

Evaluation of large-scale production of fuels from seaweed

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Who we are?

ECN is the Energy research Centre of the Netherlands
Independent research organisation (non-profit foundation)

Mission: ECN develops knowledge and technology for the transition to a sustainable society

500 staf working on:

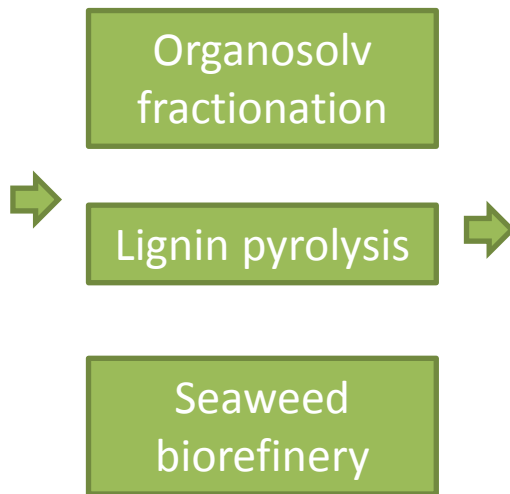
- Solar
- Wind
- Biomass
- Energy and industry
- Policy studies



ECN Biorefinery



Lignicelulosic biomass
Aquatic biomass



Fuels



Chemicals



Materials



(Feed/food)



Why/How we work on seaweed?

Bio-offshore project:

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



National Bio-offshore, **TO2-seaweed**, Port4Innovation
H2020: **Macrofuels**, MacroCascade

Fuels is large-scale!

Equivalent to ethanol biorefinery

- Abengoa bioethanol plant Rotterdam
- capacity 480 ktons/yr from 1.2 MT maize or wheat cereal



Seaweed biorefinery as large:

- 1.2 MTon_dw fresh seaweed/year (~8 MTon Fresh Weight)
- 3% of the motor fuel use in the Netherlands (2014, CBS): 16 Mton

EU: 60% lower emissions in 2050:

Biofuels are one key element herein

Impact for cultivation

For 1.2 Mton dry weight

1-D substrate @4 kg_{dw}/m → 300 000 km

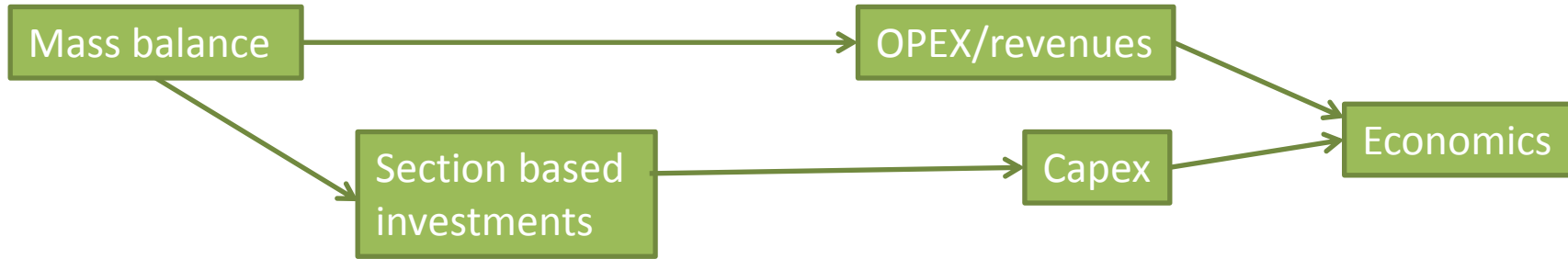
2-D substrate @ 25 kg_{dw}/m → 120 km² effective area
11x11 km → 1600 km gross area
40x40 km

Economy of repetition (not economy of scale)

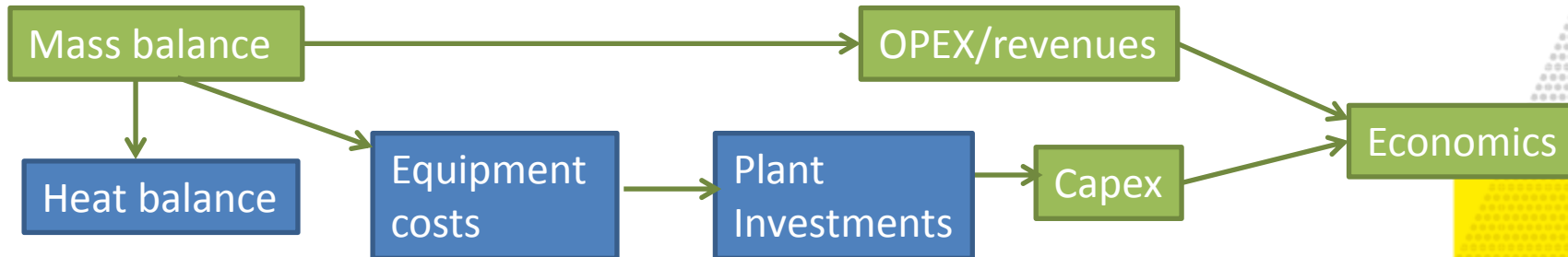
- Dedicated production lines for parts
- Dedicated deployment equipment
- Dedicated seeding and harvesting equipment

Techno/economic evaluation of biorefinery design

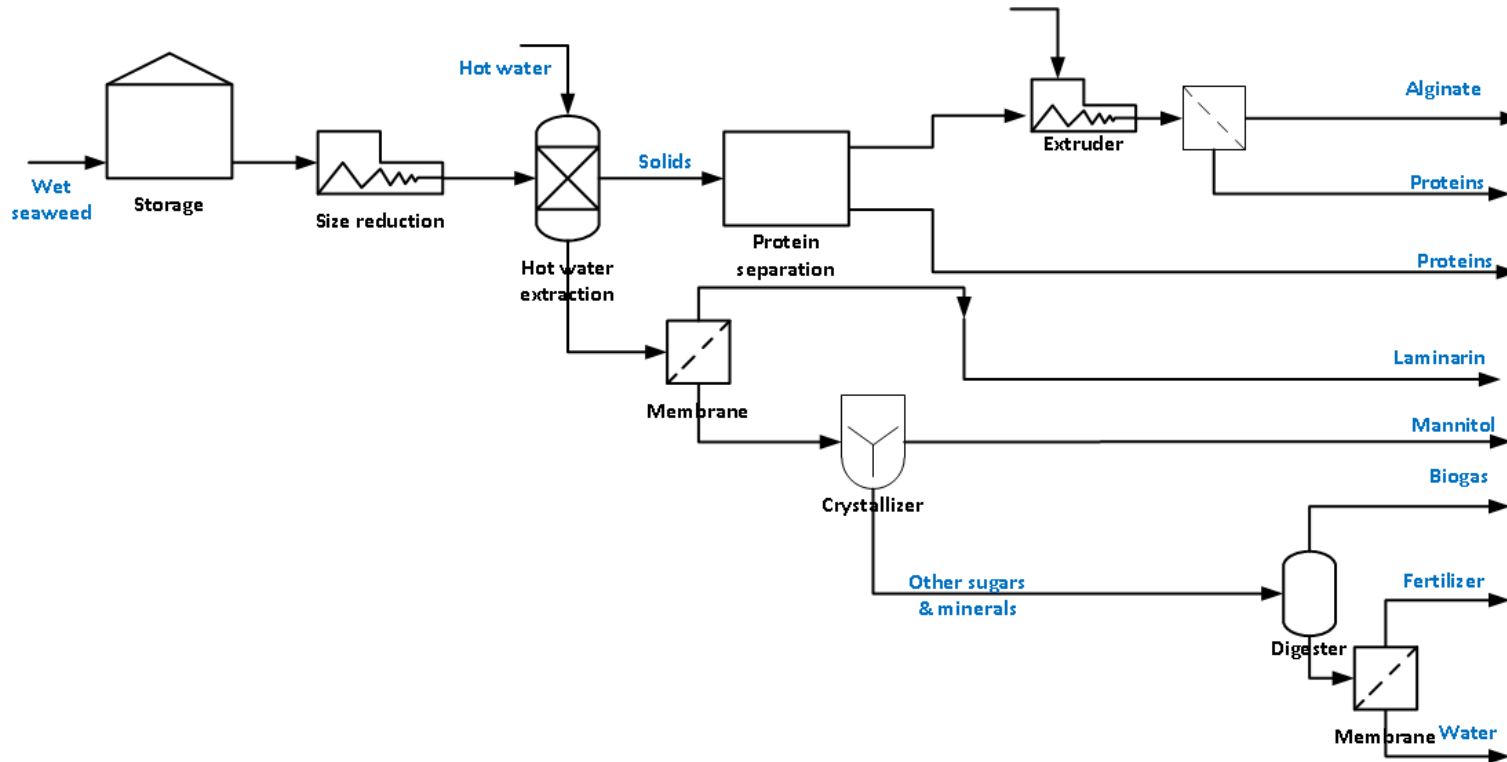
- Screening approach



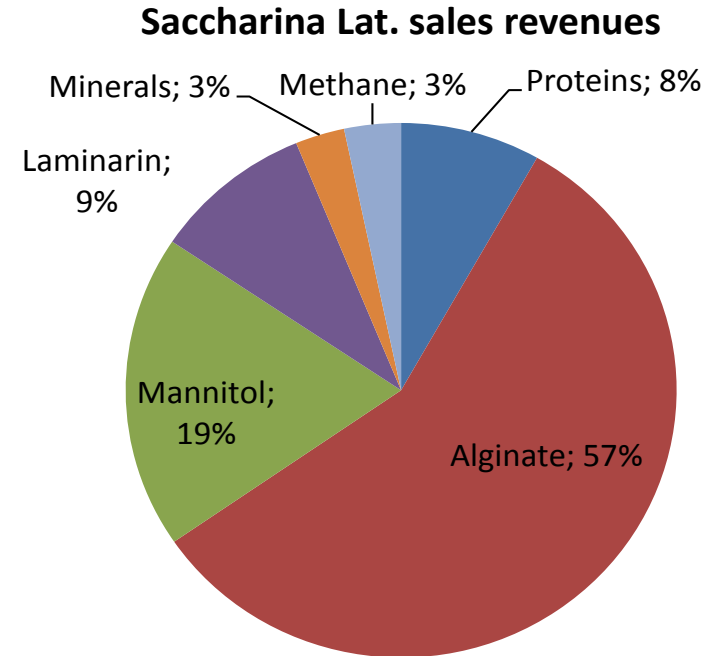
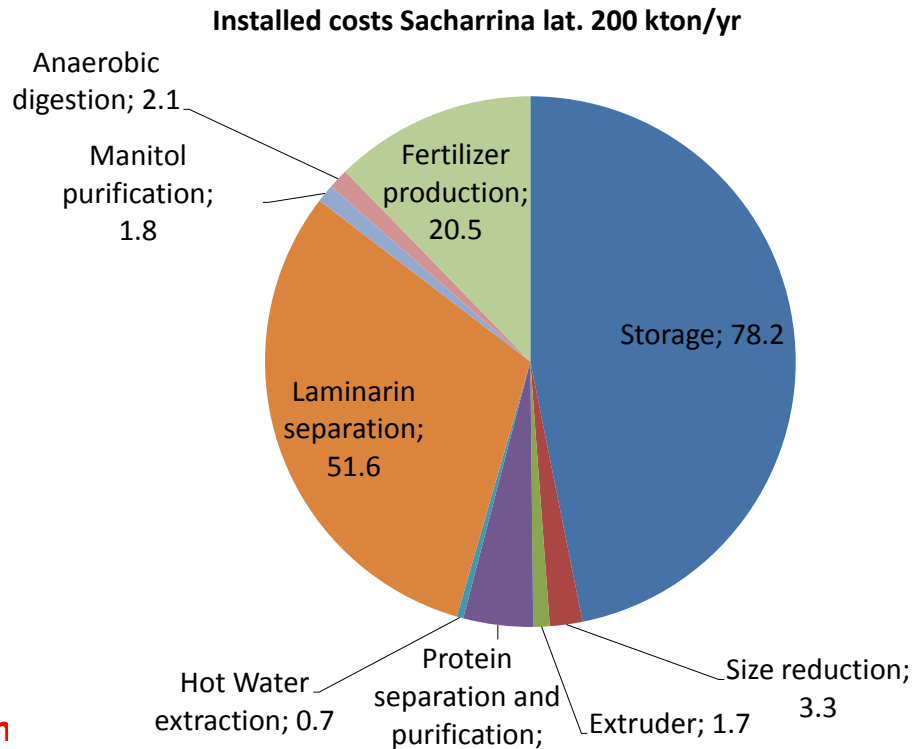
- Evaluation approach



Screening study: *Laminaria digitata*



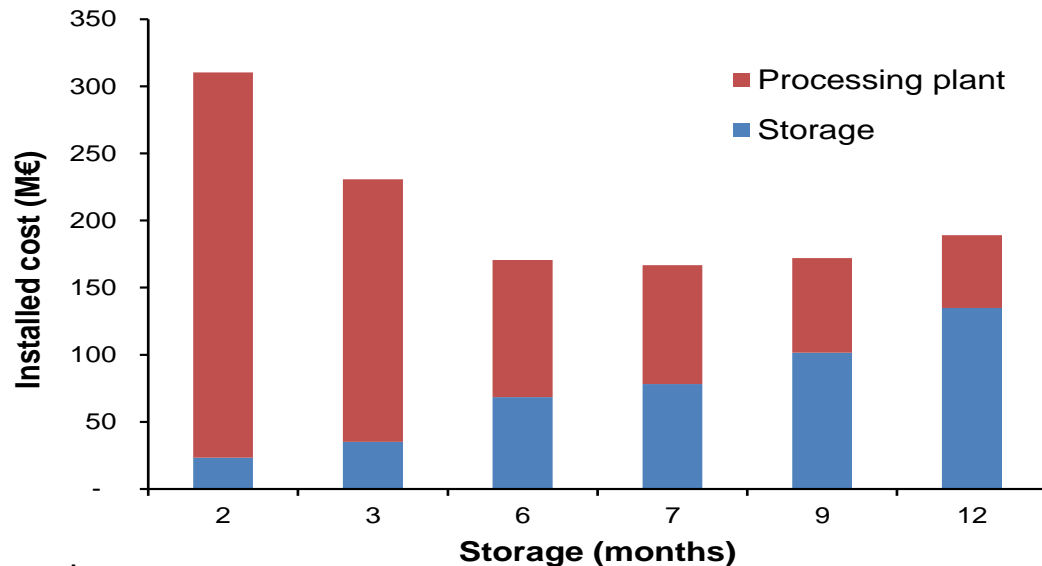
Installed costs and revenues



Economic evaluation

Storage of seaweed:

- CAPEX storage vs CAPEX Plant
- Optimum found
- Year-round not required



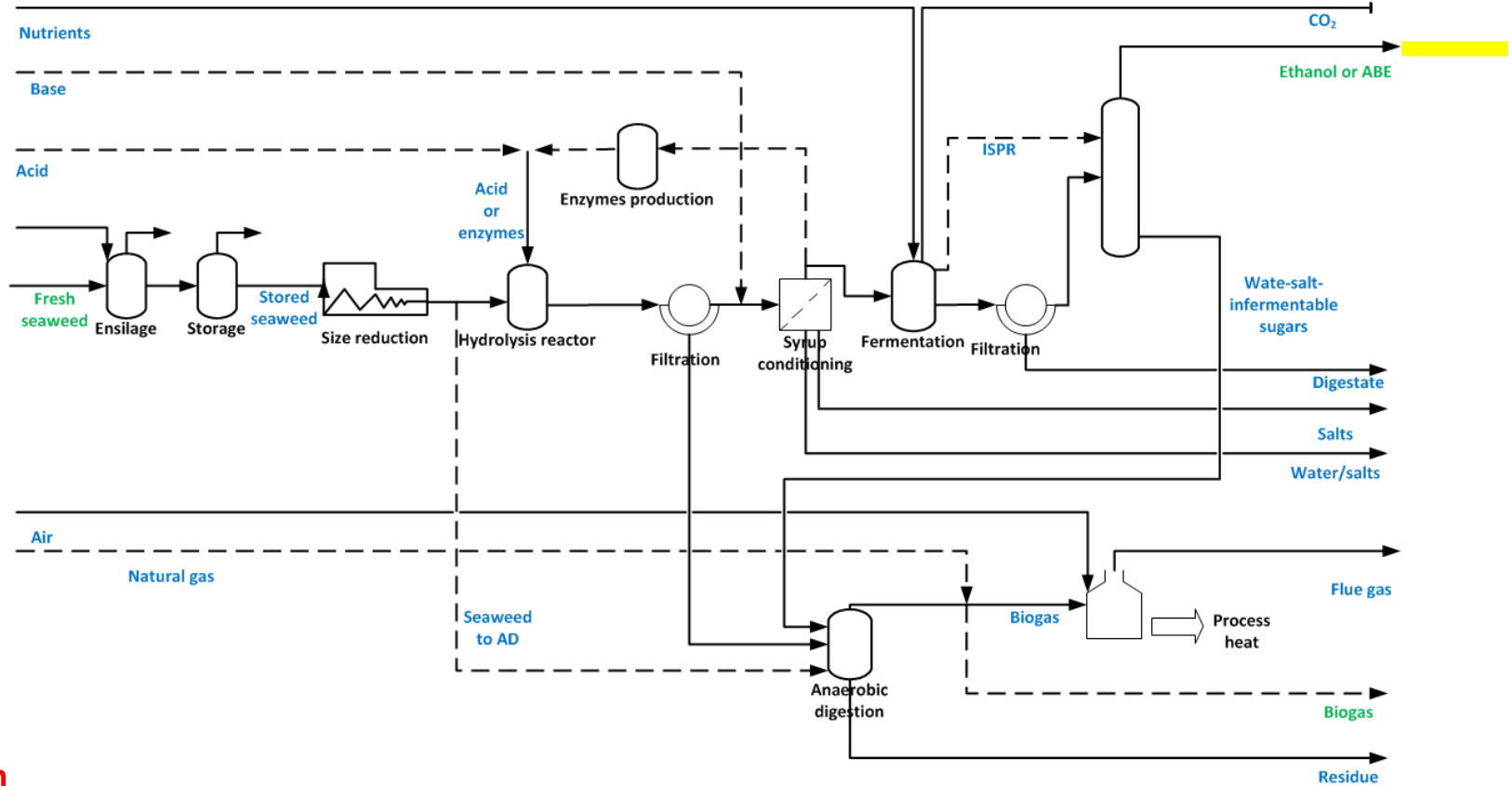
- Economics are challenging. This study:

Allowed costs (for product mix considered) = 480 €/ton_{dw}

Cultivation costs

= ~2000 €/ton_{dw}

Seaweed to fuels: EtOH and ABE



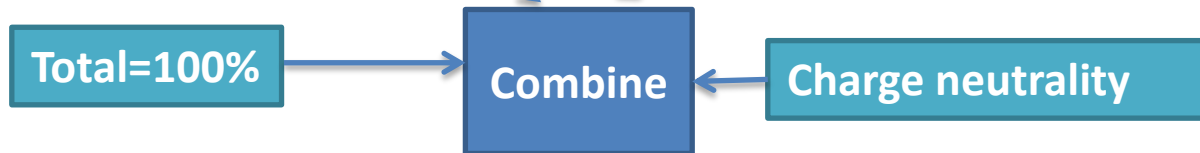
Seaweed modelling

Build on experience with wood fractionation
 Model seaweed through hydrolyzed components

Seaweed analysis

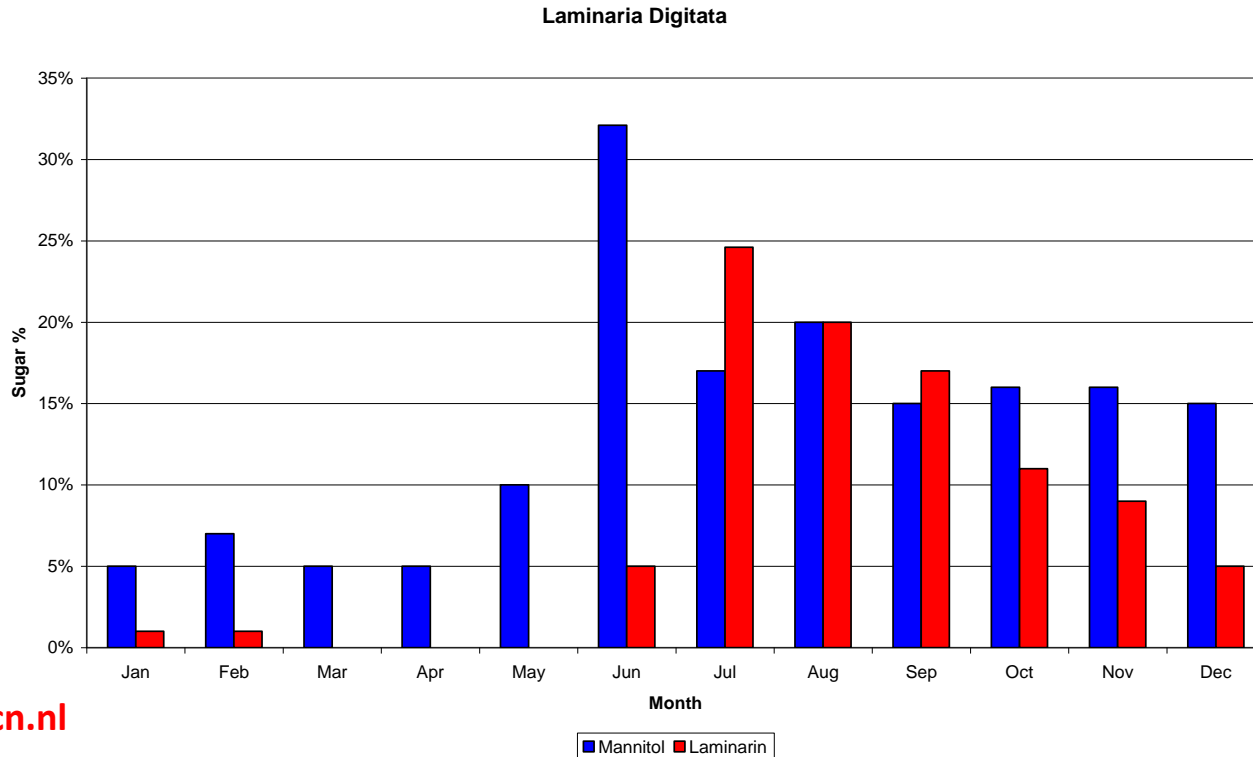
- Sugars/organics HPLC
- Inorganics ICP
- Ultimate analysis

Model assumptions	
% insoluble protein	50%
% soluble unknown organics	50%
% inorganic sulphur	90%
% Insoluble ash of unknown	90%
% Ca in CaCO ₃	10%



Model component	Mass% DW
Glucose	4.8
Xylose	0.4
Galactose	0.7
Fucose	1.5
Rhamnose	0.3
Glycerol	0.0
Mannitol	6.5
Galacturonic acid	0.0
Guluronic acid	3.6
Glucuronic acid	1.0
Mannuronic acid	6.2
Iduronic acid	0.0
Protein	6.6
Protein insoluble	6.6
Other water soluble organics	9.3
Water insoluble organics	9.3
Sulphate	3.4
Other organic sulphur comp	0.4
Ca ²⁺	5.1
K ⁺	6.0
Na ⁺	5.8
Cl ⁻ /anions	20.9
CaCO ₃	1.4
Other insoluble ash	0.0
Other soluble ash	0.1
Total	100

Seasonal variation: timing of harvest is important



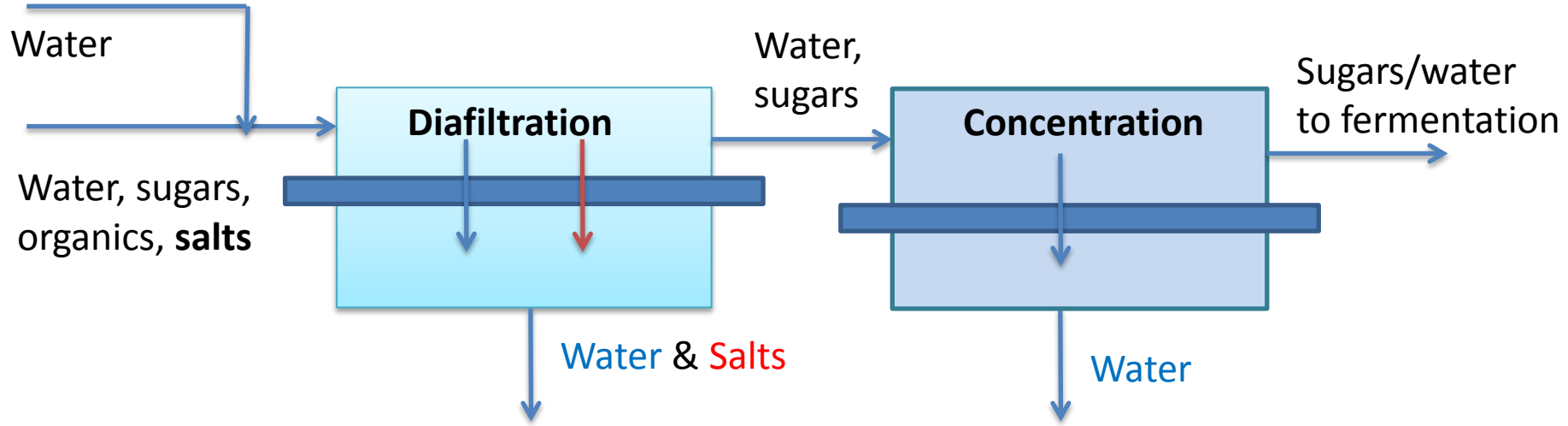
Flow sheet modeling

- Heaters, coolers, pumps etc (standard models)
- Stoichiometric reactors for insiling, fractionation, fermentation

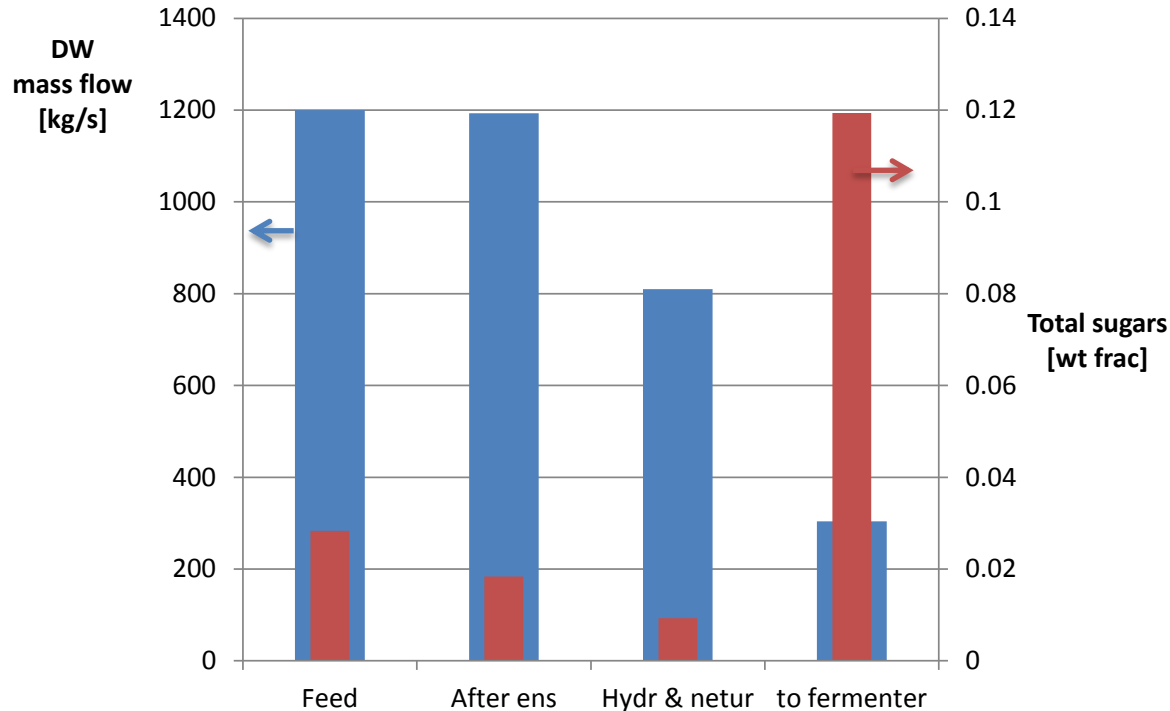
Glucose \rightarrow 2 lactic acid
Glucose \rightarrow lactic acid + ethanol+ CO₂
...etc
Mannitol \rightarrow Lactic acid + H₂
....etc
Glucose + 0.4 N₂ \rightarrow 4 LAB + 6 H₂ + 5 CO₂

- Thermodynamic database for component properties (Cp etc).
 \rightarrow Mass and heat balance, including recycles etc.

Syrup conditioning via membrane filtration



Preliminary design results



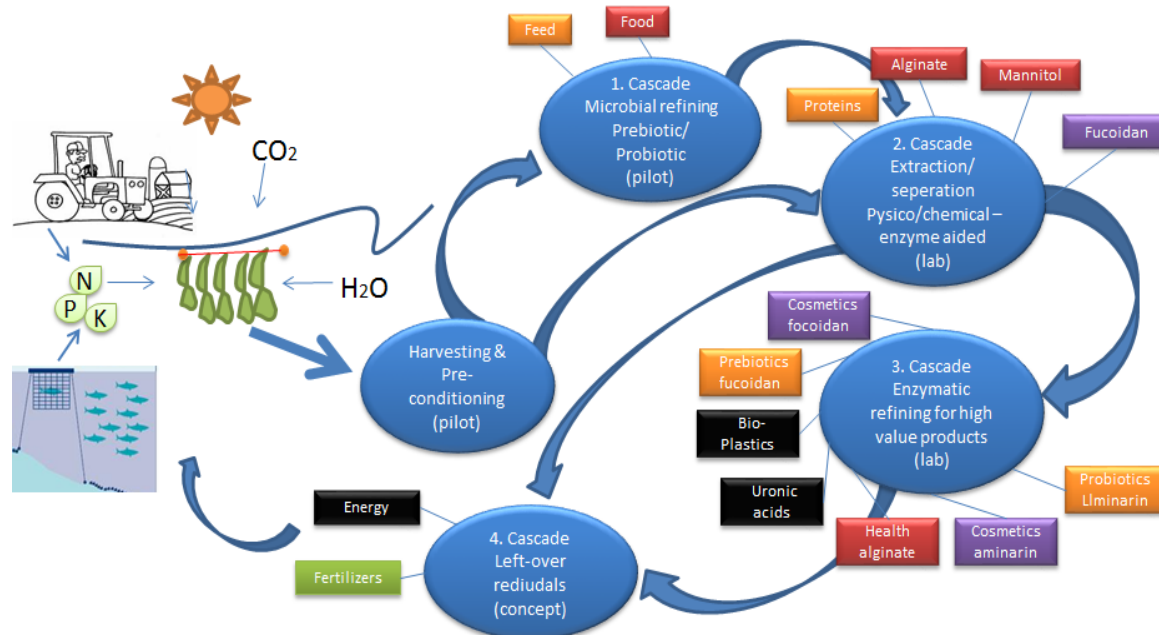
Characteristics:

- Large and diluted volume streams
- Sugar loss through ensiling
- Only part of the sugars can be fermented

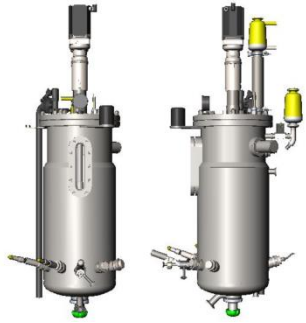
- Better data for high-sugar seaweed required

Value-added products

- Co-products are a point of attention in Macro Fuels
- High-value products focus in MacroCascade



Upscaled fractionation laboratory



100 liter autoclave



Centrifuge



Membrane filtration



Concentration

Acknowledgements

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- **Macro Cascade:** This presentation is part of the Macro Cascade project. This project has received funding from the Bio-Based Industries Joint Undertaking under the European Union Horizon 2020 research and innovation programme under grant agreement No 720755

