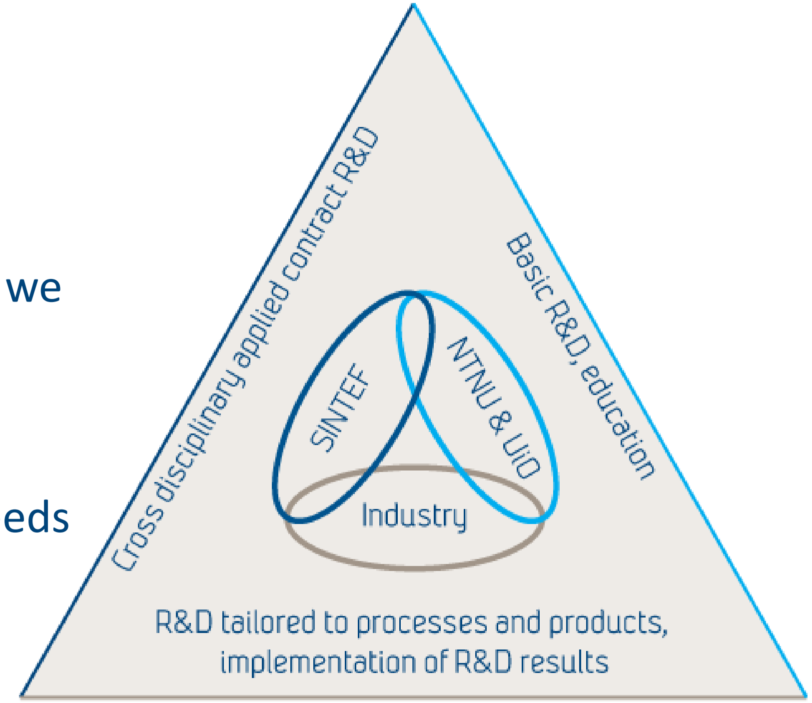
Dyrket tare - et fornybart råstoff med store muligheter?

Aleksander Handå, SINTEF Fiskeri og havbruk
Bernd Wittgens, SINTEF Materialer og kjemi

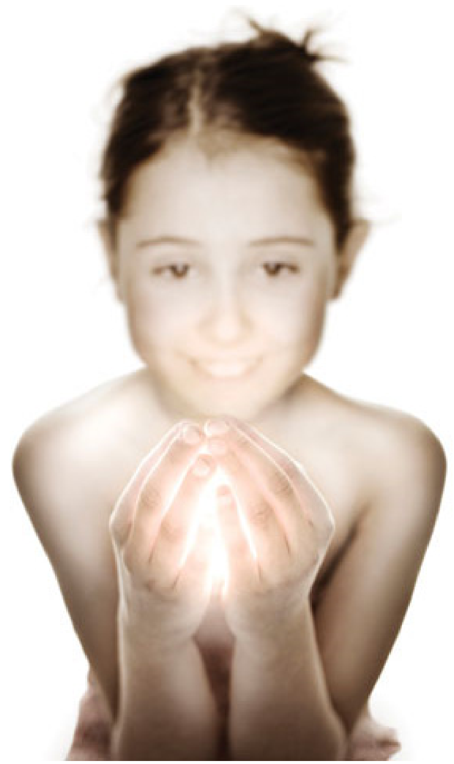
SINTEF

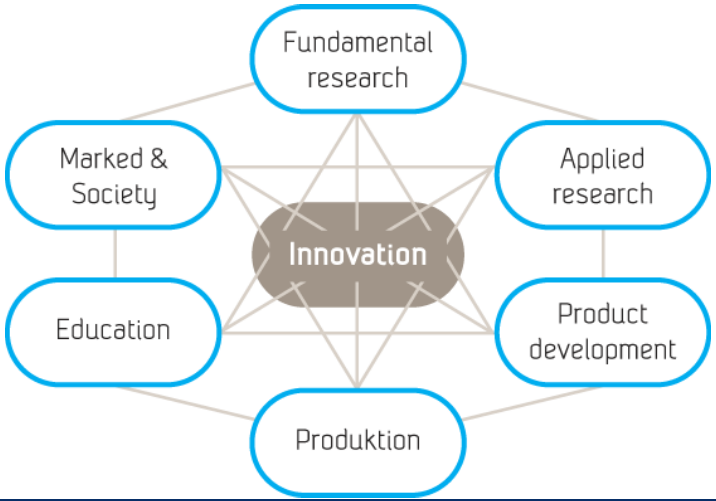
- Founded 1950 as a strategic instrument to transfer research from university to industry
- SINTEF is a non-profit polytechnic research foundation, performing contract R&D for industry and the public sector
- One of the largest independent Research and Technology Organisations (RTO) in Europe, 2200 employees, annual sales 2012: 400 M€
- Strong application-orientation in our research, i.e. we need customers; *satisfied* customers
- Project-oriented co-operation between different business units, in the context of our customers' needs (7216 projects with 2200 customers).



Our Distinctive Character:

- R&D Partner
- Knowledge Production
- Create new Businesses
- Management of R&D and Innovation Infrastructure
- A Knowledge base for Policy Development





” Excellence in the science base is not enough.

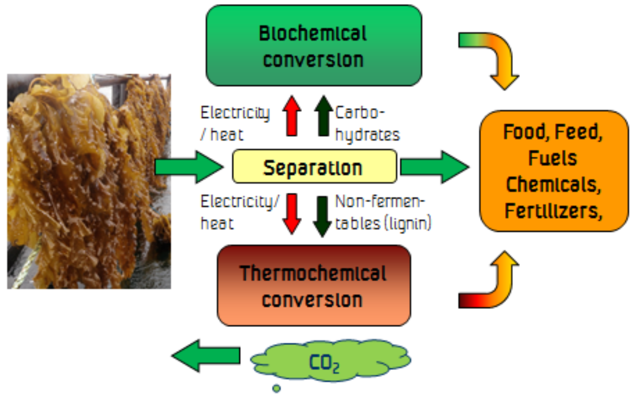
It is essential to have the capacity to translate knowledge into new products, processes and services.”

Outline

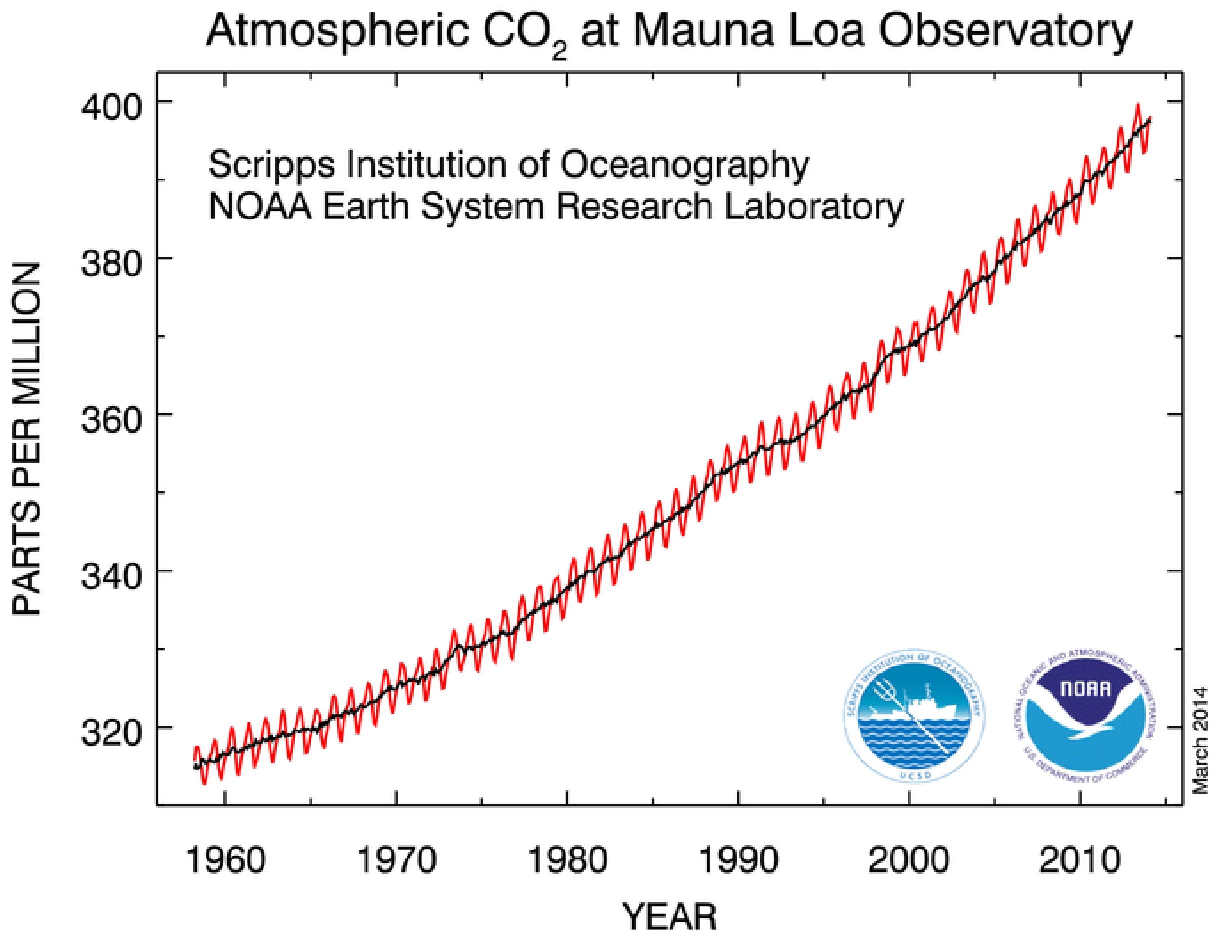
1. Global challenges

2. Renewable raw material

3. New processes and products

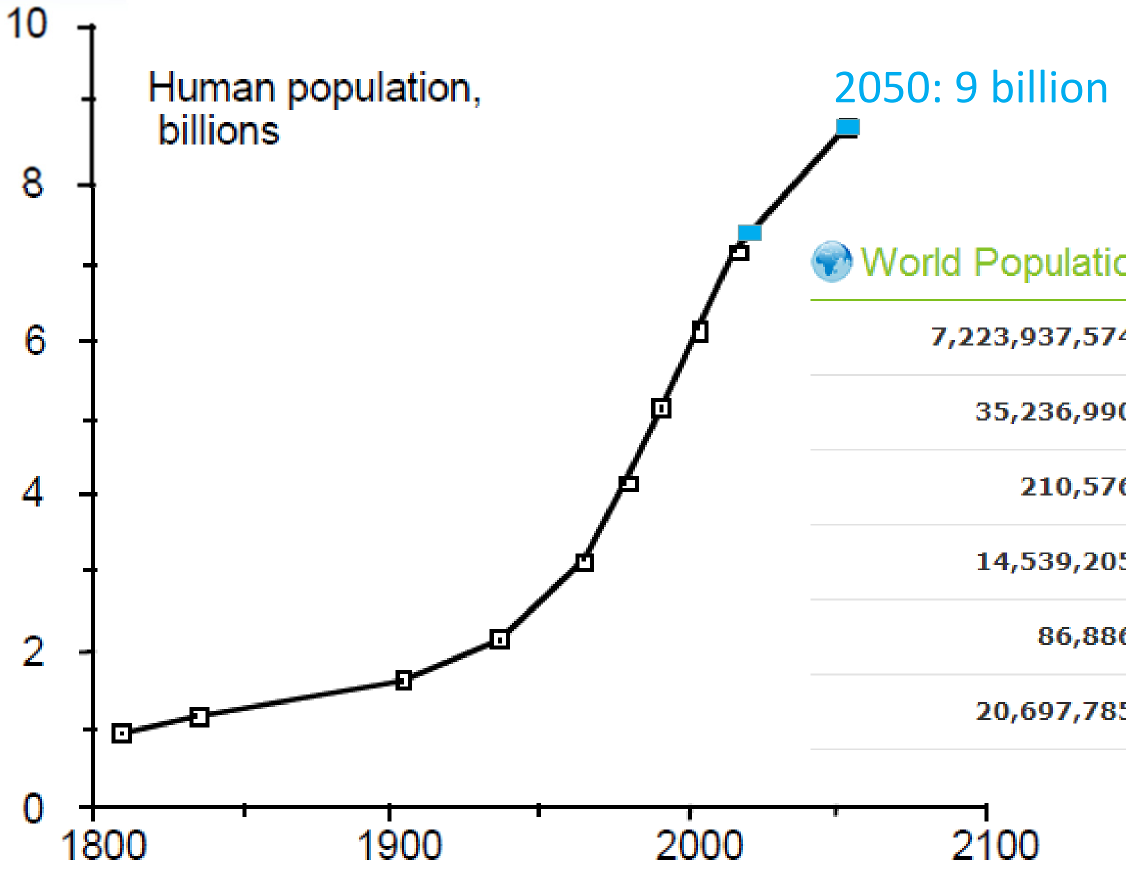


Global challenge: Increasing CO_2 levels



Global challenge: A growing human population

Malthus, 1798: "*An Essay on the Principle of Population*"



World Population

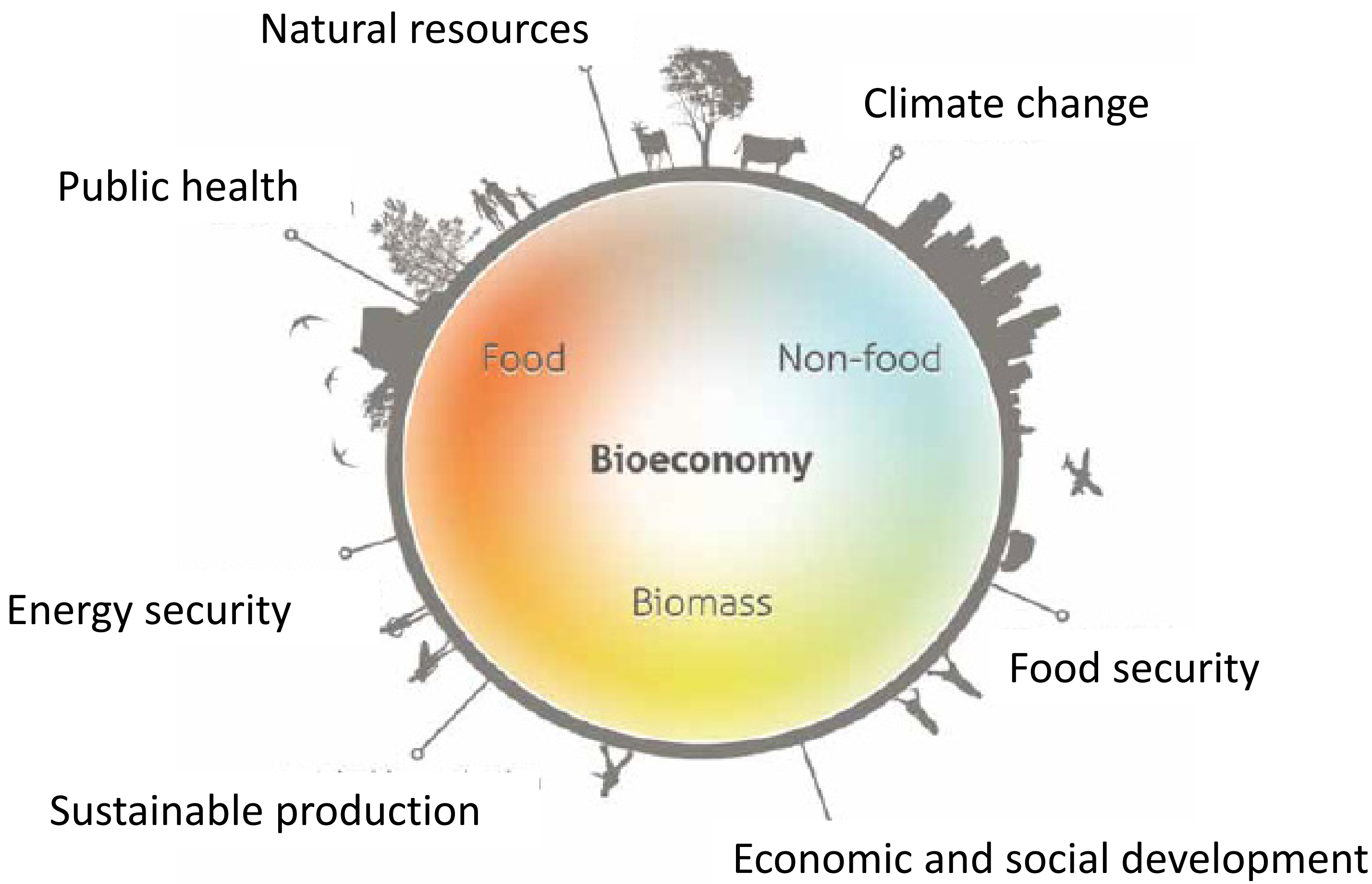
7,223,937,574	Current World Population
35,236,990	Births this year
210,576	Births today
14,539,205	Deaths this year
86,886	Deaths today
20,697,785	Net population growth this year

worldometers
real time world statistics

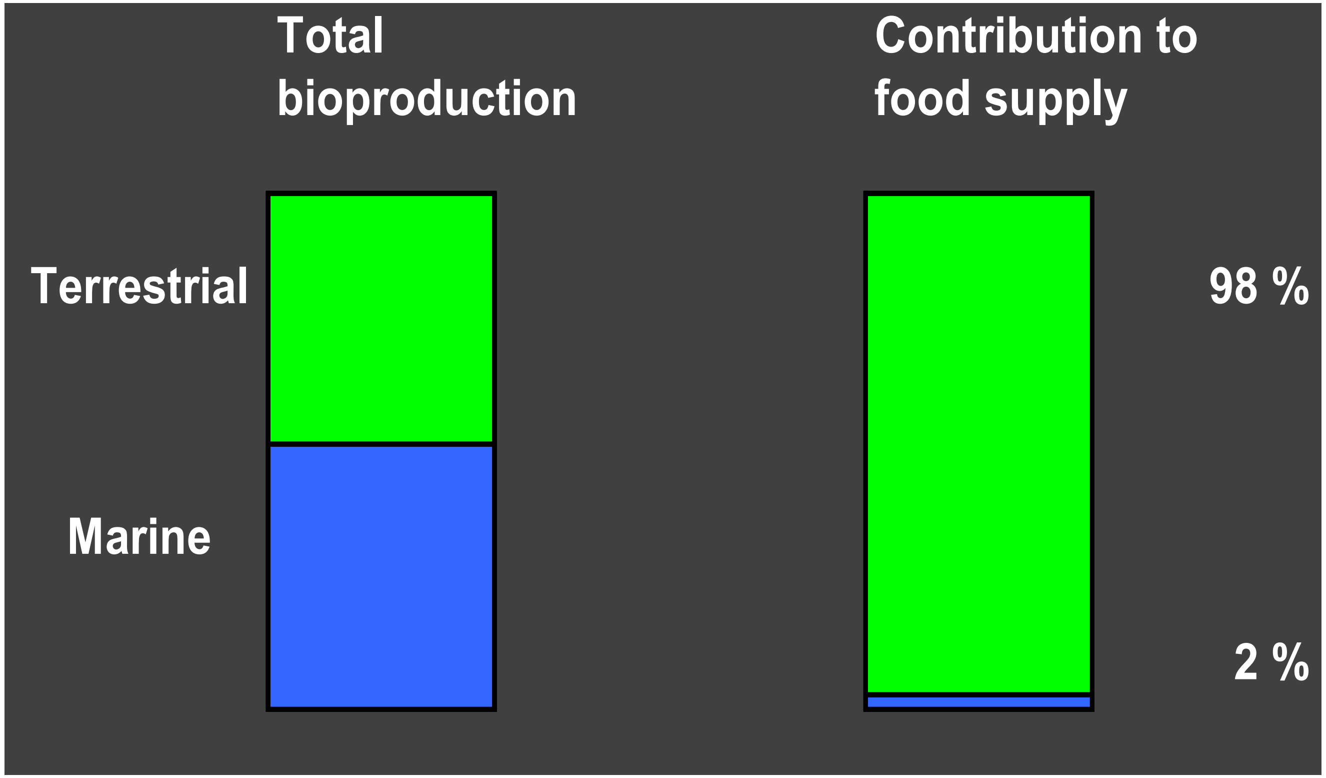
A growing bioeconomy

"The bioeconomy encompasses the sustainable production of renewable biological resources and their conversion into food, feed, bio-based products and energy"

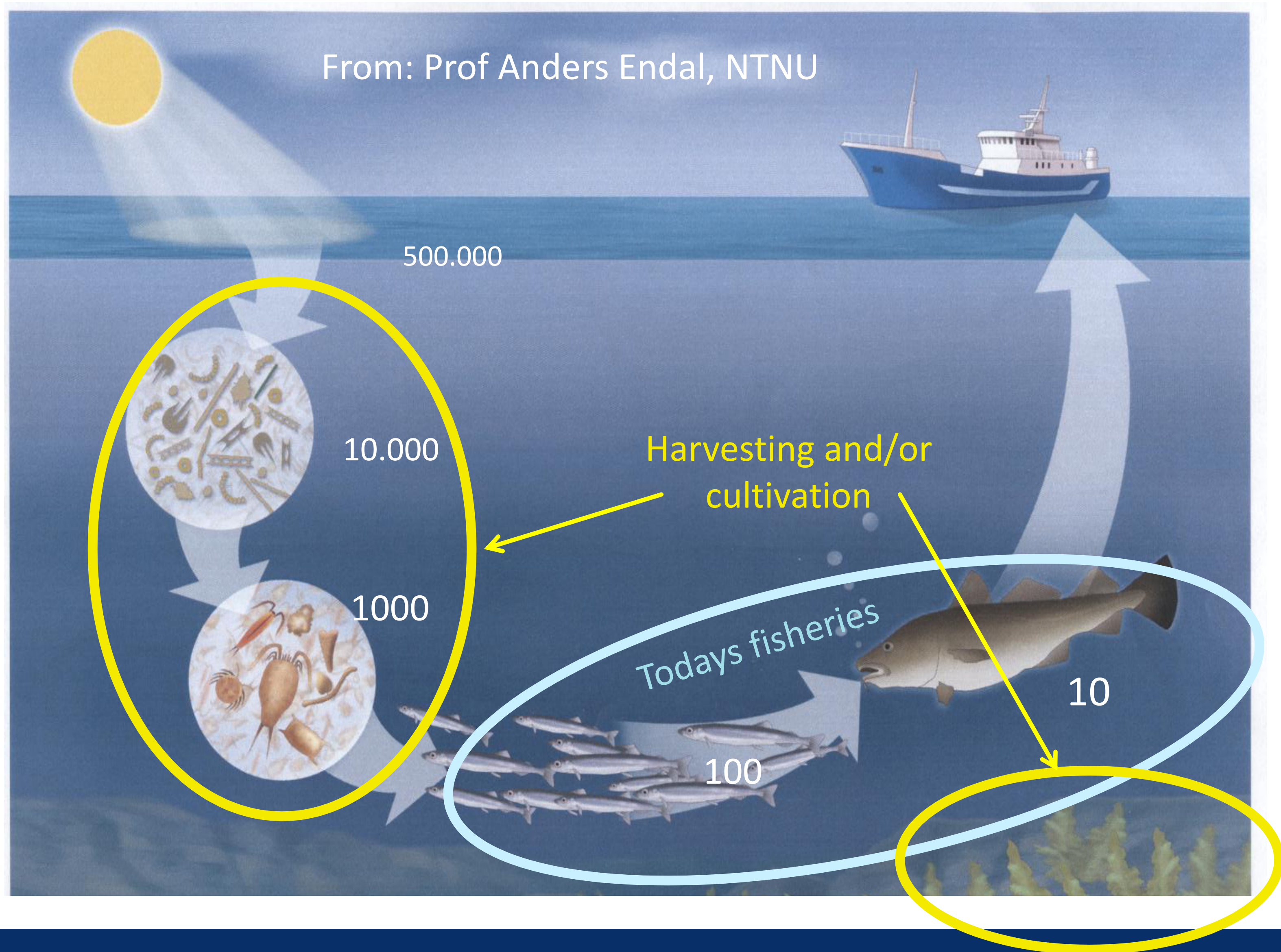
(European Commission, "Innovating for sustainable growth: A bioeconomy for Europe", 2012).



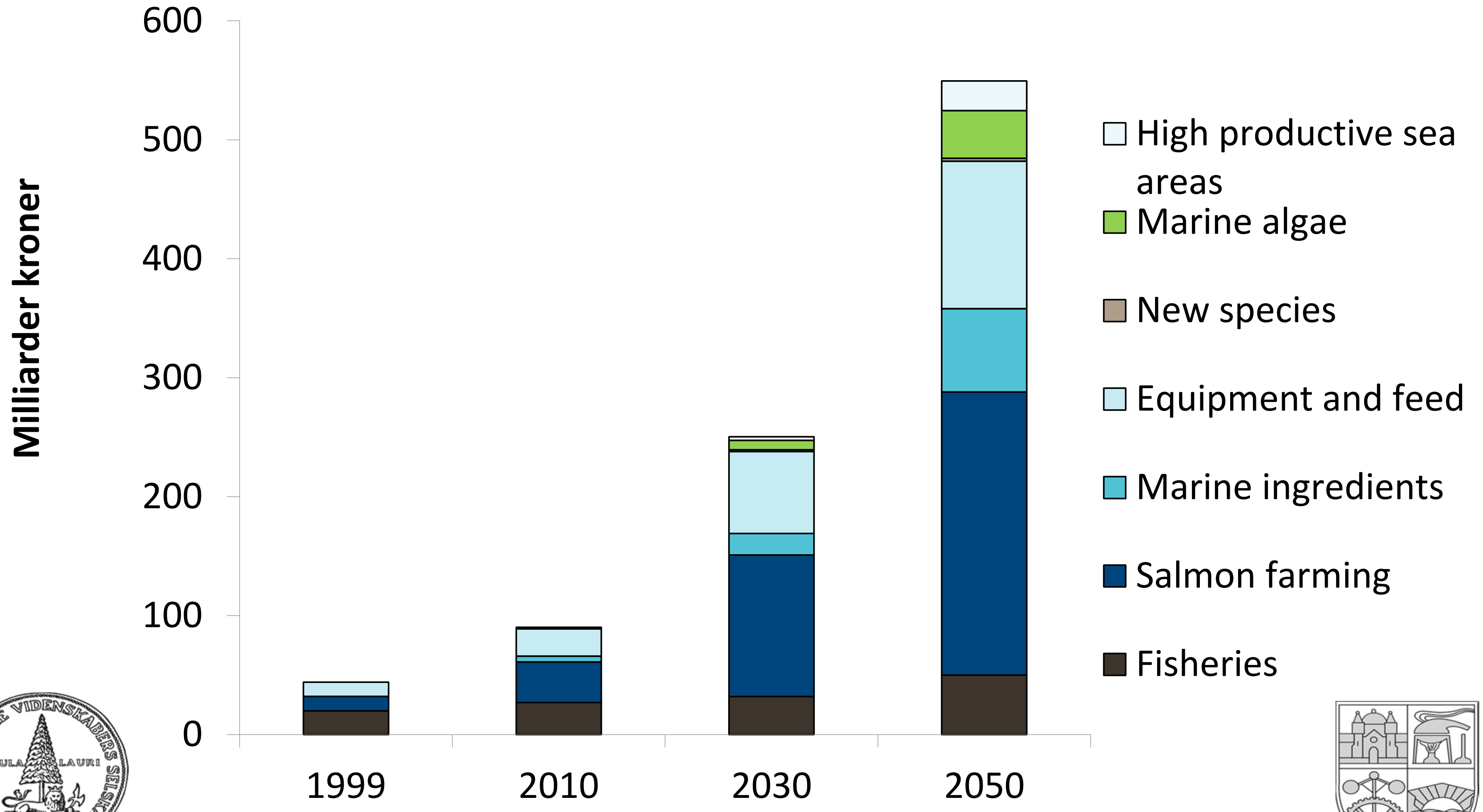
Global challenge:
How do we meet the need for food and feed?



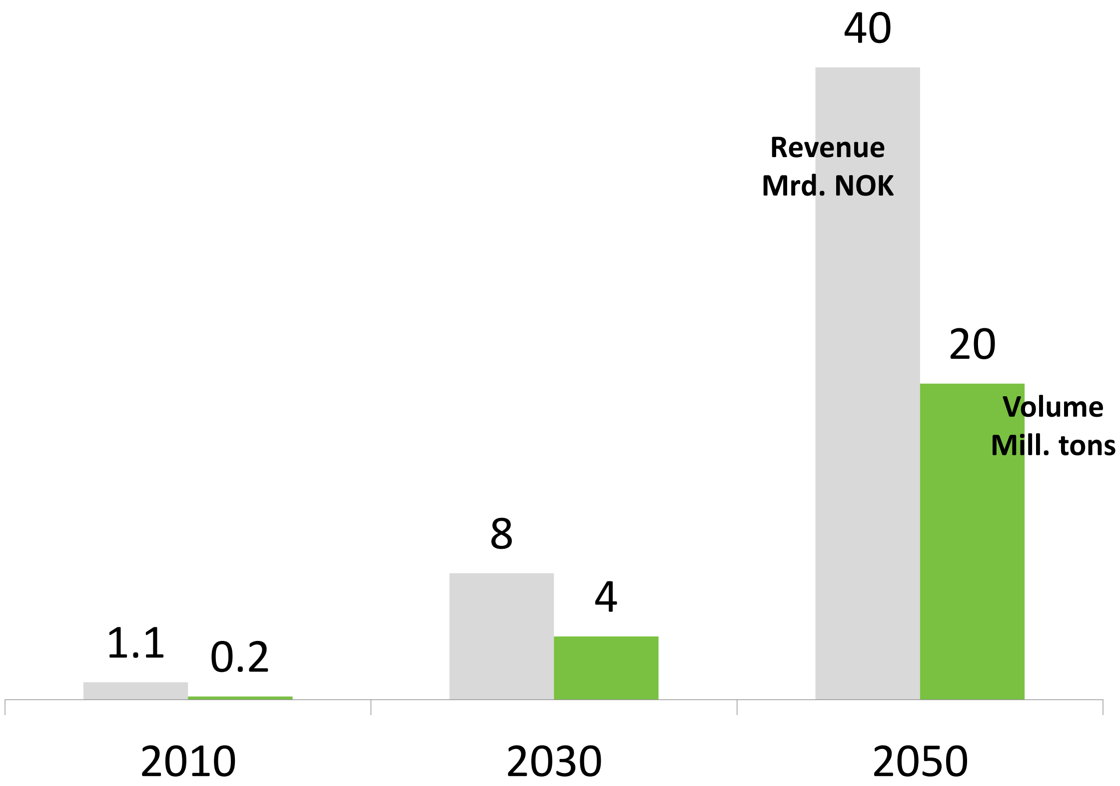
How can we increase the utilization of our marine resources?



DKNVS Scenario 2050:
Potential for marin value creation in Norway



DKNVS Scenario 2050:
Potential for marin value creation from macroalgae



<u>Cultivation do not require:</u>

- Farmable land
- Irrigation
- Fertilization
- Pesticides

- Carbon neutral
- Attractive composition

Relevant product classes

Total Market for Biorefinery value chain: ~300 Mrd $ by 2020

(The World Economic Forum)

The Norwegian Seaweed Technology Center

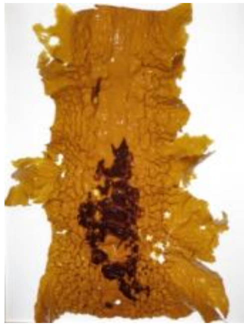
Inaugurated on 15th August 2011

- Aim: establish a knowledge platform for the development of industrial cultivation, harvesting, processing and utilisation of seaweed in Norway

- Partners: SINTEF and NTNU (main partners), Norwegian and international R&D-institutions and industry (associated)

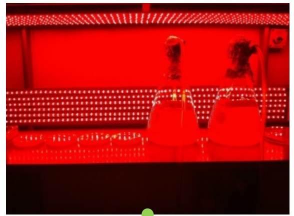
Seedlings production – Sugar kelp *Saccharina latissima*

Step 1: Induction of sorus (6-12 weeks)

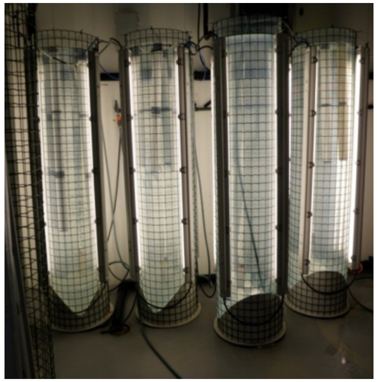


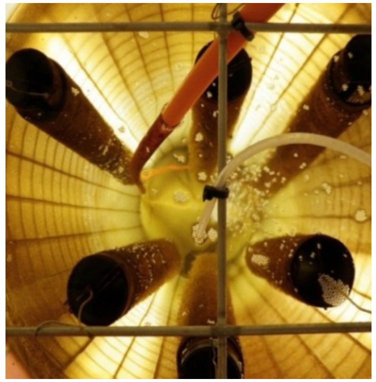
Step 2: Dehydration and spore release (24 h)

Gametophyte cultures



Step 3: Spraying and incubation (~ 2 months)



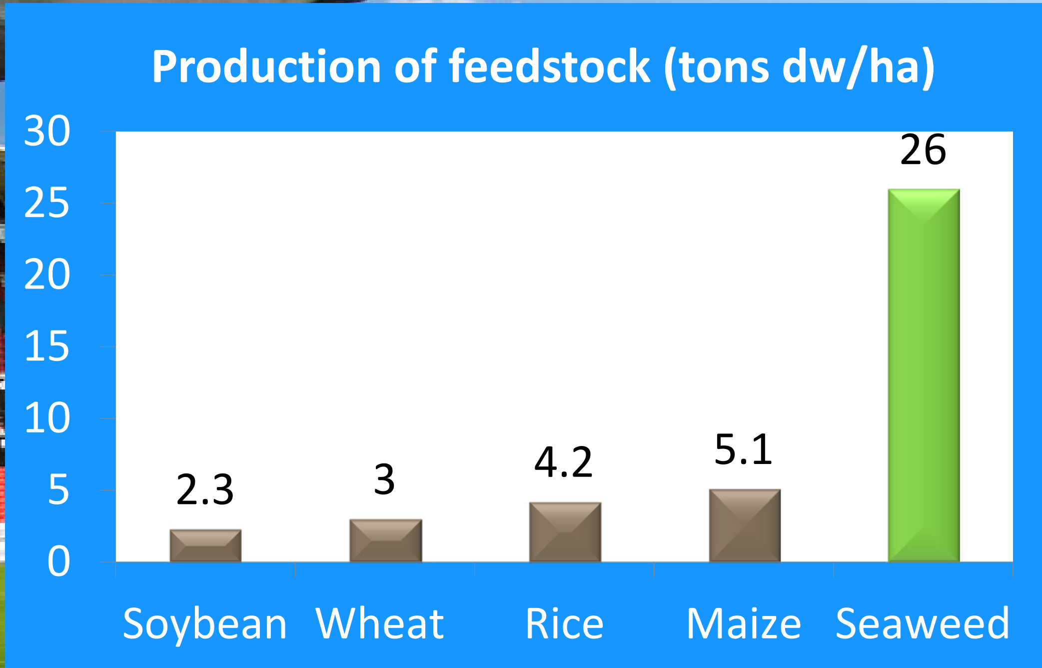


Forbord, S. et al. 2012. Development of *Saccharina latissima* (Phaeophyceae) kelp hatcheries with year-round production of zoospores and juvenile sporophytes on culture ropes for kelp aquaculture. *Journal of Applied Phycology,* 24 (3), 393-399.

Technology development – prototyping


TANGSKJÆR

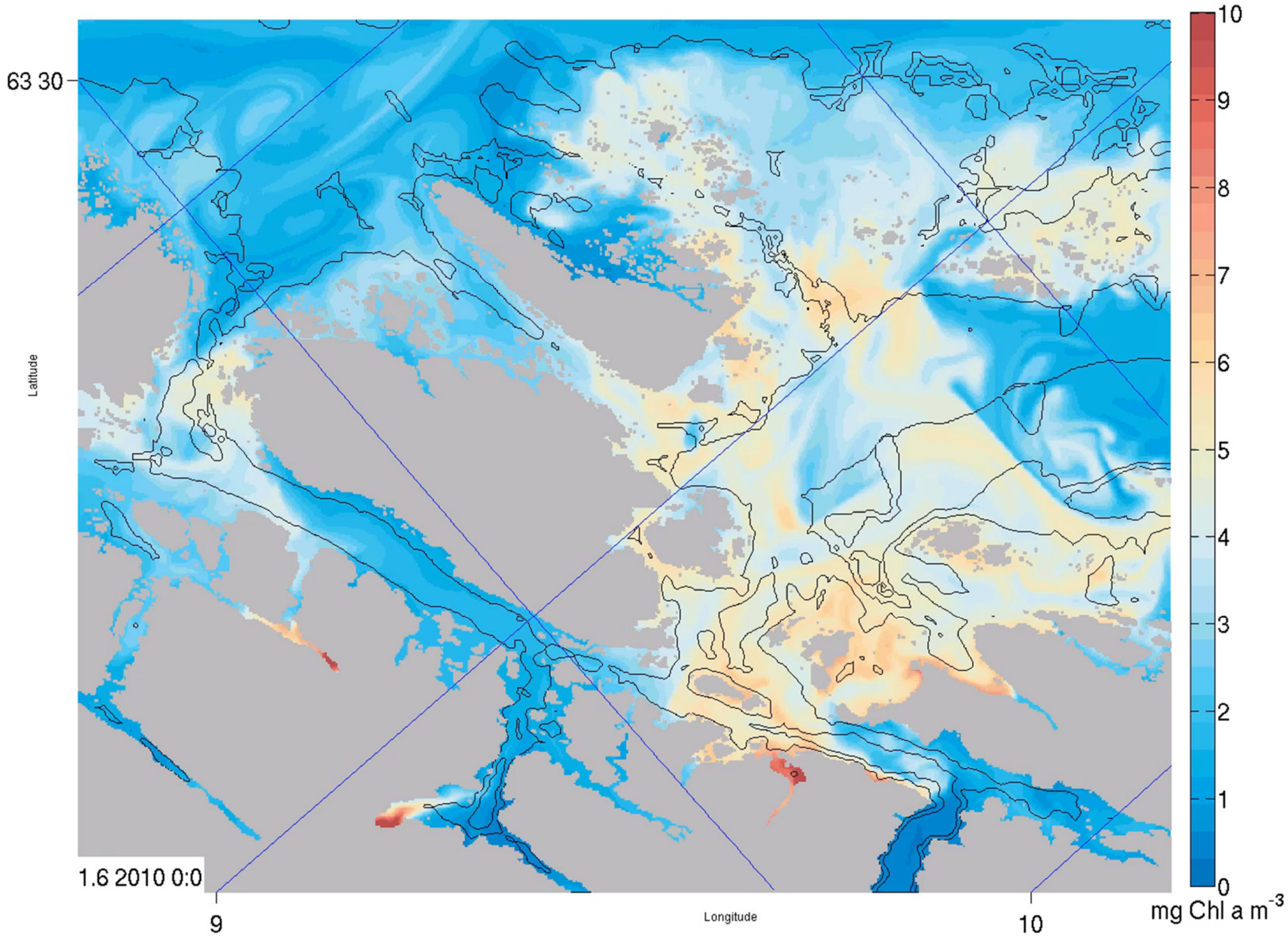
~ 1 hectar



- 170 tons ww
- 26 tons dw
- 15 tons carbohydrates
- 3.8 tons protein

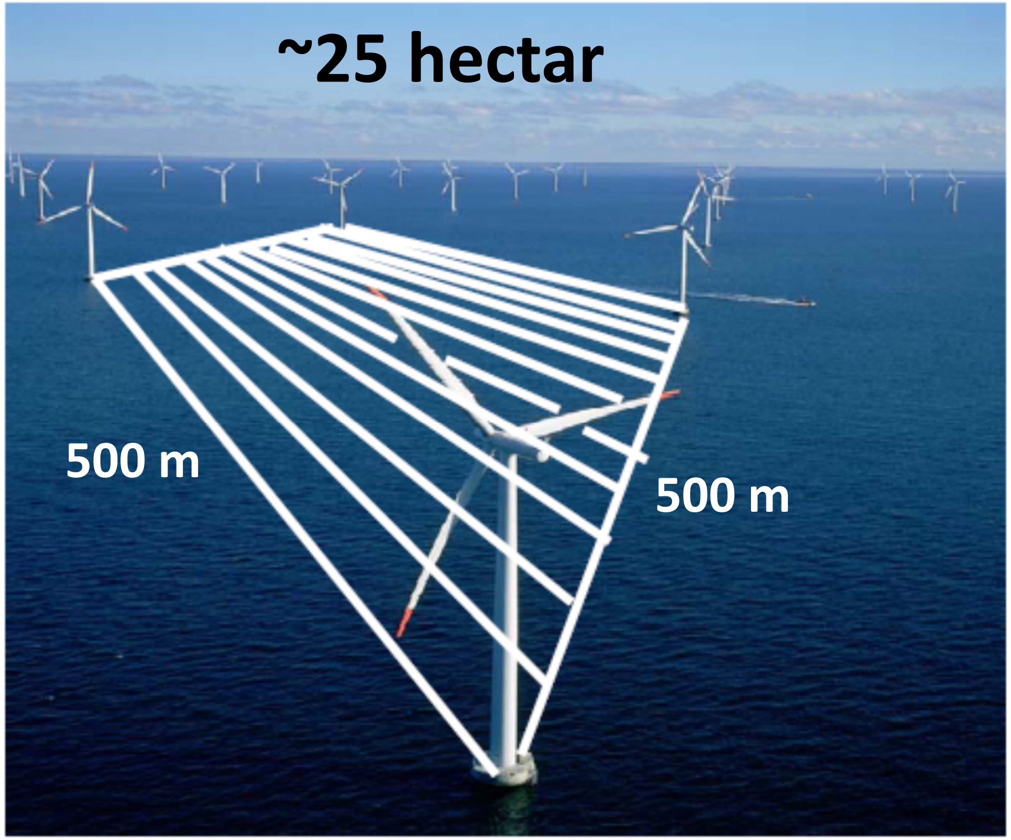
Are there available areas?

High productive areas



Broch et al., 2013. Modelling the cultivation and bioremediation potential of the kelp *Saccharina latissima* in close proximity to an exposed salmon farm in Norway. *Aquaculture Environment Interactions* 4, 187-206.

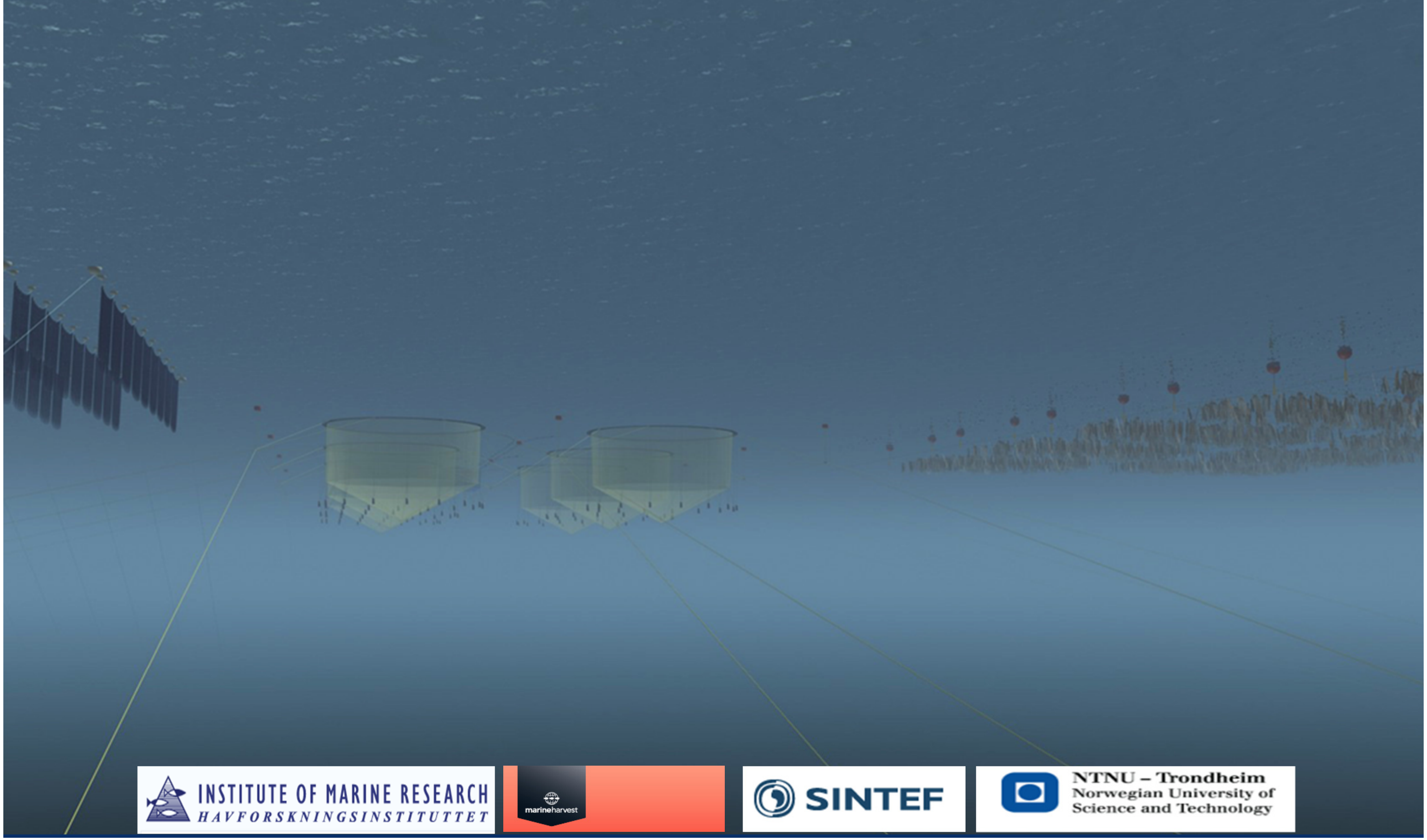
Infrastructure and area use



- 4250 tons ww sugar kelp
    - 380 tons carbohydrates
    - 95 tons protein

EXPLOIT

Infrastructure and area use

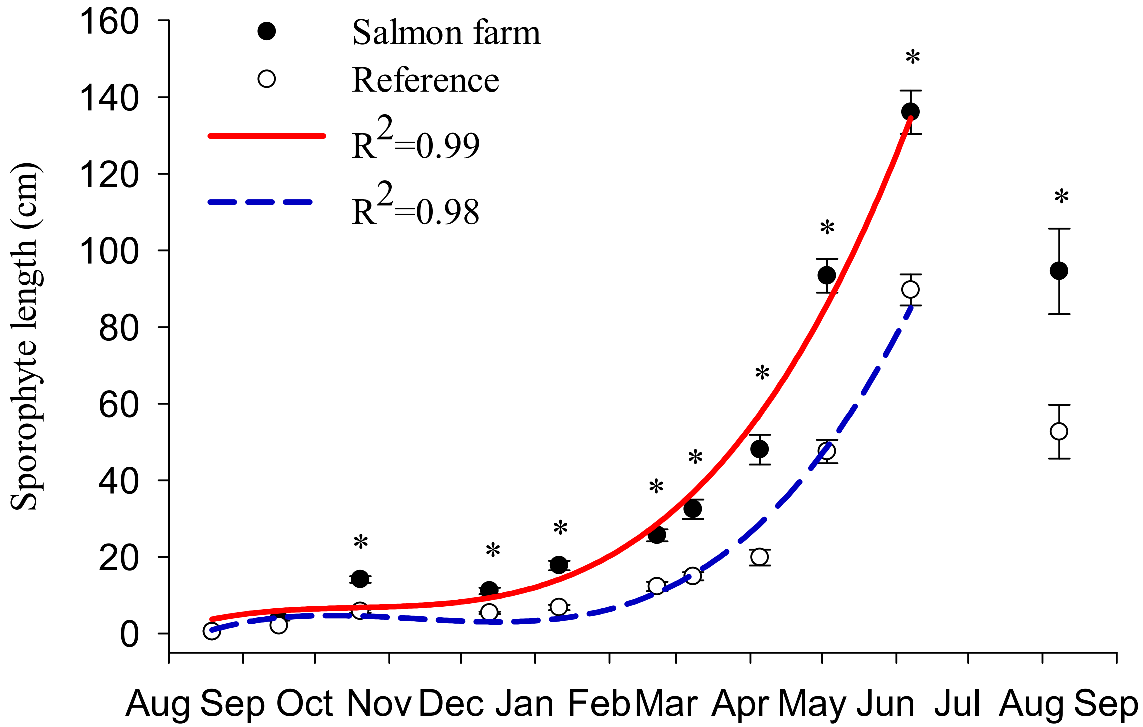


INSTITUTE OF MARINE RESEARCH
HAVFORSKNINGSINSTITUTTET
marineharvest
SINTEF
NTNU – Trondheim
Norwegian University of Science and Technology

BELLONA
YSFRI
UNIVERSIDADE FEDERAL DE SANTA CATARINA
UNB EST. 1785 UNIVERSITY of NEW BRUNSWICK
WAGENINGEN UR
For quality of life
Fisheries and Oce
Canada
Universidad De Los Lagos

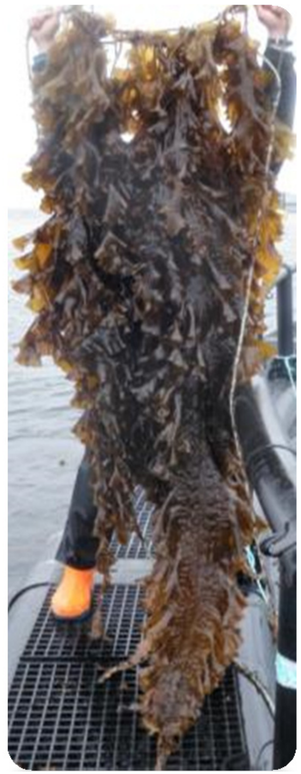
Length of S. *latissima in IMTA with Salmo salar*

5 m depth



Reference

Salmon farm



Handå, A. et al., Seasonal- and depth-dependent growth of cultivated kelp (*Saccharina latissima*) in close proximity to salmon (*Salmo salar*) aquaculture in Norway. *Aquaculture* 414-415, 191-201.

– Taredyrking gjer oppdrettsnæringa grønare

FLORØ: – Taren gror raskare i oppdrettsanlegg ved å nytte avfallsstoffa til fisken som næring, fortel Silje Forbord i SINTEF Fiskeri og Havbruk. Det er hypotesa bak forskingsprosjektet til SINTEF, NTNU og Havforskingsinstituttet ved Skorpa.

MAIKEN AANNEVIK SOLBAKKEN

SINTEF, NTNU og Havforskingsinstituttet forskar på tareproduksjon som del av integrert havbruk ved oppdrettsanlegget til Marine Harvest i Skorpefjorden. Forskingsprosjektet byrja i september i fjor, og målet er å finne ut i kva grad ein kan nytte næringssalt frå lakseoppdrett til å dyrke andre organismar. Slik kan ein sei at produksjon av skjel og tare i oppdrettsanlegget gjer havbruket «grønare» ved at det minskar utslepp av forureinande stoff og minskar utslepp av ekstra næringssalt.

– Taren tar opp uorganiske næringsstoff som elles ville vorte skilt ut i fjorden. I staden brukar taren desse stoffa til vekse, seier forskar Silje Forbord ved SINTEF Fiskeri og Havbruk.

VANLEG I AUSTEN: *Tare er ein naturleg del av kosthaldet i delar av Austen.*

KAMSKJEL: *Dyrking av kamskjell er også del av forsøket.*

MARINE HARVEST: *Prosjektet går føre seg i Skorpefjorden i og ved oppdrettsanlegget til Marine Harvest for å utnytte organisk og uorganisk materiale i miljøet.*

Alle foto: SINTEF

Om tareproduksjon

Andre delar av verda har lange tradisjonar for tang- og tareproduksjon, som til dømes Asia. Også i Canada produserer dei tare i same anlegg som laks.

– Tare er ei ganske ny næring i Norge, men har lange tradisjonar andre stader i verda, som i store delar av Aust-Asia. Her blir det dyrka til bruk i mat. I Europa har det ganske nyleg fått merksemd etter at trendar innan helsekost har gjort det kjent som matvare, seier ho.

– Kva kan det nyttast til?

Den framdyrka taren kan nyttast i biodrivstoffproduksjon og som matvarer, sjølv om førstnemnde er forskingsstudier i hovudsak rettar seg mot. Forbord seier sjølv om det er hovudbruksområder hausten, seier Forbord at den førebelse taredyrkinga peikar på at taren veks monaleg betre ved lakseanlegget enn ved kontrollstasjonane. Dette kan ifølgje Forbord ha fleire andre årsaker som straumen og forholda i sjøen.

– Vi har sett ein betre vekst i anlegget. Vi kan ikkje sei noko om akkurat kva dette skuldast for vi har ikkje gjennomført kjemiske analyser enno der vi ser etter restar av lakseför og laksefeitt i plantane, seier Forbord.

Men betre vekst hadde dei også på ei studie gjennomført på trøn-

– SINTEF nyttar lokal tare

I september 2012 henta SINTEF tare frå Skorpefjorden. Denne er no attende og vert nytta i tareeksperimentet ved anlegget til Marine Harvest.

Sukkertaren nytta i prosjektet er henta frå Skorpefjorden og førebudd i SINTEF sitt laboratorium i Trondheim. På laboratoriet til SINTEF vert det produsert kimplanter som vart gjeninnført i Skorpefjorden i februar.

SINTEF har utvikla ein metode for å dyrke taren på tau som sprayast med taresporer. Plantane vert stimulert til å produsere sporer året rundt ved å minimere mengda dagslys over ein periode. Etter perioden med kunstig dagslys vert den tørrlagt i nokre timar. Når den vert lagt i vatn att produserer dei millionar av sporer som vert festa til taua. Etter 4–6 veker med vekst på lab vil dei små kimplantane vise seg som ein halvmillimeter tjukt brunt belegg på tauet.

Taua vert festa til bereliner ned mot ti meters djupne, og veks fram til hausting på sommaren.

Forskingsgruppa har to referansegrupper i nærleiken av anlegget, men i så stor avstand at dei ikkje vert påverka oppdrettsanlegget.

TAREDYRKING I FLORA KOMMUNE

- Næringsstoff oppdrettsanlegg slepp ut kan nyttast til dyrking av andre artar, kjent som Multi-trofisk Akvakultur (IMTA).
- Tareplantar kan ta opp næringssalta medan skjel kan filtrere partiklar.

Fakta

- Februar – september 2013 på lakseanlegget til Marine Harvest utanfor Reksta, lokalitet Flåtegrunnen.
- Forskingsprosjekt finansiert av forskingsrådet der SINTEF Fiskeri og Havbruk, NTNU, Havforskingsinstituttet og Bellona har gått saman.

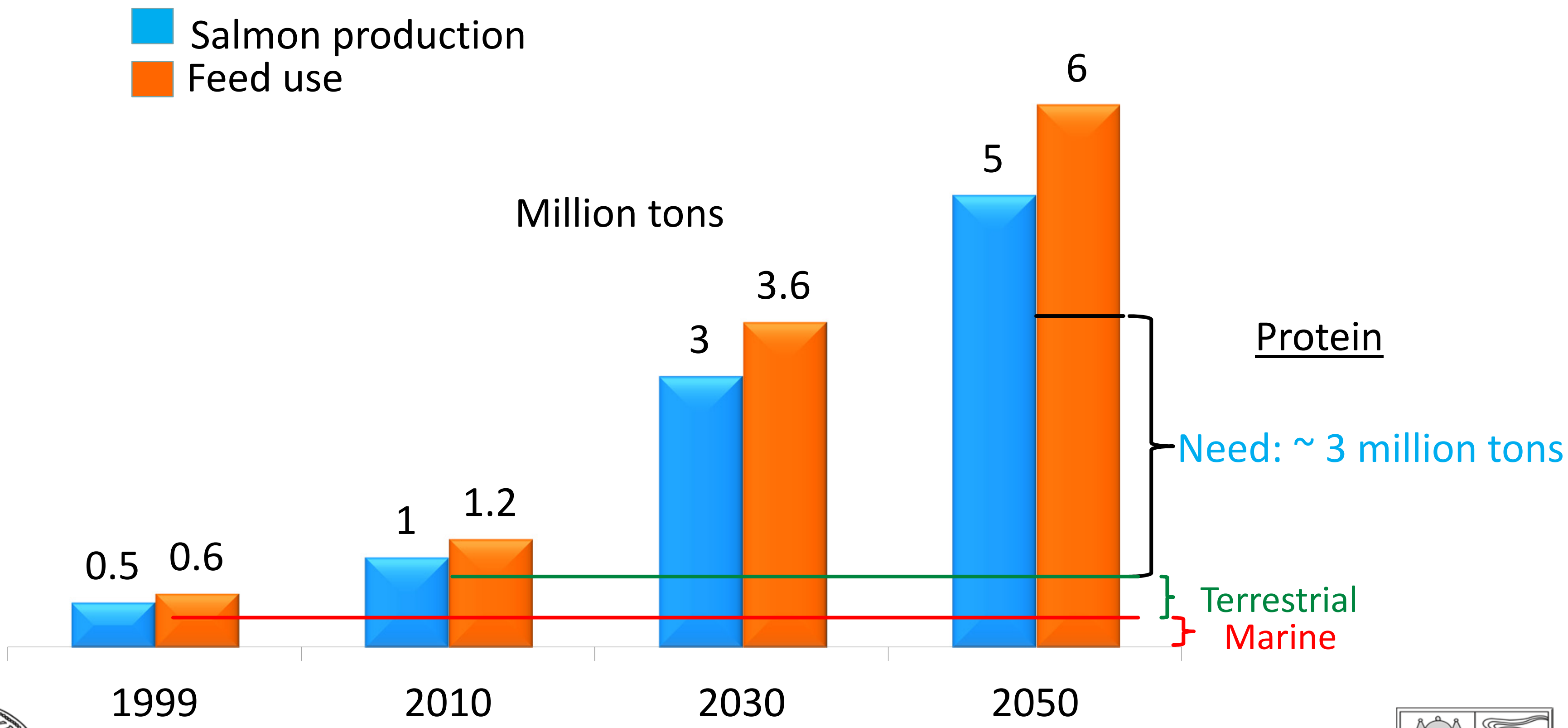
Målet til prosjektet

- Det skal dokumenterast og modellerast for næringssalt- og partikkeldynamikken kring dette anlegget.
- Ein skal registrere opptak av næringssalt og vekst hos tareplantar.
- Dokumentere opptak av planteplankton, fôr- og avføringspartiklar i skjel.

Bruksområde for dyrka tare

- Det kan vere etanolproduksjon.
- Tare er rik på karbohydrat og mineral, og kan nyttast som menneskemat slik ein gjer i austen.
- Taren kan nyttast som gjødsel og i dyre- og fiskefôr.
- SINTEF seier at forsøk at har vist at berre ein halvprosent innblanding av tare i fôret til laks har ein positiv verknad på fiskehelsa.

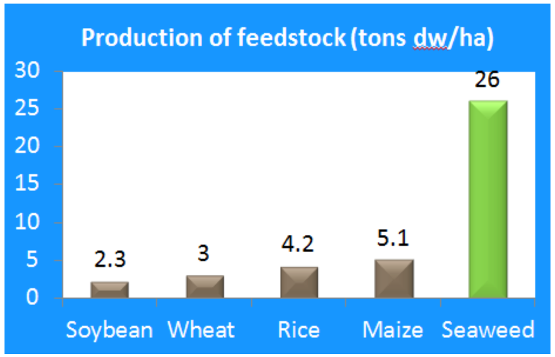
DKNVS Scenario 2050:
Prospected growth in salmon aquaculture



Global challenge: Food, feed and energy resources

Terrestrial vs Marine

- Farmable land
- Irrigation
- Fertilization
- Pesticides



Outline new processes and products

- Motivation for the SINTEF Priority project
- Lignocellulosics vs. seaweed
- Feedstock availability
- Pre-treatment and hydrolysis
- Biochemical conversion
- Catalytic upgrading
- Hydrothermal processing

Biobased products from seaweed

a value chain approach

Feed Stock → Pretreatment → Conversion → Products Recovery

Process design & Optimization
Technical & economical Evaluation

Energy

Chemicals

Bernd Wittgens, Duncan Akporiaye, Inga Aasen, Nils Dyrset, Paul Dahl, Morten Frøseth; SINTEF MC
Berta Matas Güell, Gonzalo del Alamo; SINTEF Energy Research AS
Jorunn Skjermo, Aleksander Handå; SINTEF Fishery and Aquaculture

Motivation of the project

Feed Stock
- Harvesting
- Conservation
- Storage

Pretreatment
- Mechanical processing
- Enzymatic hydrolysis

Conversion
- Digestion
- Fermentation
- Catalysis

Products Recovery
- Distillation
- Membrane
- Extraction

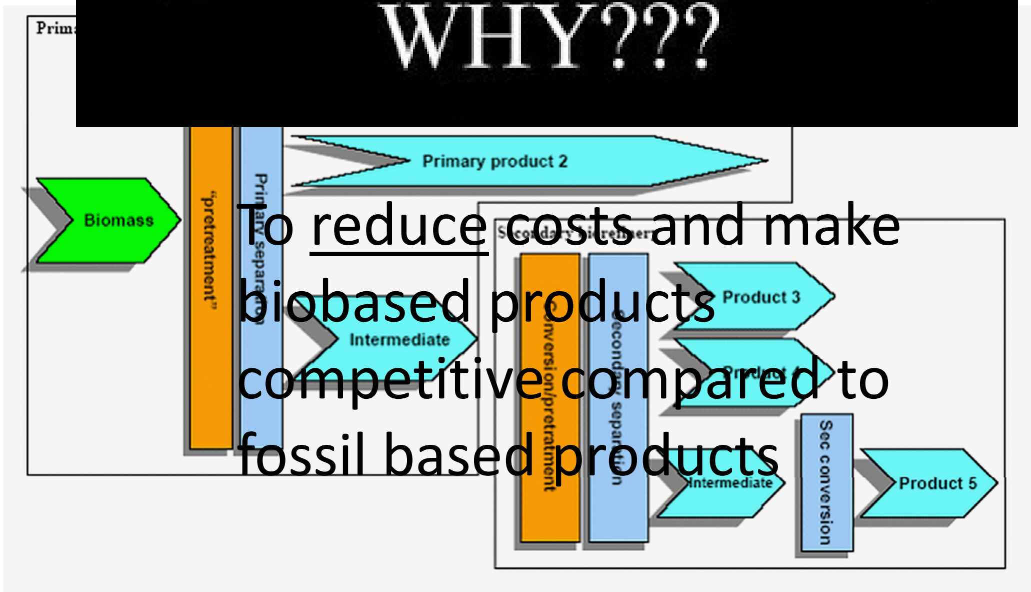
Process design & Optimization
Technical & economical Evaluation

Chemicals

- The Norwegian authorities intend to double the use of bioenergy by 2020 as a way of utilizing renewables and rural development.
- Replacement of fossil feedstock requires an alternative abundant feedstock
- Develop efficient technologies for given products
- The challenge in the bio-economy market is the present uncertainty in which direction the market for energy, chemicals and materials will develop

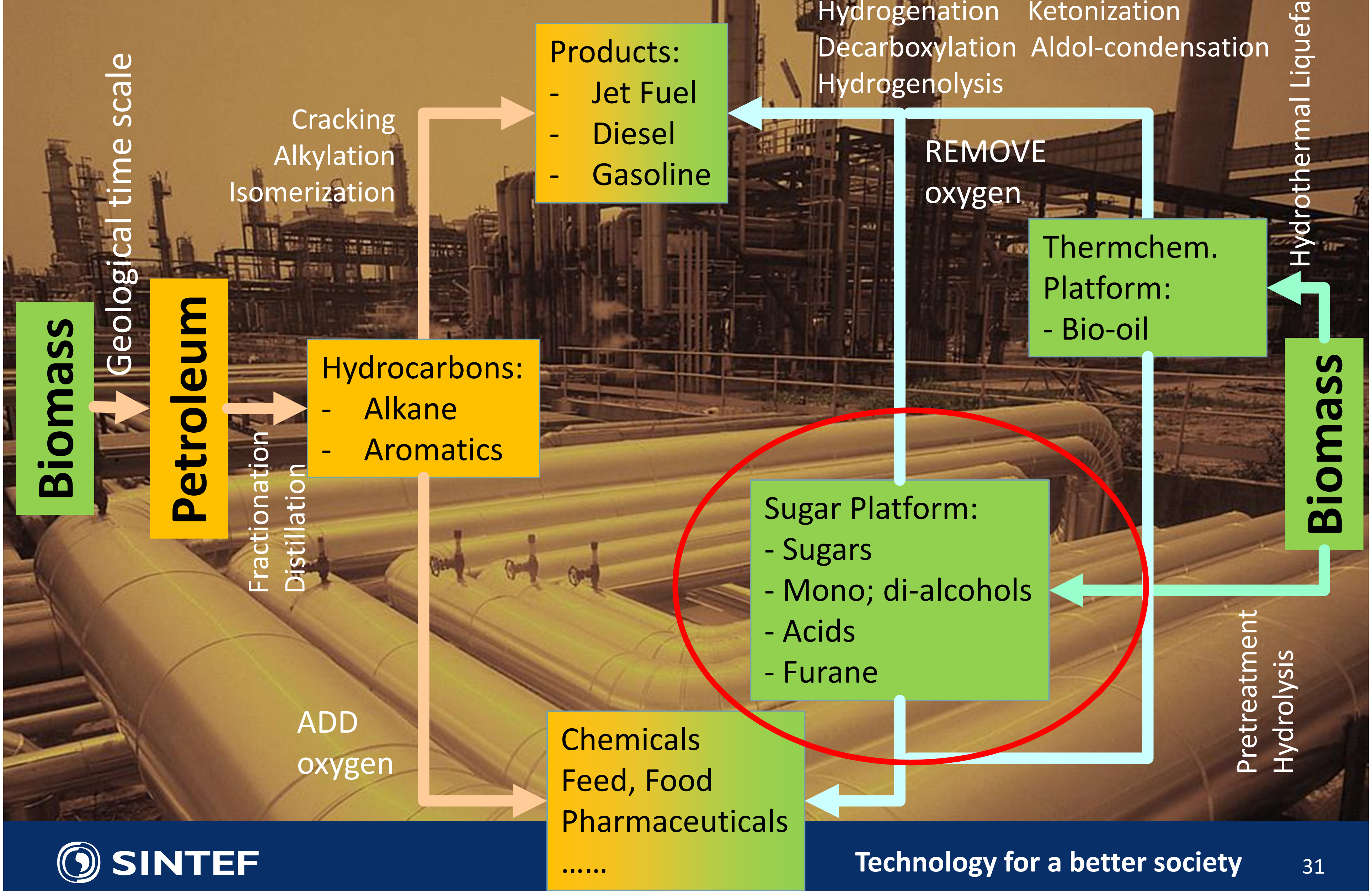
Biorefinery (IEA Task 42)

- Fractionating biomass into various separated products that undergo a further conversion:
  - biological
  - (bio)chemical
  - physical and/or
  - thermal chemical processing and
  - separation.
- By means of co-producing
  - relatively (high) value chemicals like fine chemicals, pharmaceuticals, polymers and
  - secondary energy carriers like transport fuels, heat, power



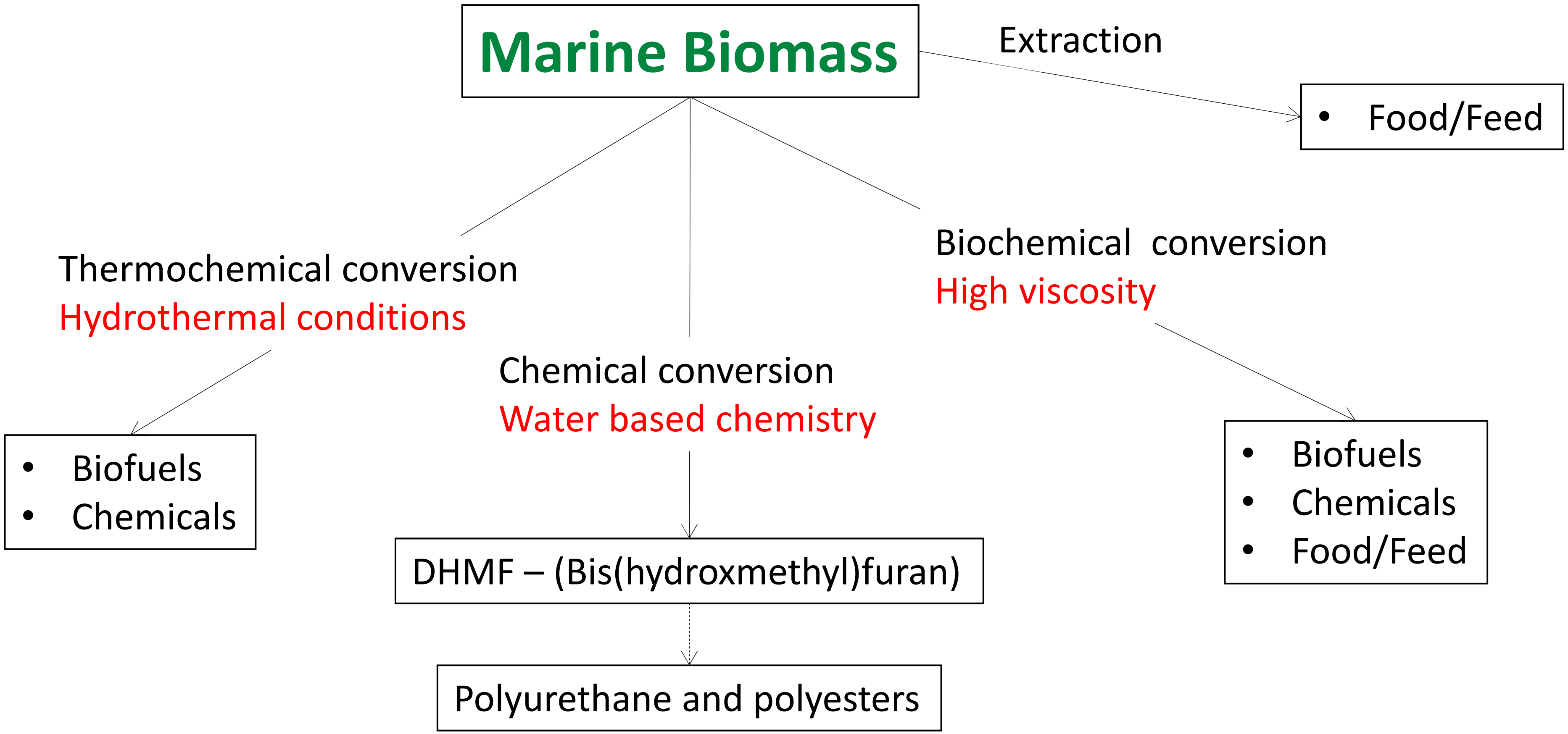
To reduce costs and make biobased products competitive compared to fossil based products

From Feedstock to Product

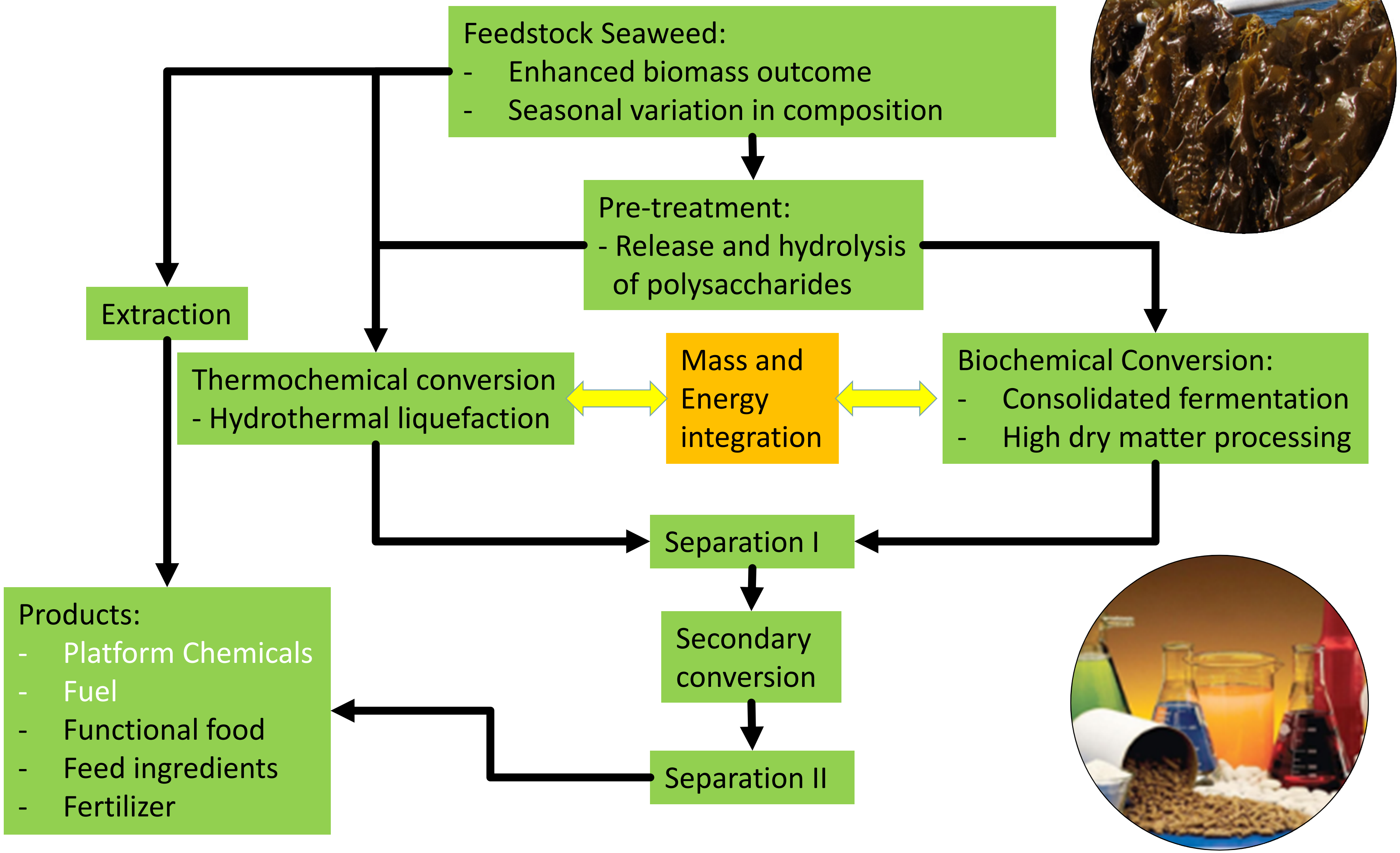


Address challenge of economic production of products from marine Biomass

$\Rightarrow$ transfer of new knowledge to forestry biomass



Value chain = Project structure



Lignocellulose vs. seaweed

Lignocellulose	Composition	Seaweed	Composition
Water	50%	Water	82-91%
Cellulose Linear polymer of glucose	17%	Laminaran	3-9* (33)% **
Hemicellulose Branching polymer of C5, C6-sugars, uronic acid, acteyl derivates	14%	Mannitol	2-18* (19)%**
Lignin Complex crosslinked polymer of phenolic monomers	12%	Alginate Anionic polysaccharide of β-D-mannuronate and α-L-guluronate	6-27* (47)%**
Resin & ash	7%	Salt / Ashes	4%
		Protein	3 – 20 %

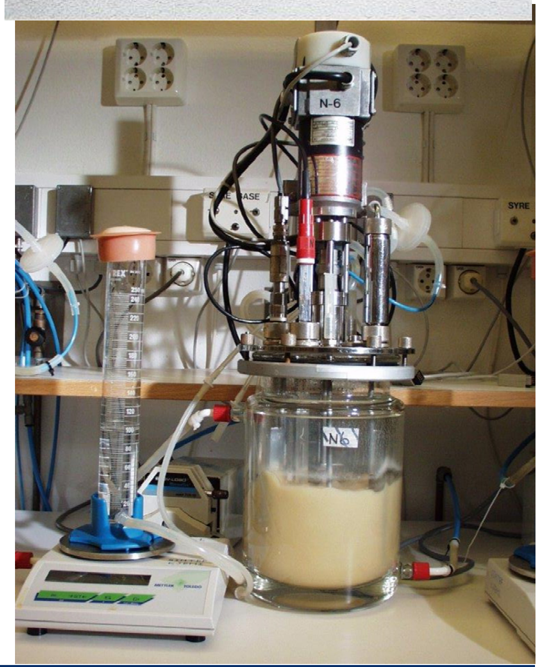
*Values for young cultivated S. latissima (Handå et al 2013).
**Max values found in literature (Holdt&Kraan 2011).

Biochemical conversion

- Generation of clean and cheap sugars
- Minimum formation of inhibitors
- High efficient enzymatic conversion
  - Alginate: less complex structure than lignin
  - No lignin or recalcitrant fibres
- Microbial laminaran and alginate hydrolysing enzymes are widespread
- Sugar acids open new area for enzymatic and chemical conversions
- Other sugars (mannitol, uronic acids) than in terrestrial biomass
  - New production strains must be developed
- New possibilities for new products

Products:

- Diols: 2,3-Butanediol
- Di-carboxlic acids (Succinic acid)
- 2-oxo-carboxylic acids (Pyruvic acid)



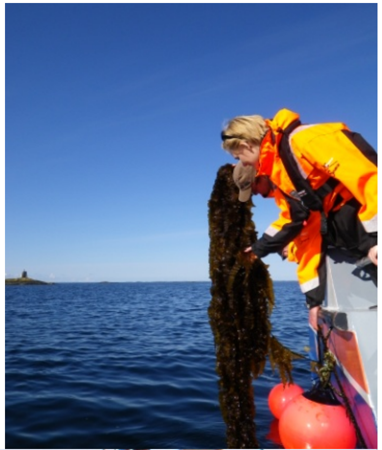
Thermochemical conversion

- High conversion rates under subcritical water conditions
- Avoid energy-demanding dewatering and vaporization
- Improved conversion through inexpensive catalysts
- Control of pH during liquefaction
- Processing of the seaweed residues derived from biochemical conversion

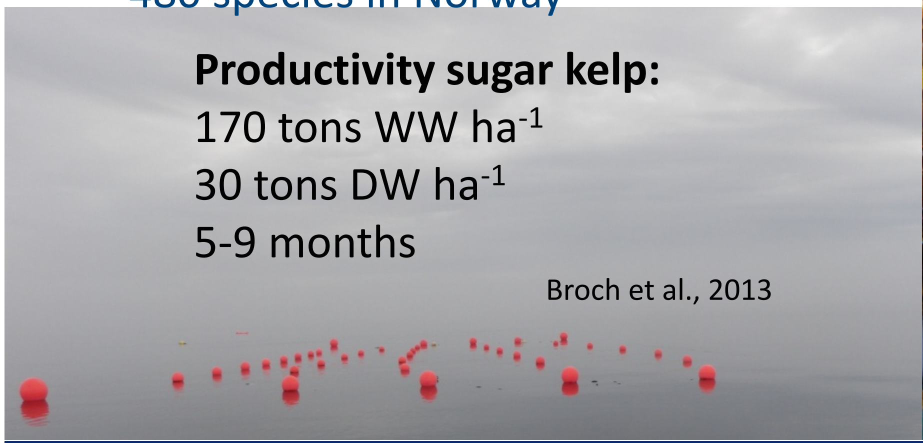
Products:

- High-chain length alkanes
- Carboxylic fatty acids (palmitic and palmitoleic acid)
- Polyaromatic hydrocarbons (PAH)
- Biochar
- Methane-riched gas for energy purposes

Feedstock seaweed – cultivated macroalgae



- Attractive biomass, large range of possible valuable products
- Eco-physiological effects on the chemical composition – an opportunity
- Sustainable production of biomass, no negative effect on the benthic ecosystem
- Large volumes possible
- Effective harvesting and freshness of biomass
- Possibilities for nutrients recycling (Integrated Multi-trophic Aquaculture)
- 480 species in Norway

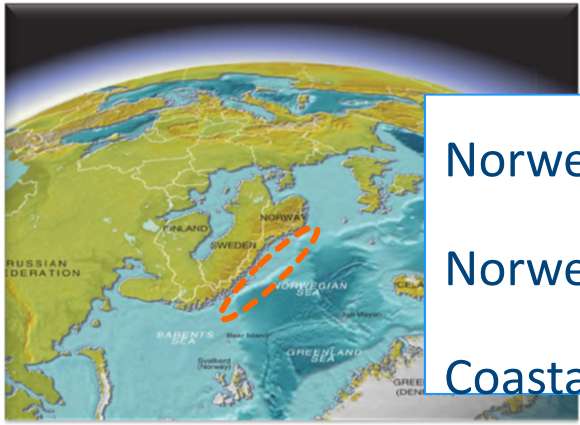


Productivity sugar kelp:
170 tons WW ha^{-1}
30 tons DW ha^{-1}
5-9 months

Broch et al., 2013

Cultivated Macroalgae

- Production potential in Norway?



Norwegian coast line: 103.000 km

Norwegian Economical Coastal Zone: 788.000 km^2

Coastal Zone within Sea boundary: 89.000 km^2

- Presently Norwegian salmon aquaculture produces 1.2 Mt yr^{-1} using 800 km^2
- Using a similar area for macroalgae cultivation will yield 7 Mt yr^{-1}

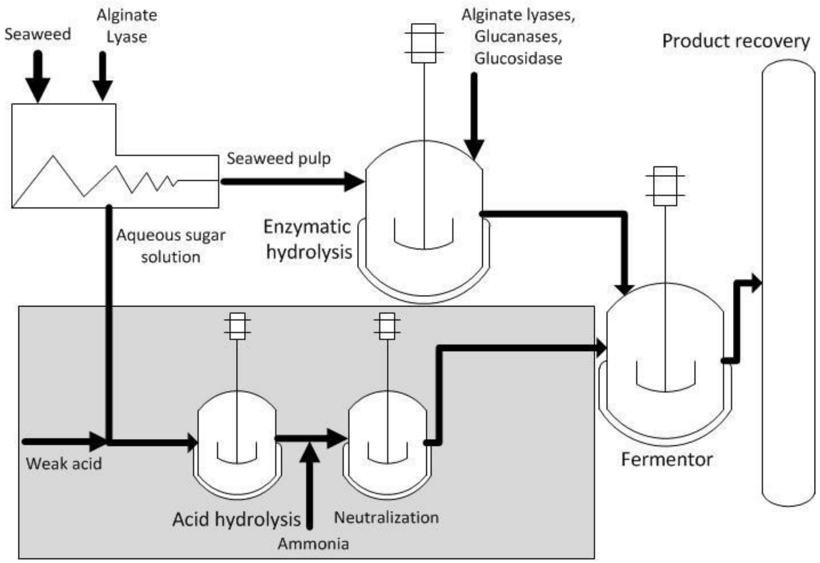
  - **7.Mt wet weight** ↓
  - 1.050 Mt dry matter
  - 500 – 630 kt carbohydrate to platform chemicals
  - 100 – 210 kt protein to functional food or
  - 70 kt amino acids to fish feed

Pre-treatment and Hydrolysis

Development of new, efficient pre-treatment/ hydrolysis processes for seaweed biomass, enabling utilization of min. 85 % of the alginate

Challenges:
- Release of sugars with minimum dilution
- Alginate: Ca-gel in native state,
  high-viscosity when dissolved

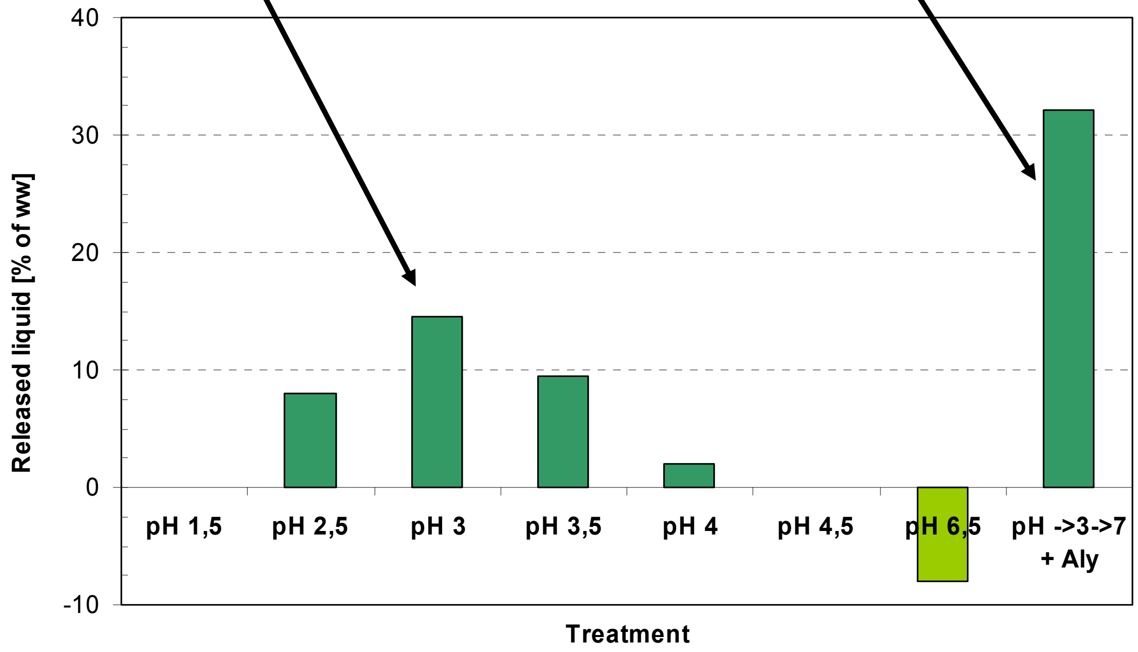
Strategy:
- Chemical and/or thermal pre-processing
- Addition of alginate hydrolysing enzymes to degrade the alginate matrix
- Hydrolysis of separated fractions



Pre-treatment and Hydrolysis

Strategy:

- Reduction of pH reduces the water binding, facilitating release of water soluble compounds (carbohydrates)
- Addition of alginate hydrolysing enzymes further enhance the liquid release



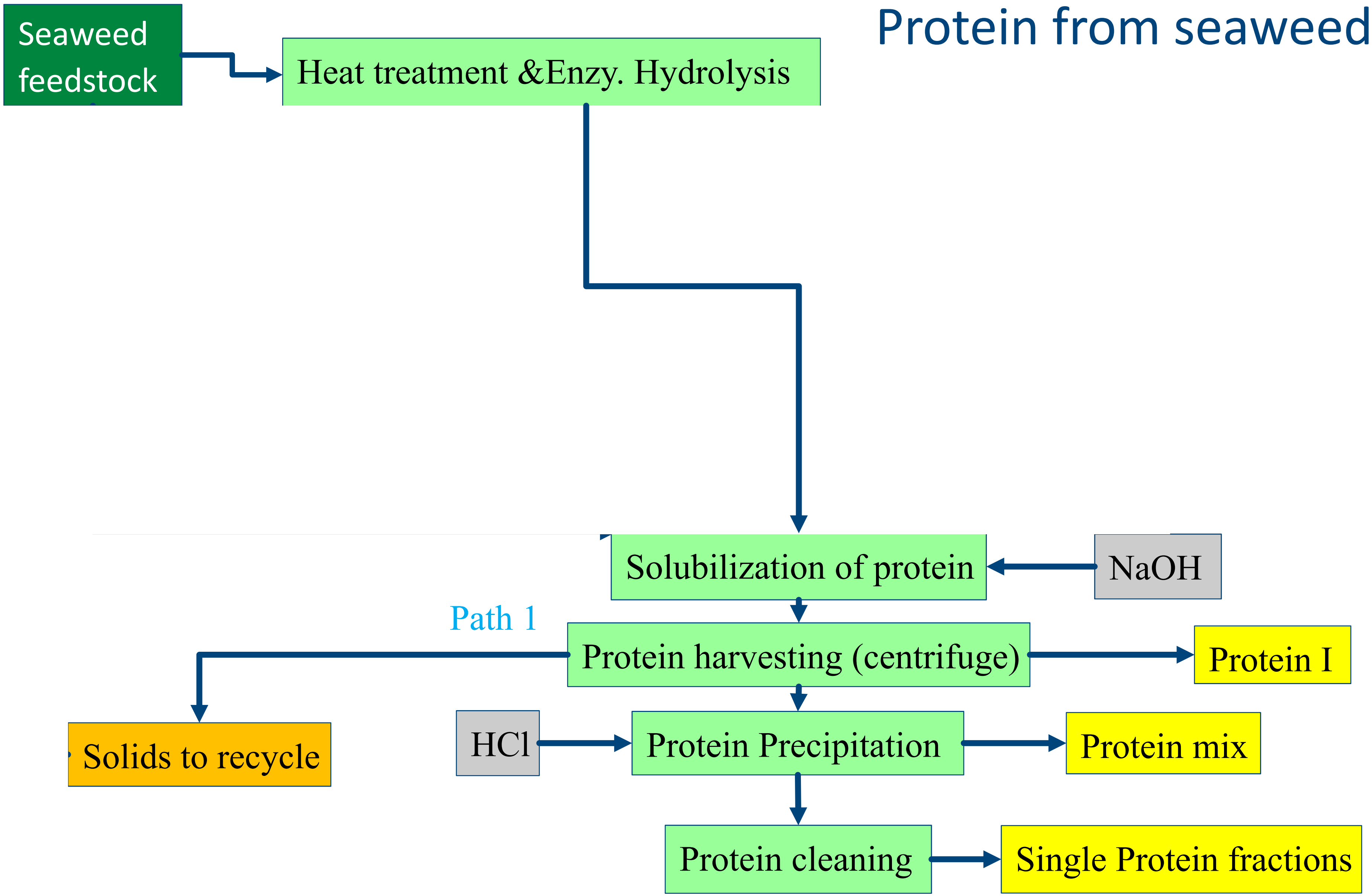
Biochemical conversion

Fermentative production of platform chemicals from seaweed hydrolysates

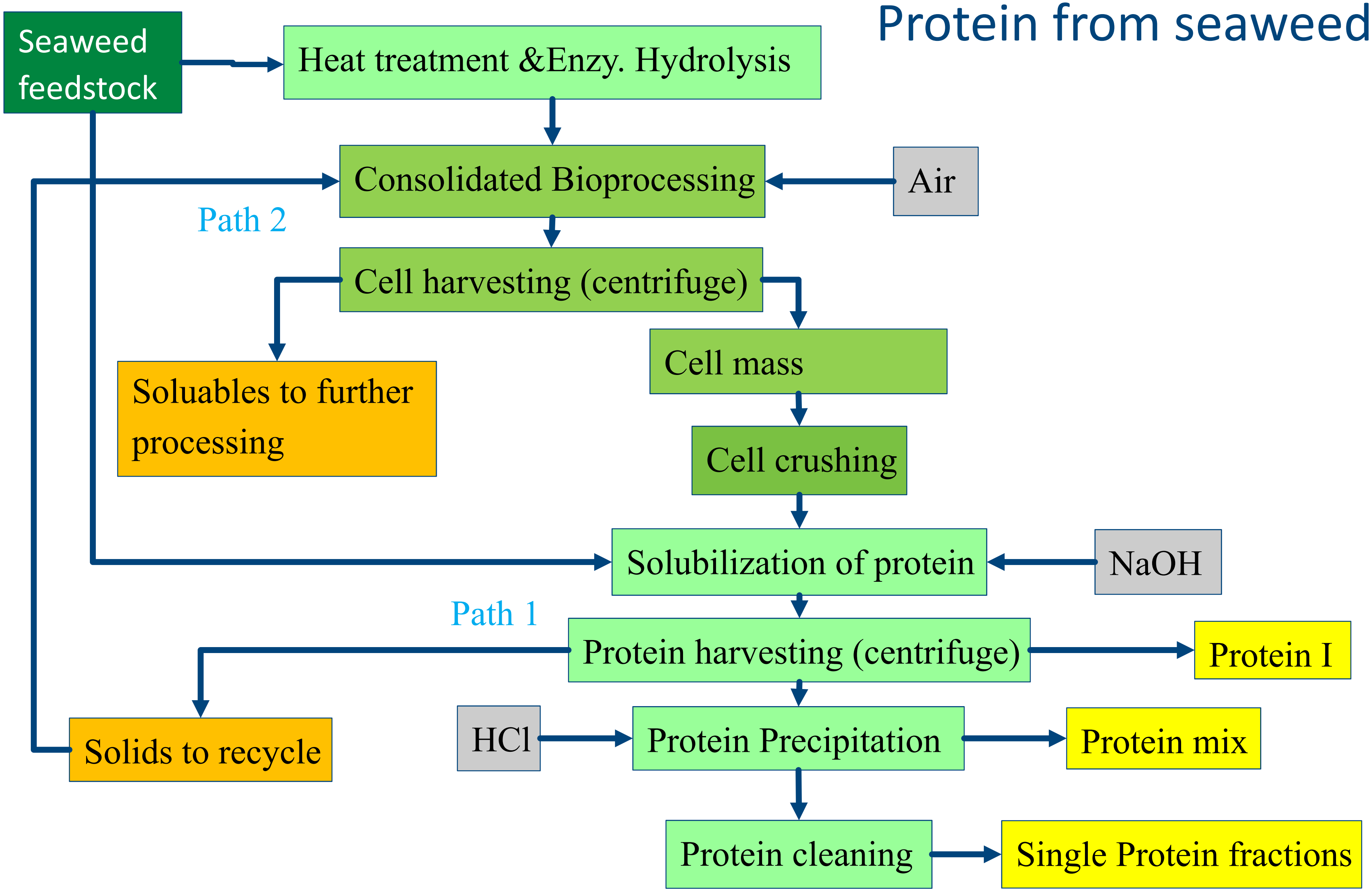
Main objective:

- Selection of potential wild type microorganisms for future development of production strains optimized for seaweed based biorefinery
- Evaluate model microorganisms (*E. coli*, *C. glutamicum* and *B. methanolicus*, *S. cerevisiae*) for potential growth on seaweed hydrolysates.
  - Screening different wild type and laboratory strains
  - Investigate tolerance to hydrolysates and inhibitors
  - Tolerance to high concentration of monosugars in hydrolysates
  - Salt tolerance

Protein from seaweed

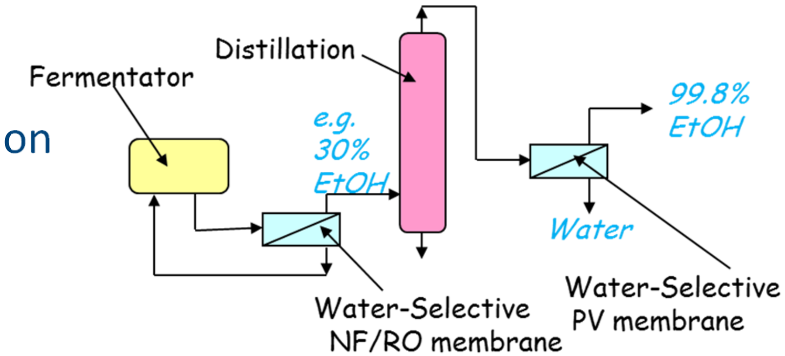


Protein from seaweed



Advanced separation of microbial products from fermented seaweed polysaccharides

- Design of separation systems for platform chemicals: Diols, Di- / 2-Oxo-Carboxylic acids
- Address total cost of conversion and separation
- Evaluation of novel separation sequences for removal of bio-chemicals from fermentation broths.
  - Separation procedures highly dependant on chemicals to be separated (2,3-butanediol / acetoin / di-carboxylic acids)
  - Pre-treatment (e.g. particle filtration) of fermentation broth prior to separation to avoid clogging
  - Review of suitable hybrid separation systems:
    - distillation combined with membrane separation
    - Crystallization



Example from bio-ethanol

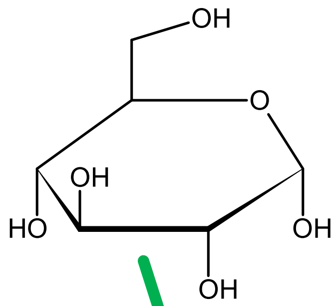
Catalytic upgrading of microbial produced platform chemicals to value-added products

Starting materials:

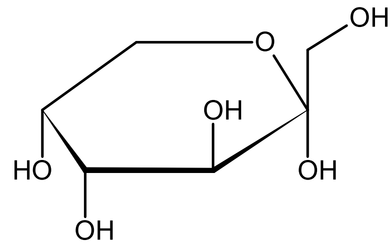
- **Laminaran, Glucose, Succinic acid** and components from WP4

  Common features:

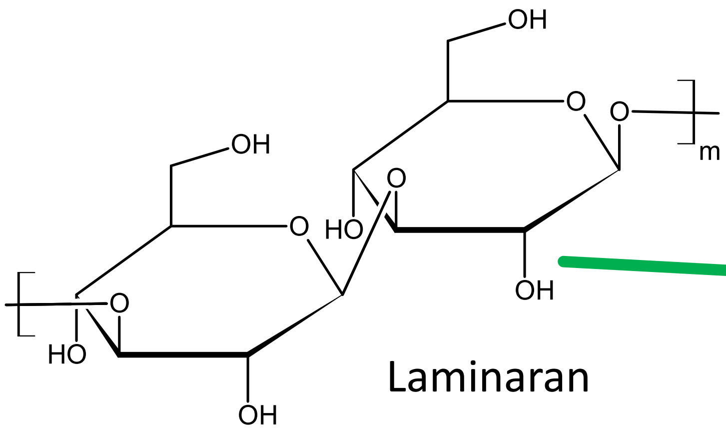
  - Oxygen rich
  - Dissolved in water
  - Fermentation impurities
  - Salt from sea water



Glucose



Fructose



Laminaran

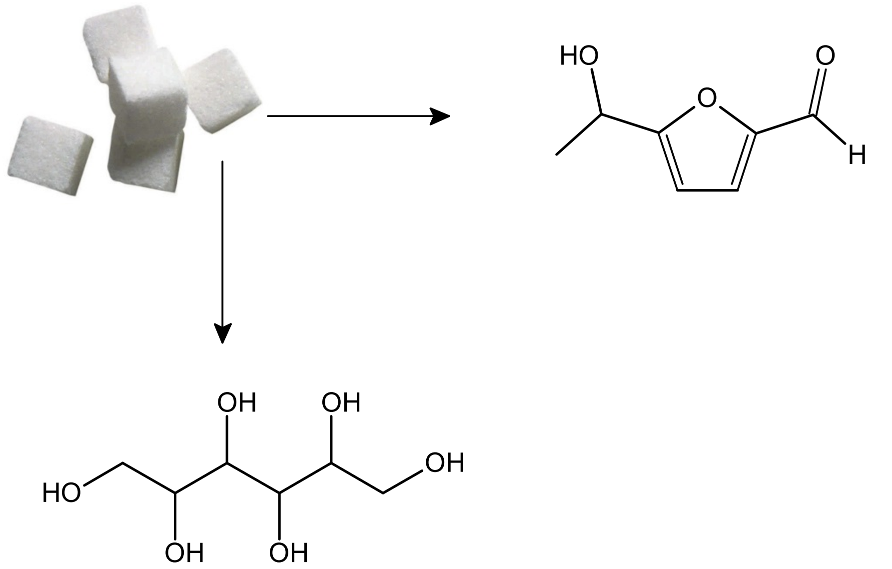
Small structural differences
Big differences in reactivity

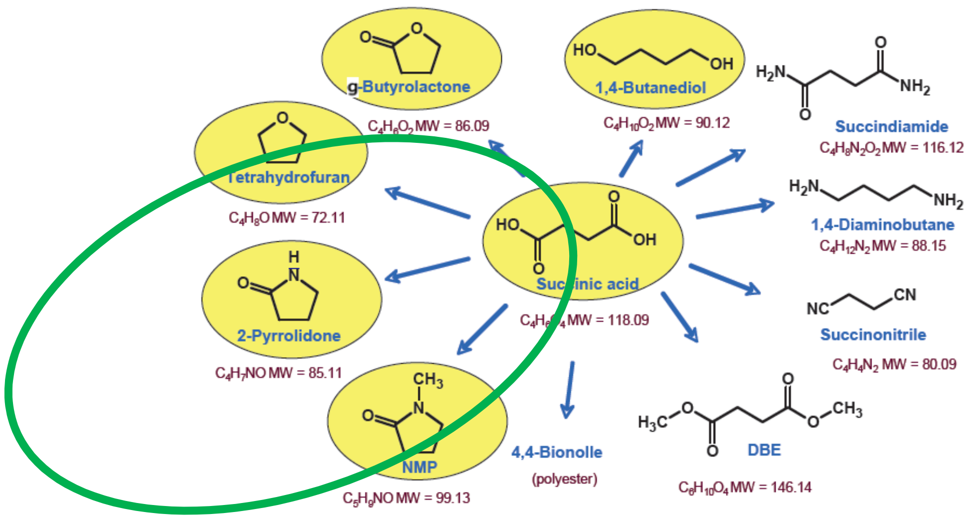
Value-added products

Possible Routs from Sugars/Laminaran

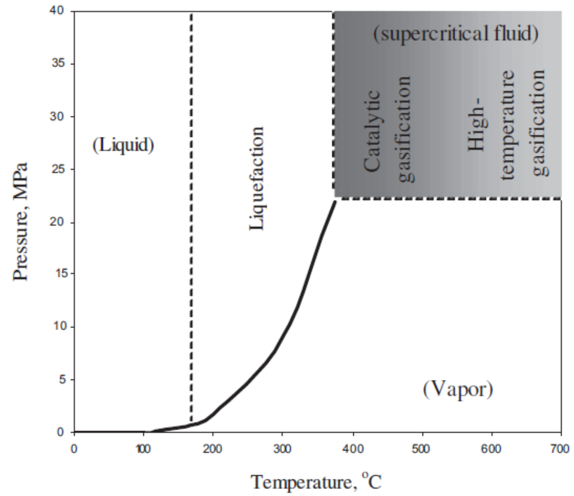
Two main processes possible:

1. Formation of hydroxumethylfurfural:
   - Acidic catalysis
   - Yields depend on type of sugar used. 95% is good!
   - Many possibilities for further products without H_2
2. Formation of sorbitol:
   - H_2 demanding from the start
   - Less products
3. Succinic acid
   - Nice starting point with succinic acid derived by fermentation for the production of pyrrolidinones





Hydrothermal processing



Advantages of hydrothermal processing

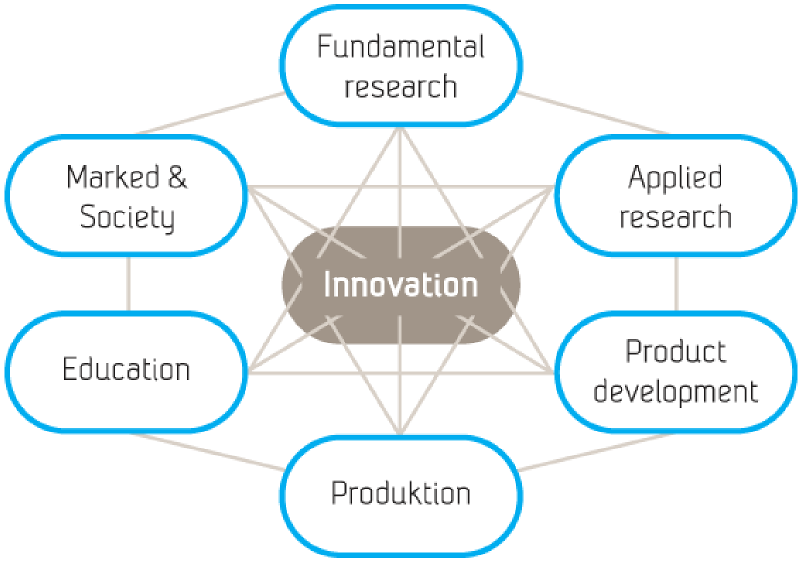
- **No drying** of wet biomass is needed, reduces energy consumption
- Multiple feed streams seaweed, waste streams and "micro-organisms"
- High **carbon conversion** rate into bio-oil (high-chain alkanes, carboxylic fatty acids, polyaromatic hydrocarbons (PAH)), biochar and methane-containing gas
- Fast conversion as compared to other routes
- The **product gas is pressurized** simplifying downstream processes.
- **CO_2 is easily separated** from the gas product because of its higher solubility in water than CH_4 and H_2.
- Advanced process integration is needed for high thermal efficiencies

Biofuels, Bioprod. Bioref., 2 (2008) 415-437

Technical and economical evaluation
Is there money to be made? Yes, but

- Find the right combination of feedstock and product
- Extract valuable first
- Maximize utilization of feedstock
- Minimize feedstock decomposition
- Minimize energy consumption for
  - Conversion
  - Separation

  through
  - Reduce water amount in the system
  - Increase dry matter content in processes
- Integration of biochemical, thermochemical and catalytic processes



Dyrking av makroalger som fornybart råstoff kan bli et av Norges viktigste, og mest langvarige bidrag for miljøet og den nye bioøkonomi

Takk for oppmerksomheten!

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Bio-based Products: Market potential

Feed additives (amino acids & enzymes) ~7 Mrd US$

Pre-treatment chemicals ~10 Mrd US$ by 2020

- Bulk chemicals: ~25 Mrd US$ by 2017
- Fine & Speciality Chemicals 2012:
  - EU: 4 Mrd US$; US: 6 Mrd US$,
  - approx. 10 Mrd US$ increase/a
- Bioplastics: US: ~3 Mrd US$

Energy (Heat & Power): 15,5 TWh, US: 65 Mrd US$

Biofuels 1,6 TWh **Globally 70 Mm^3 bioethanol**

Total Market for Biorefinery value chain:
~300 Mrd $ by 2020 **(The World Economic Forum)**