)

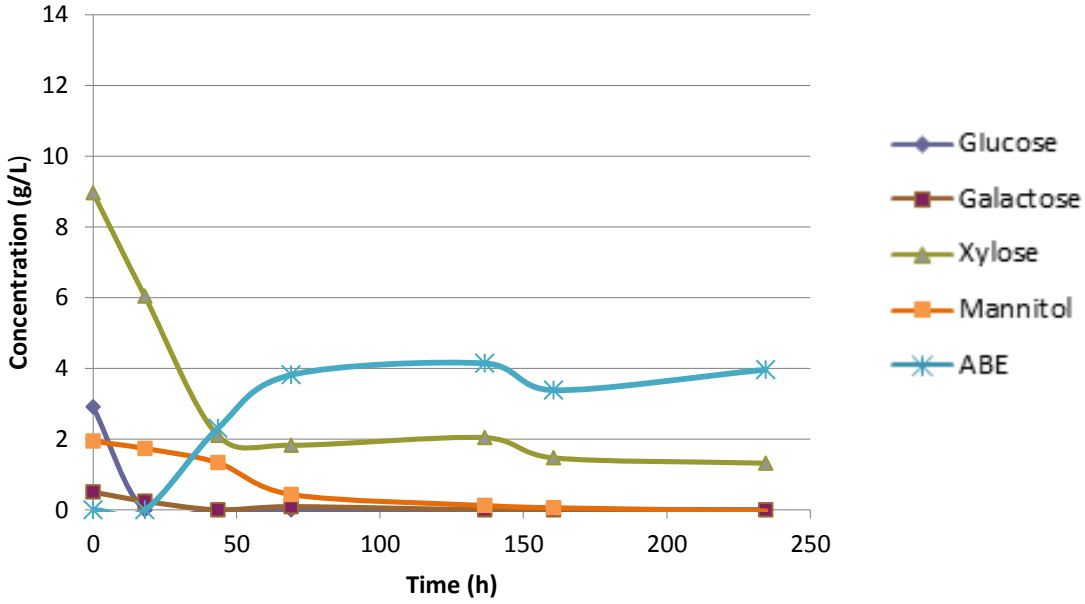
	Extract	Extract + GC220
t=0 h		
Glucose	0	2.7
Xylose	0.8	8.3
Galactose	0.6	0.4
Acetic Acid	4.0	3.3
t=250 h		
Glucose	0.0	0.0
Xylose	12.0	1.6
Galactose	0.0	0.0
Acetic Acid	1.0	1.7
ABE	0.0	3.8
Butyric Acid	6.9	3.0

ABE Fermentation

***Palmaria palmata* extract**



Hydrolysed *Palmaria palmata* extract



ABE fermentation of *Palmaria palmata* extract by *C. beijerinckii*.

Summary and Outlook

Summary

- Goal biorefinery project:
  - Proof-of-Principle biorefining of fresh seaweeds native to the North Sea.
- Example presented:
  - Successful saccharification of *Palmaria palmata*.
  - Monomeric sugar content extracts tested too low to support ABE production.
  - After post-hydrolysis, extracts were fermentable to ABE.
- Other processes being developed:
  - Mannitol production from brown seaweeds.
  - Rhamnose production from green seaweeds.
- Outlook:
  - Pre-extraction of high-value components to improve process economy.
  - Utilization of residual streams (digestion, feed, mineral use, …).
  - Reactor: seaweed-optimized reactor concept for biorefining.

Thank you for your attention

More information:

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http://seaweed.biorefinery.nl

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