# Resource Recovery: The Power to Change

*Melissa Conference 2020*

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# Overview

- The past:  Experiences in RR
- The present:  What drives the cyclic economy
- The future:  The magics of upgrading

# The past: Our experiences with Recovery


- **The  year 1969 : Cornell University:**

**-  Carl Sagan : the moon dust**

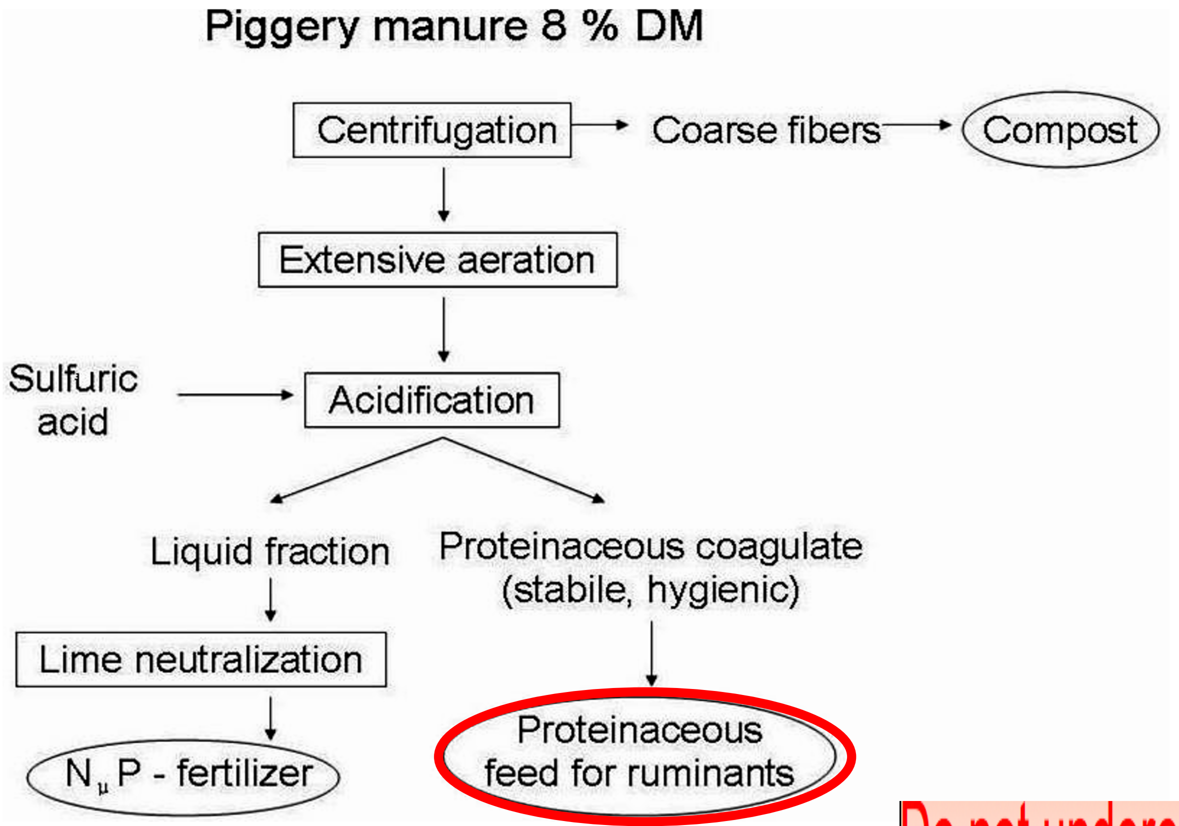
**- LIFE IN THE UNIVERSE -**

**- Martin Alexander : N& nitrification /  key elements of (microbial) life**

- **The year 1971  Ghent University :** Fermenting **pig manure to feed**: Excellent conversion to  single cell protein , but  we  learned a hard lesson ..

# Production of SCP in intensive husbandry

Piggery manure to single cell protein (SCP) to feed
(Beernem (1974) IWA/R&D prize; LabMET).




Do not underestimate the Tabloids !!

# The past: Our experiences with Recovery

- **The year 1975:** Fermenting **manure to biogas** / this became an ever increasing success – a handful of spin-off companies
- **The year 1980:** Fermenting **MSW to biogas /** continuous progress - a major spin-off company

# ANAEROBIC DIGESTION OF HOUSEHOLD WASTE ORGANICS

- DRANCO technology: dry continuous digestion technology
- OWS >30 years experience in anaerobic digestion of solid and semisolid organics
- 100 people
- 30 full-scale reference plants

- DRANCO plant in France (Bourg-en-Bresse):
  - 66.000 t/y of mixed waste
  - 40.000 t/y to DRANCO digester
  - Production of electricity: > 10.000.000 kWh/y
  - Production of clean compost: > 21.000 t/y

# The past: Our experiences with Recovery

- The year 1985 : The **Rhodospirillaceae** ‘mesmerization “

Short Communications | Published: January 1985

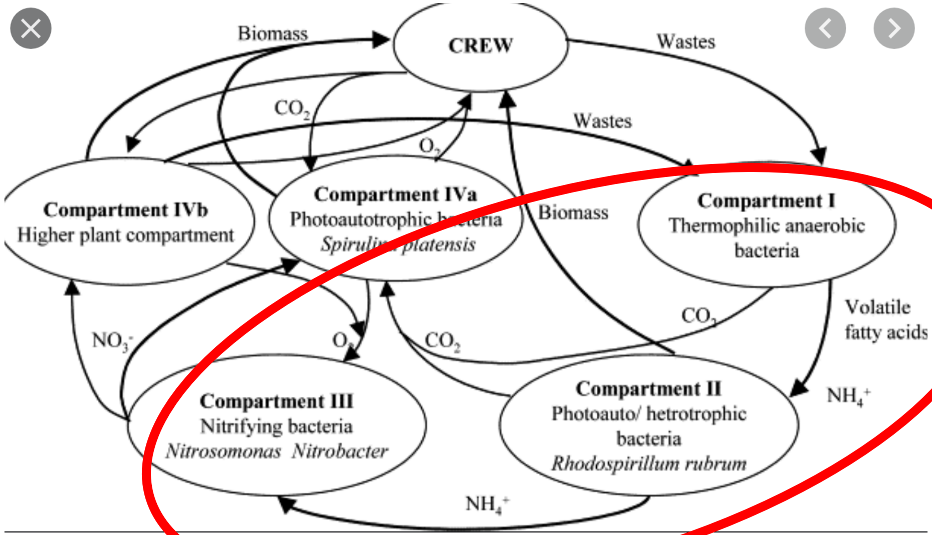
Chemical control of eucaryotic and blue-green algae in anaerobic photoreactors culturing Rhodospirillaceae

L. Segers & W. Verstraete

*Experientia* **41**, 99–101(1985) | Cite this article

# The past: Our experiences with Recovery

- The 90's : The phone call from **Max Mergeay** /The beer ticket




- The year 1994 : **The combi** of ( AD + Photobacteria + Nitrifiers) in Melissa

MELISSA IS EITHER AN ECOSYSTEM OR A UNIT FOR WASTE RECYCLING

By: GROS, JB; LASSEUR, C; VERSTRAETE, W

BIOFUTUR Issue: 137 Pages: 35-37 Published: SEP 1994

# The past: Our experiences with Recovery

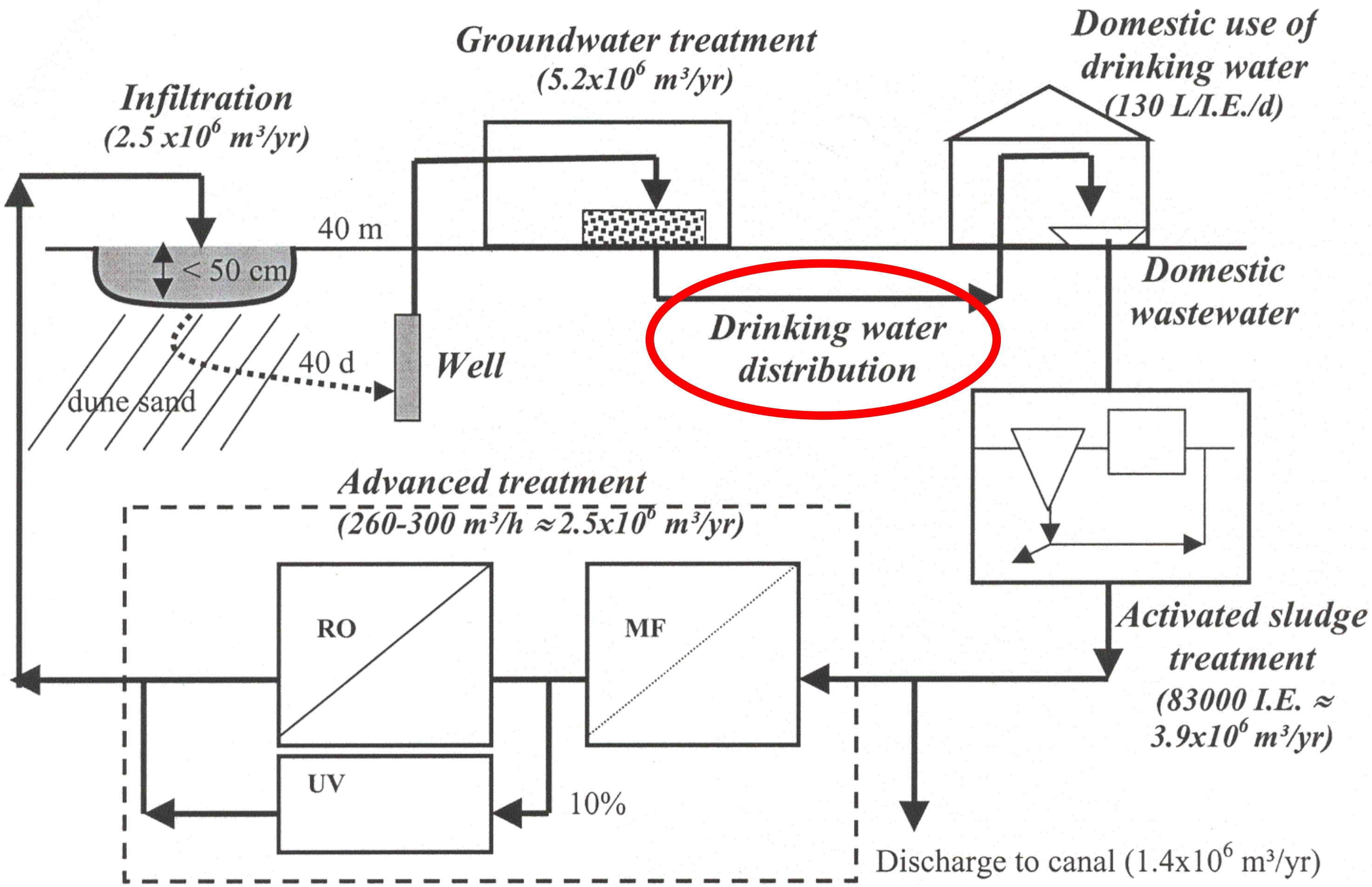
- **The year 2000: Full reclamation of used water** to become drinking water at Oostduinkerke B;

Unique in its kind. Very proud!!!

HACCP as cornerstone !

# Closed water cycle / HACCP and plenty of PR !!!

Oostduinkerke - Belgium (Dewettinck et al. 2001)



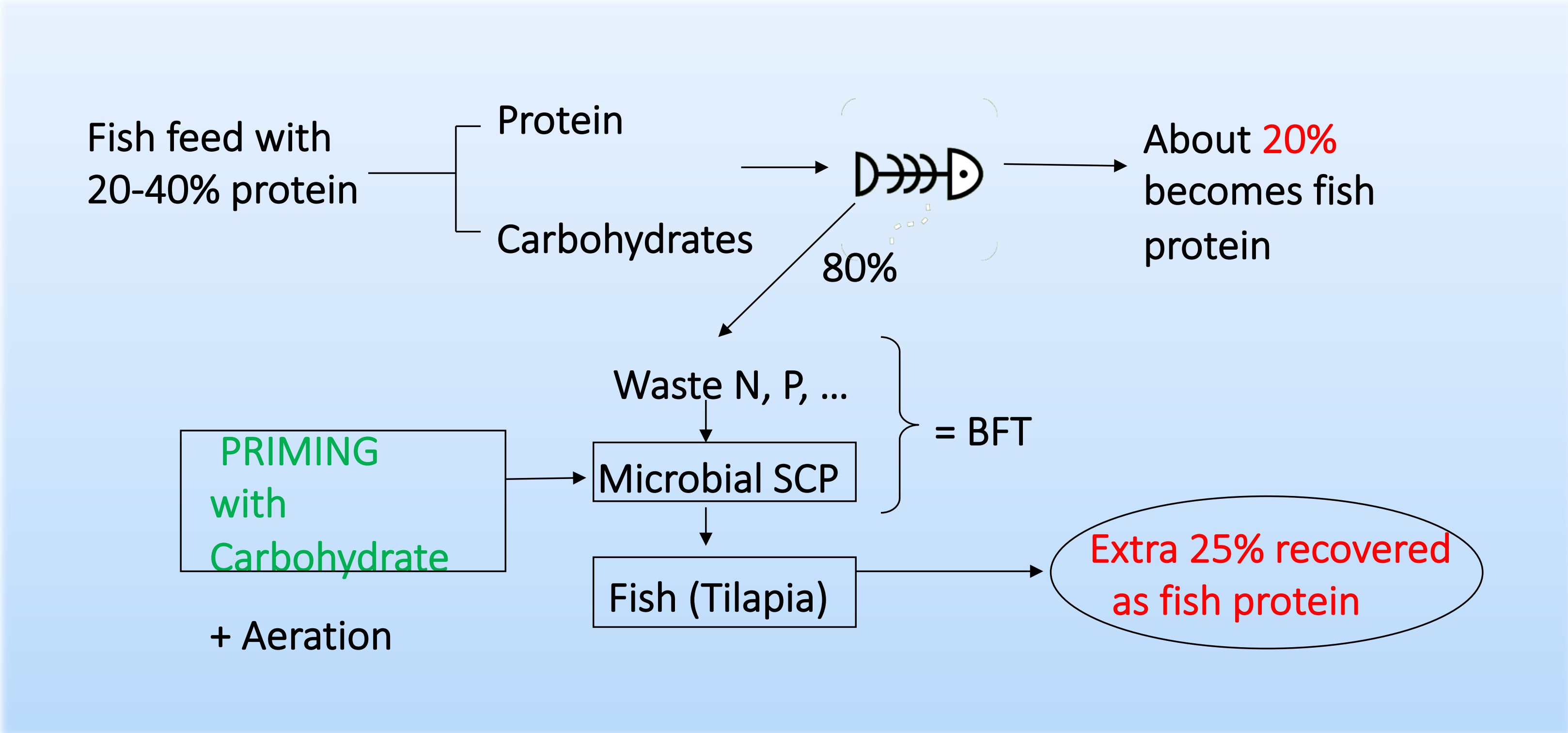
# The past: Our experiences with Recovery

- **The year 2003:** Outcry from Aquaculture **:** why not in situ **direct upcycling of fish fecal matter** –Avnimelech

  The biofloc technology / Ever since a growing application

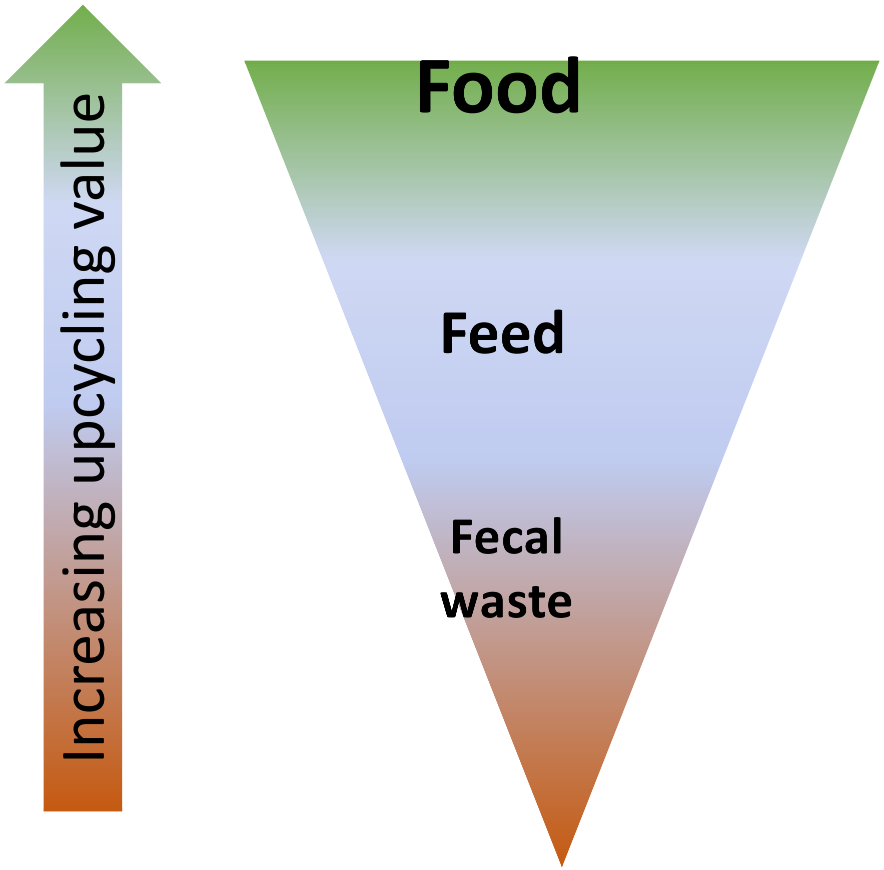
# The Aquaculture BioFloc Technology

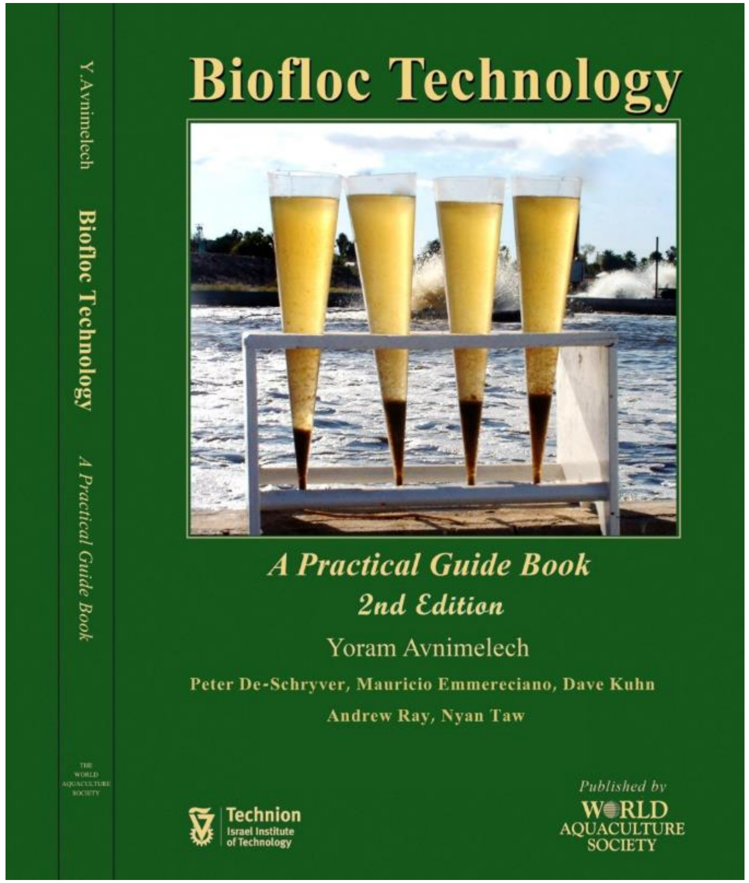
## Direct recycling of fecal N as feed in aquaculture




*(Crab et al., 2007; Aquaculture 270: 1-14; LabMET;*
*(De Schryver et al. 2008; Water Res. 42: 1-12; LabMET )*

# From fecal to feed to food !! This time Nice acceptance !



# The past: Our experiences with Recovery

*The year 2004 : The extra barrier : the combi of

**thermal treatment (wet oxidation)** and microbial upgrading

Advanced anaerobic bioconversion of lignocellulosic waste for bioregenerative life support following thermal water treatment and biodegradation by Fibrobacter succinogenes

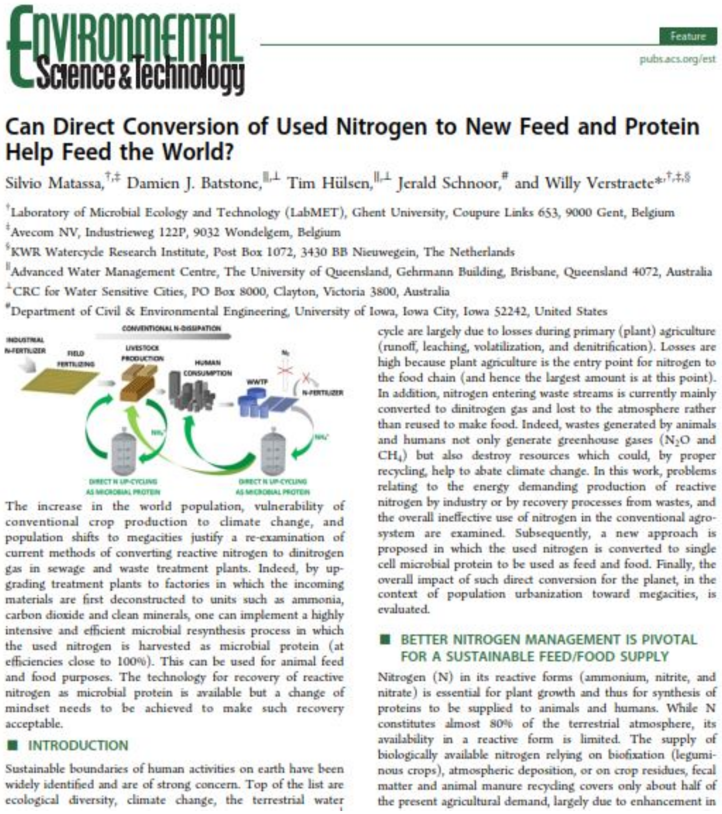
By: Lissens, G (Lissens, G); Verstraete, W (Verstraete, W); Albrecht, T (Albrecht, T); Brunner, G (Brunner, G); Creuly, C (Creuly, C); Seon, J (Seon, J); Dussap, G (Dussap, G); Lasseur, C (Lasseur, C)

BIODEGRADATION
**Volume:** 15 **Issue:** 3 **Pages:** 173-183
**DOI:** 10.1023/B:BIOD.0000026515.16311.4a
**Published:** JUN 2004

- **Finally, the year 2011: The return to the conversion of mineral N and carbon** into **single cell biomass (SCP)**

Gradually catching on …..

# POWER TO PROTEIN – PROMIC



Environmental Science & Technology

Feature

pubs.acs.org/est

## Can Direct Conversion of Used Nitrogen to New Feed and Protein Help Feed the World?

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The increase in the world population, vulnerability of conventional crop production to climate change, and population shifts to megacities justify a re-examination of current methods of converting reactive nitrogen to dinitrogen gas in sewage and waste treatment plants. Indeed, by upgrading treatment plants to factories in which the incoming materials are first deconstructed to units such as ammonia, carbon dioxide and clean minerals, one can implement a highly intensive and efficient microbial resynthesis process in which the used nitrogen is harvested as microbial protein (at efficiencies close to 100%). This can be used for animal feed and food purposes. The technology for recovery of reactive nitrogen as microbial protein is available but a change of mindset needs to be achieved to make such recovery acceptable.

### INTRODUCTION

Sustainable boundaries of human activities on earth have been widely identified and are of strong concern. Top of the list are ecological diversity, climate change, the terrestrial water cycle are largely due to losses during primary (plant) agriculture (runoff, leaching, volatilization, and denitrification). Losses are high because plant agriculture is the entry point for nitrogen to the food chain (and hence the largest amount is at this point). In addition, nitrogen entering waste streams is currently mainly converted to dinitrogen gas and lost to the atmosphere rather than reused to make food. Indeed, wastes generated by animals and humans not only generate greenhouse gases ($N_2O$ and $CH_4$) but also destroy resources which could, by proper recycling, help to abate climate change. In this work, problems relating to the energy demanding production of reactive nitrogen by industry or by recovery processes from wastes, and the overall ineffective use of nitrogen in the conventional agro-system are examined. Subsequently, a new approach is proposed in which the used nitrogen is converted to single cell microbial protein to be used as feed and food. Finally, the overall impact of such direct conversion for the planet, in the context of population urbanization toward megacities, is evaluated.

### BETTER NITROGEN MANAGEMENT IS PIVOTAL FOR A SUSTAINABLE FEED/FOOD SUPPLY

Nitrogen (N) in its reactive forms (ammonium, nitrite, and nitrate) is essential for plant growth and thus for synthesis of proteins to be supplied to animals and humans. While N constitutes almost 80% of the terrestrial atmosphere, its availability in a reactive form is limited. The supply of biologically available nitrogen relying on biofixation (leguminous crops), atmospheric deposition, or on crop residues, fecal matter and animal manure recycling covers only about half of the present agricultural demand, largely due to enhancement in



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*Matassa et al., 2015, ES&T 49:5247-5254*

***FIRST RUNNER UP OF "BEST ES&T PAPERS" 2015***

# Overview

- The past : - Take Home with respect to Resource Recovery :

  **Communication to and acceptance by the public is crucial !!**

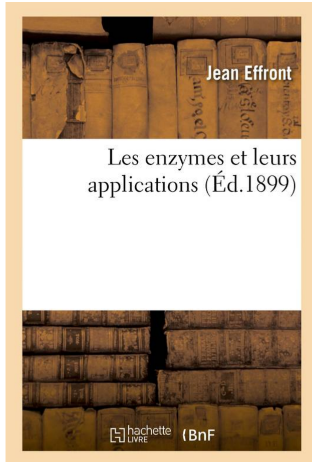
- **The present : The cyclic economy**

  **Quoi de neuf ?**

*The future: The magics of upgrading

# **Jean Effront** 1899. Famous  Belgian Chemist

- Waste can be turned into ‘pseudo steaks’




Human nutriments might be recycled from the refuse of breweries and distilleries ; the resultant paste can be 3x more nourishing as meat ..

The human nutriments would be more economical because **they do not need to go through the intermediary of the animal**

# Winston Churchill 1932

- Quote : ”Fifty years hence , **a headless ,wingless chicken genetically engineered** to maximize meat production and reduce waste will be used “

# NASA space food in the 70's

- The meal pill
- The rehydratables squeezed through a tube in the mouth of the astronaut
- **The Cornell's vegans space-food research /Chlorella**

# Warren Belasco 2006 : “Meals to come ”

Be very aware of the ongoing duality :

a) Malthus related thinkers / **dystopian mindset** / the limits of growth

b) Marquis de Condorcet related thinkers / **utopian mindset** / the techno-cornucopian approach

Special note: **When people are living in a closed system** , food becomes larger than life ; eating is all about enhancing social attitudes and moral !!

# Today


- The Paris agreements (2015) were hope giving ; BUT are not not respected

- In terms of the EU , enormous barriers on RR , see for instance 'novel foods ' ( they are regulated as pharma-chemicals )

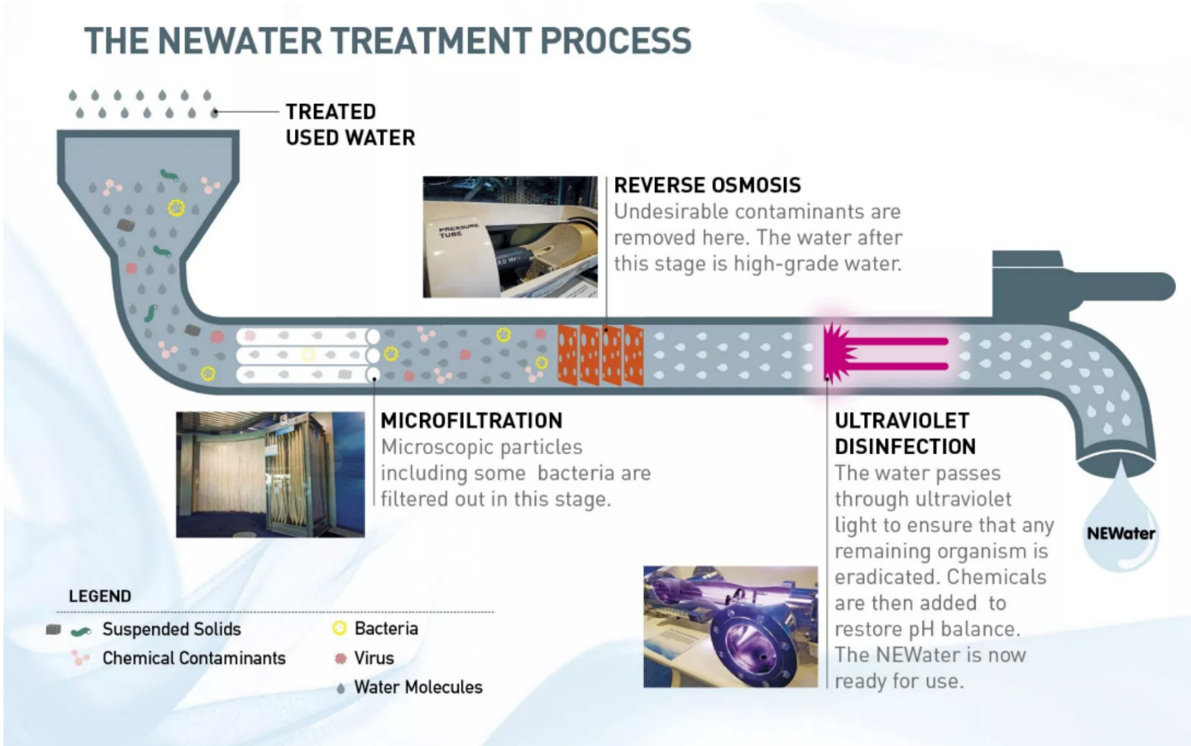
# Key features of today:

1 - The consumer is afraid of *"contaminants"* in general and fecal contaminants in particular: physical, chemical, microbiological, …

Be aware of major cultural & religious barriers !!!

Example : **Singapore**

NEWater



# Key features of today:

**2** - Recovery from waste should follow paths in which the consumer has **confidence:**

a) The involvement of **heat** / fire (CHP, ashes,..)

b) Transition into a **gas phase** (methane, $CO_2$, $NH_3$, …)

c) **Change in outlook** (mushroom on horse manure, plants on soil fertilized with feces, …)

## The law of contagion !!!

# Key features of today :

**3** - Recovered products – **as such** – tend to get only **some 20% of the value of "virgin" ones**
Example: Fertlizers (Chojnacka et al. 2019)

Price of nutrients in waste-based products in comparison with mineral NPK fertilizers [8,4(

| | Mineral NPK Fertilizer | Waste-based products | | |
|---|---|---|---|---|
| | | Compost | Digestate | pyrolysis and gasification materials |
| Phosphorus [euro/kg P] | 0.99 | 0–0.3 | 0.19–1.19 | 0.55–8.57 |
| Nitrogen [euro/kg N] | 0.85 | 0–0.2 | 0.55–5.6 | 3–46 |
| Potassium [euro/kg K] | 0.51 | 0–0.3 | 0.13–1.2 | 0.2–3.1 |

# Key features of today :

**4** - The final product from waste recovery should relate to the market economy: **there should be a real demand by the consumer**

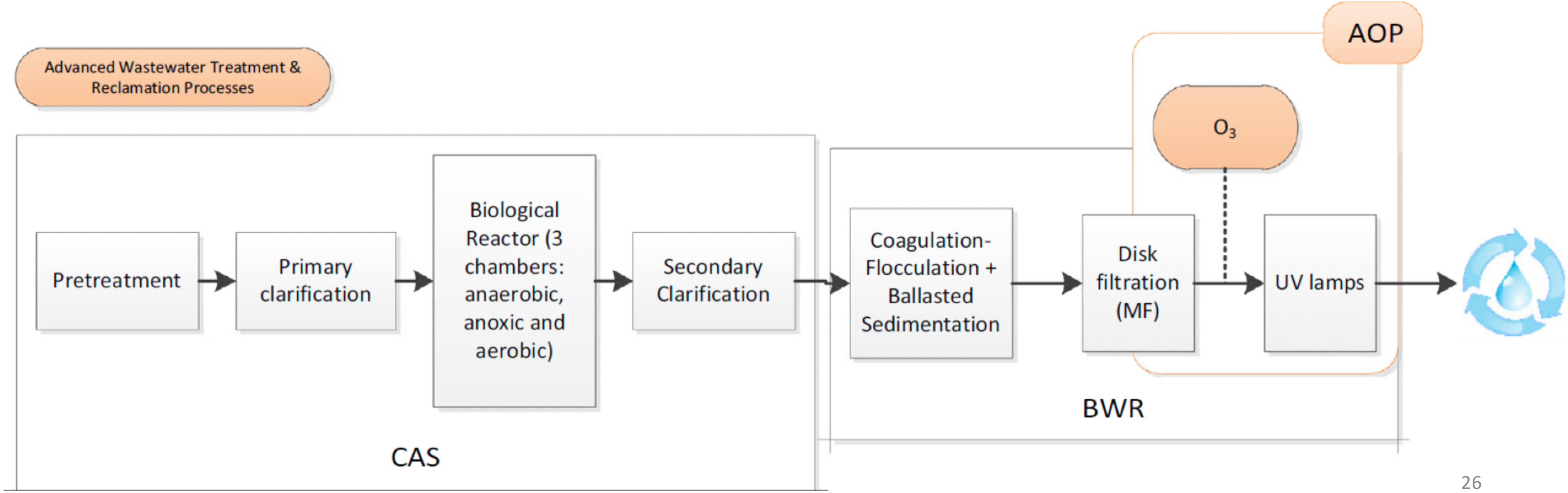
**Hence**

**Try to combine a "cleansing technology" with a "new outlook" and integrate recovery in a "supply chain which offers several perspectives"**

# Key features of today:

**5** - Things rapidly become very complex  and confusing for the consumer
Example: The issue of **basic water reclamation**: a sequence of 10 treatment steps is required to remove organic micro-pollutants

*C. Echevarría et al. / Science of the Total Environment 671 (2019) 288–298*



6 - The *game changer* often comes unexpectedly .
Food wastes in supermarkets: not AD , but **gasification** is the solution ( Kok Siew Ng et al. 2019 ). Dare to think out of the Box !!

(c)

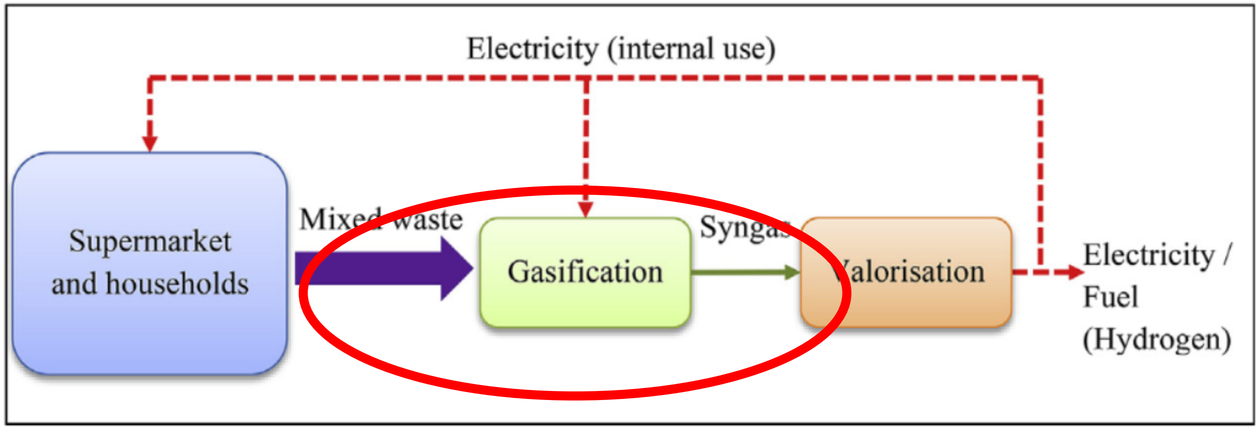



**Fig. 5(c).** Scenario 3 – AS2 with GAS-E/H2, MW. Completely decentralised mixed waste management through gasification and valorisation of syngas for electricity or fuel (hydrogen) production. Gasification facility is located on-site at the supermarket.

# Key features of today:

7, Be aware that there is **a strong dystopian mindset** in society :

In terms of microbiology : mysophobia / germophobia - Ken Timmis

Note :
NATURAL OPEN **microbiomes** are generally conceived
TO BE UNRELIABLE /TO BE STOCHASTIC …

-How about conventional crops in the field -plenty of potential invaders
-How about natural ferments such as cheese from raw milk ,
mushroom , how about raw fruit , salads , ….

# Key features of today:

7, **a strong dystopian mindset** (cont )

YET : **Yet demonstrated : dense cultures (biofilms )are deterministic ( Xu et al. 2019 )**

**YET : Yet clearly established : to reach the SDG. , we need the ecosystem services of naturally evolving microbiomes**

microbial biotechnology

sfam society for applied microbiology

Open Access

Editorial: Microbial Biotechnology for Sustainable Development Goals | Open Access

**Stochasticity in microbiology: managing unpredictability to reach the Sustainable Development Goals**

Jo De Vrieze, Thijs De Mulder, Silvio Matassa, Jizhong Zhou, Largus T. Angenent, Nico Boon, Willy Verstraete

First published: 20 April 2020 | **https://doi.org/10.1111/1751-7915.13575** | Citations: 1

# Take home messages on RR today

- Resource Recycling and Cyclic Economy must be "do-able" and "understand-able" **for the man and the woman in the street**

- Not imposing major costs;
- Being safe and sound and understandable
- Showing net environmental benefits despite the complexity of the processes involved.

EDUCATION EDUCATION EDUCATION, AND ONCE AGAIN EDUCATION

# Overview

- The past
- The presence: Be aware of

  Plenty of history in Resource Recycling

  Consumer psychology is crucial

  Serendipity is much needed:

  Dare to think out of the box

  Educate and communicate !!!

- The future: Upgrading to what ?

# The magics of upgrading

Three topics

- Biogas in general
- $CO_2$ in particular
- C, N, S and P resources

# Biomethane

**Verbeeck et al. ( 2018 )**

“Decentral biogas - Biomethane” can be scaled up via  the available large <u>gas networks</u>

Thus one can couple Biomethane

* to the  transport  sector


* to  very efficient  use eg in district heating / 80-90 % CHP ...)

* to achieve CO2 capture and production of **green chemicals**

# Biomethane Verbeeck et al. ( 2018 )



- By doing the combi of <u>**agriculture**</u> **and RR via AD , one really opens major new perspectives**
- **We must pass this message to**

**the MILLENIALS**

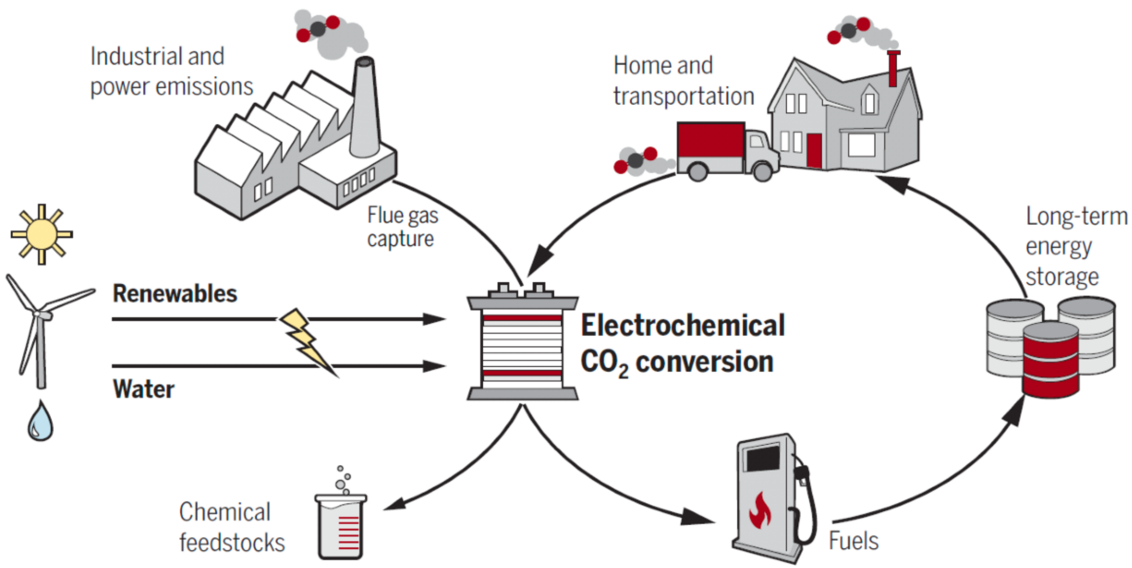
**Yes we listen to you !!**

# The magics of upgrading

- Biogas in general
- **$CO_2$ in particular**
- C, N, S and P resources

# What would it take for renewably powered electrosynthesis using CO2 to displace petrochemical processes ?

- De Luna et al. 2019 / recent article in Science




**Electrochemical $CO_2$ conversion.** Reduction of $CO_2$ using renewably sourced electricity coul transform waste $CO_2$ emissions into commodity chemical feedstocks or fuels.

# The answer:

Conversion efficiencies above 60% / Electricity below 4 ct per kWh / and value creation by Biotech

Think innovative !!

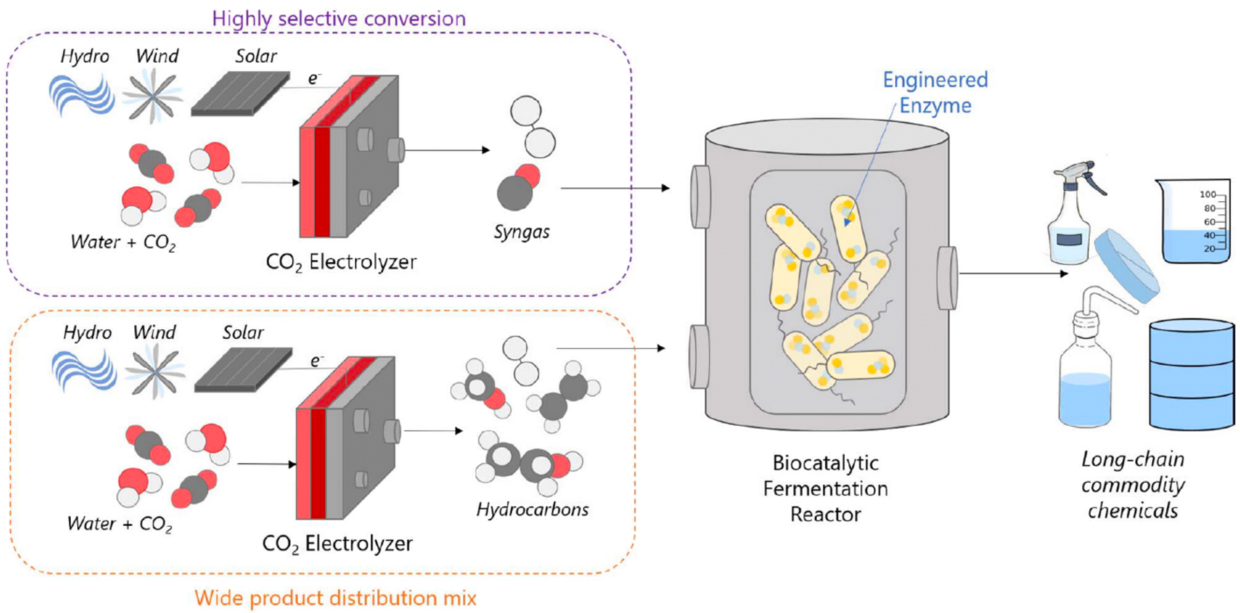



**Fig. 4. Bio+electrocatalytic pathways toward long-chain commodity chemicals.** Today, $CO_2$ may be converted to syngas at very high selectivity using silver- or gold-based catalysts (top left). Alternatively, $CO_2$ can be converted into a wide range of hydrocarbon and oxygenate products using copper-, tin-, or palladium-based catalysts (bottom left). These products can then be used as inputs for genetically engineered enzymes and bacteria to convert to more complex commodity chemicals.

# The magics of upgrading

- Biogas in general
- $CO_2$ in particular
- **C, N, S and P resources**

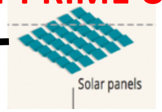
# Cyclic economy: The dream / the future

[C, N, P, S]

WASTE

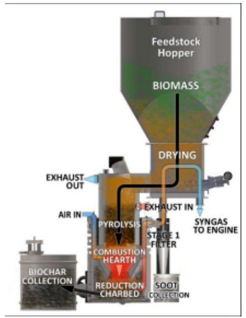
DO NO LONGER

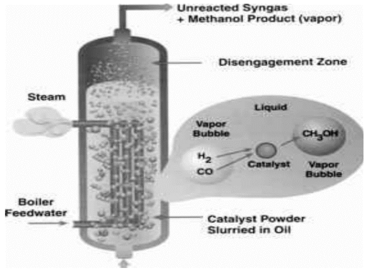
CHOP UP BUT PRIME UPFRONT




CAPTURE

GASIFY


AEROBIC FERMENTATION

[C, N, P, S]

SINGLE CELL BIOMASS

# Aerobic fermentation to microbial biomass

**Organotrophic route**

- Oxygen
- Organic **Carbon**
- Reactive Nitrogen

**Autotrophic route**

- Oxygen
- **$CO_2$**
- Reactive Nitrogen
- Hydrogen/CO/$CH_4$

In-reactor
**Microbial Biomass**
production

**Microbial Protein**
PROMIC

**Food /Animal Feed**

OR

Carbon captured in the form Microbial Based Biomass = Slow Release **Organic Fertilizer**
This in case the Quality of Product is low

OR

**Material Composites**

# Valpromic: Potato waters to Promic
## Demo scale 2020 at Wielsbeke

- Amino acid composition better than soy; almost that of fish protein
- Piglets, Shrimps: Excellent digestibility, feed uptake and conversion
- Schrimps challenge tests with pathogenic *Vibrio* (Immaqua Lab): dose from 0 tot 75% of diet with Promic: **survival factor 2 better; weight gain factor 1.5 better when Microbial Protein is fed**

LSAQUA
aquafeed innovators

# The autotrophic route

Avecom/KWR /Waternet/AEB:

power to PROTEIN

**AUTOTROPHIC upgrading of recovered $NH_3$**

The first hydrogenotrophic biomass producing reactor (0.7 $m^3$)

Since 1 week running continously

Upscaling to 20 kg DM/d is planned

# THE FECAL MATTER HURDLE

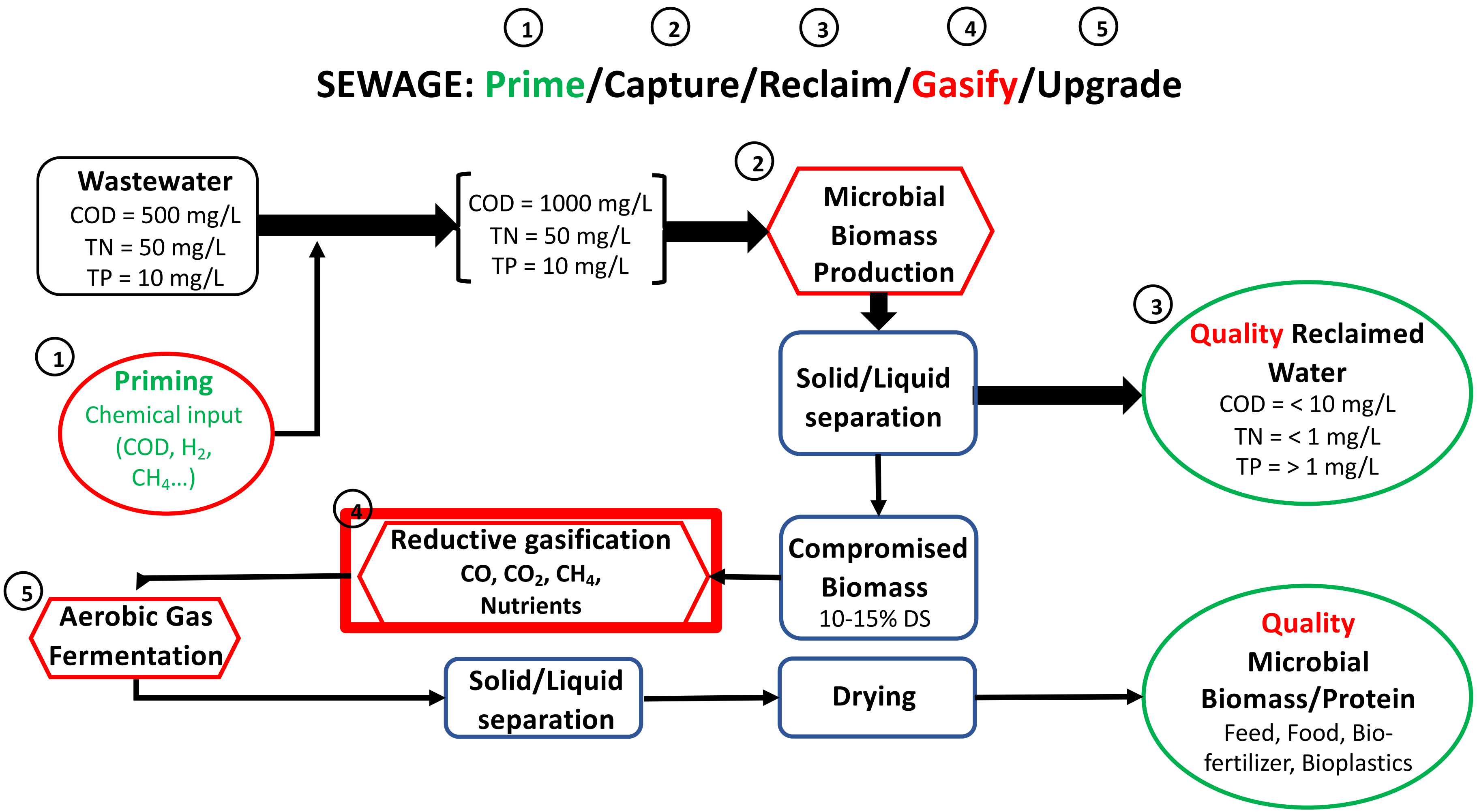
Our line of work :

- Convert to a **quality** **gas** ( AD / Torrefaciton -Gasification)

- Use the gas to produce gas based **quality** SCP

**We must move away from the dystopian mindset !**

# Reclamation cfr Matassa et al. (2020)



# Gasification of biomass /low tar but high $H_2$ + CO and also $NH_3$ ,$H_2S$ and even $PH_3$ (Burhenne et al. 2013; Hu et al. 2019; Ebadi et al. 2019)

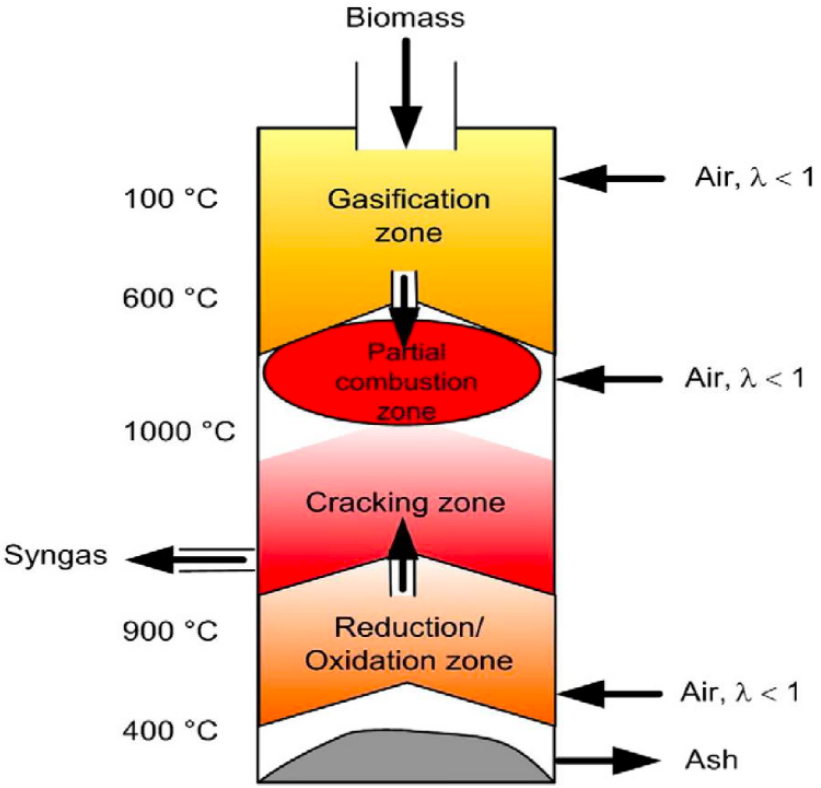
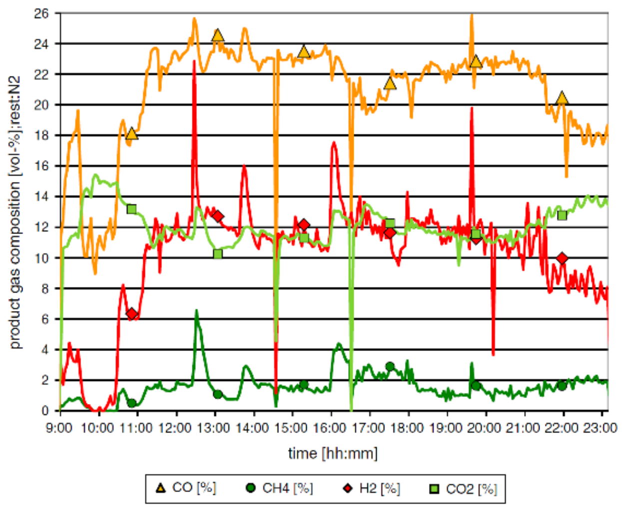



**Fig. 1.** Scheme of the *Fraunhofer ISE* gasifier.

L. Burhenne et al. / Fuel Processing Technology 106 (2013) 751–760




Dry product gas composition from operation with wood pellets at a biomass feeding rate of 12 kg/h (LHV of 60 kW) and a stoichiometric air ratio λ between 0.2 and 0.27.

Note :

# Quoi de neuf with respect to SCP ?

- **Old**: Microbial protein from $CH_4$ (=pruteen) already at 50,000 tons per year in the 70's → to valorise the *excess* of fossil fuel
- **Today**: Environmental costs of conventional protein are very high

  There is a need to design meaningful processes in terms of

  $CO_2$ avoidance and carbon capture and storage
- **Tomorrow:**

*We use 'teams' **(microbiomes**) of microorganisms that **"take-it-all" and can be made deterministic**

*We can apply **green** HYDROGEN/SYNGAS/CH4 or combi's as the "driver" to recycle CNPS

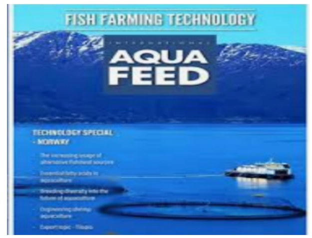
# The market potentials for Microbial Biomass-Protein (Pikaar et al. 2018 )

- **Food**: 100 g highly nutritious protein per person per day, and the demands will double in the next decade → say a total market potential of: 1,000,000 tons of top quality protein

for food per year

- **Feed**: The current world market for animal feed has a size of:

200,000,000 ton medium quality protein/year - it is massive!



# The market potentials for Microbial Biomass-Protein (Pikaar et al. 2018 )

- **Organic fertilizer**: Demand is on the rise since chemical fertilizer becomes less reliable in case of climate change, say 5% of the total fertilizer demand *i.e.*, some:

  10,000,000 ton microbial protein in the form of New MBB slow release organic fertilizer per year


- **Biobased biodegradable plastics**: use protein as a component of biodegradable plastics, at 2% biodegradables of total of a total of all plastics, this still represents:

  6,000,000 ton microbial protein per year


.

# Paris, Microbes and $CO_2$

- **Microbial biomass based carbon storage can reach a substantial part of the $CO_2$ mitigation (Paris agreements, 2015) (Pikaar et al. 2018)**

This route comes at a COST, rough estimation: €500-1000 per inhabitant per year

(Compare with sewage-garbage levies: €100 -300 per inhabitant per year )

- **About 6% of the land area** now used for production of animal feed can be re-destinated (= all agricultural area of China )


Science of the Total Environment 644 (2018) 1525–1530

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Carbon emission avoidance and capture by producing in-reactor microbial biomass based food, feed and slow release fertilizer: Potentials and limitations

Ilje Pikaar [a,b,**], Jo de Vrieze [c], Korneel Rabaey [c], Mario Herrero [d], Pete Smith [e], Willy Verstraete [c,f,*]

# Conclusions on Resource Recovery 1/4

*Powerful Threats: The consumer prefers the easy going / The industry tries to maximize sales of new goods / The regulator tends to adhere the 'pure culture ' dystopic thinking patterns – We must step up efforts to eductate him /her .

*Inspiring Successes:

- Oostduinkerke-Belgium : 50% of tap water consists of recycled water

- Aquaminerals/ Vitens : iron sludges and humic acids from drinking water

- Biofloc Technology : world wide acceptance of fecal matter to food

# Conclusions on Resource Recovery 2/4

**Powerful Threats:*
**Inspiring Successes*:

- **Essential on the RR block**: **Gasification /Pyrolysis ( Matassa et al . 2020 )**

It can produce '**quality gases '**
**The latter** can be fermented in various ways to
**microbial products /SCP**

They in turn can be the start-up of **an extended value chain**

# Conclusions on the Cyclic Economy 3/4

What will urban water and waste management look like in 2040 ?

Top priorities :

1*Reclaimed water ( climate change )

2*Zero disposal ( shortage of goods , eg P )

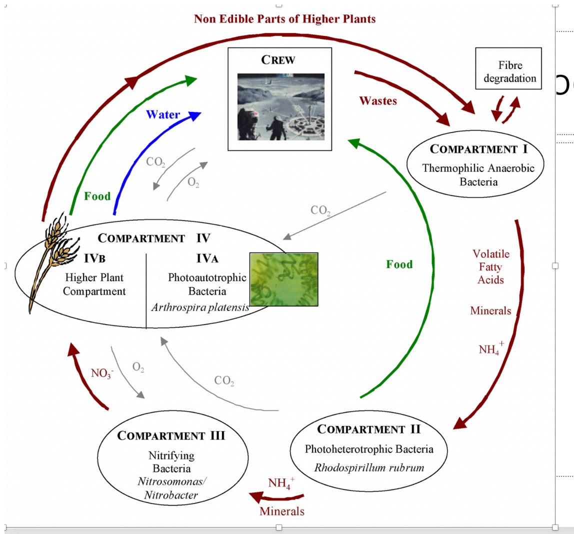
We have plenty of tools, but still there is a long way to go to educate the public

The Law of Contagion must be overcome !!

From a Malthus to a Marquis de Condorcet mindset !!

# The good news : The mindsets evolve forward !!

## In space




pegen

Converts organic matter
Recovers nutrients
Produces food
- Via plants
- Via bacteria

Produces drinkable water
Balances atmosphere

## On earth

**RESOURCE RECOVERY : THE POWER TO CHANGE**

**BY**