Power-to-Protein: next step towards consumable single cell proteins from waste water and renewable hydrogen

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TOPSECTOR WATER & MARITIEM

Introduction

Future global challenges

- **Population increase:**

  9 billion people in 2050

- **Increased protein requirement:**

  From 473 in 2014 to 943 MT protein in 2054

- **Environmental concerns:**

  Sustainability was a "nice to have"; now it is a priority

- **Climate change:**

  Extreme weather including droughts will undermine future food production potential

Power-to-protein concept

Biochemical conversion with carbon capture and ammonia recovery

power to PROTEIN

“*Can direct conversion of used nitrogen to new feed and protein help feed the world?*”

Ammonia from waste water

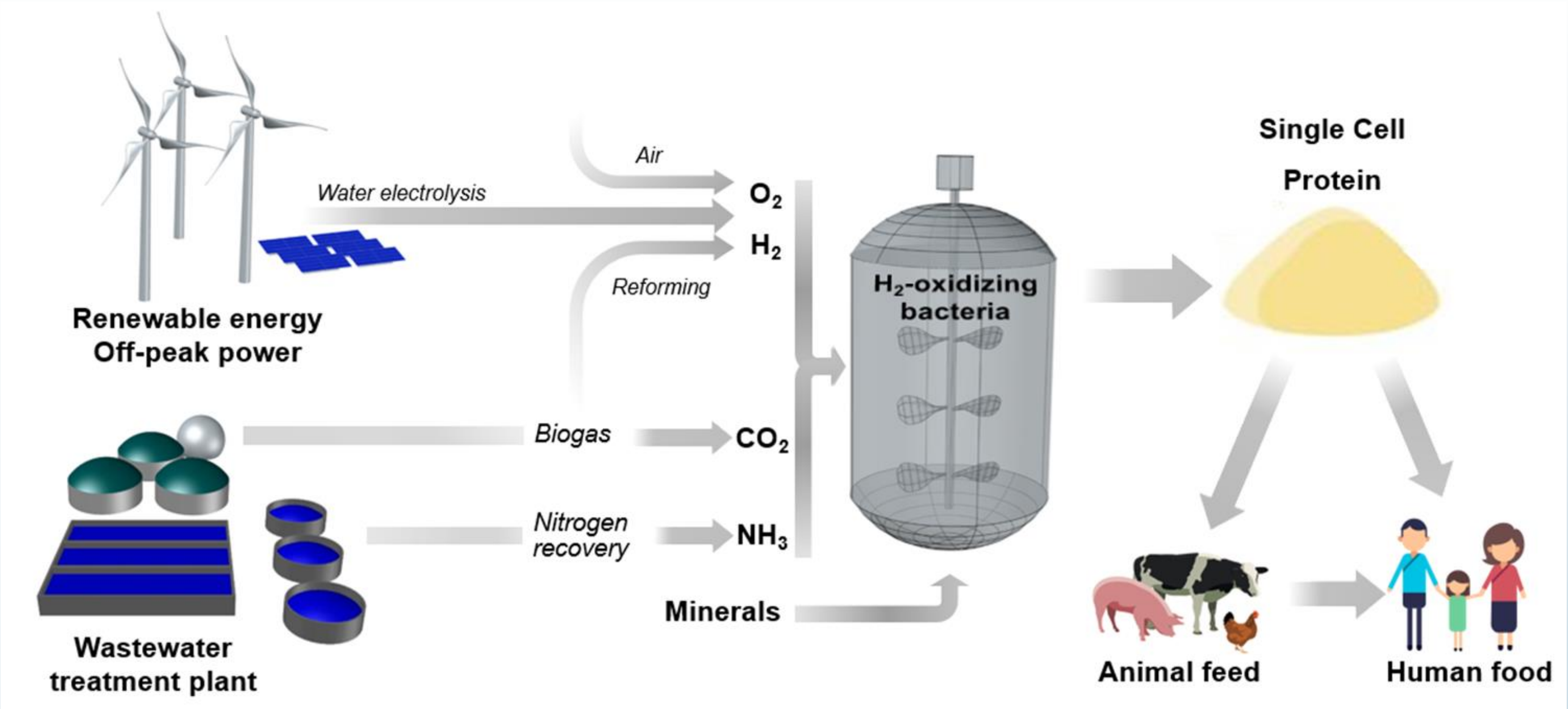
Hydrogen Oxidizing Bacteria (HOB):

Aerobic, facultative autotrophic bacteria
By means of H_2 oxidation, CO_2 and NH_3-N are incorporated into **protein-rich biomass: SCP**

$$5.2\ \mathbf{H_2} + 1.5\ O_2 + 1.0\ \mathbf{CO_2} + 0.2\ \mathbf{NH_3} \rightarrow \mathbf{CH_{1.7}O_{0.5}N_{0.2}} + 4.6\ H_2O$$

Power-to-protein concept

All sources from the waste water chain

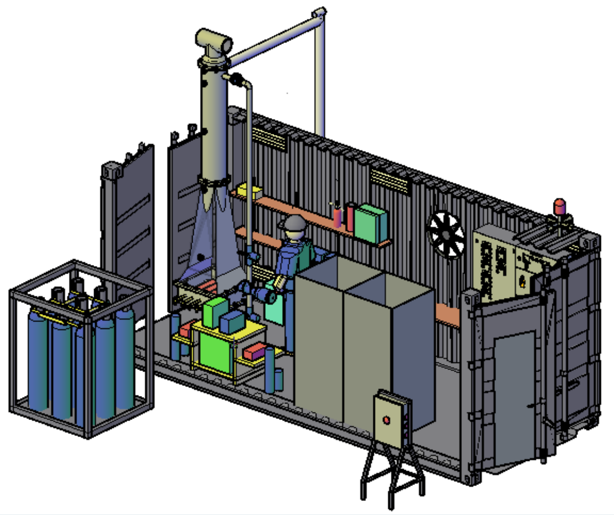


Power-to-protein project

Under the TKI Water Technology Programme

TOPSECTOR WATER & MARITIEM

KWR Watercycle Research Institute
Avecom Bioproducts & Apps
aeb amsterdam
BARENTZ
waternet
Waterkracht



Early 2016
Desk study

Late 2016
Pilot plant design and building

2018
Pilot test start on site of WWTP

co-financed with TKI-funding from the Topconsortia for Knowledge & Innovation (TKI's) of the Ministry of Economic Affairs

Power-to-protein pilot study

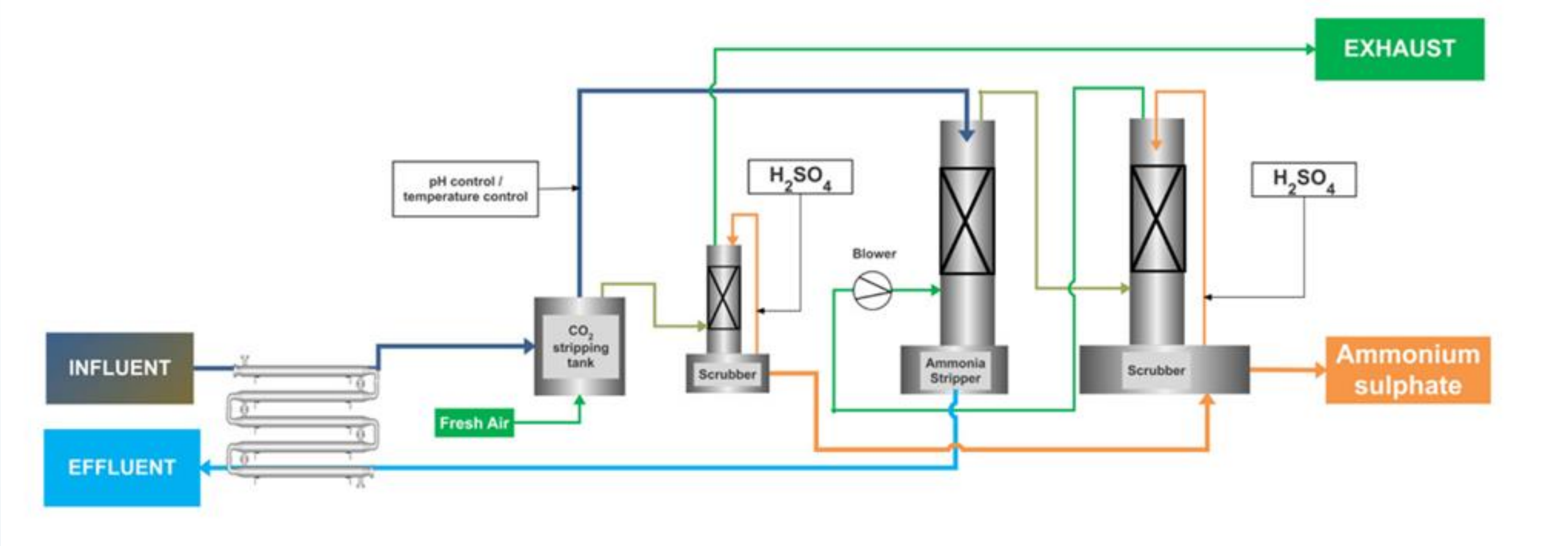
Upscaling from 5 to 400 liter reactor volume

- Ammonia recovery by air stripping (NAR pilot plant; Nijhuis Water Technology)
- H_2 and O_2 produced on site with water electrolysis
- Reactor volume 400 L
- Expected productivity of 1 to 2 kg dry biomass per day
- 2 testing sites

POWER-TO-PROTEIN REACTOR AT SWTP HORSTERMEER (AMSTERDAM)

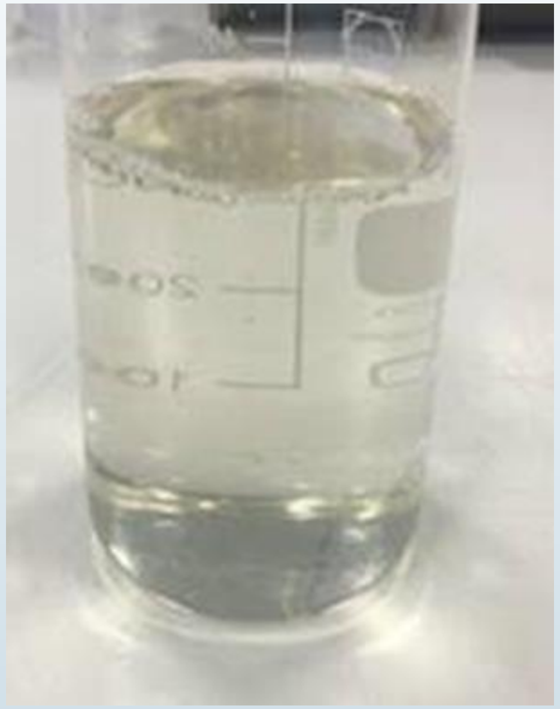
Power-to-protein pilot study

Ammonia recovery from reject water sludge digestion



SCHEME NIJHUIS AMMONIA RECOVER (NAR) PILOT

PRODUCED AMMONIA SULPHATE



Power-to-protein pilot study

Business case ammonia recovery from reject water

Parameter	Unit	Value
Average flow centrate	m^3/d	690
Maximum hydraulic capacity	m^3/d	850
Average NH4-N concentration	mg/l	1667
Required removal	%	90%
Effluent value NH4-N	mg/l	167
Temperature centrate	°C	25
Days per year running	days	365
Hours per day	hours	24

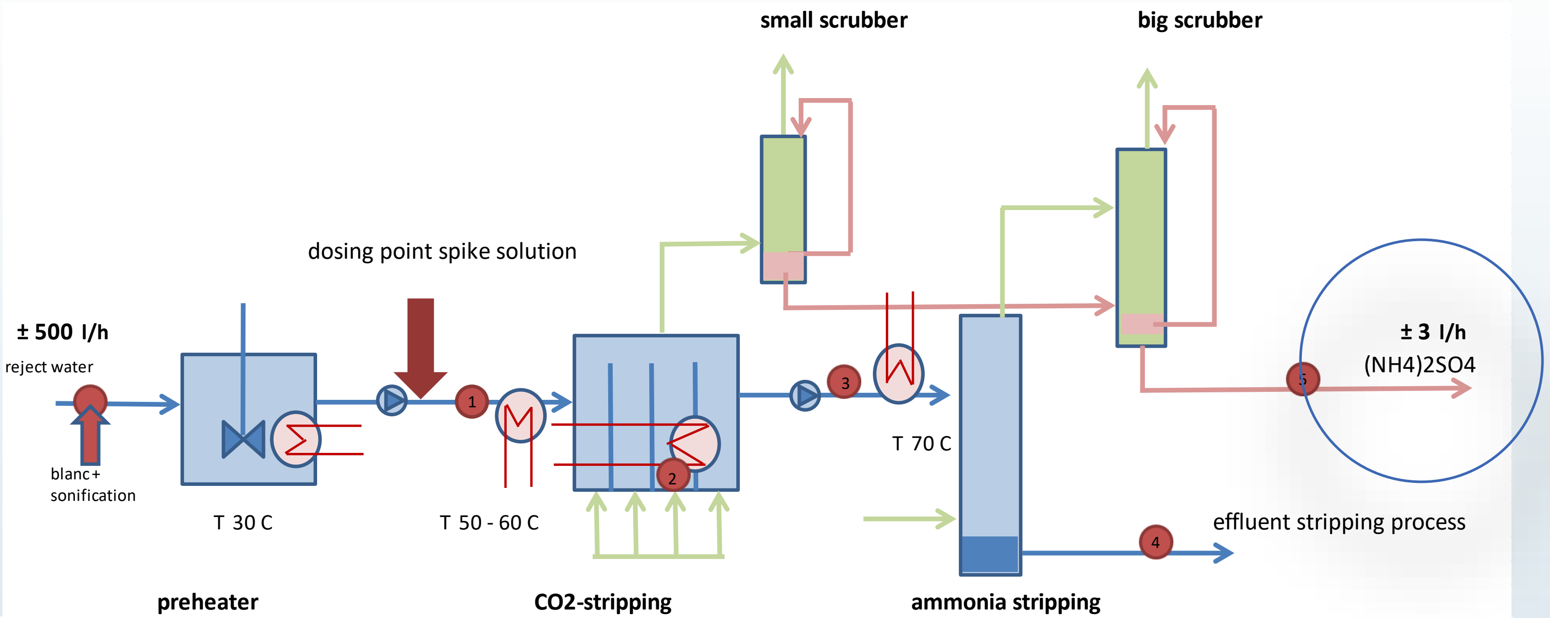
Cost can be further optimised by increasing the ammonia concentration in reject water.

E.g. at 2.500 mg/l costs will be reduced to €1,60 resp. €1,17 per kgN

Parameter	Unit	Case WB Vechtstromen	
Operational costs		Total costs	Costs per kgN
Electrical	€ or €/kgN	€ 19,100	€ 0.05
Heat	€ or €/kgN	€ 243,000	€ 0.64
H2SO4 (96%)	€ or €/kgN	€ 137,500	€ 0.36
NaOH (33%)	€ or €/kgN	€ 205,500	€ 0.54
Anti-foam	€ or €/kgN	€ -	€ -
Citric acid/HCl	€ or €/kgN	€ 10,500	€ 0.03
Maintenance	€ or €/kgN	€ 35,000	€ 0.09
Benefits Ammonium sulphate	€ or €/kgN	€ -47,000	€ -0.12
Total OPEX without residual heat	€ or €/kgN	€ 603,600	€ 1.60
Total OPEX with residual heat	€ or €/kgN	€ 360,600	€ 0.95
Investment costs			
Total investment	€ or €/kgN	€ 1,750,000	
Yearly costs CAPEX	€ or €/kgN	€ 220,000	€ 0.58
Total costs AECO-NAR per kg N recovered			
Total costs (no residual heat available)	€/KgN		**€ 2.18**
Total costs (residual heat available)	€/KgN		*€ 1.54*

Power-to-protein pilot study

Challenge tests Ammonia recovery from reject water sludge digestion



	Temperature [ºC]	Mean HRT [min]
Preheater + heater	35	30
Dosing point caustic		
CO_2-stripping + heater	50 - 60	300
Heater	65 - 75	1
Ammoniak stripping	65 - 75	1

Transfer of m.o. from reject water to ammonia sulphate

Challenge test by spiking:

- colifaag phiX174 (thermoresistent virus)
- Salmonella senftenberg
- spores of sulphite reducing clostridia (SSRC)

Inactivation/removal by:

- Combination of Heat + HRT
- Water to air transfer

Power-to-protein pilot study

Challenge tests Ammonia recovery from reject water

m.o. sensitive to T are inactivated to a large extent

m.o. not T sensitive are reduced substantially

Transfer of pathogens from the waste water chain is unlikely

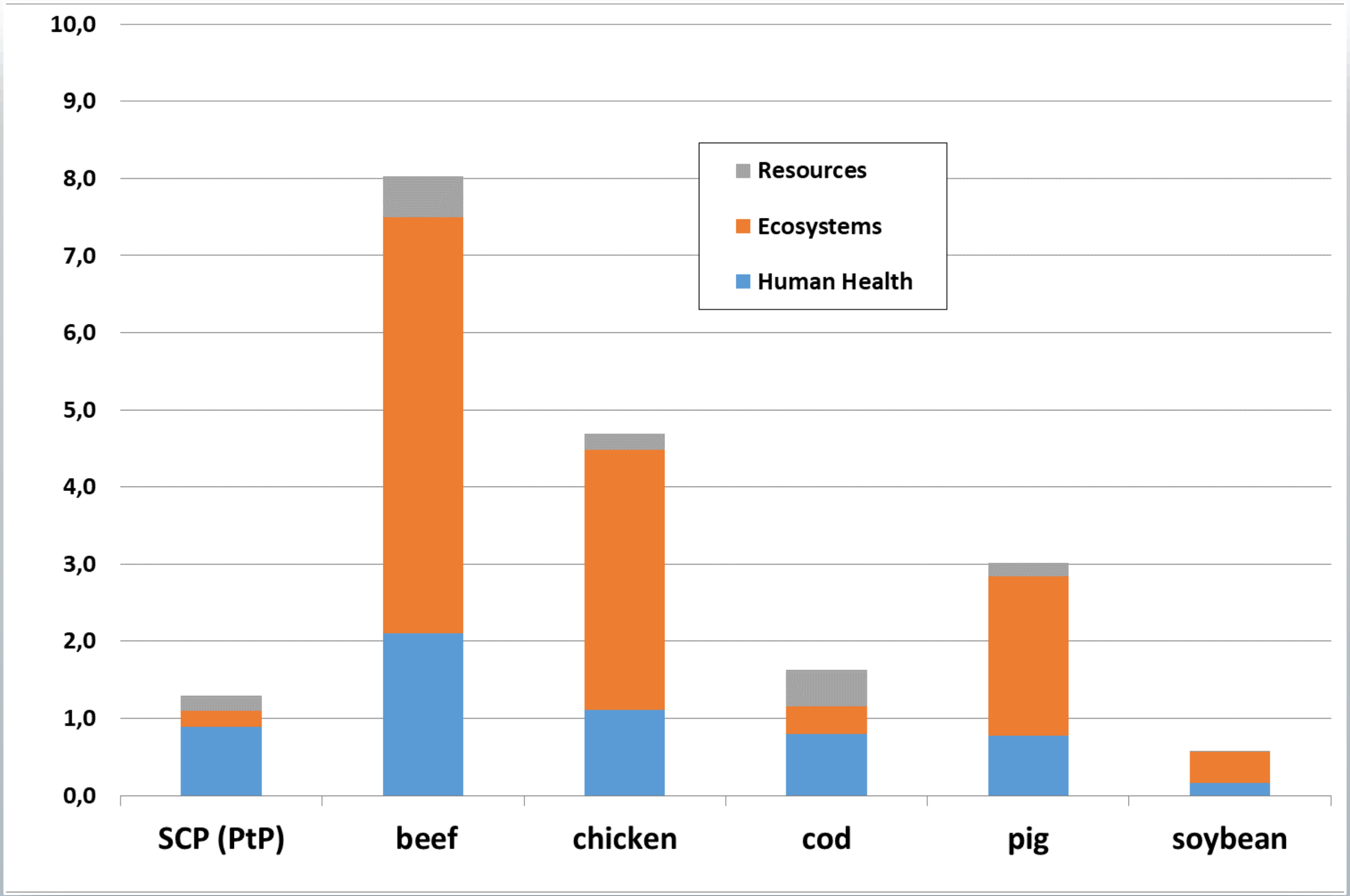
Thermoresistent bacterial spores will determine the shelf life of the product

Challengetest August 7 2018	Salmonella senf.	SSRC	colifaag phiX174
	MPN/l	cfu/l	pfu/l
Influent + spike	$7,8*10^7$	$8,4*10^6$	$7,7*10^6$
Effluent CO_2-stripping	< 0,6	$4,6*10^5$	$3,3*10^3$
$(NH_4)_2SO_4$ from scrubber	< 0,6	$1,7*10^3$	< 100
Log-removal			
after CO_2-stripping	> 8,1	1,3	3,4
after NH_4-stripping and scrubber	> 2,1	4,4	> 3,5
overall	> 10,1	5,7	> 6,9

Power-to-protein pilot study

LCA study

- SimaPro 8 EcoInvent 3.0 database
- Electricity from “off shore wind”
- Including ammonia recovery
- *Hydrogen uptake efficiency 80 %*
- *Reactor productivity 2 kg TSS/m³.day*



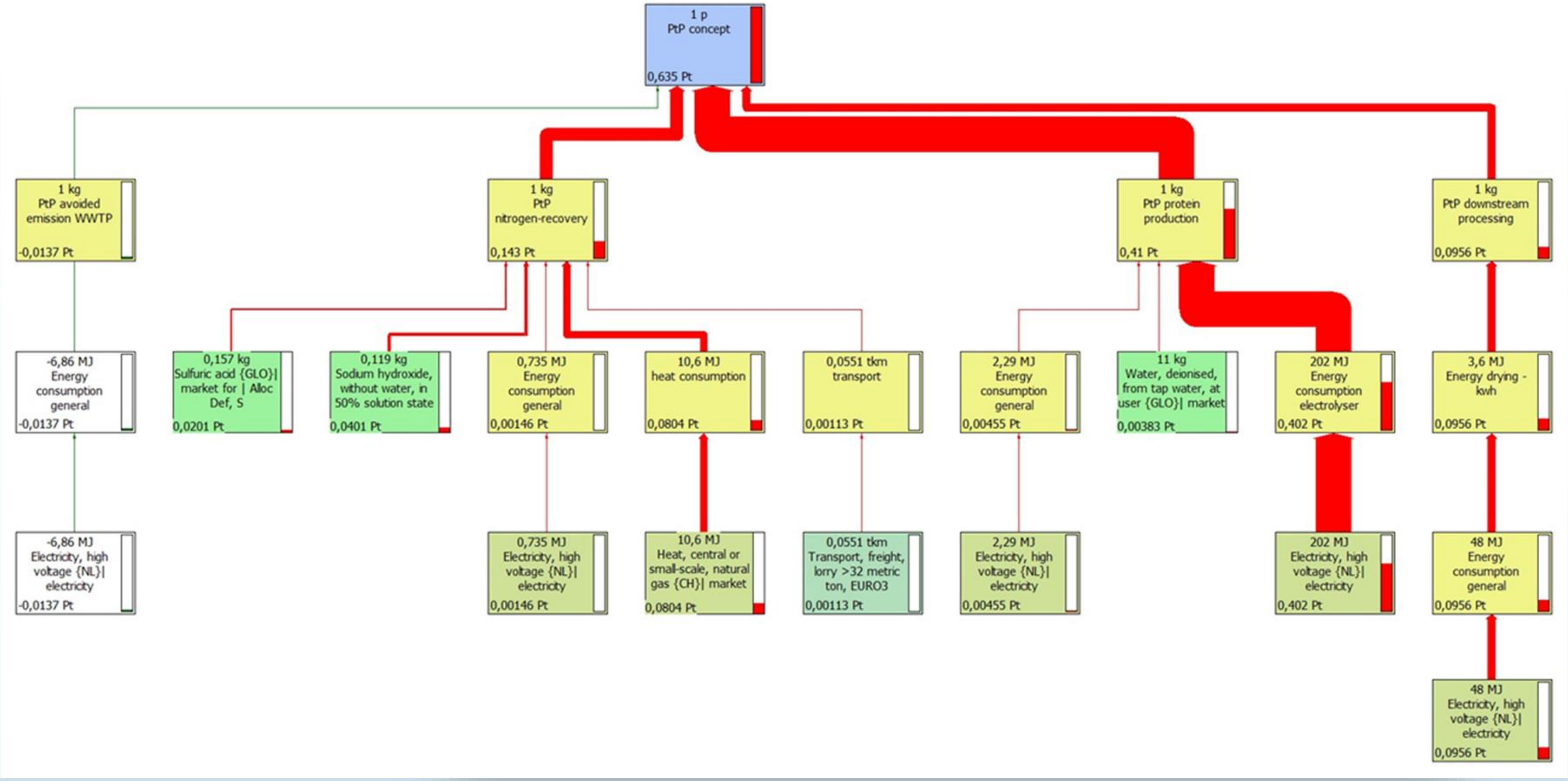
NUMBER OF ECOPOINTS PER KG PROTEIN FOR SCP AND CONVENTIONAL PROTEINS

Power-to-protein pilot study

LCA study

Tree structure LCA

Impact per unit operation



Power-to-Protein pilot study

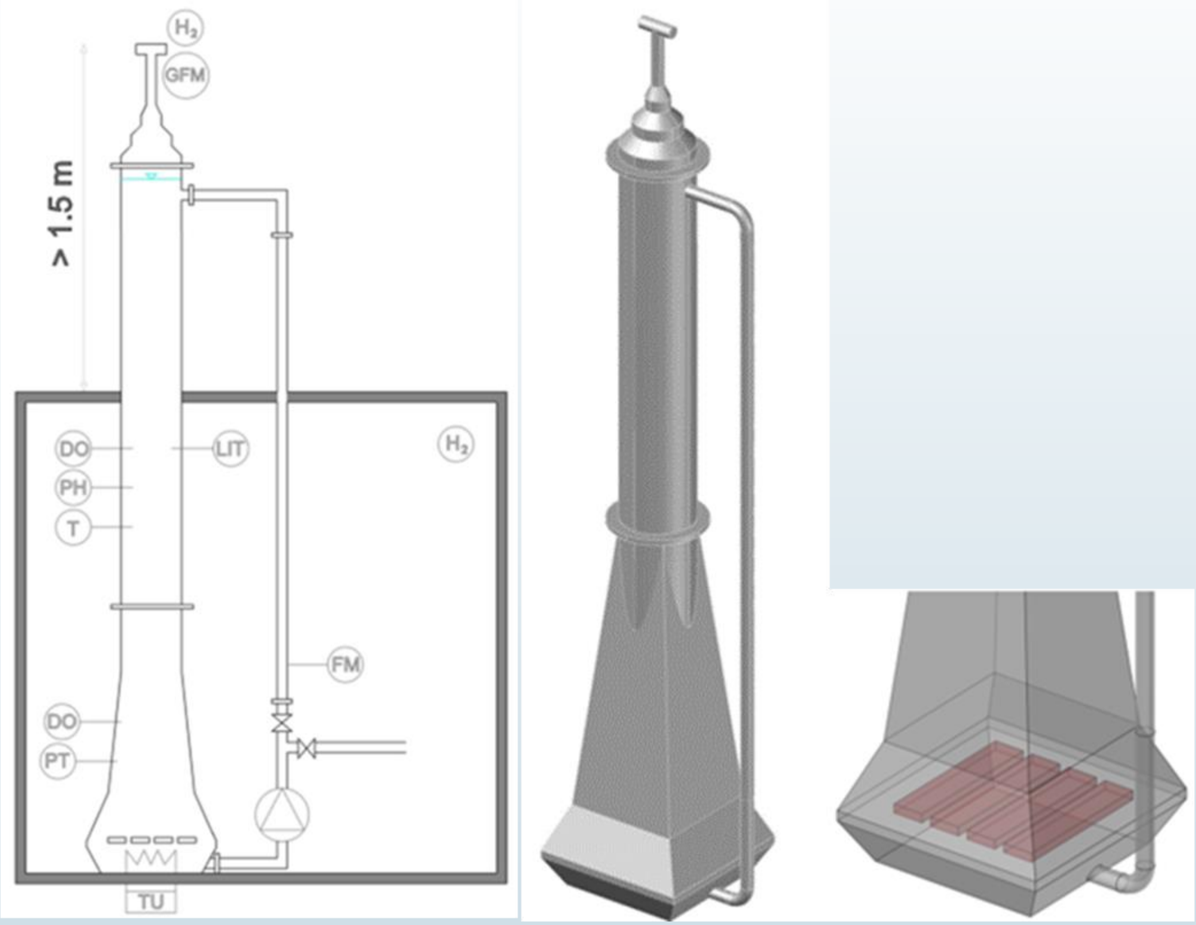
Hydrogen transfer in pilot was bottle-neck

Production goal was not reached

Pilot	*CSTR 5 liter bench scale*
Max. production = 0,7 kg CDW/m^3.day	(*9,0*)
Max. Yield = 0,05 kg CDW/kg COD-H_2	(*0,28*)
Max. hydrogen conversion = 10 %	(81 %)

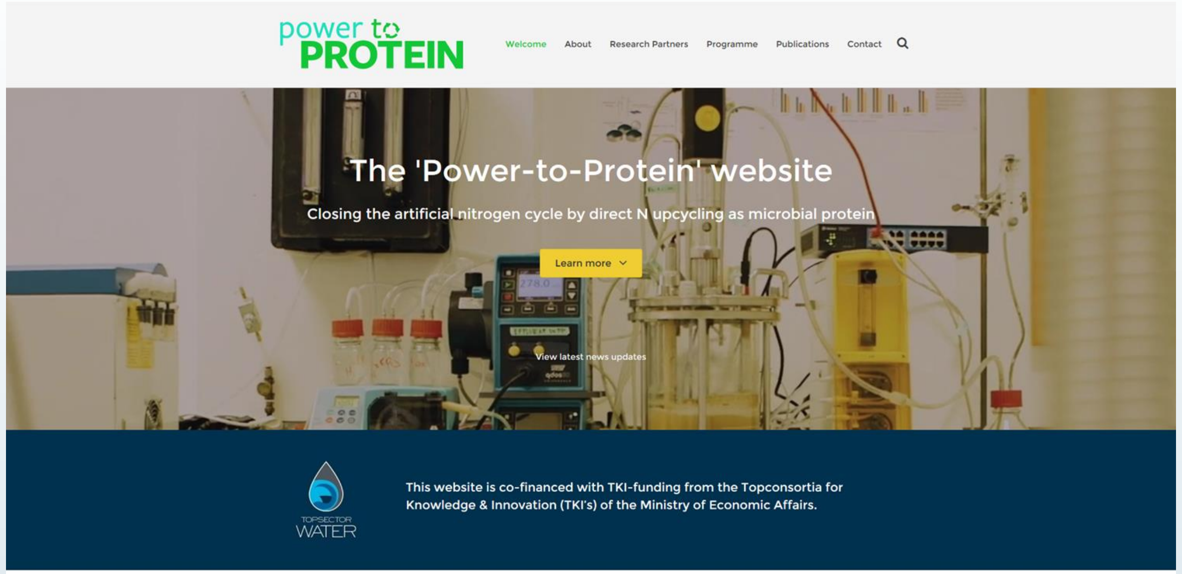
Research on fundamentals hydrogen mass transfer in biological reactors

Focus on pressurized bubble reactor or air-lift reactor



Acknowledgement

See www.powertoprotein.eu for more info



Project partners:

Waternet

AEB

Waterschap Vechtstromen

Barentz Foods

Avecom

KWR

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