ATHENS2017

Athens, 21-24 June 2017

Recovery of Volatile Fatty Acids from cellulosic sludge to enhance phosphorus bio-uptake or PHA production

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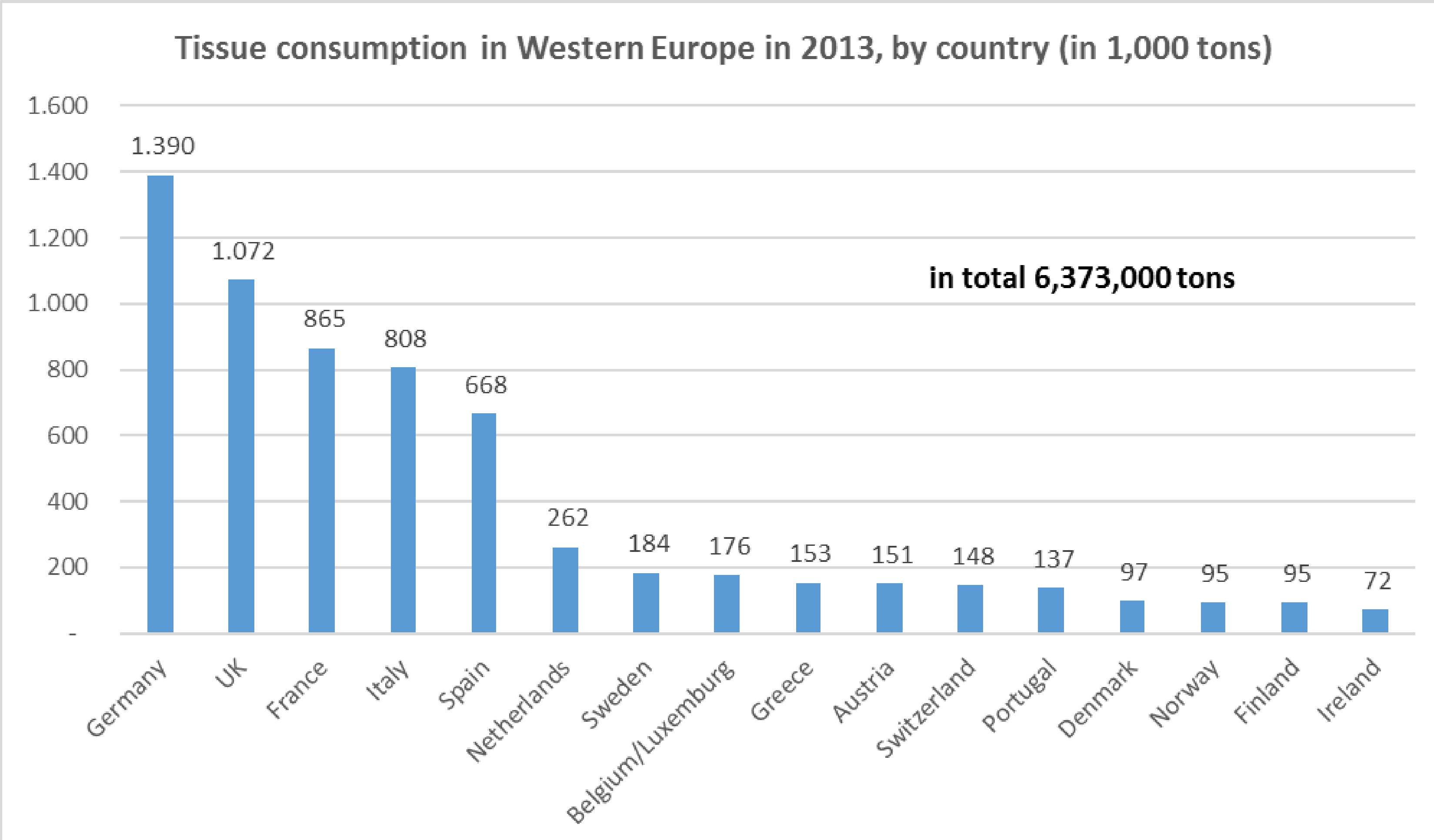
Outline

- The Horizon2020 SMART-Plant Innovation Action
- Cellulose in wastewater and recovery/reuse routes
- Fermentation for Volatile fatty Acids recovery for
  - Biopolymers (PHB-coPHV) production
  - Enhanced BioP recovery
- What comes next: scale-up to demo and full scale in real environment

It's all about toilet paper?

- ✓ 12 to 18 kg per person per year
- ✓ 8.5 pieces of paper per visit to the restroom
- ✓ On average, a person spends 43 hours a year on the toilet
- ✓ 70% folds the sheets before using them, 29% make a proper use

Facts and figures



Source: www.statista.com

Not only toilet paper: resources embedded to municipal wastewater

Parameter	Value
Reusable water (m^3/capita year)	80-120
Cellulose (kg/capita year)	5-7
Biopolymers; PHA (kg/capita year)	2-4
Phosphorus in P precursors (kg/capita year)	0.5-1.5
Nitrogen in N precursors (kg/capita year)	4-5
Methane (m^3/ capita year)	12-13
Organic Fertilizer (P-rich compost) (kg/capita year)	9-10

Verstraete et al. (2009) *Bioresource Technology* 100, 5537–5545
Salehizadej and van Loosdrecht (2004) *Biotechnology Advances* 22, 261–279

Key Enabling Strategy: upstream solid concentration, integration and innovation of the sewage sludge treatment

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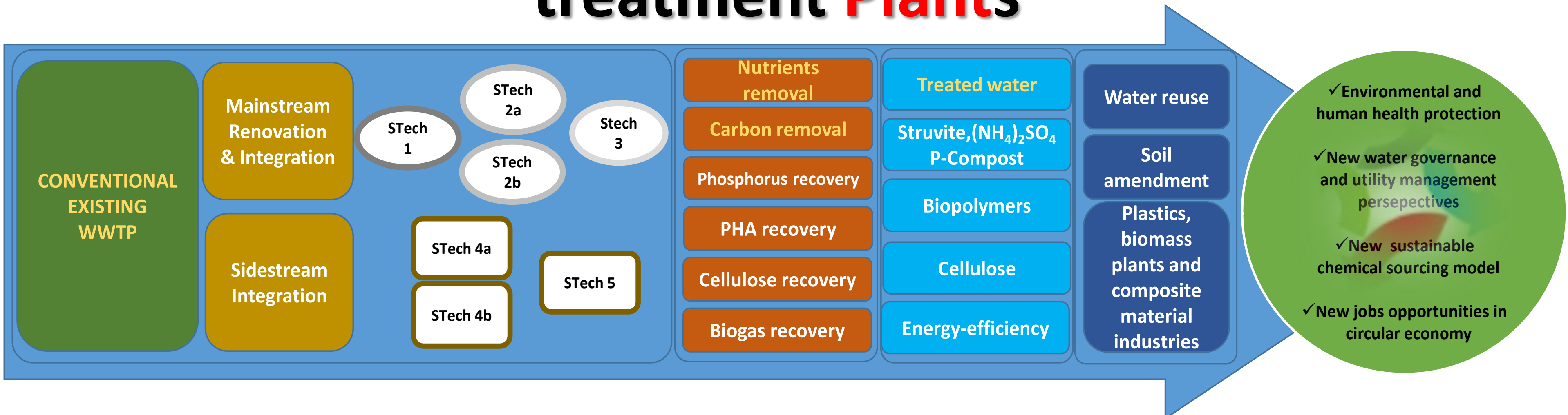
Scale-up of low-carbon footprint MAterial Recovery Techniques for upgrading existing wastewater treatment Plants



The overall target of SMART-Plant is to validate and to address to the market a portfolio of SMARTechnologies that, singularly or combined, can renovate and upgrade existing wastewater treatment plants and give the added value of instigating the paradigm change towards efficient wastewater-based bio-refineries.

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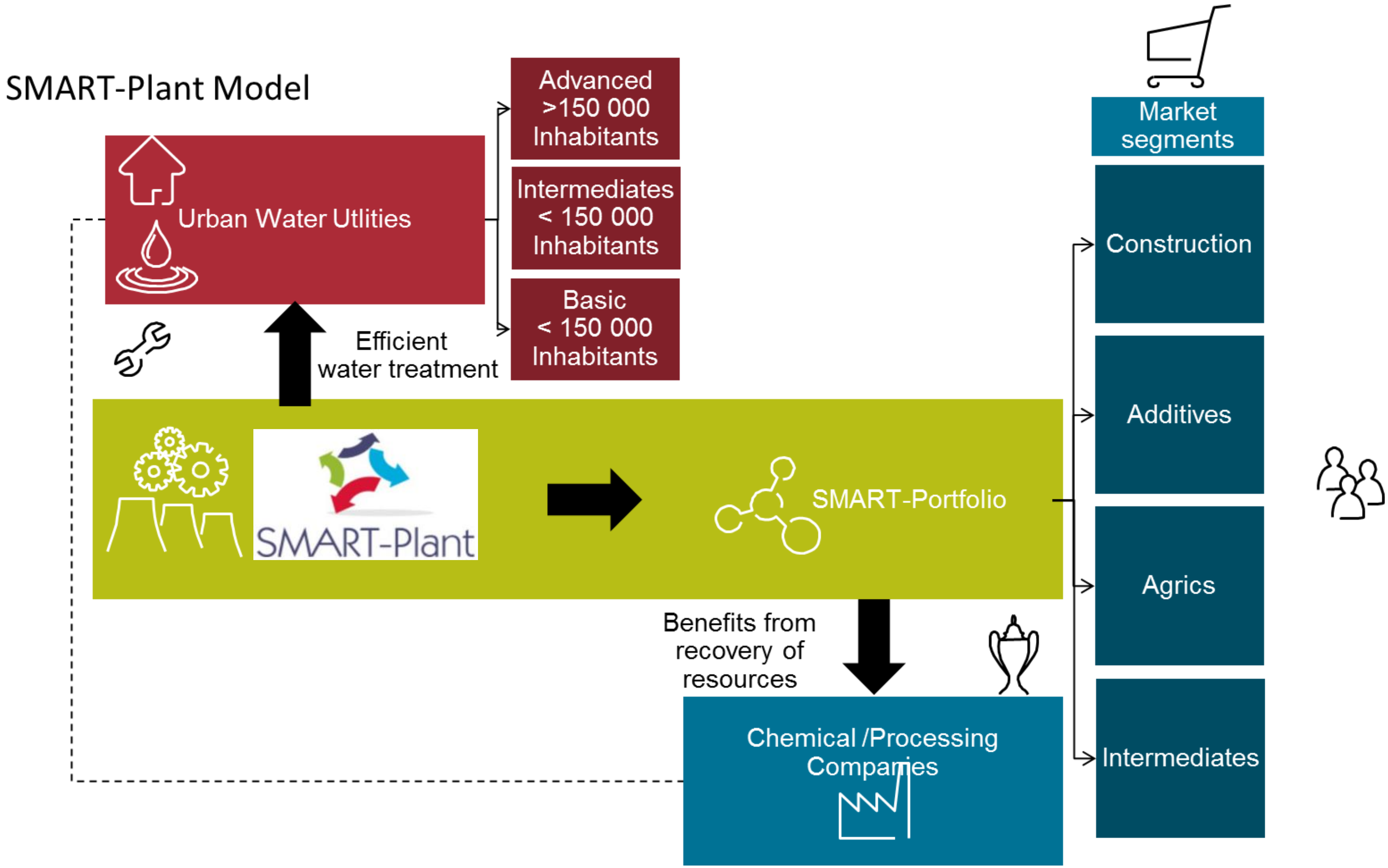
SMART-Plant Business plan and market deployment strategy



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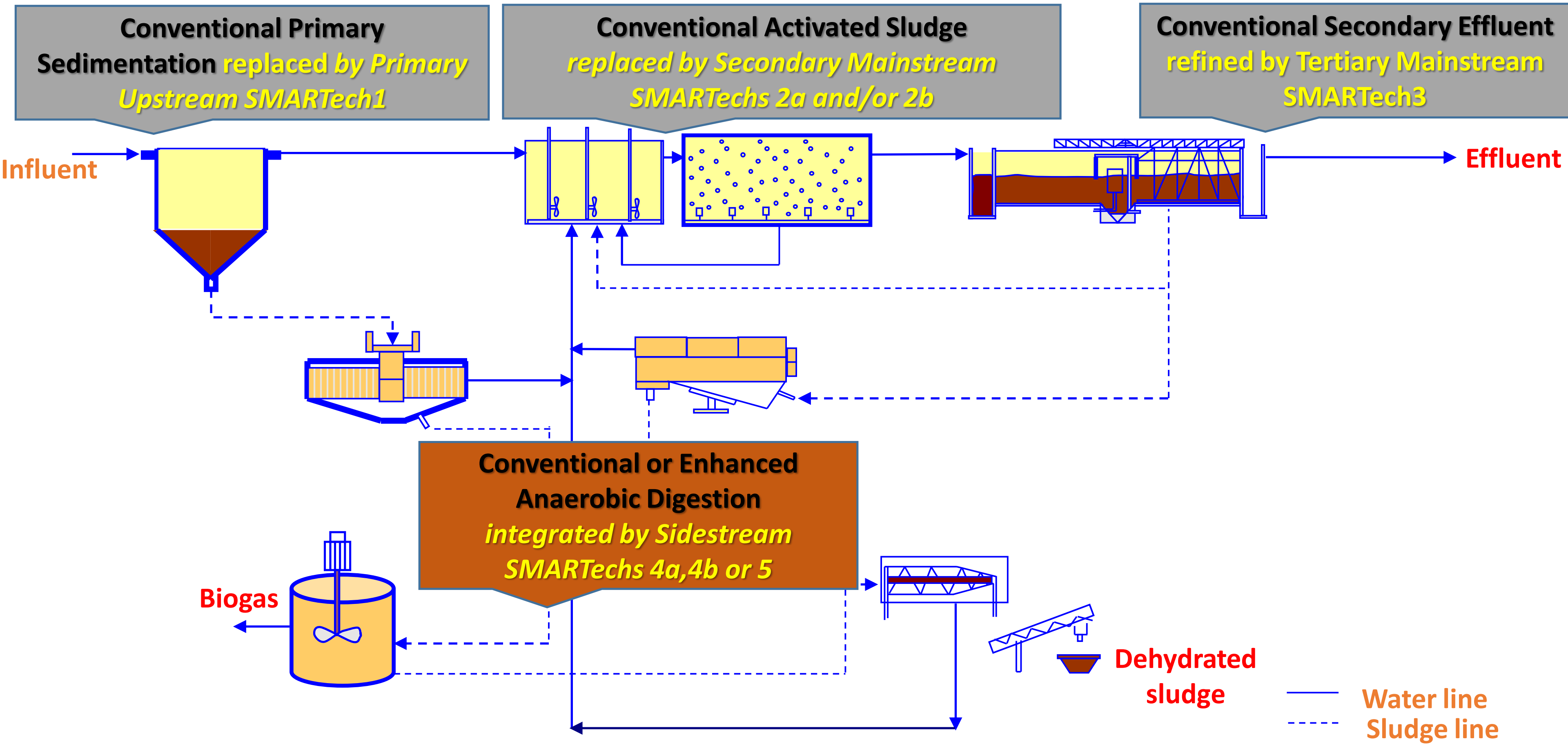
The SMARTechnologies to integrate and renovate existing WWTPs



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The SMART-Plant integrated WWTPs

SMARTech n.	Integrated municipal WWTP	Key enabling process(es)	SMART-product(s)
1	Geestmerabacht (Netherlands)	Upstream dynamic fine-screen and post-processing of cellulosic sludge	Cellulosic sludge, refined clean cellulose
2a	Karmiel (Israel)	Mainstream polyurethane-based anaerobic biofilter	Biogas, Energy-efficient water reuse
2b	Manresa (Spain)	Mainstream SCEPPHAR	P-rich sludge, PHA
3	Cranfield (UK)	Mainstream tertiary hybrid ion exchange	Nutrients
4a	Carbonera (Italy)	Sidestream SCENA+conventional AD	P-rich sludge, VFA
4b	Psyttalia (Greece)	Sidestream SCENA+enhanced AD	P-rich sludge
5	Carbonera (Italy)	Sidestream SCEPPHAR	PHA, struvite, VFA

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Background

- Municipal wastewater contains around **100-120 gCOD/(inhabitant per day), however diluted in 250-350 L/(inhabitant per day);**
- Around 50-80% of the suspended solid can be efficiently removed by the dynamic sieving of the wastewater, in which up to 35% is toilet paper (Ruiken et al., 2013, Water Research);
- The sewage sludge is a **challenging feedstock** to be processed for bio-based applications (waste-to-chemicals and bio-product value chain);
- **Short–chain Volatile Fatty Acids (SCFAs)** are the intermediates for a wide range of applications

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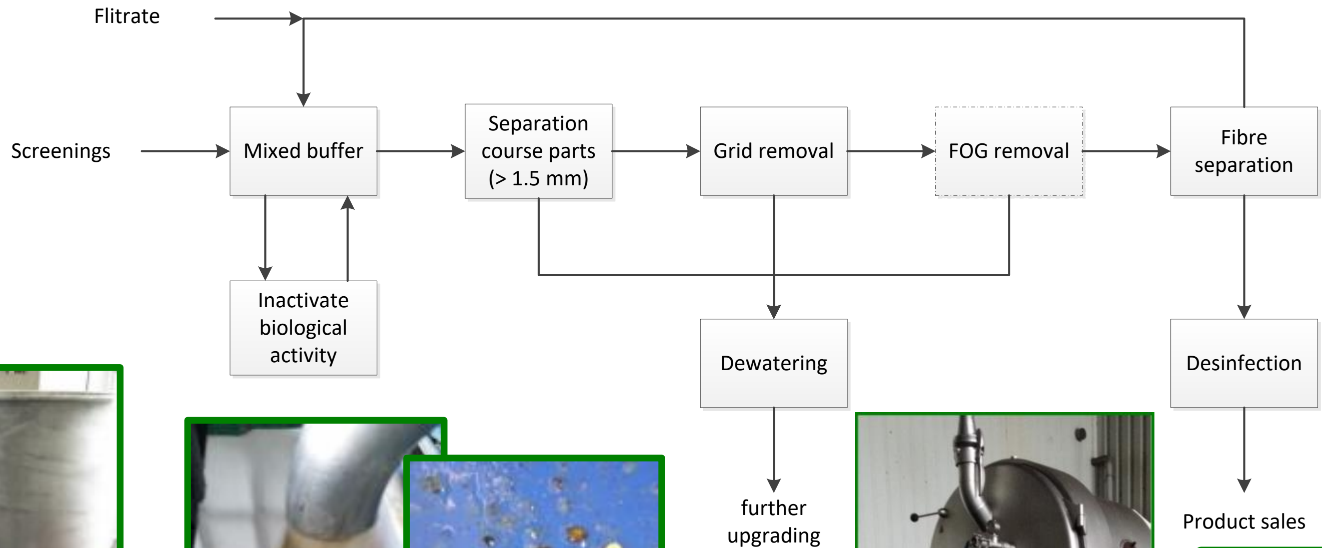
SMARTech1: Primary (upstream) dynamic sieving and clean cellulose recovery



Inactivation biological activity

Separation course parts

Sand-/grid removal

Fibre separation

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SMARTech1: Primary (upstream) dynamic sieving and clean cellulose recovery

- 79% cellulose fiber,
- 5 % other organics,
- 6% inorganic (ash),
- 10% other contaminants (average in The Netherlands).

Potentially marketable product, but the economic feasibility depends mainly on savings at the WWTP

salsnes Filter

BWA

Market development

Marketing and valorization of recovered cellulose

- ✓ Reuse in asphalt
- ✓ Raw material for composite
- ✓ Insulation materials (In development, not sure yet)

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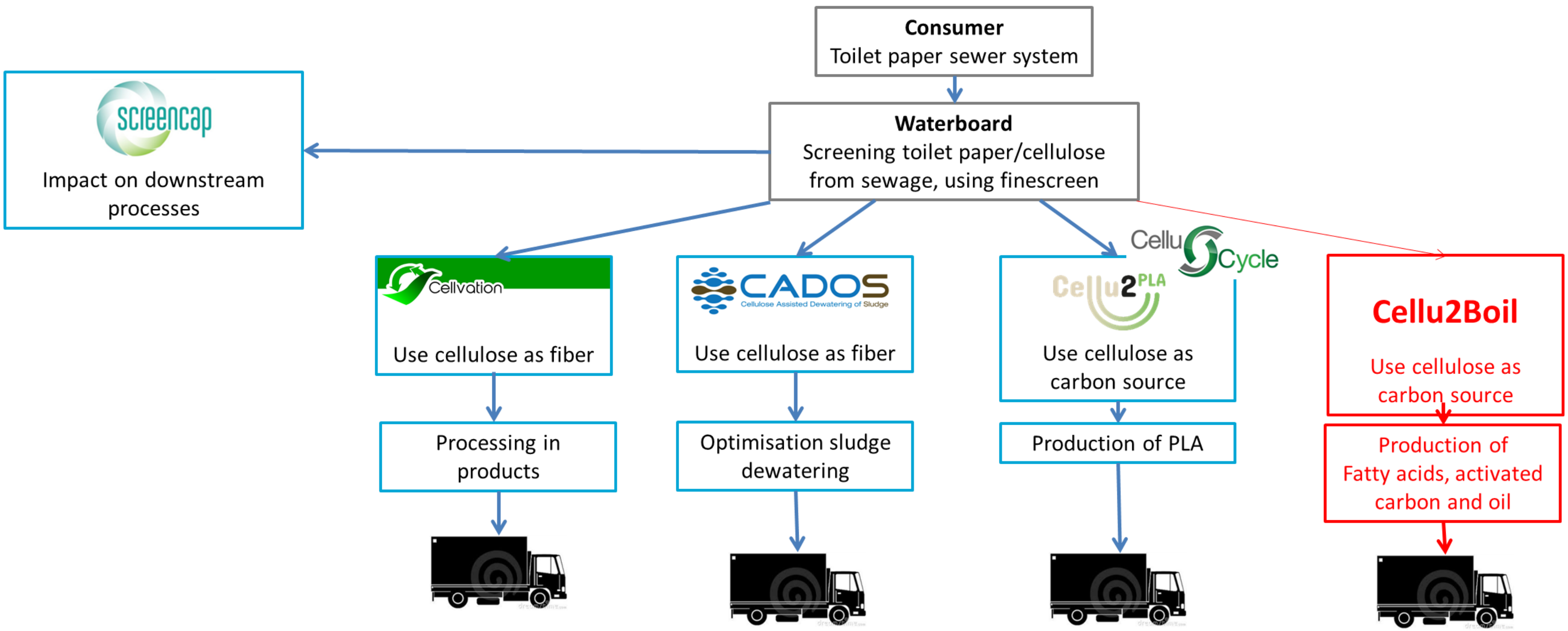
Research projects for re-use of cellulose



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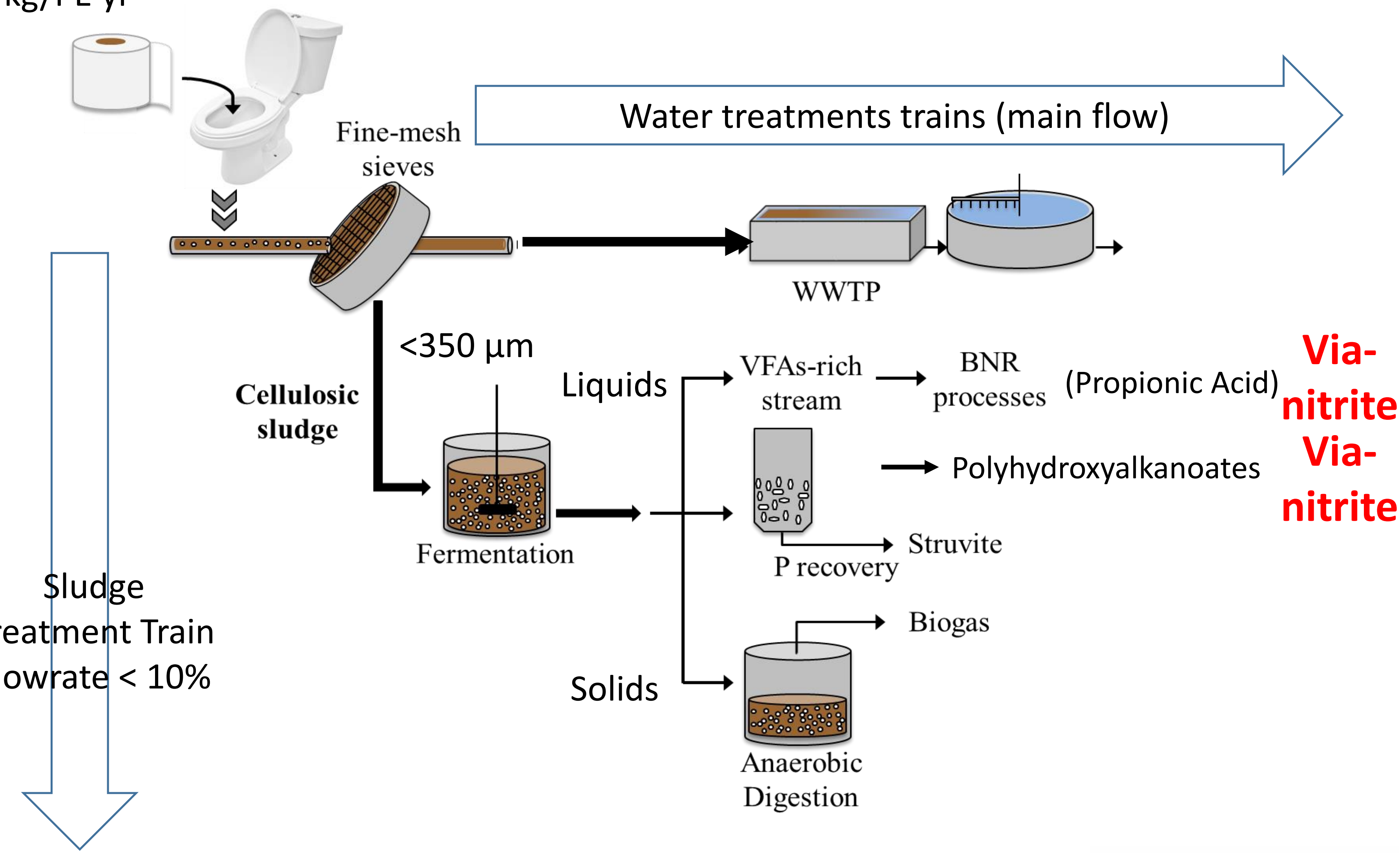
Overview about valorization of cellulosic sludge

5-15 kg/PE yr



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Role of propionic acid in the VFA mixture

- To enhance the growth of PAO vs GAO, thus the biological phosphorus removal and recovery
- To increase the content of 3-hydroxyvalerate (3HV), thus the thermoplastic properties of the recovered biopolymer

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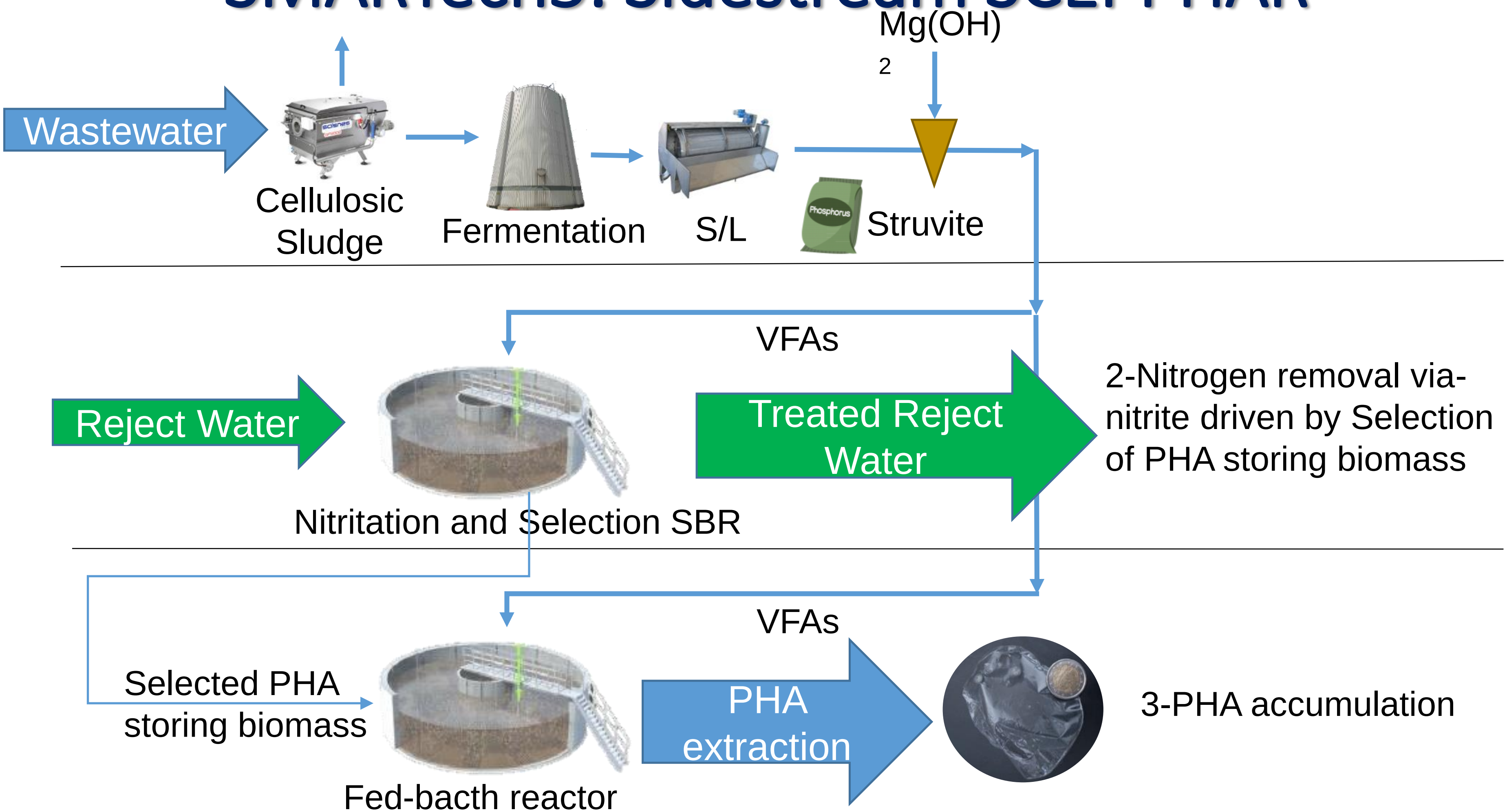
Valorization of cellulosic sludge within SMARTech5: Sidestream SCEPPHAR



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Controlled best fermenting conditions based on the sludge type: results of > 90 batch test

Sludge Type	Initial pH	Days (d)	T (°C)	Max VFAs production (mgCOD/gTVS fed)	HPr (%)
Primary Sludge (PS)	5-8	4-5	37	250-270	30-35
Mixed sludge (PS&WAS)	8-9	4-5	37	250-270	25-30
Waste Activated Sludge (WAS)	>9	4-5	37	250-270	10-25
Cellulosic sludge (CS)	**7.5-8**	**5-8**	**37**	**300-340**	**30-33**

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Characterization of the semi-continuous fermentation liquid of cellulosic primary sludge

Parameter	Average (±st.dev) (~100 days of operation)
pH	5.5-6.2
Total COD (gCOD/L)	15.9±4.1
Soluble COD (gCOD/L)	14.1±3.3
Volatile Fatty Acids (gCOD/L)	11.2±1.1
% Acetic acid (HAc)	46±4
% Propionic acid (HPr)	40±3
NH_4-N (mgN/L)	478±78
PO_4-P (mgP/L)	146±12

1) The VFAs is around 80% of the soluble COD

2) High % of HPr: ratio HPr:HAc ~ 0.9. The production of 3-HV is promoted (Albuquerque, et al. 2007)

3) High concentration of PO_4-P enable the potential recovery of struvite (10- 15 kgStruvite/tonTVSfed)

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Characterization of the anaerobic supernatant

Parameter	Average (Min- Max)
pH	7.4 (7.3 – 7.5)
Total COD (mgCOD/L)	607 (540 – 750)
Soluble COD (mgCOD/L)	360 (200-520)
Total Nitrogen (mgN/L)	720 (605-855)
NH_4-N (mgN/L)	650 (600-750)
Total Phosphorus (mgP/L)	53 (22-55)
PO_4-P (mgP/L)	39 (20 – 44)

- Total COD/ Total Nitrogen ratio ≈ 1
- VFAs represent 5-10% of the soluble COD;
- The rbCOD is les than 20% of the soluble COD.

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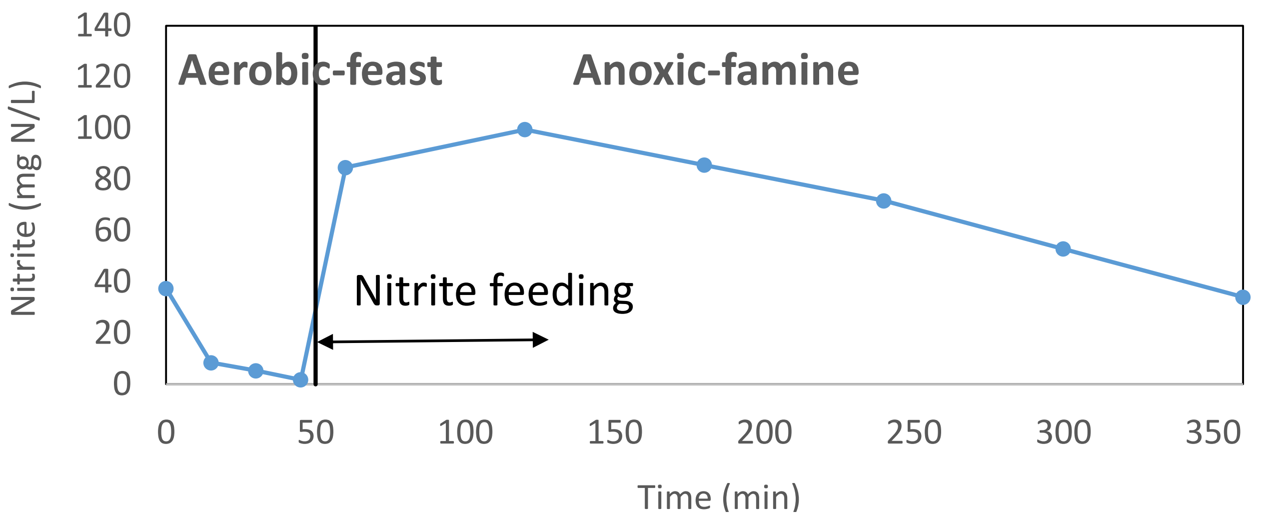
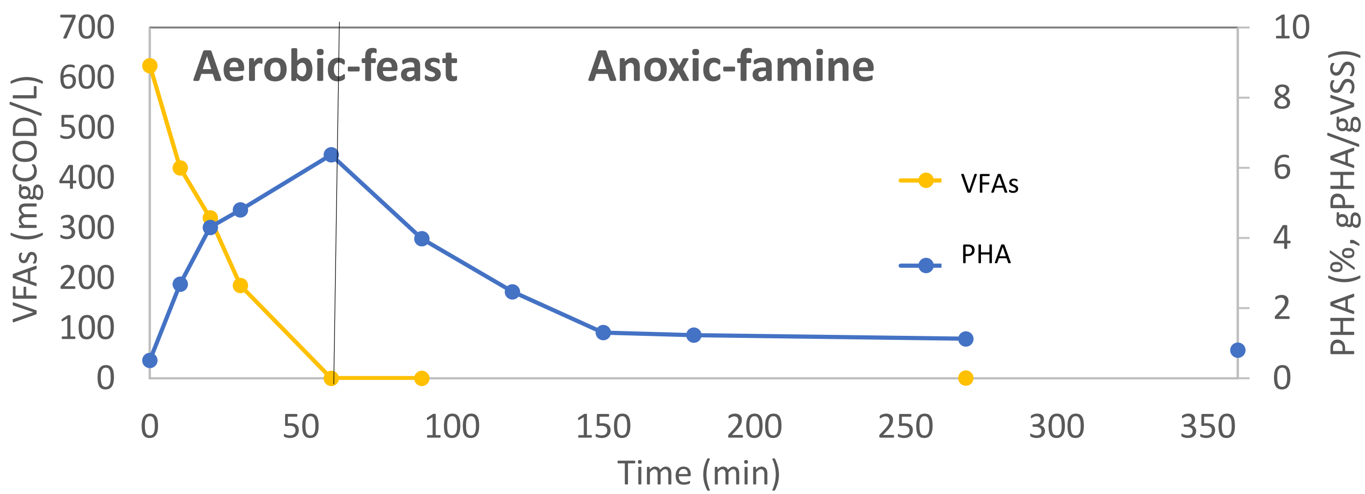
Enrichment of PHA storing biomass: S.C.E.P.P.H.A.R. cycle



Nitrite denitritation driven by PHA

Kn(20°C)=
6-8 mgNO_2-N/gVSS h



Feast phase 16% of the total cycle

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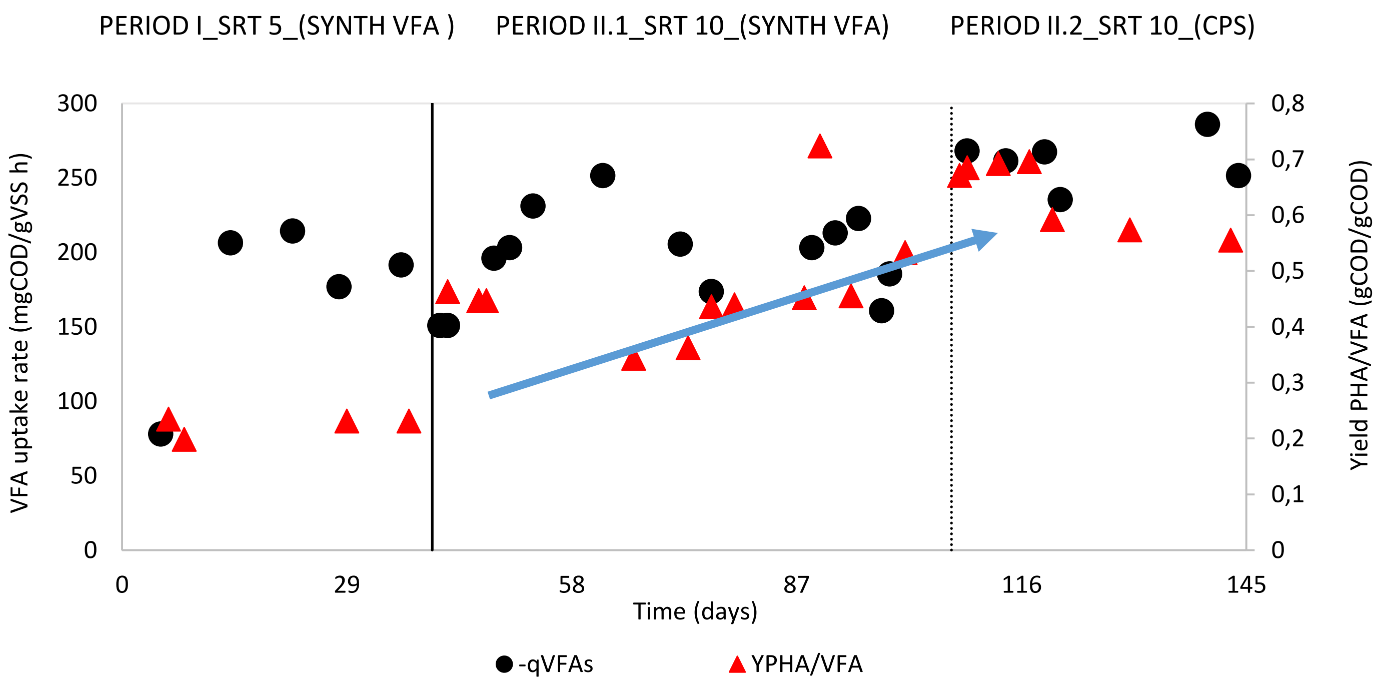
Performance of the PHA storing biomass selection

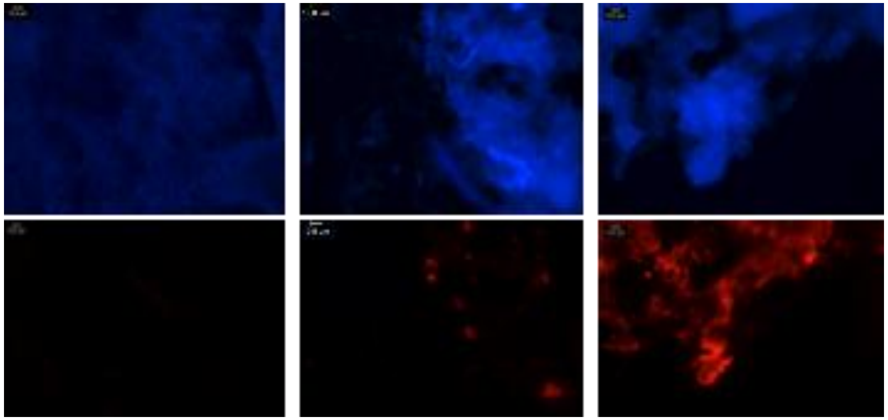
From the day 40, the $Y_{PHA/VFA}$ gradually increased (from 0.22 to 0.51 $gCOD_{PHA}/gCOD_{VFA}$), reaching the better results when the CPS was used as C-source in the period II.2 (up to 0.65 $gCOD_{PHA}/gCOD_{VFA}$).

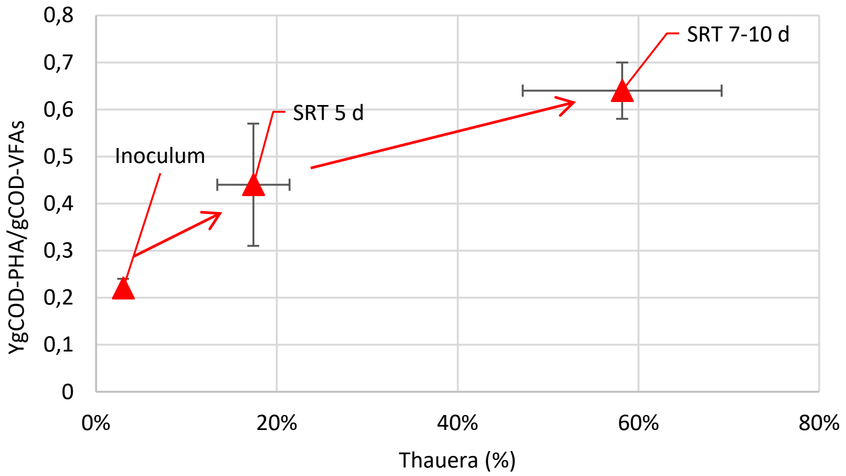


Analyses of the microbial community

Link between process performance characteristics and microbial population

Significant increase of **Thauera** concentration from 3±0 (Period I) to 58±11% (Period II.2), according with the increase of the PHA storage yields at SRT of 7-10 days.





The increase of the $Y_{PHA/VFA}$ from 0.42 (with SRT 5 days) to 0.64 (with SRT 7-10) $gCOD_{PHA}/gCOD_{VFAs}$ could be attributed to the presence of other type of organisms such as Paracoccus and Azoarcus.

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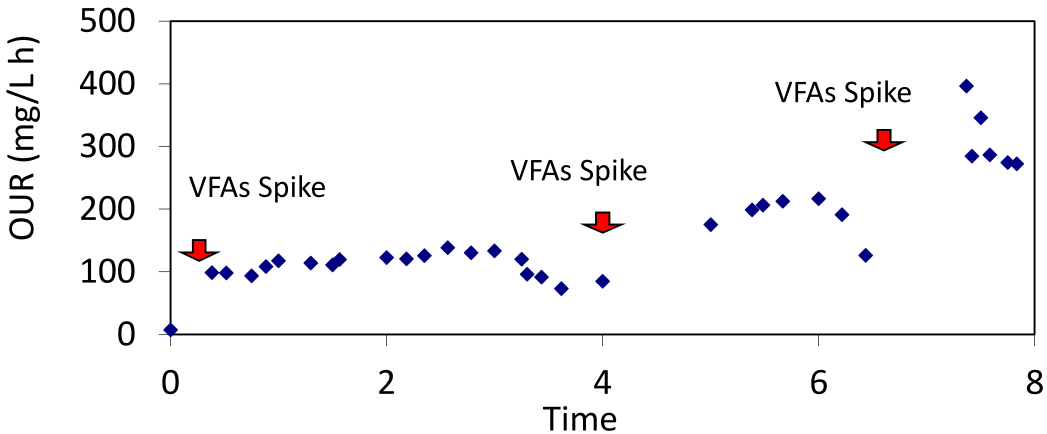
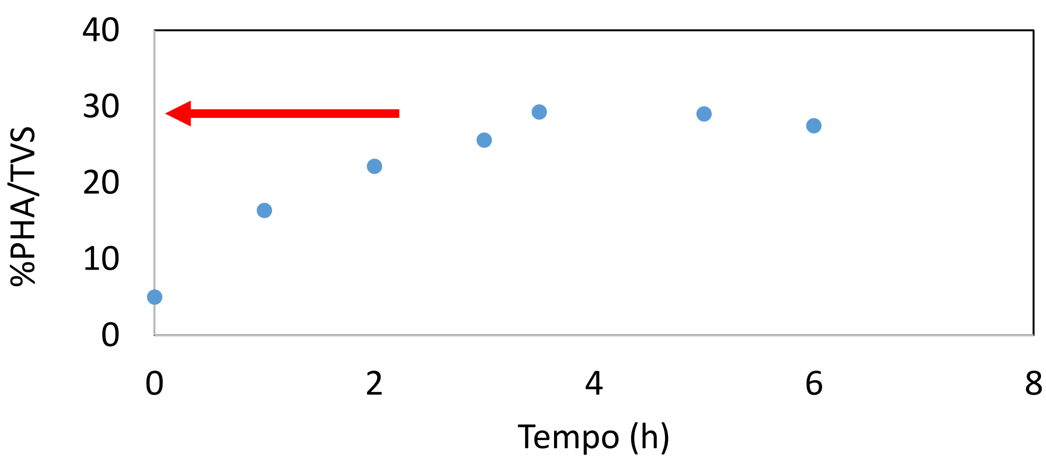
PHA accumulation



- The addition of fermentation liquid from cellulosic sludge was controlled based on the registered **Oxygen Uptake Rate** (OUR)



- High PHA storage response in the first part of the test ($Y_{PHA/VFA}$ = 0.42-0.48 gCOD/gCOD);

- Biomass growth and PHA storage are balanced in the second part of the test.

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Conclusions: via-nitrite PHA production

- The fermentation of cellulosic primary sludge from sieved wastewater provides a suitable source of VFAs for the PHA production;
- Aerobic/Feast with Anoxic/Famine regime was coupled with the via-nitrite route to treat high nitrogenous anaerobic effluent;
- After 4 hours of accumulation, the maximal fraction of PHA obtained in the biomass was around 30% (gPHA/gTVS).
- Struvite recovery from cellulosic primary sludge could be a strategy to promote the PHA storage during the accumulation stage.
- The Sidestream S.C.E.P.P.H.A.R. is the **SMARTech5** of the **Horizon2020 Smart-Plant** which will be scaled up at pilot scale (potential 0.5-0.8 kgPHA/d) within the WWTP of Carbonera (TV);

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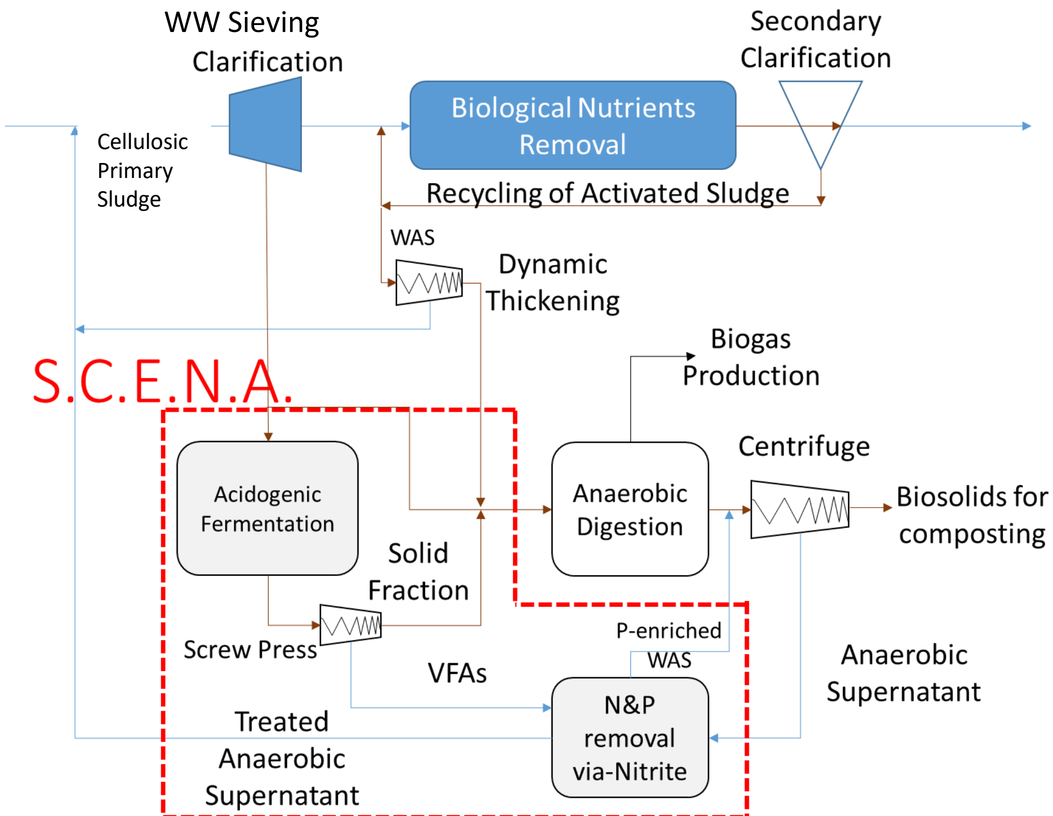
Short Cut Enhanced Nutrient Abatement (Smartech 4a)



- Volatile Fatty Acids (VFAs) production from cellulosic primary sludge (CPS) by acidogenic fermentation at 37°C;
- Nitrogen and phosphorus removal via-nitrite in a Sequencing Batch Reactor (SBR);

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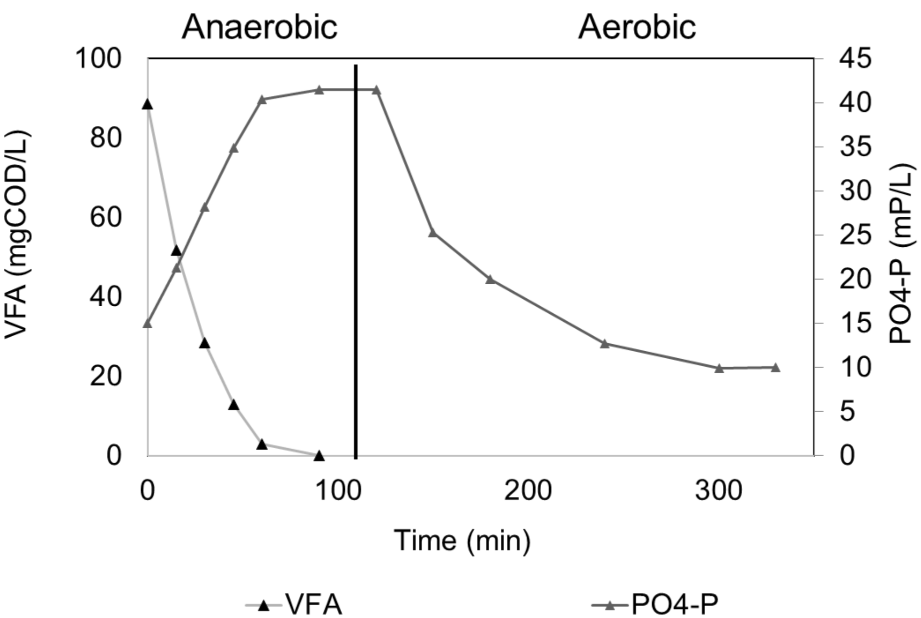
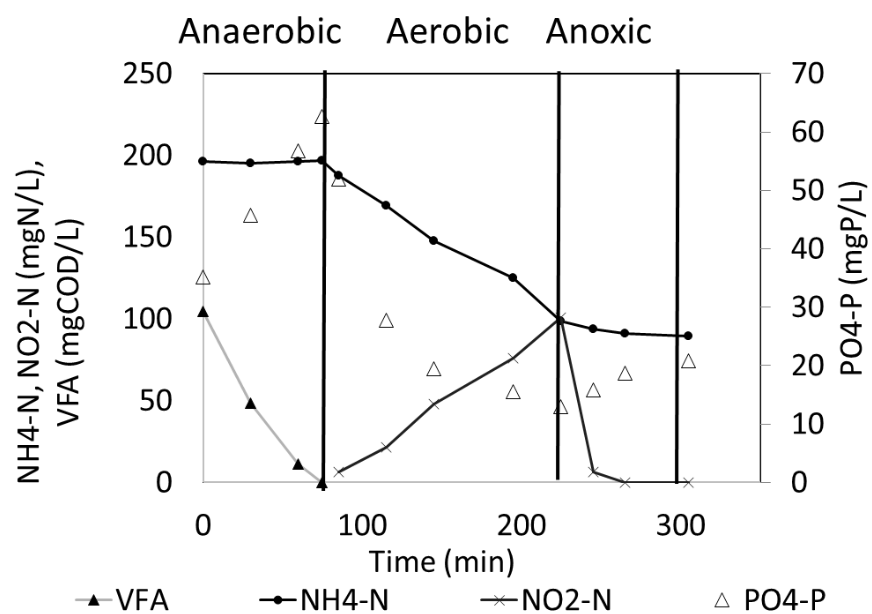
Enhanced via-nitrite BioP: Results 1/2

PAOs enrichment using fermented cellulosic primary sludge

- Effective enhanced bio-P removal process was achieved.
- The sPRR and the sPUR were stable at 3.7 and 4.7 mgP $gVSS^{-1}h^{-1}$ respectively.





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VFA for Enhanced via-nitrite BioP Conclusions

- The Short-Cut EBPR was validated at lab scale SBR using VFAs derived from the fermentation of cellulosic primary sludge for the treatment of anaerobic supernatant.

- The phosphorus concentration in the biomass cell achieved 57 mgP gTS^{-1}.

- FISH analyses showed that the presence of PAOs decreased from 50% to 20% when the short-cut EBPR was established, probably due to the increase of presence of GAOs.

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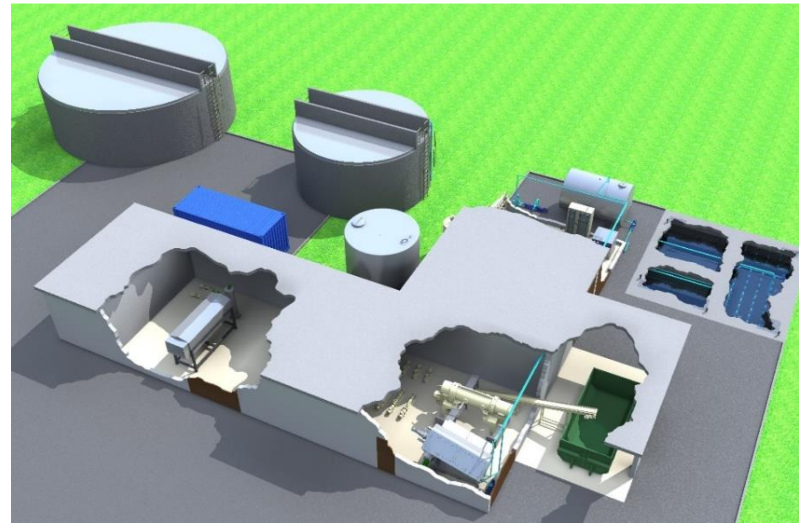

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