Innovative food processing supporting sustainable food systems

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EcoFood Lab

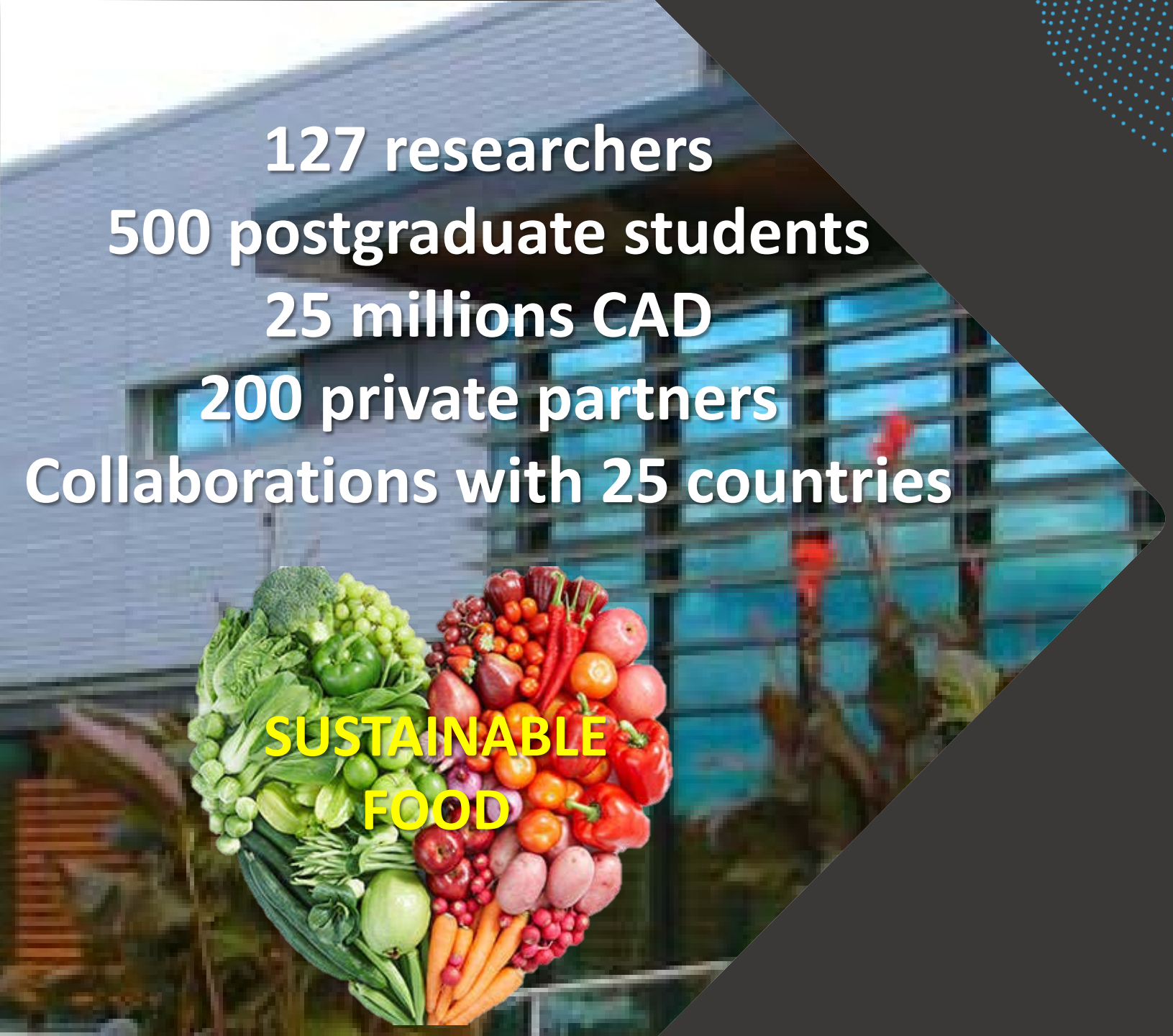
UNIVERSITÉ LAVAL
DÉPARTEMENT DES SCIENCES DES ALIMENTS

INAF
INSTITUT SUR LA NUTRITION ET LES ALIMENTS FONCTIONNELS

STELA
CENTRE DE RECHERCHE EN SCIENCES ET TECHNOLOGIE DU LAIT

GastronomiQc Lab


EcoFood Lab
UNIVERSITÉ LAVAL
Food Science Department
INAF
Institute of Nutrition and Functional Foods
STELA
Dairy research center STELA
GastronomiQc Lab
Univrsité Laval - ITHQ
LAAN
Univrsité Laval – Université de Lille



INAF

127 researchers
500 postgraduate students
25 millions CAD
200 private partners
Collaborations with 25 countries

SUSTAINABLE FOOD

Université Laval
Université de Montréal
McGill
TransBIOTech
UQAR
Université du Québec
Institut national de la recherche scientifique
INRS-Institut Armand-Frappier
Agriculture et Agroalimentaire Canada
Agriculture and Agri-Food Canada
Université de Sherbrooke
UQÀM
Cégep de la Gaspésie et des Îles
Collège de Maisonneuve
cégep lévis
UQTR
Université du Québec à Trois-Rivières
HEC Montréal
ITHQ
Cégep de Saint-Hyacinthe

Sustainable development

NEEDS

SD is development that meets the needs of the present without compromising the ability of future generations to meet their own needs

United Nations

Global population

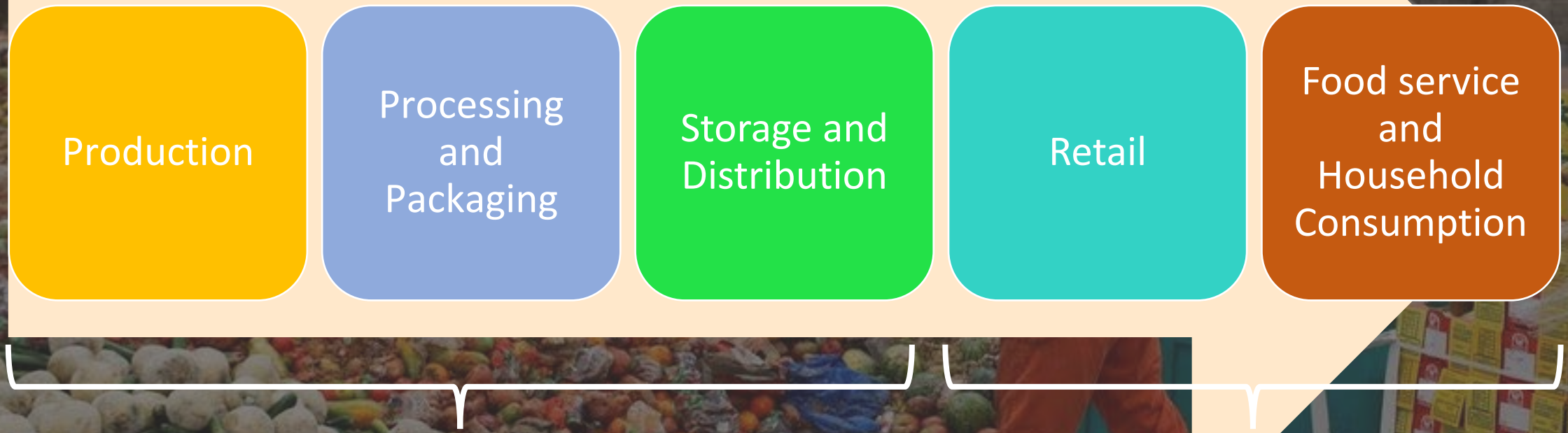
year	1950	1975	2000	2025	2030	2050
population (in billion)	2,6	4,0	6,0	8,2	8,5	9,7

Agro-food industry

50% increase in global food demand by 2050

FAO, 2017

Agro-food industry



FOOD LOSSES

14%

FAO, 2019

FOOD WASTE

18%

UNEP, 2021

3.3 billion tons of produced food

Health issues

~800 million people are affected by hunger

2 billion people have different nutrient deficiencies

More than 1.9 billion adults, 18 years and older, are overweight. Of these over 650 million are obese

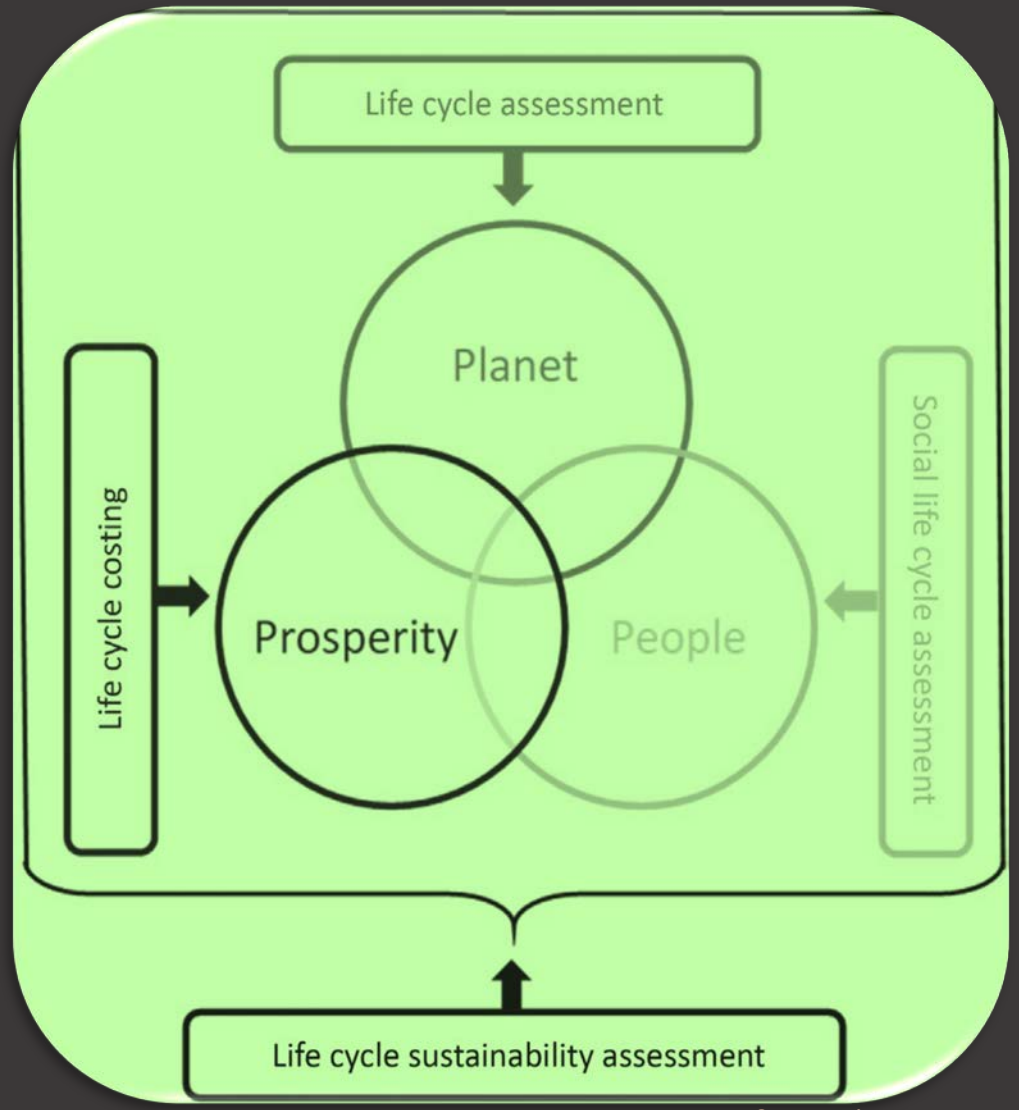
Socioeconomic costs (USD 3.5 trillion per year)

FAO and WHO, 2019, FAO, 2017

9.7 billion people

Expansion of conventional food production lines and infrastructure

Sustainable development



Ren & Toniola, 2020

Sustainable development

LCA

environmental impacts associated with a product, process, or activity

LCC

costs expended from product conception and production, through its operation, to the end of its useful life

S-LCA

addresses the social impacts of products and services along their life cycle

Maturity levels and data availability of life cycle approaches (x-axis: progress/development)

Valdivia et al. 2021

Sustainable development

ECO-EFFICIENCY

Eco-efficiency

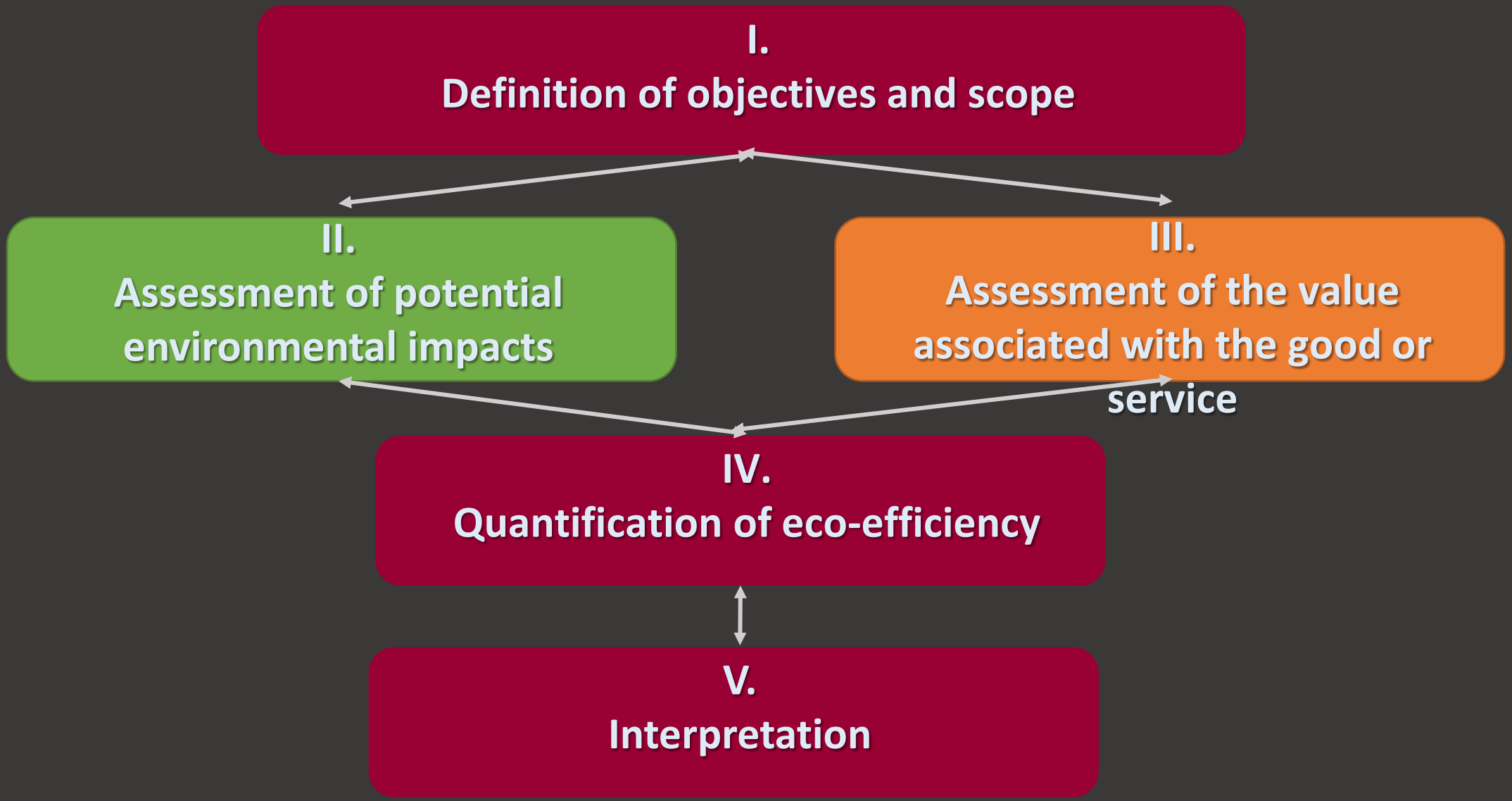
1990 – Introduction - Schaltegger & Sturm. Öologische Rationalität (Environmental rationality).

1992 – Popularization - World Business Council for Sustainable Development (WBCSD) at the United Nations Conference on Environment and Development (Earth Summit or Rio Conference).

unmultimedia.org

2012 – Standardization – ISO 14045

Eco-efficiency



ISO 14045-2012

Environmental impact

Energy consumtion, water uptake, consumtion of chemicals, etc.

GHG emissions, human health, ecosystem quality, etc.

Environmental impact

ECOSPHERE






RELATIONS

TECHNOSPHERE




GOAL and SCOPE

LIFE CYCLE INVENTORY ASSESSMENT

Environmental impact

LIFE CYCLE INVENTORY ASSESSMENT

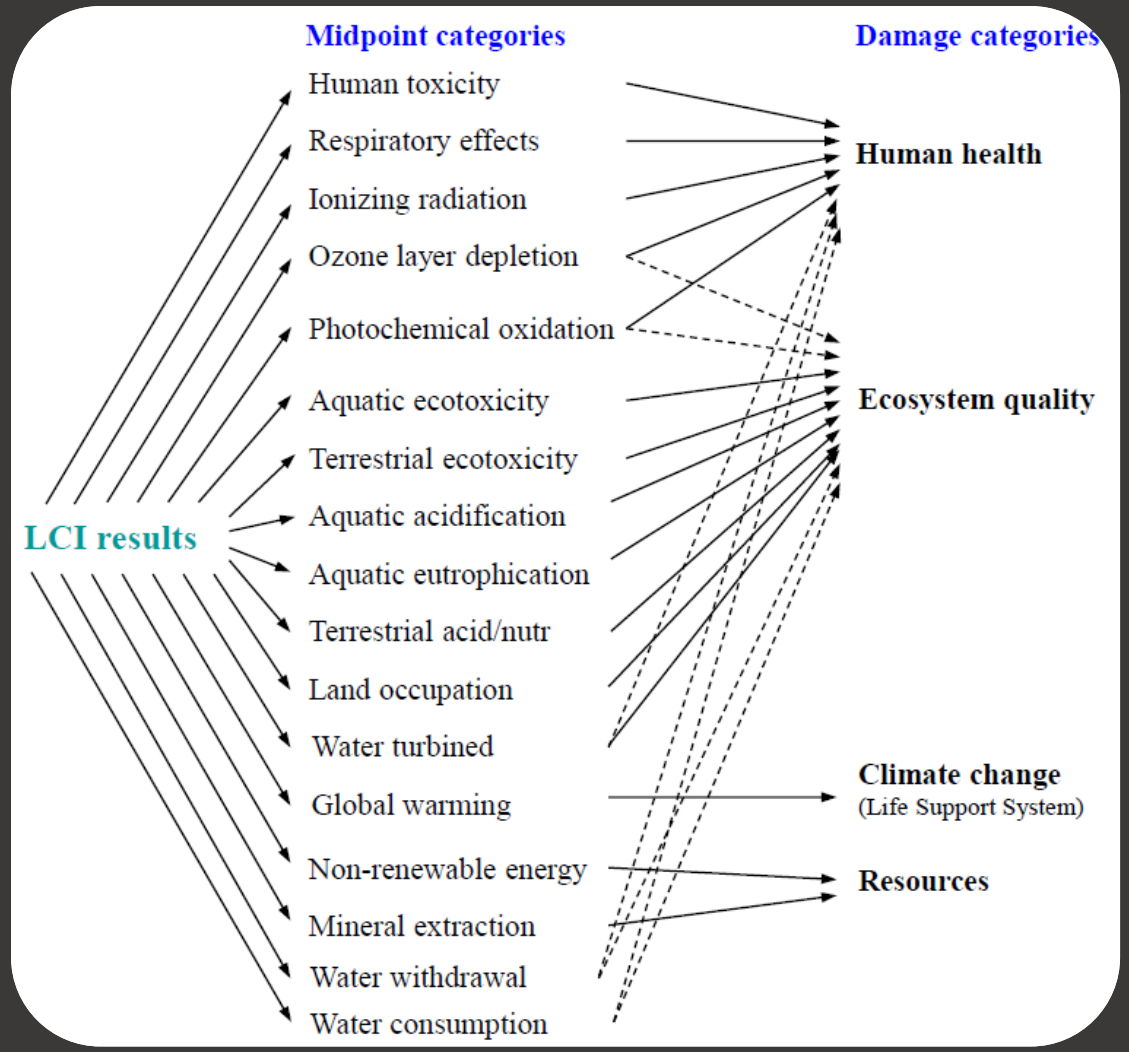
Table 1. Input and output flows for dairy processing in Canada, in 2006

Item	Unit	Amount	Source
Milk production and hauling			
Raw milk production, at farm	L	7,410,083,200	Dairyinfo, 2011
Loss at farm and during hauling	%	0.9	Calculated from balance
Average hauling distance	km	176.4	FPLQ, 2007
Average volume per haul	L	16,934	FPLQ, 2007
Dairy processing input			
Raw milk[1]	L	7,392,032,100	Dairyinfo, 2011
Electricity	MWh	916,148	CIEEDAC, 2010
Natural gas	TJ	6,418	CIEEDAC, 2010
Heavy fuel oil	TJ	213.2	CIEEDAC, 2010
Middle distillates	TJ	225.2	CIEEDAC, 2010
Propane	TJ	4.1	CIEEDAC, 2010
Water use	kg/kg of raw milk	1.5	Kershaw and Gaffel, 2008
Sodium hydroxide	mg/kg of raw milk	897	Kershaw and Gaffel, 2008
Nitric acid	mg/kg of raw milk	285	Kershaw and Gaffel, 2008
Sulfuric acid	mg/kg of raw milk	436	Kershaw and Gaffel, 2008
Phosphoric acid	mg/kg of raw milk	63	Kershaw and Gaffel, 2008
Refrigerant make-up (HCFC-22)	mg/kg of raw milk	7.13E-04	Nutter et al., 2009
Dairy processing output			
Cheese	kt	547.8	Dairyinfo, 2011
Cottage	kt	27.8	Dairyinfo, 2011
Creams	kt	238.7	Dairyinfo, 2011
Sour cream	kt	46.0	Dairyinfo, 2011
Yogurt	kt	243.6	Dairyinfo, 2011
Fluid milks	kt	2,809.3	Dairyinfo, 2011
Buttermilk	kt	14.1	Dairyinfo, 2011
Frozen dairy products	kt	237.0	Dairyinfo, 2011
Powders	kt	102.2	Dairyinfo, 2011
Concentrated milks	kt	45.8	Dairyinfo, 2011
Butter	kt	78.8	Dairyinfo, 2011
Wastewater	kg/kg of raw milk	1.7	Kershaw and Gaffel, 2008
Refrigerant (HCFC-22)	mg/kg of raw milk	7.13E-04	Nutter et al., 2009

[1]Raw milk at 3.7% fat; specific gravity: 1.031 kg/L.

Environmental impact

LIFE CYCLE IMPACT ASSESSMENT



Environemental impact

Impact par étapes du cycle de vie

Agriculture	84.2 %
Transformation	9.9 %
Emballage	2.1 %
Transport	2.2 %
Supermarché et distribution	1 %
Consommation	0.2 %

Agribalyse 3.1

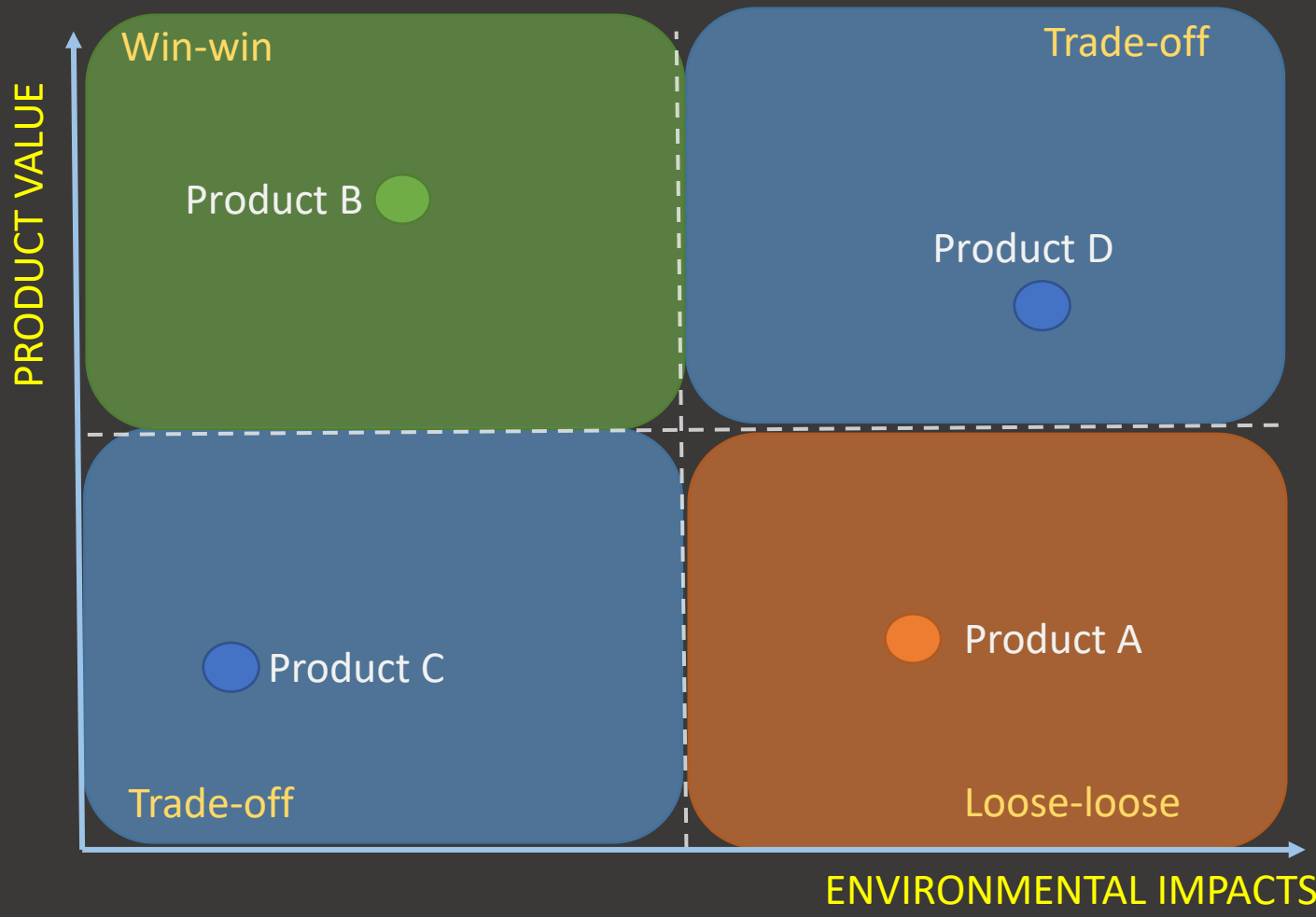
Value assessment

Monetary value (net profit, production cost),
Physical value (units or volume of production)

Functional value (nutritional quality, health benefit effects)
Aesthetic value (product appearance)

Eco-efficiency

$$Eco\text{-}efficiency = \frac{Value\ of\ the\ product\ or\ service}{Environmental\ impacts}$$



Sustainable development

Production

Processing and Packaging

Storage and Distribution

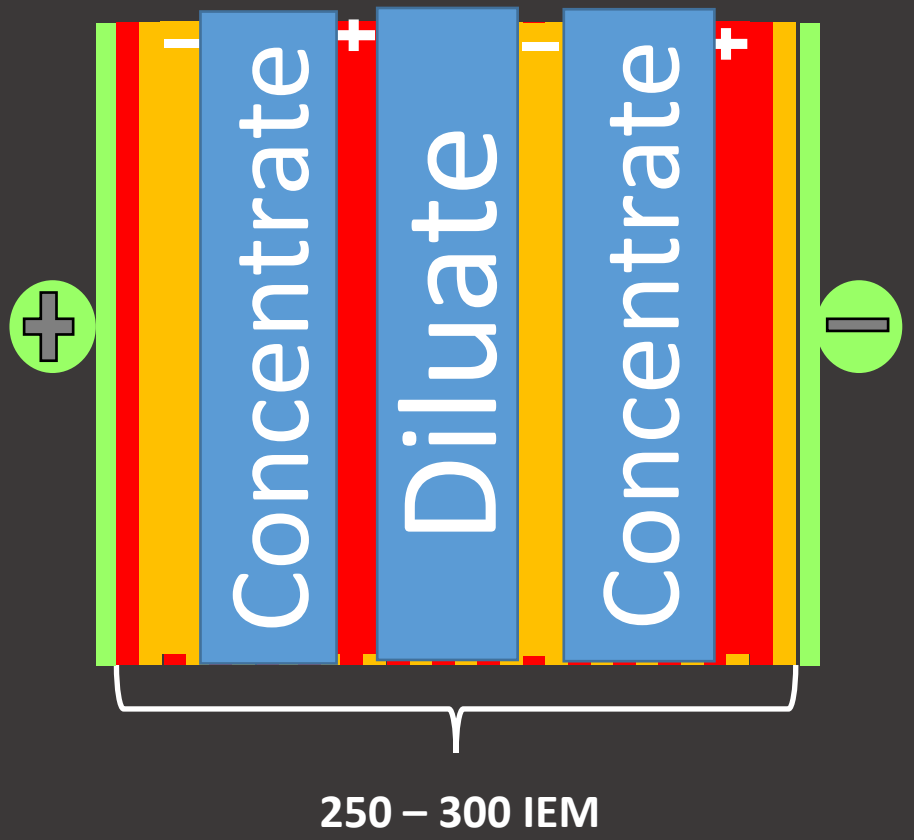
Retail

Food service and Household Consumption

Technological innovation

NEEDS ***IMPACTS***

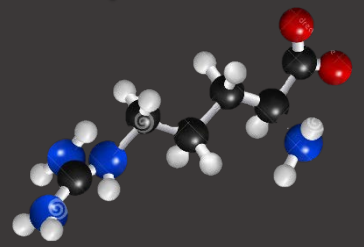
Electrodialysis



- Purification

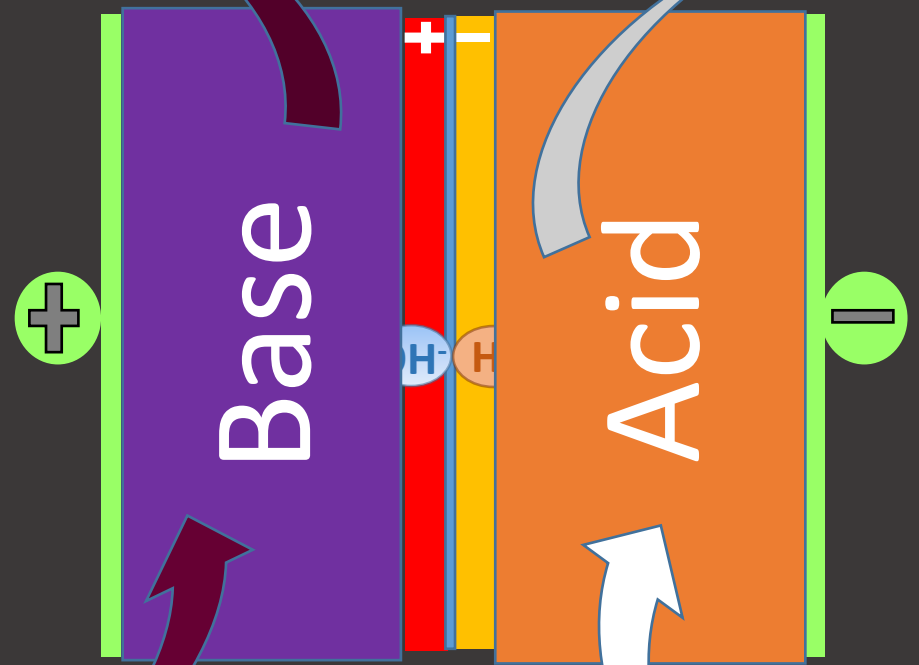
- Concentration

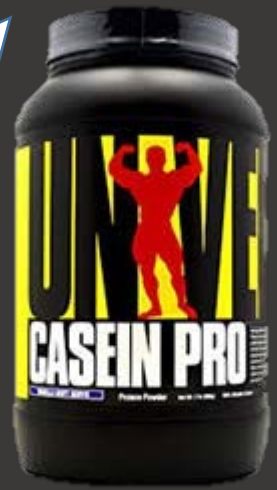
- Separation



- Modification

Electrodialysis



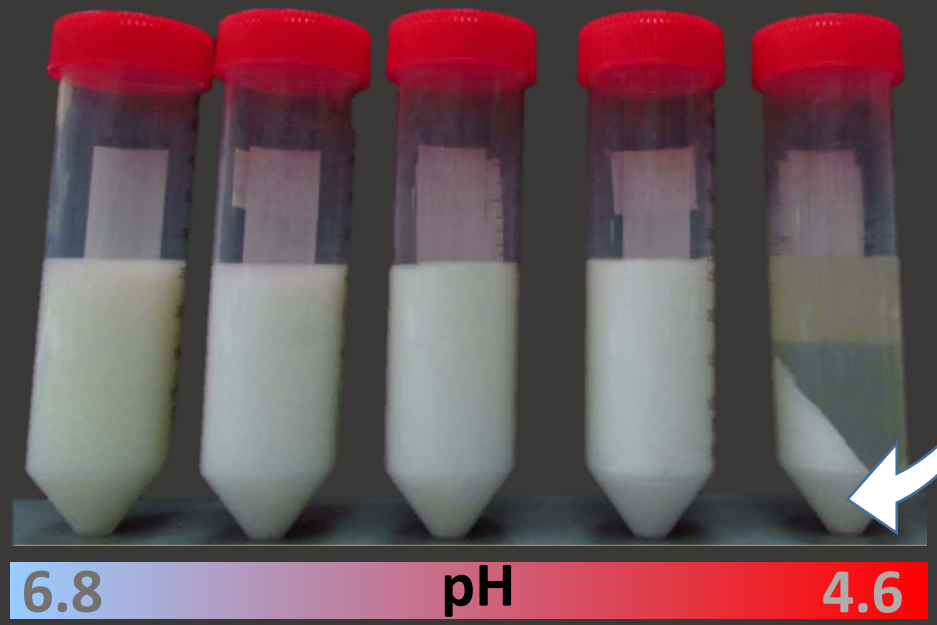


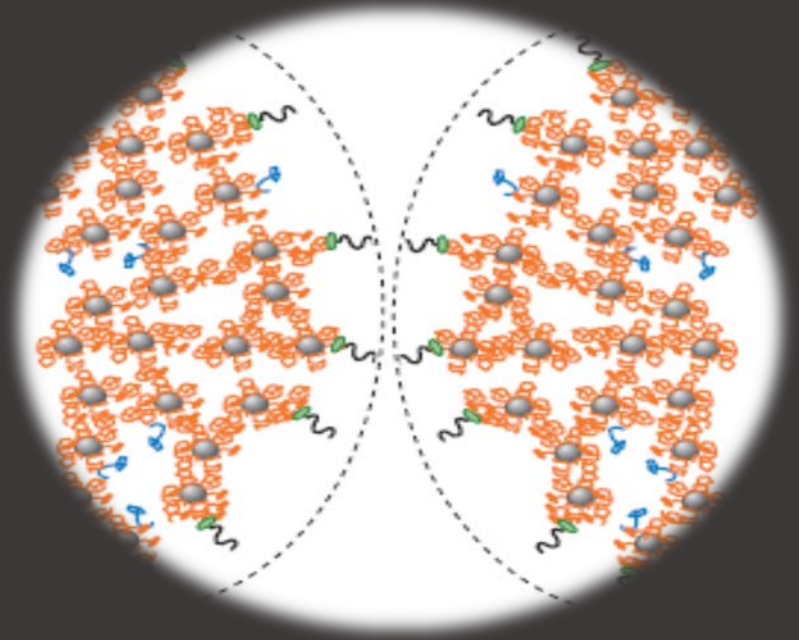
M.Fidaelio et al. (2006), Bazinet et al. (2004)

Electrodialysis

$Cas^- + Enz. \rightarrow Cas + GMP$

$Cas^- + H^+ \rightarrow CasH^0$

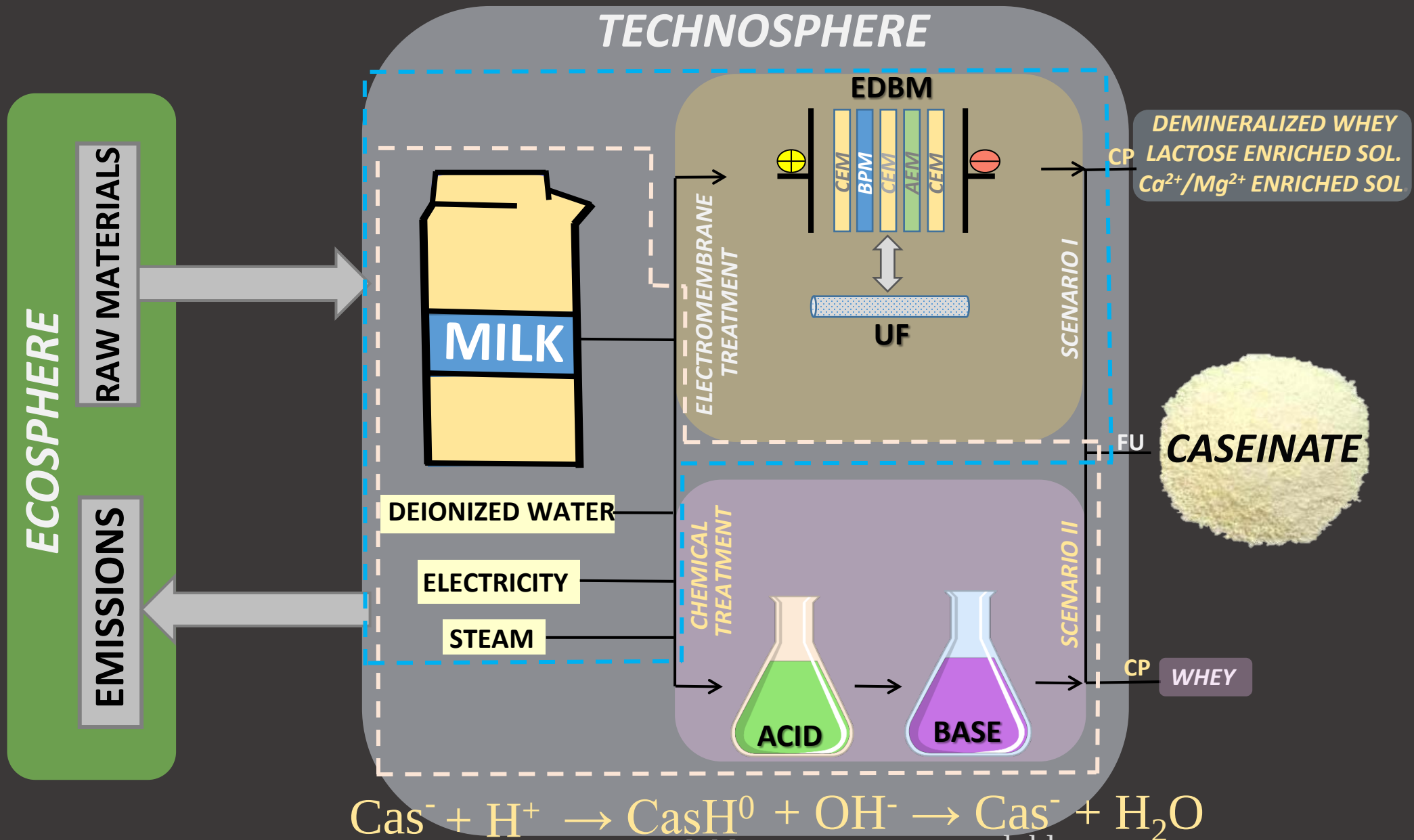




- Inorganic acid
- Lactobacteria
- Electrodialysis

PEM ECO

Electrodialysis

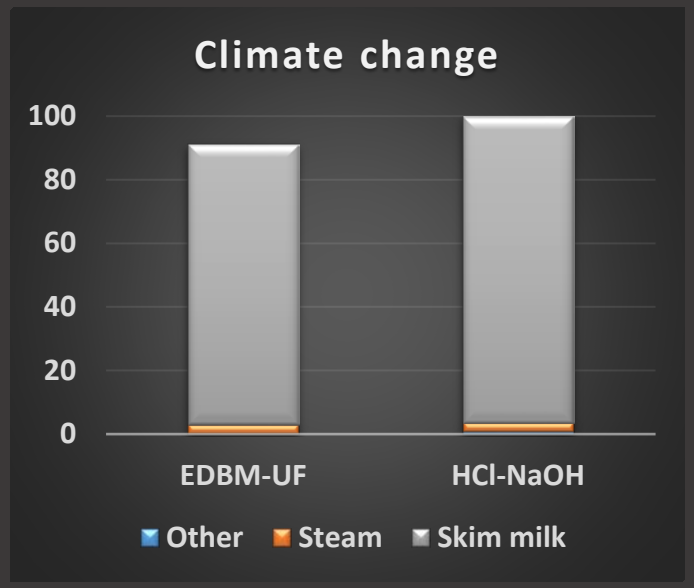


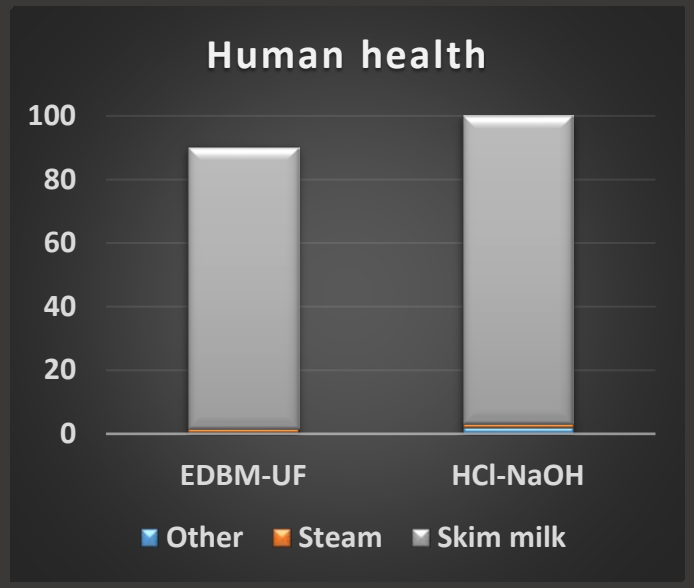
Laurent Bazinet

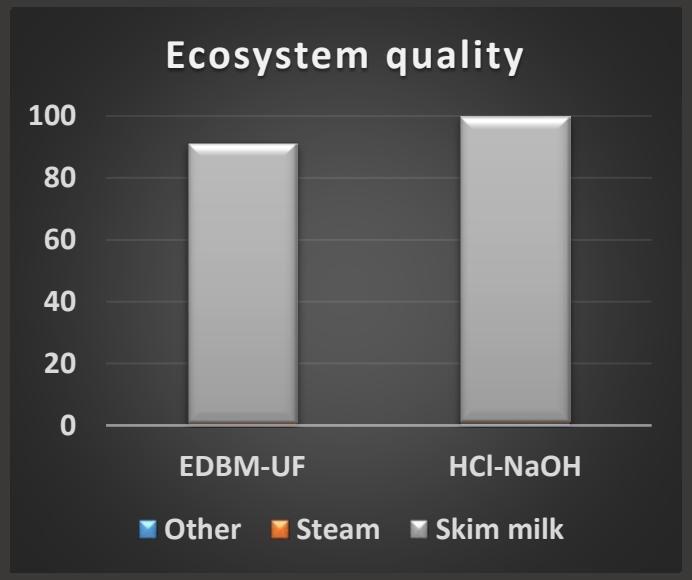
Rosie Deschênes Gagnon

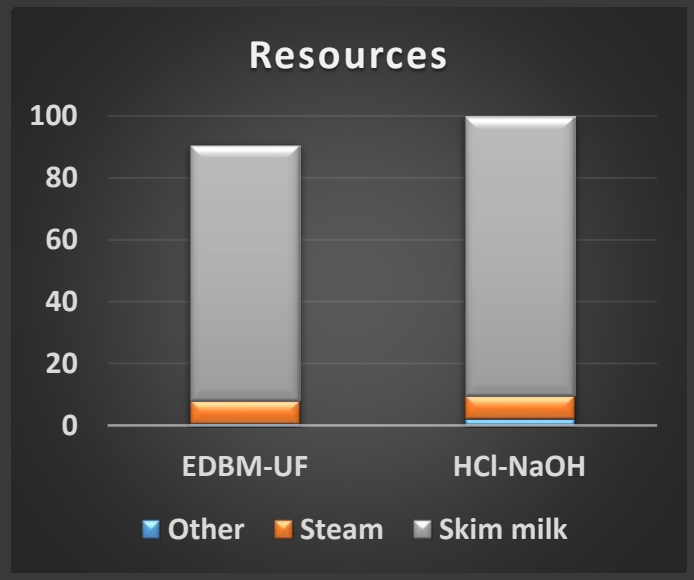
$$Cas^- + H^+ \rightarrow \underset{\text{insoluble}}{CasH^0} + OH^- \rightarrow \underset{\text{soluble}}{Cas^-} + H_2O$$

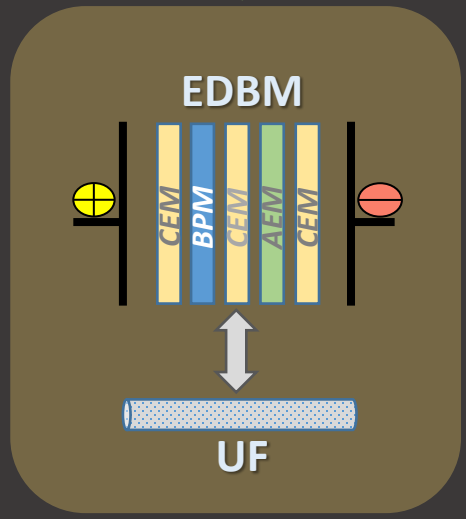
Electrodialysis

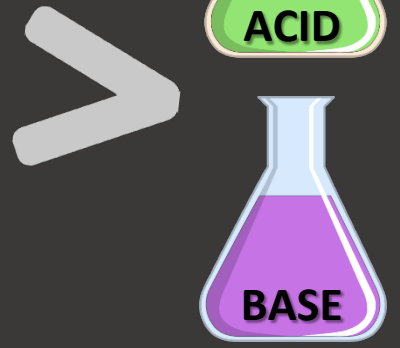












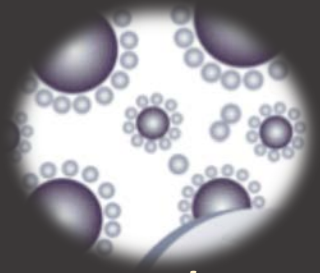
Mikhaylin et al. Green Chemistry, 2018

Eco-efficiency

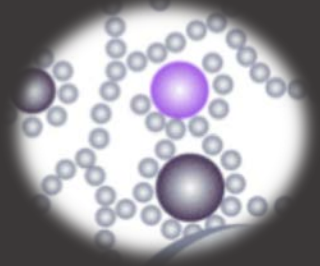
Caseinate value

Production costs ?

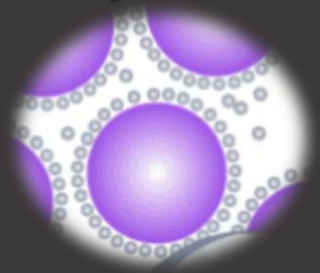
emulsion



gel



foam

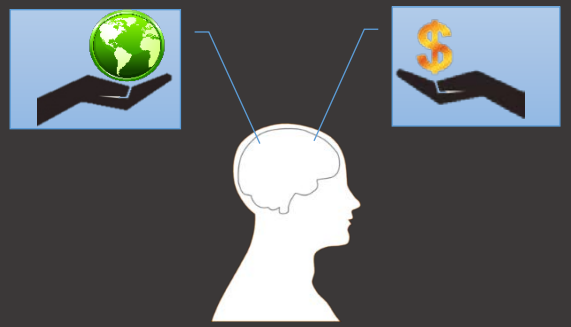


hygroscopicity

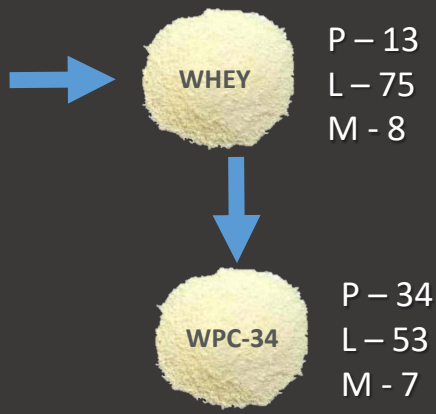
Chemical		EDBM-UF
	=	
	=	
	< 4 X More stable	
	1.2 X >	

Deschênes Gagnon et al., 2022

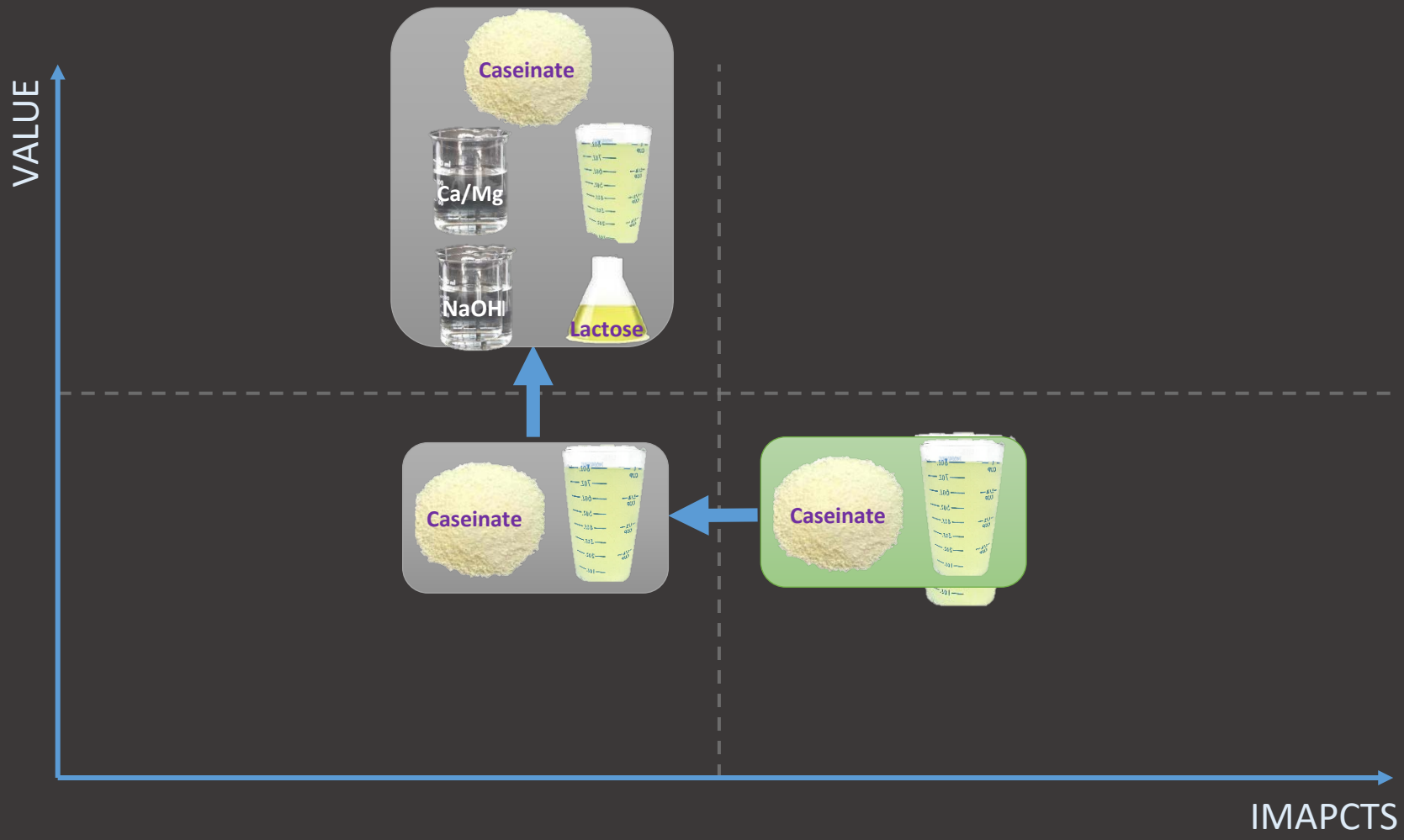
Eco-efficiency



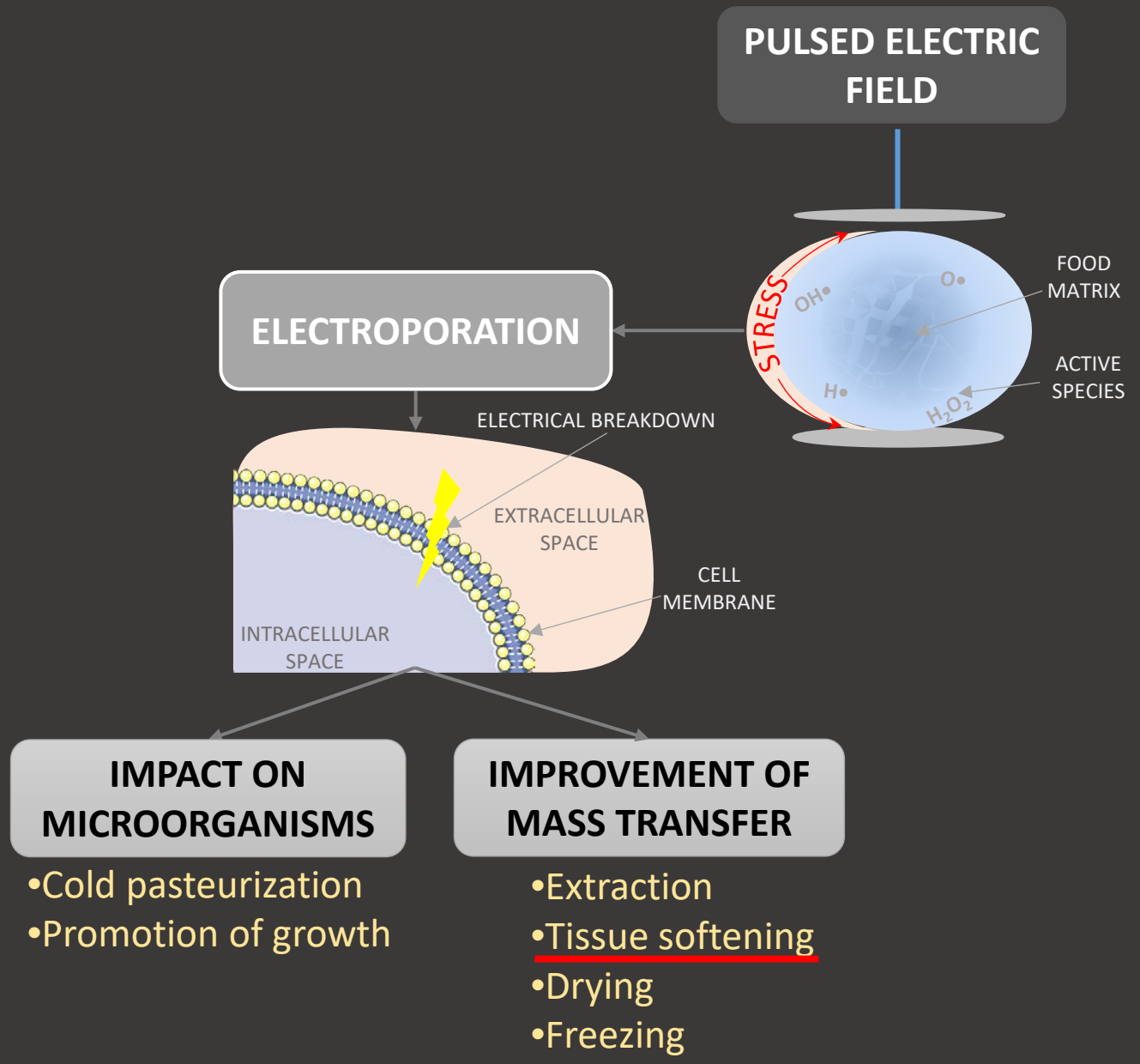
1100 $US/ton



2700 $US/ton

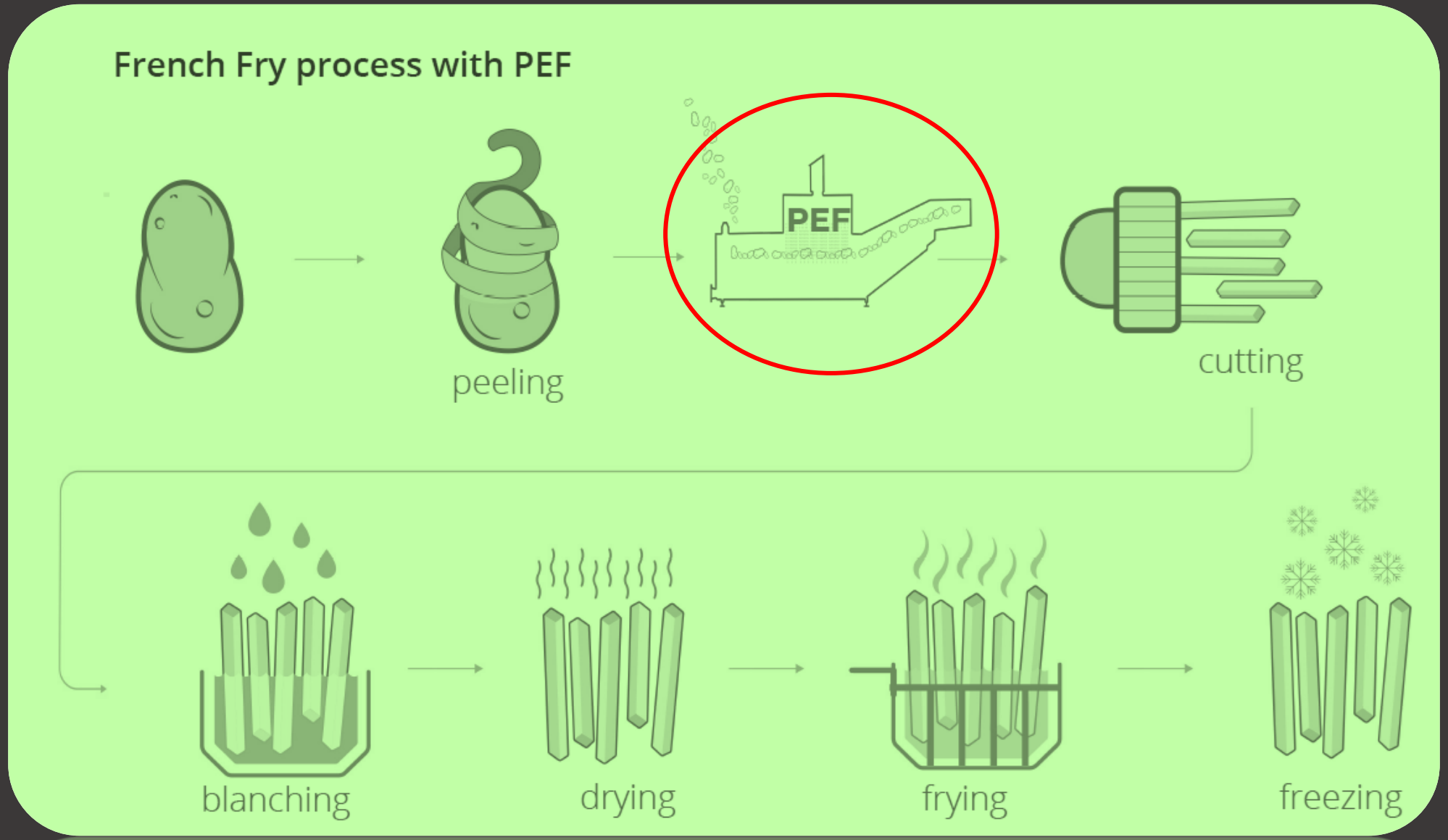


Pulsed Electric Field

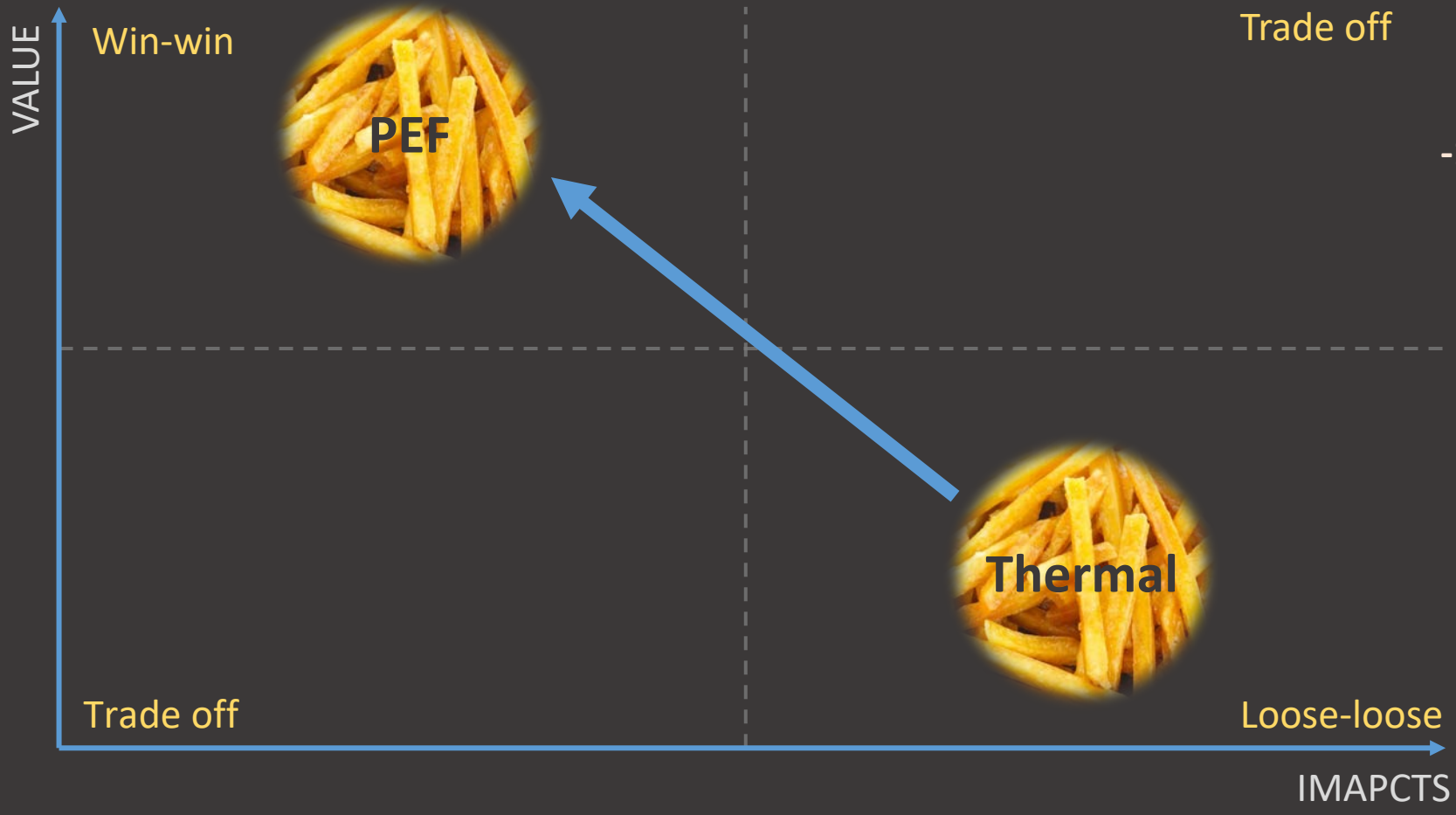


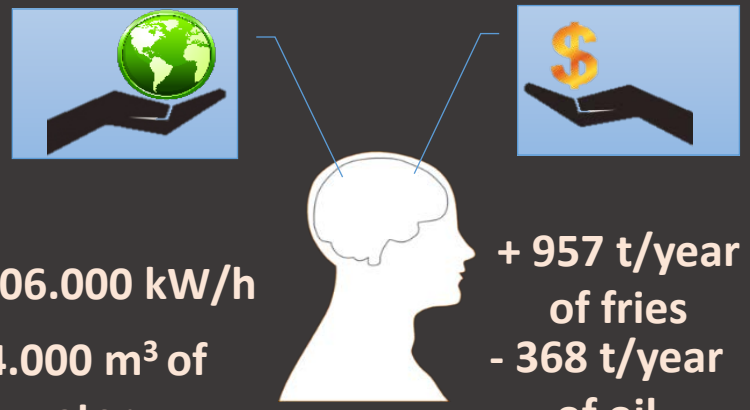
elea

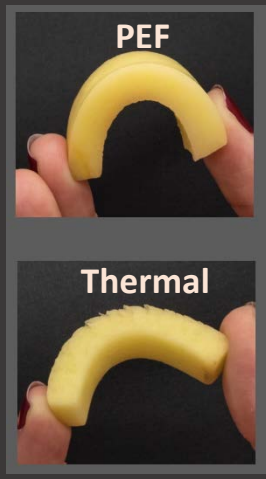
Pulsed Electric Field



Eco-efficiency







Less breakage

Smoother cut (less feathering)

Reduced oil uptake

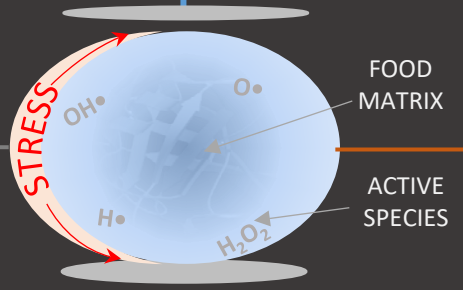
Even colour

Longer fries

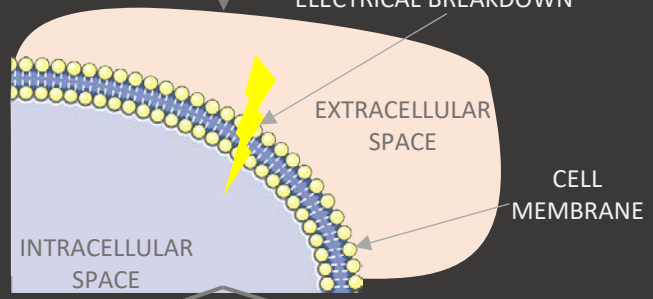
26 t/h raw material French fries (FF)
7.700 production hours per year

elea

PULSED ELECTRIC FIELD



ELECTROPORATION



INACTIVATION OF MICROORGANISMS

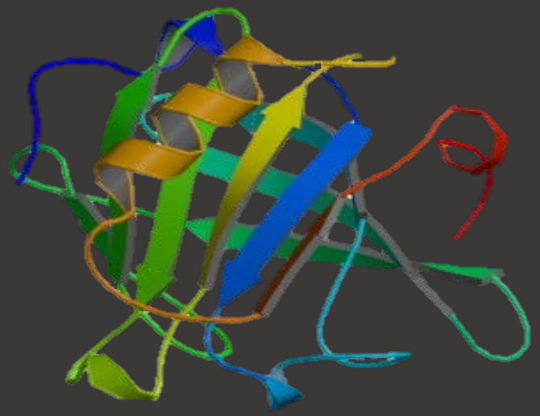
- Cold pasteurization

IMPROVEMENT OF MASS TRANSFER

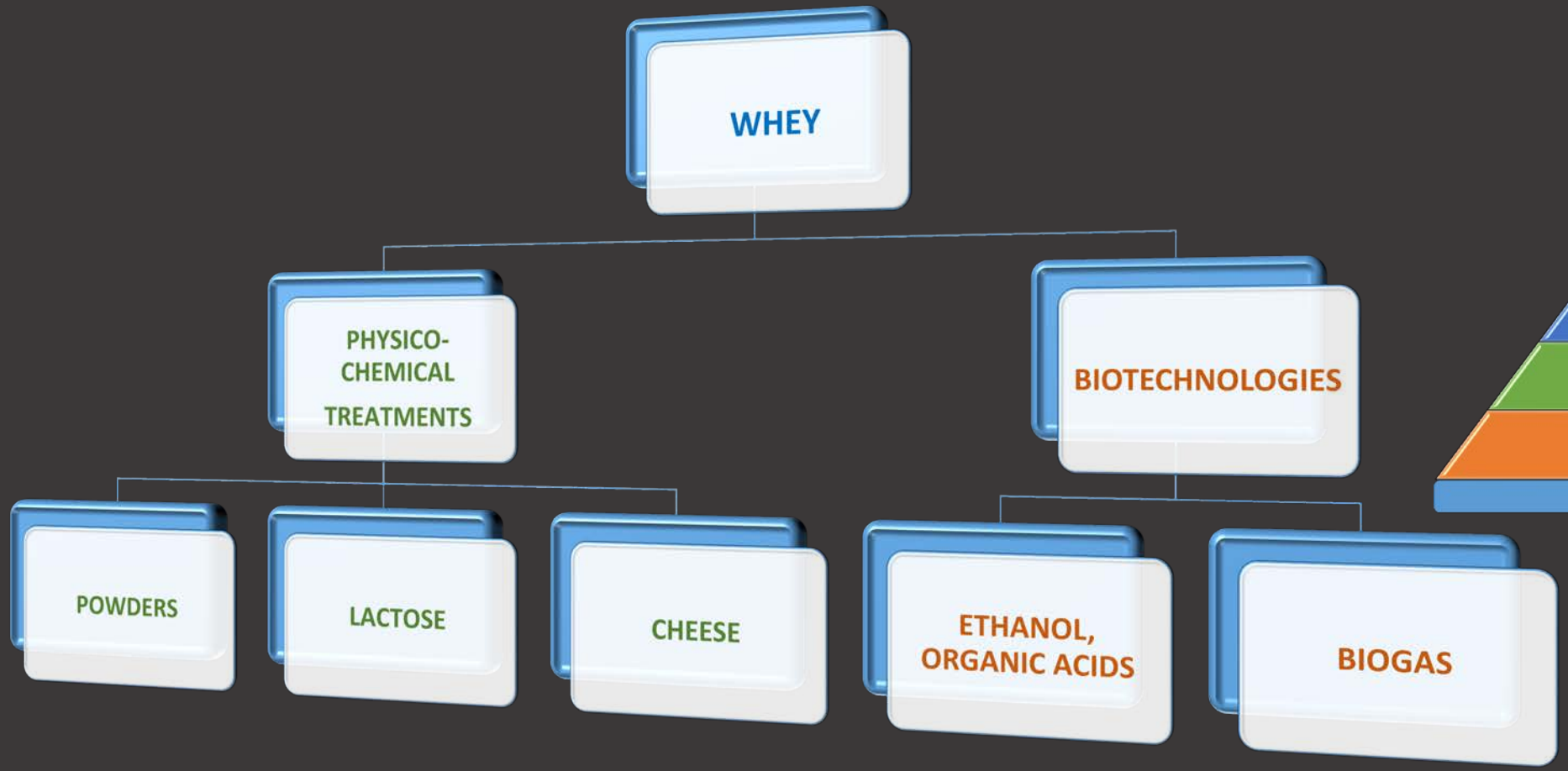
- Extraction
- Tissue softening
- Drying
- Freezing

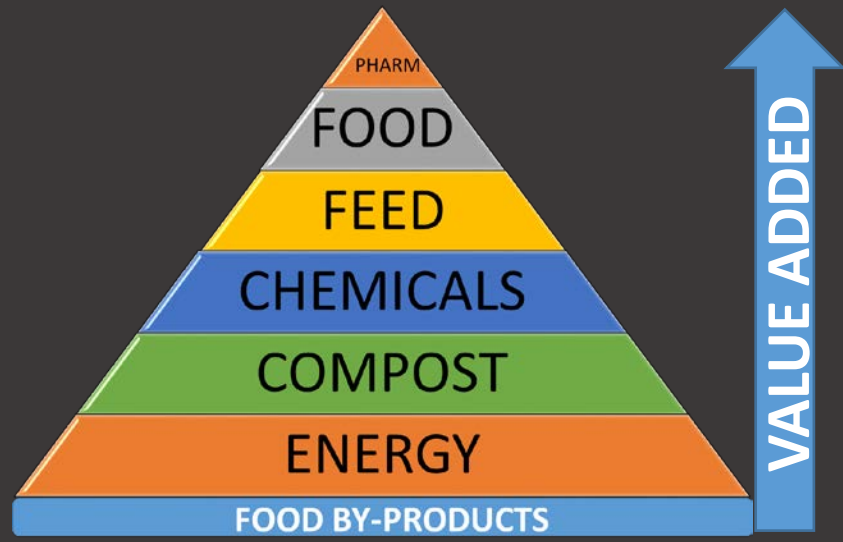
Influence on the structure and properties of food constituents

- Functionality improvement
- Reduction of allergenicity
- Improvement of interactions with other molecules



PROTEINS





Asveld et al. 2011.

ENZYMATIC HYDROLYSIS OF PROTEINS

Market demand for whey protein hydrolysate was estimated at more than 302 million USD in 2018

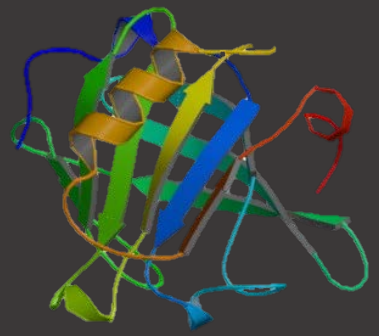
Global Market Insights, Inc.

Infant formula

Sport nutrition

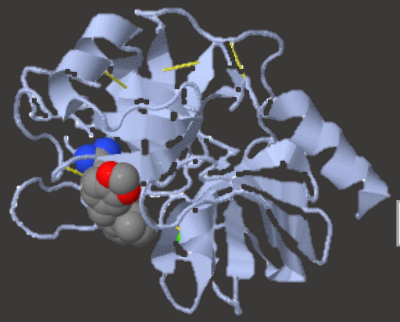
↑EFFICIENCY

HIGH VOLTAGE ELECTRICAL TREATMENTS

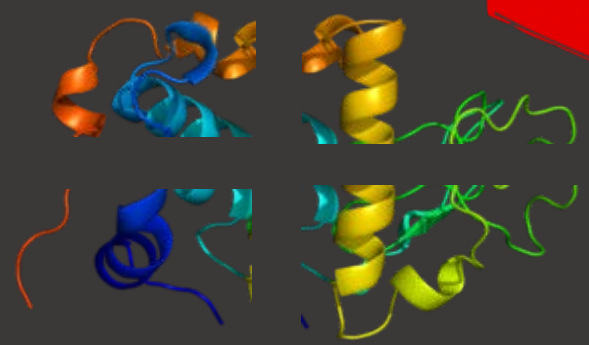


PROTEIN

+



ENZYME

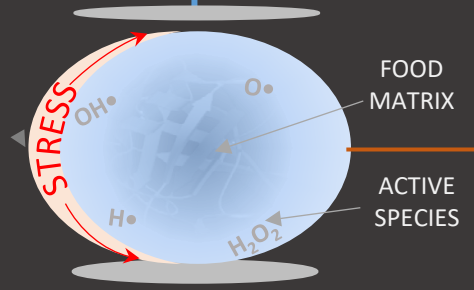


P^- P^+ $P^\pm$ P^+ P^- $P^\pm$ $P^\pm$ P^+

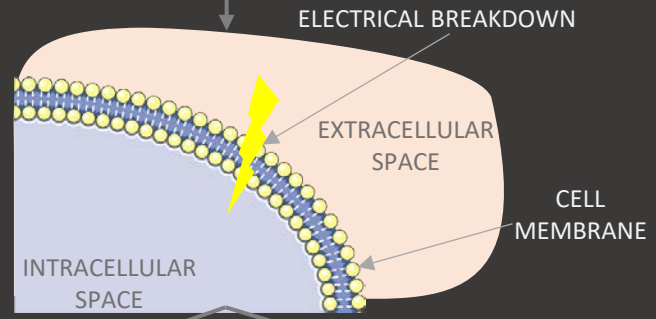
ACCESSIBILITY OF ACTIVE SITES IN THE PROTEIN FOR ENZYMACTIC ACTION…

Hernández-Ledesma, 2008

PULSED ELECTRIC FIELD



ELECTROPORATION



INACTIVATION OF MICROORGANISMS

- Cold pasteurization

IMPROVEMENT OF MASS TRANSFER

- Extraction
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- Drying
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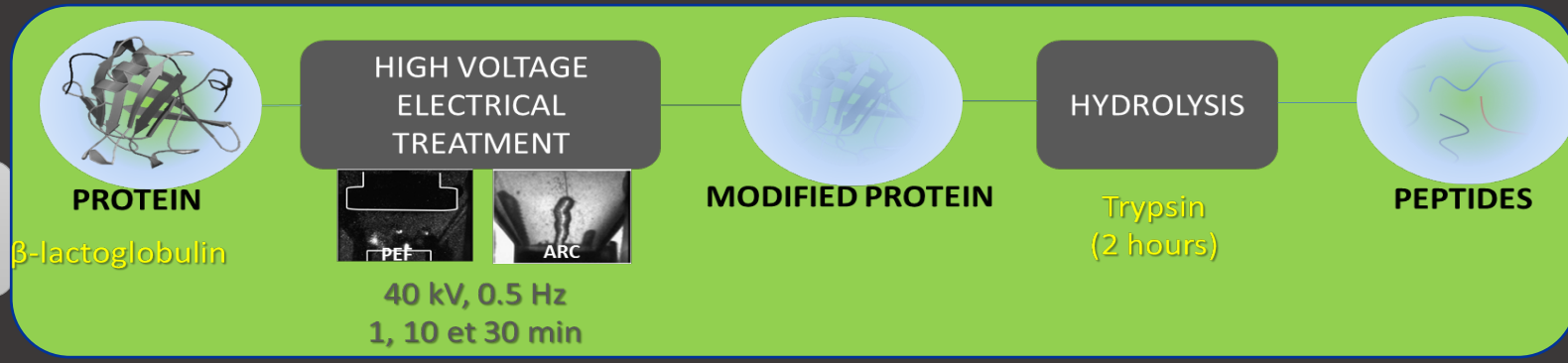
Influence on the structure and properties of food constituents?



Eugène Vorobiev

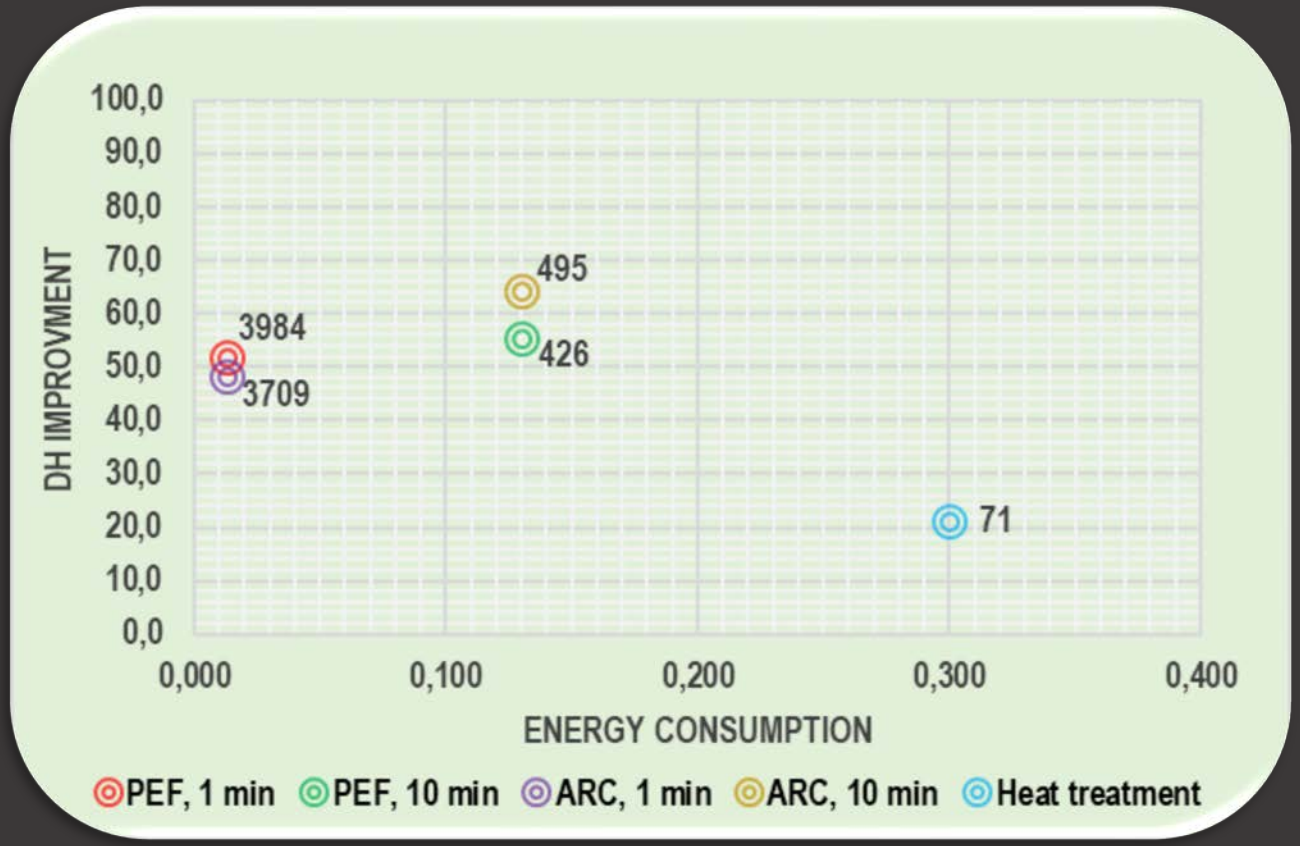
Nabil Grimi

Nadia Boussetta

Rock-Seth Agoua

High voltage electrical treatments

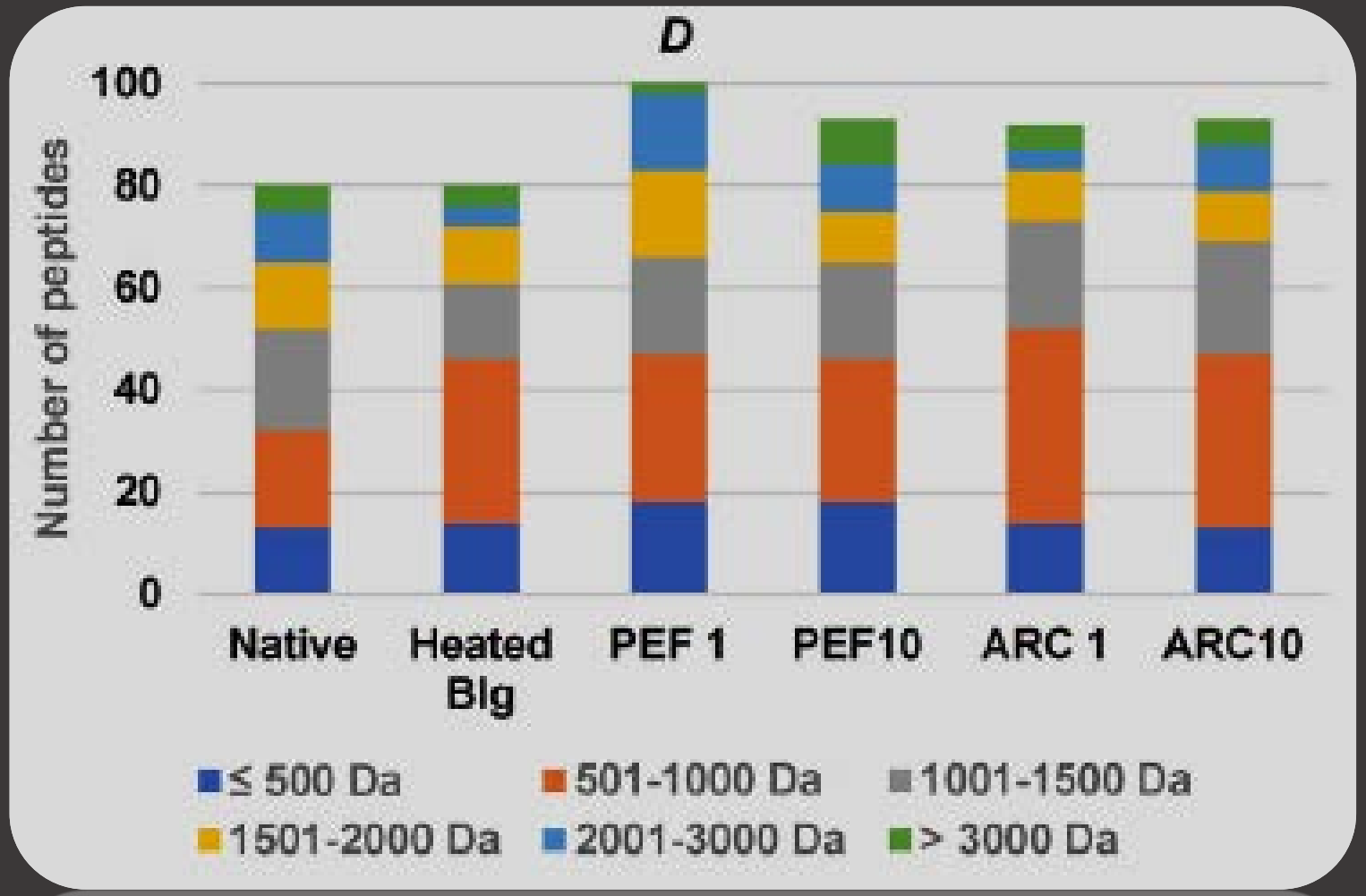
$$EE = \frac{DH\ improvment}{Energy\ consumption}$$



Eco-efficiency assessment of β-lg heated up to 85°C and pretreated with HVET after chymotrypsinolysis. The value beside each point of the graph represents the eco-efficiency score

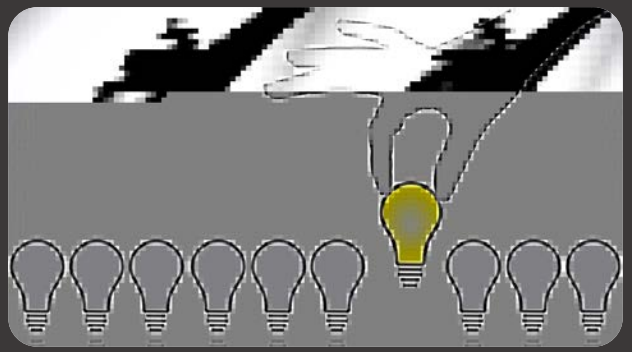
Agoua et al., 2021

High voltage electrical treatments



Identification des peptides

RP-UPLC-MS/MS



DIFFERENCE OF SELECTIVITY

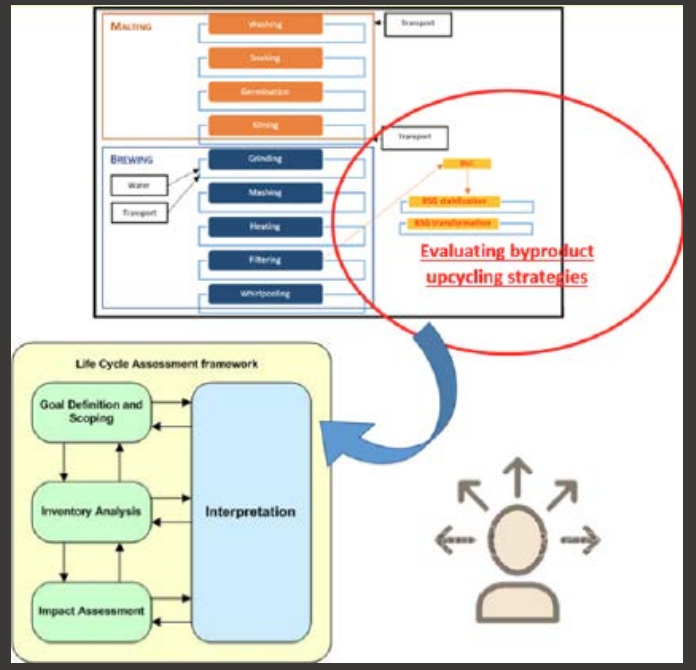
Agoua et al. Food Bioscience, 2022

Brewer's spent grain

→ *Preservation pathways*

→ *Functionality of proteins*

→ *Bioactive potential*



Petit et al., 2021

Émilie Korbel

Samira Rousselière

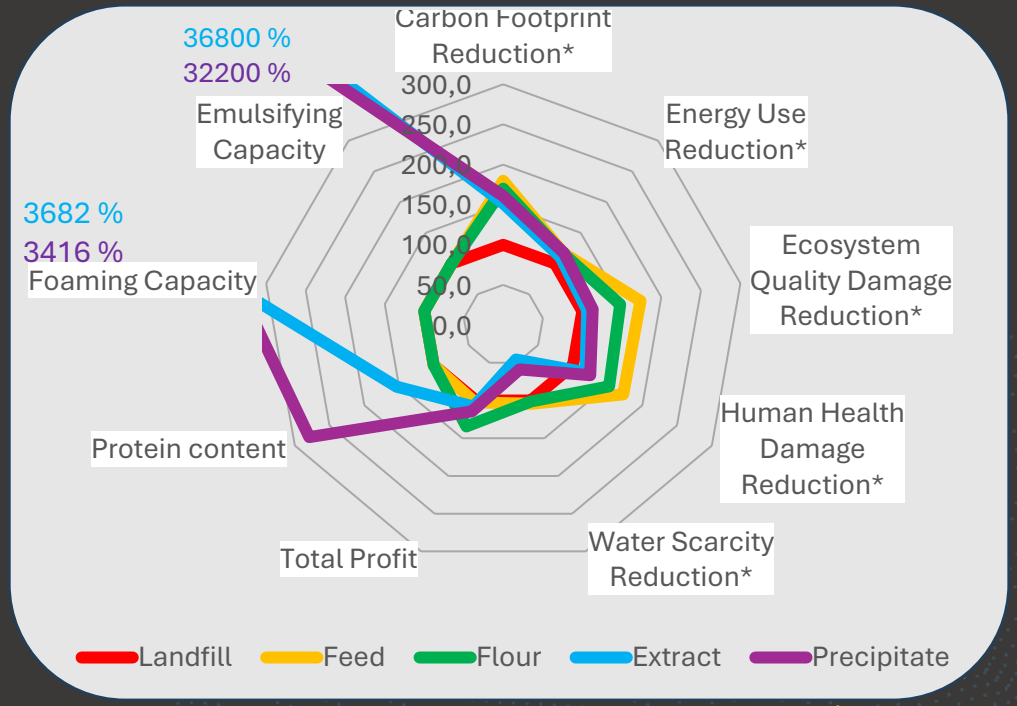
Gaëlle Petit

Sylvie Turgeon

Rozenn Ravallec

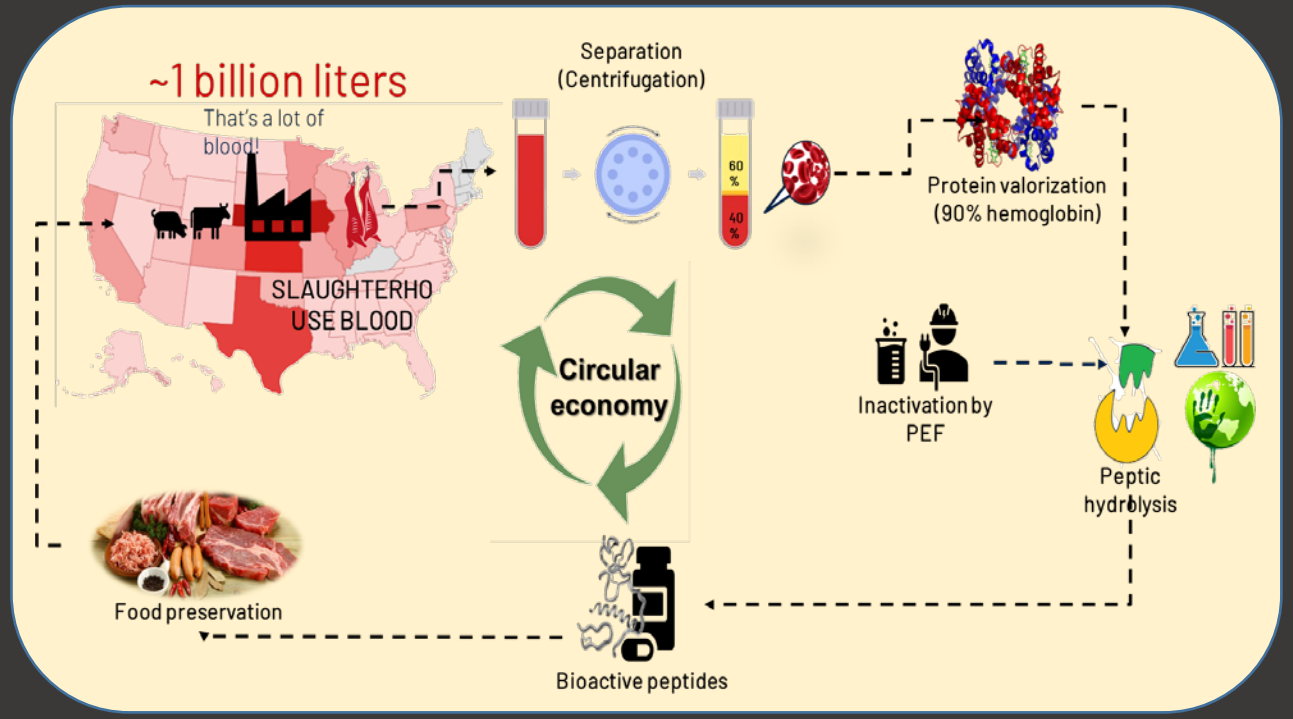
Eya Rouissi

Jonathan Gagnon



Gagnon et al., 2025

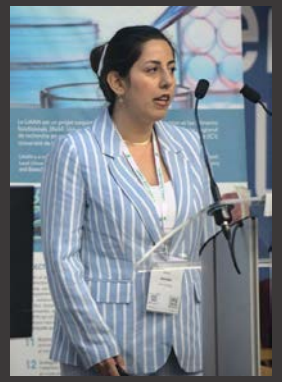
Valorization of by-products



Ismail Fliss

Laurent Bazinet

Zain Sanchez Reinoso



Delassa Rahimi

Houssine Fliss

ECO-EFFICIENCY

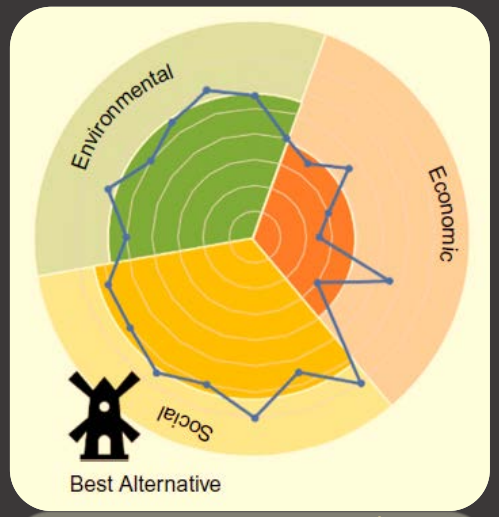
operationalization

Sustainable development

Challenges of emergent technologies

Multicriteria aspect of sustainability assessment

Methodological issues of sustainability assessment (e.g. lack of uniformity between different available tools, data availability and transparency, extrapolation of results from lab to industrial scale, geographical location)



Lin et al. 2020

Particular challenge is considering social aspects (impacts on human capital, human well-being, cultural heritage, and social behavior)

Thank you for your attention!

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