ESTABLISHING A SEAWEED INDUSTRY IN NORWAY: STRATEGIC, ECONOMIC AND ENVIRONMENTAL PERSPECTIVES

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ProMac Final Conference | 2018-11-09

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OVERVIEW

1. Background
2. The research question
3. Approach
4. Literature review
5. Cost modeling
6. Differentiators and their value
7. Findings
8. Discussion
9. Summary

BACKGROUND

1. Norway has a long coastline with huge potential for seaweed farming
2. Currently, the industry is handcraft delivering high-end products to human consumption and pharmaceutical products
3. This is interesting for those involved, but relatively uninteresting from a national, industrial perspective (i.e. employment and basis for taxation)
4. For Norway, an industrial approach means large-scale contributing to fish-feed products where Norway already has a large-scale industry established
5. Today, Soy Protein Concentrate (SPC) is the main protein contributor in fish-feed but with large environmental impacts
6. Can Seaweed Protein Concentrate (SWPC) substitute SPC and, if so, under what circumstances?

THE RESEARCH QUESTIONS

1. Can SWPC be produced at cost parity to SPC?

2. What research must be conducted to achieve such cost parity if it does not exist today?

THE APPROACH

1. Literature review (what has been done in both industry and academia)
2. Model the value chain
3. Discuss two important ramifications;
   a) The commercial potential for seaweed in industrial scale – what is the product and what is its value?
   b) Due to SPC being a commodity, a biorefinery for seaweed must operate similarly as the refineries for soybeans
4. Conduct a strategic analysis to investigate possible avenues;
   a) Establish a reference case
   b) Use the Power law to scale it up
   c) Discuss possible differentiators for SWPC
   d) Financial analysis

LITERATURE REVIEW FINDINGS

1. By 2016, out of 598 species and/or species groups farmed around the world, 40 were aquatic plants which reached 31.2 million tons wet weight out of which 30.1 million tons were farmed (96.5%)
2. Aquatic plant farming has expanded at 8 % per year in the past decade
3. Main farming nations are China (47.9%) and Indonesia (38.7%) – Asia is 99.4%
4. In Norway (ca 144 tons in 2017);
   a) Small and very few species are commercially exploited
   b) The utilization of seaweeds for food purposes is limited to industrial production of thickeners, such as alginate, agar and carrageenan
5. A likely usage of seaweed is as a substitute, partially or fully, for SPC, which has very negative environmental impact yet demanded in vast quantities

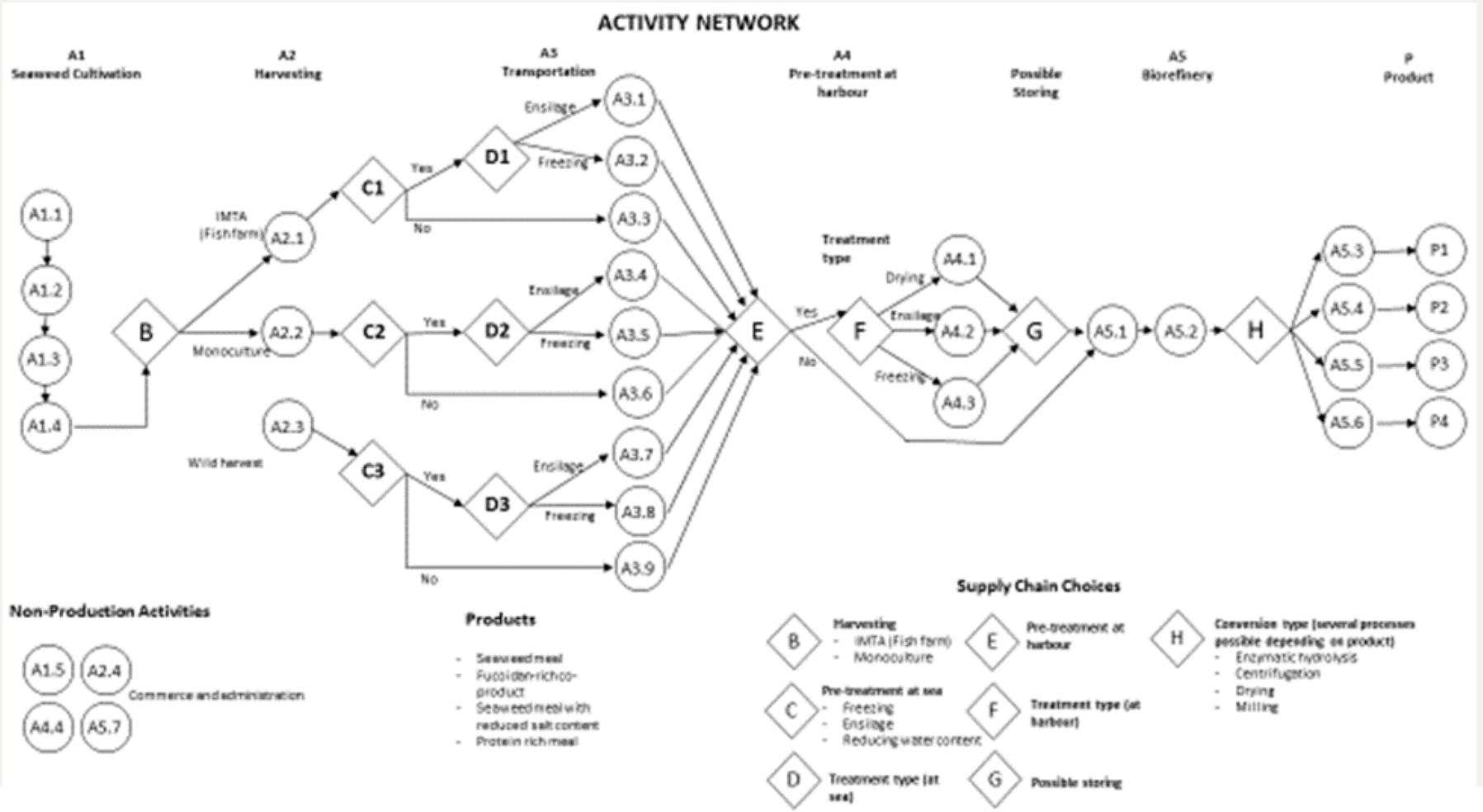
IDENTIFIED CHALLENGES

1. Short season for harvesting the seaweed
2. Most nutritious water is offshore – but so is the worst weather and mooring (depth and external forces)
3. Collection and transportation of fresh seaweed
4. Seaweeds decay fast
5. There is currently no industrial-size biorefineries for seaweeds

MODELING

1. Model the value chain options
2. Establish reference case
3. Scale up using Power law to estimate costs
4. Identify differentiators
5. Estimate value of differentiators
6. Calculate costs and revenues
7. Analyze uncertainty using Monte Carlo simulations
8. Sensitivity analysis

MODELING THE VALUE CHAIN



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REFERENCE CASE (HORTIMARE)

[EUR/kg]	20 hectare	600 hectare
Cost genetics and crop/seedling material	2.53	0.27
Cost cultivation and harvesting	2.59	0.86
Yield (dry mass / m2)	1.5	2.0
S U M	**5.12**	**1.13**

Chapman, Annelise , Pierrick Stévant, Job Schipper, Øyvind Kråkås, Bjørn Aspøy, and Asbjørn Stavland. 2014. Markendsvurderinger for bærekreftig algedyrking i Integrert Multitrofisk Akvakultur (IMTA)-anlegg. Alesund: Møreforskning.

Some comments:

- This is the case we found that is closest to the level of scale we talk about
- 30-fold increase in scale gives 78% reduction in costs
- But the biorefinery part is still missing…

BIOREFINERY MUST BE INFERRED FROM SPC

- Assume that the costs of refining soybean flour to SPC is similar to the costs of refining dry seaweed to SWPC – similar biorefinery costs
- SPC normally costs 2 to 2.5 times more to process than soybean flour (Berk 1992) and SPC is traded at ca 1.1 USD/kg (non-GM)
- The cost of soybean flour is about 0.40 USD/kg which implies that the costs of soybean flour is about 40% cheaper than SPC
- SWPC will cost about 2.5 EUR/kg

SCALING UP USING POWER LAW

$$\frac{C_1}{C_2} = \left(\frac{S_1}{S_2}\right)^p * t$$

- C1 – Investment cost for scale S1
- C2 – Investment cost for new scale S2
- t – a correction factor for taking into account differences in date, location, pressures, temperatures and materials of construction. We have set it to 1
- P – see next slide

CHOOSING THE VALUE FOR P

Table 7 – Typical values of exponent p for common biorefineries. Source: (Tsagkari et al. 2016).

p	Biorefinery type	Phase type	Cost items (FOB)
>1.0			Piping
0.9 – 1.0	Seed crushing units	Solids	Multiple fermenters or other equipment items, catalysts, chemicals, civil works, construction.
0.7 – 0.9	Grains to bioethanol, lignocellulosic biomass-to-ethanol, renewable diesel, biomass-to-ethanol (by gasification)		Crushers, compressors, electrostatic precipitators
0.6 – 0.7	Oil to biodiesel	Liquids	Blowers, pumps, crystallizers, pressure vessels
0.3 – 0.6		Gas	Agitators, conveyors, dryers, filters, shell-tube heat exchangers, jacketed reactors, horizontal tanks

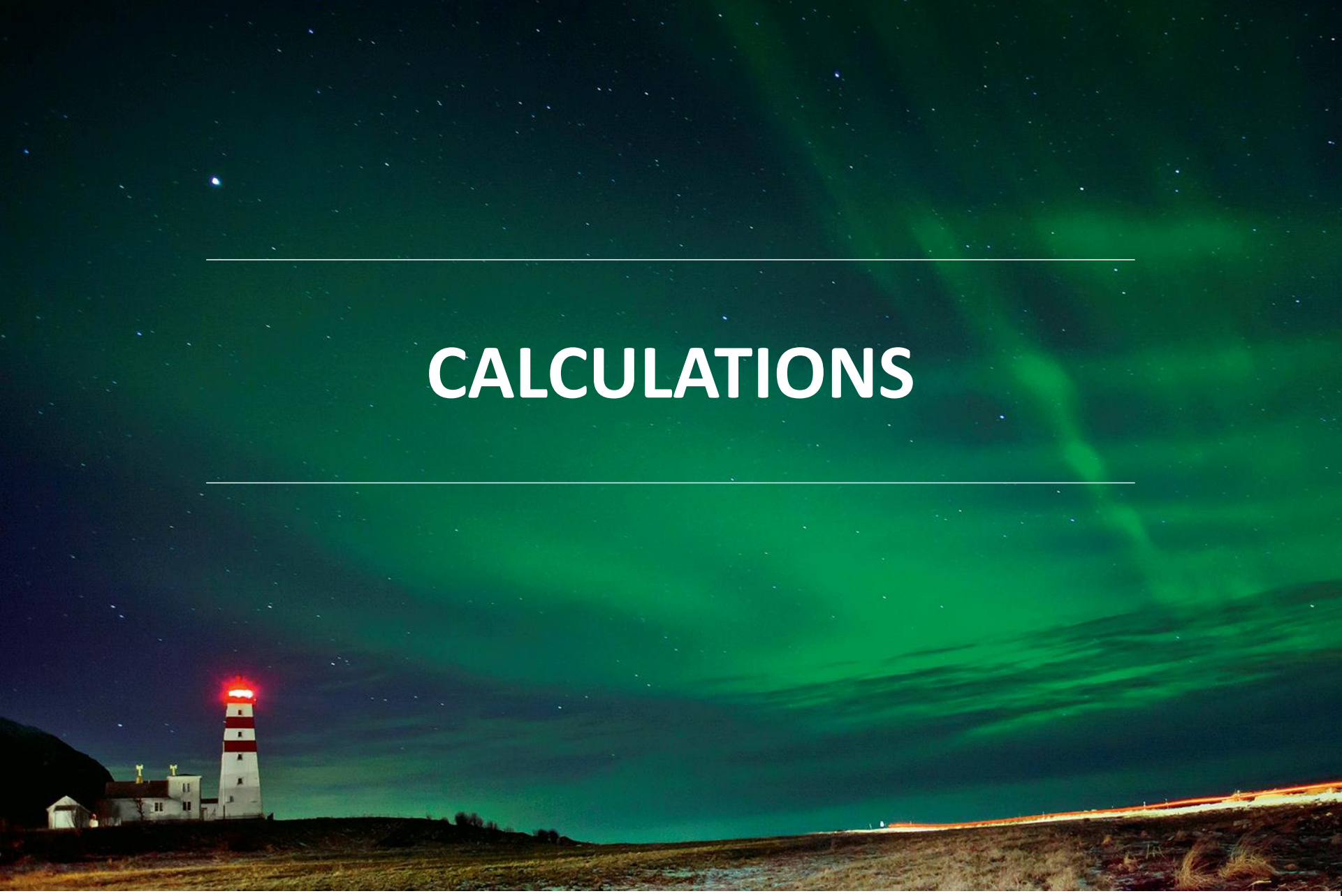
DIFFERENTIATORS AND THEIR VALUE

Table 10 – Components from brown macroalgaes such as *Saccharina latissimi* and Laminaria digitate and resulting market value after biorefinery. Source: Holdt Kraan

Component	Application	Market value [EUR/ton]	Percent in kelp dw	Value in dry kelp [EUR/ton]
Protein	Fish feed	1,400	15	210
Mannitol	Food	1,500	12	180
Phycocolloids	Food	3,000	23	690
Laminaran	Food, pharmacy	350	14	49
Fatty acids (PUFA)	Food	1,250	4	50
Polyfenols	Anti-oxidant	20,000	0.5	100
Iodine	Food, pharmacy	25,000	0.4	100
Fucoxanthine	Pigment, anti-oxidant	200,000	0.05	100
Fucoidan	Pharmacy	8,000	5	400

NB! Large variations in these numbers depending on sources

CALCULATIONS



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DETERMINISTIC FINANCIAL CALCULATION

- Scale 1 is the Hortimare case with 12 tons dw
- Scale 2 is our case with 25 000 tons dw
- Scale 2 gives 0.41 EUR/kg dw seaweed

BUT

- SPC has about 60% protein
- SWPC har about 10% protein
- Correcting for this…
- SWPC costs 2.46 EUR/6 kg
- We need differentiators

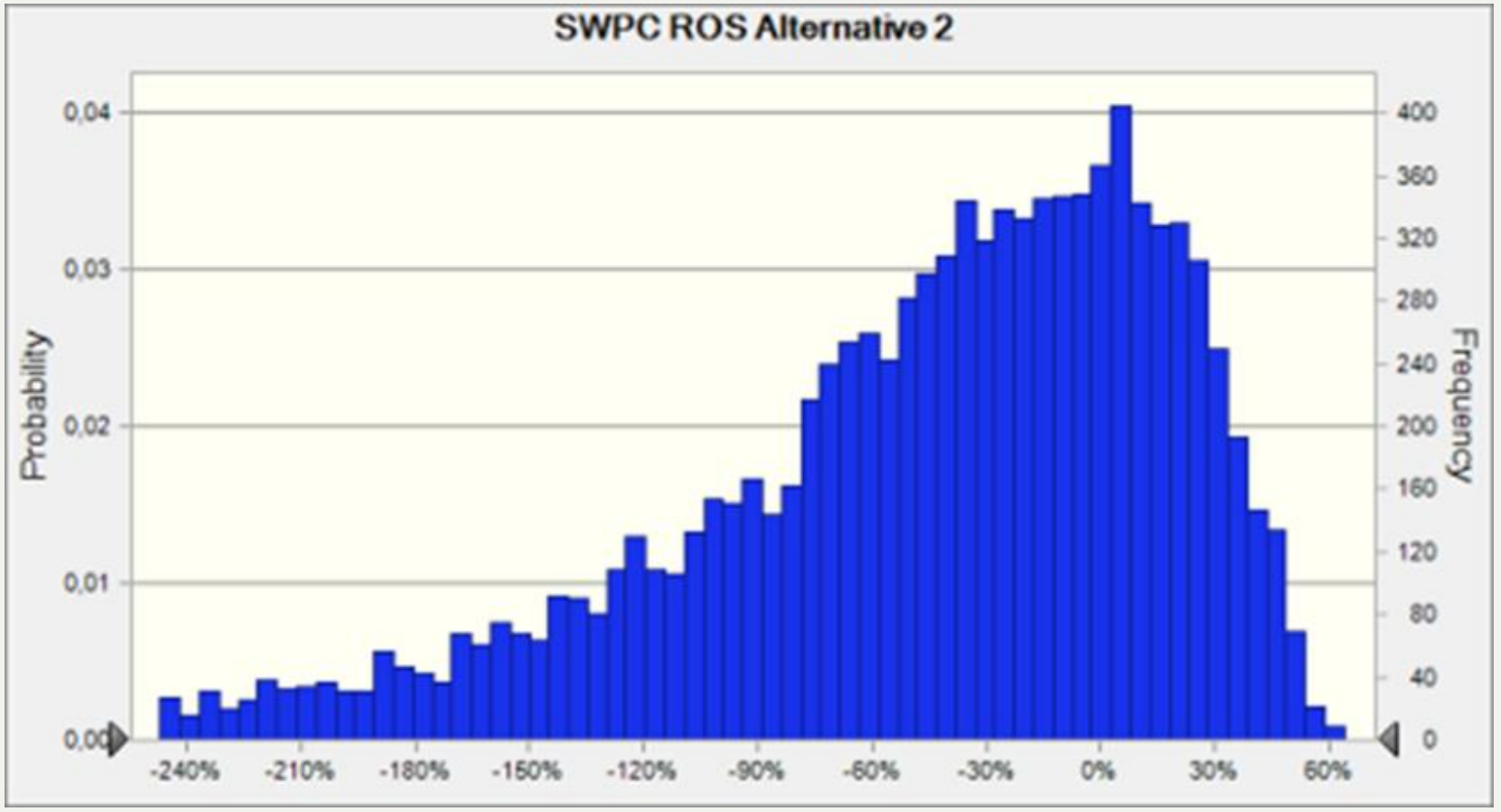
DETERMINISTIC FINANCIAL CALCULATION

Table 11 – The value model for SWPC.

Chemical composition of SWPC	Fraction	Value [EUR/kg]	Mass [kg]	Cost [EUR]	Value [EUR]
SWPC		0,41	6,0	2,46	
Protein	10 %	0,41	0,6		0,54
Laminaran	14 %	0,35	0,8		0,29
Mannitol	12 %	1,50	0,7		1,08
Sum	**36 %**			**2,46**	**1,91**

- SWPC has only a future IF customers are willing to pay for the differentiators AND we manage to improve the parameters in the right direction
- Deterministic break-even point is a scale of 65 000 tons per year

UNCERTAINTY ANALYSIS (25 000 TONS DW PER YEAR)



Break-even probability is about 25% - 30%

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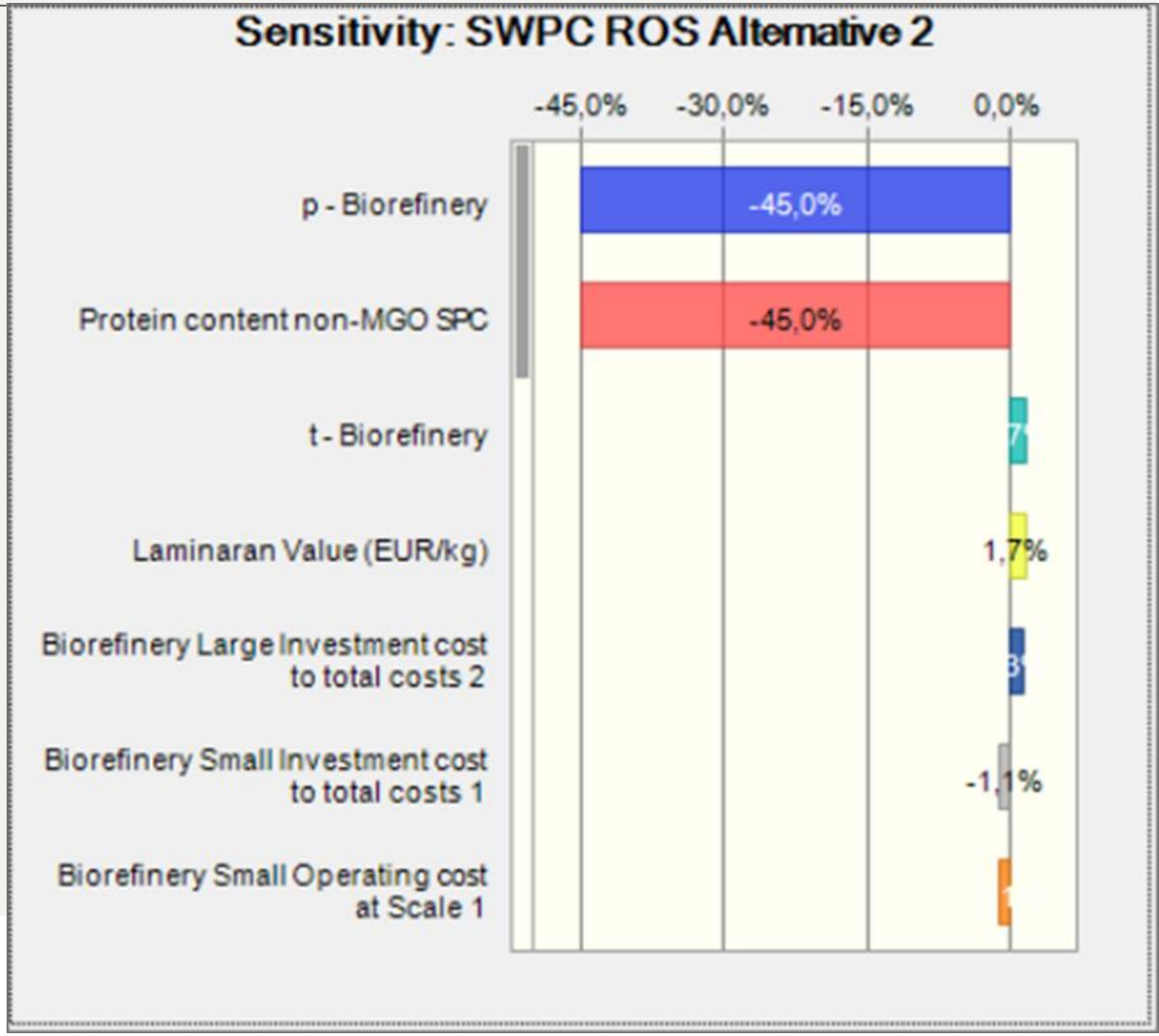
SENSITIVITY ANALYSIS

Process characteristics of the biorefinery is key



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FINDINGS AND DISCUSSION

FINDINGS

1. There is hope for establishing a profitable biorefinery producing SWPC
2. This requires large scale biorefineries and large enough seaweed farms to support industrial collection and -transportation
3. To achieve this some critical research questions must be addressed;
   a) How to establish large enough seaweed farms?
   b) How to collect and store seaweed for all-year operation (we believe freezing is the approach for both)?
   c) How to design of a biorefinery that preserves the differentiating compounds while ensuring there is enough protein left?
   d) How will the market find SWPC as a product and what are they willing to pay?

DISCUSSION

- There is chronic lack of data due to the fact that nobody has ever farmed, harvested, transported and processed seaweed on this scale
- We work on the ‘order of magnitude’ accuracy to ensure relevance and consistency, but this introduces large uncertainties
- Yet, the uncertainty analysis shows that there are possibilities for a realistic solution – but today it is too early to guarantee
- More research is needed along the lines on the previous slide

Read the report when it comes…