UNIVERSITÀ DEGLI STUDI DI PALERMO

Integrazione energeticamente efficiente della linea fanghi di impianti esistenti con sistemi via nitrito

Innovative wastewater treatment technologies *for energy saving and environmental protection*

May 20, 2016 - Palermo

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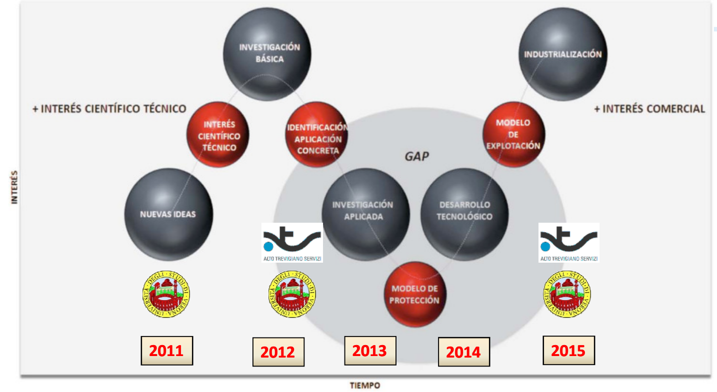
University of Verona and Alto Trevigiano Servizi srl

PRIN

IWA the international water association

DICAM Università di Palermo Dipartimento di Ingegneria Civile, Ambientale, Aerospaziale, dei Materiali (DICAM)

UNIVERSITY & WATER UTILITY - PUBLIC OVERCOMING OF THE "DEATH VALLEY" OF INNOVATION -



* M. Cermerón et al (2013) "Ecosistema de innovación sostenible. El conocimiento circular. La Transferencia de Tecnología Universidad – Empresa. Nuevos instrumentos y horizontes. Fundación CYD.

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Agenda

- **How to revamp/upgrade the sewage sludge treatment line**
- ***Short-cut Enhanced Nutrient Abatement (S.C.E.N.A.)***
- ***Short-Cut Enhanced Phosphorus and PHA Recovery (S.C.E.P.P.H.A.R.)***
- ***The Horizon2020 SMART-Plant innovation action: circular economy in wastewater treatment plant…under Italian coordination!***

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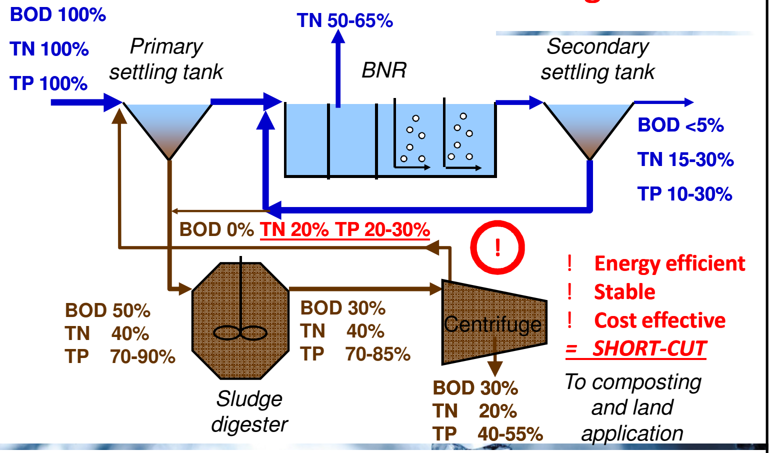
A major concern in sewage sludge treatment in WWTPs: sidestream nutrient management



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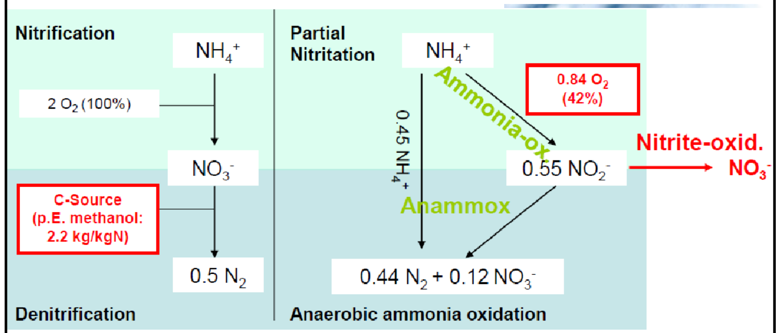
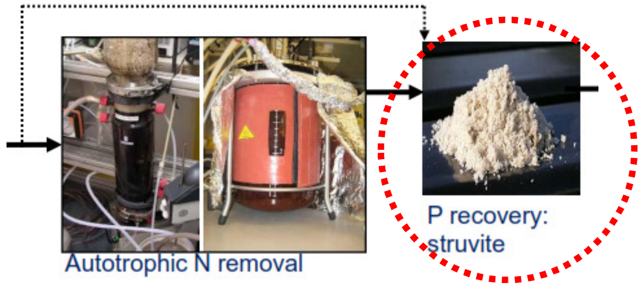
How to short-cut the nitrogen cycle



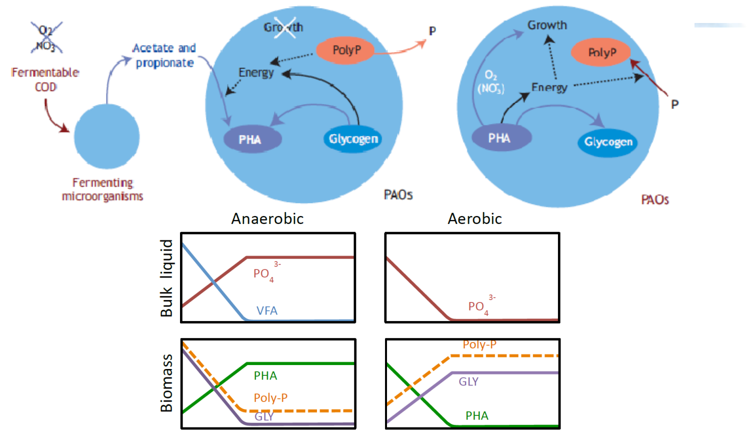
AnAmmOx is the best option for nitrogen removal, validated and robust to treat reject water. However…

What about Nitrogen and Phosphorus?

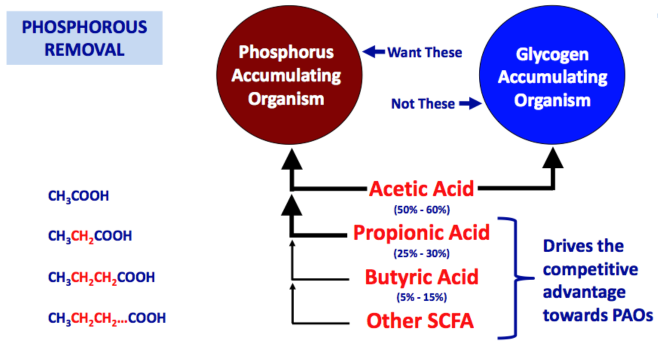


AnAmmOx + Struvite Recovery

Enhanced biological phosphorous removal (EBPR): what about NO_2 effect on anoxic uptake?



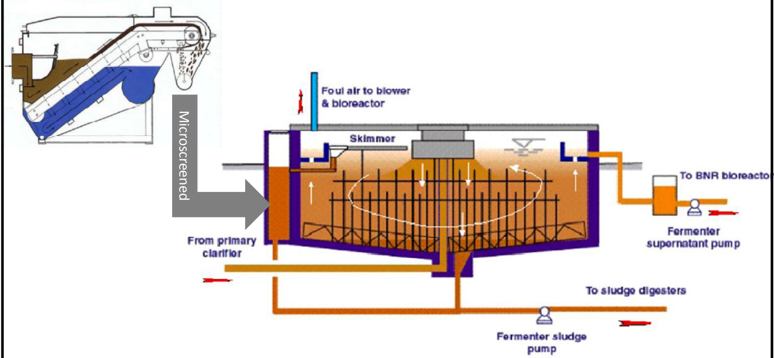
Best Available Carbon Source



Fermentation promotes production of acetate and propionate as primary by-products

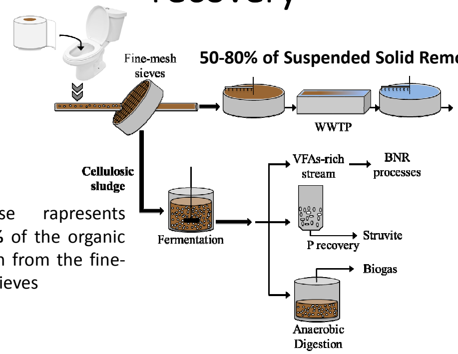
Zeng, et al (2006)
Bouzas, et al (2000)

How to recover the Best Available Carbon Source?



Controlled sewage sludge fermentation

Valorization of cellulosic sludge for VFAs and biogas production and phosphorus recovery



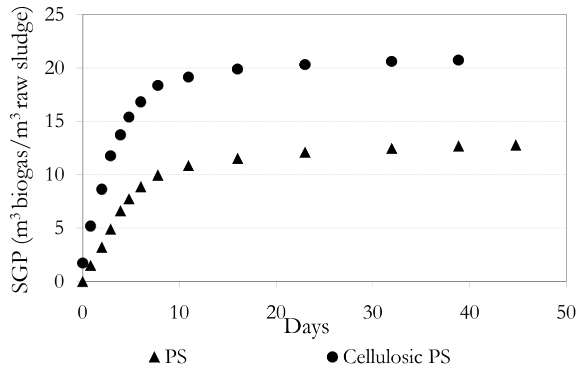
Cellulose rapresents **60-80%** of the organic fraction from the fine-mesh sieves

Controlled fermentation and sludge

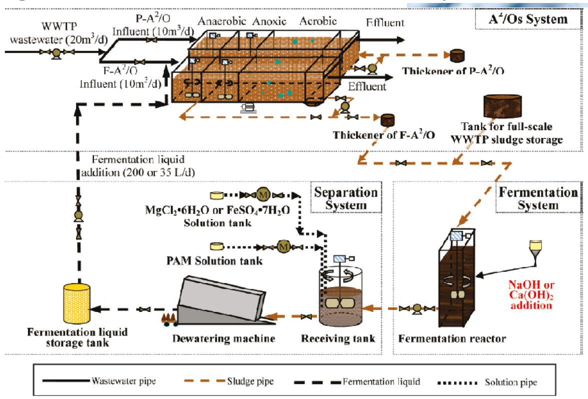
Sludge Type	Total Volatile Solid (gTVS/L)	Max VFAs production efficiency (mgCOD/gTVS fed)	HPr percentage (%)	Initial fermentation pH	Temperature (°C)
Primary sludge (PS)	20-25	250-270	30-35	5-8	37
Mixed sludge (PS&WAS*)	25-35	250-270	25-30	8-9	37
Waste Activated Sludge* (WAS)	45-50	250-270	10-25	>9	37
Cellulosic sludge	40-50	300-340	12-33	7.5-8	37

*after dynamic thickening with screw drum

Biogas production: PS vs cellulosic PS



Sludge alkaline fermentation liquid for EBPR

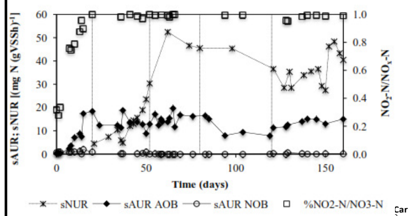


...and Chen, ES&T, 2011

The bioprocesses in the Short-Cut Enhanced Nutrients Abatement (S.C.E.N.A.)

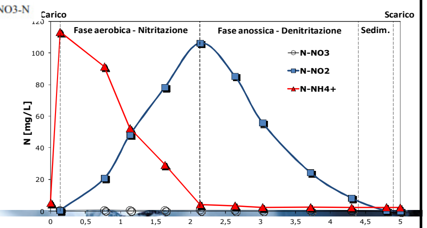
- Alkaline production of Best Available Carbon Source (BACS) from sewage sludge (or OFMSW)
- **Nitritation in aerobic conditions** (so as to also minimize N_2O emissions)
- **Denitritation and EBPR** (thanks to the BACS)
- *Sequencing Batch Reactor*
- *Control Automation on the basis of pH, ORP and conductivity*

Short-cut nitrogen removal (nitritation-denitritation)



Start-up and long term operation

Typical cycle in steady state

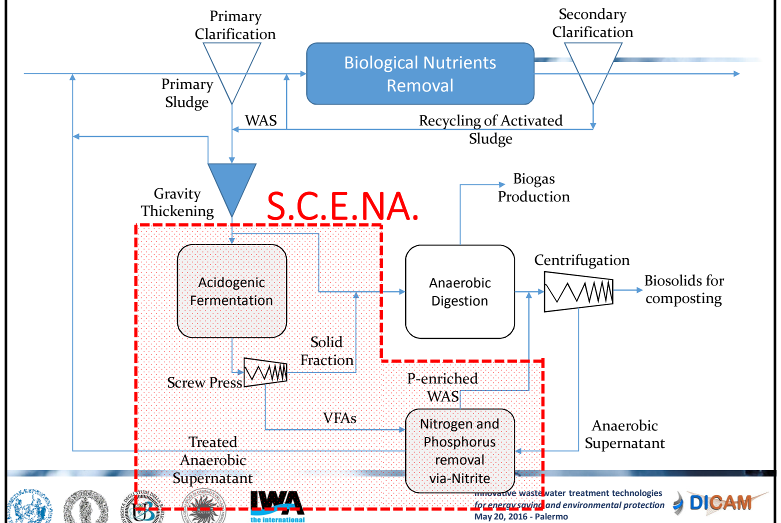


Frison et al. (2013) Chem Eng. J.

Comparison of the via nitrite with the via nitrate EBPR

- Guisasola et al. (2009) found a **higher anoxic NUR/PUR** ratio for the via nitrite EBPR compared to the respective ratio found in literature for the via nitrate EBPR. Since the energy obtained from the denitrification of one mole of nitrite is lower than the respective one for one mole of nitrate a higher amount of nitrite is required to uptake 1 mole of phosphate.
- Lee et al. (2001) found that **PUR was higher when nitrite was the electron acceptor rather than nitrate.**
- Martín et al. (2006) showed that **the dominant DPAOs of *Accumulibacter* used nitrite instead of nitrate as electron acceptor.**
- Peng et al. (2011) found that the **short-cut nutrients removal process could save more than 22.3% and 49.4% of poly-b-hydroxyalkanoate (PHA)** for phosphorus and nitrogen removal respectively compared to the conventional BNR process when a real-time step feed was employed.

Short-Cut Enhanced Nutrient Abatement



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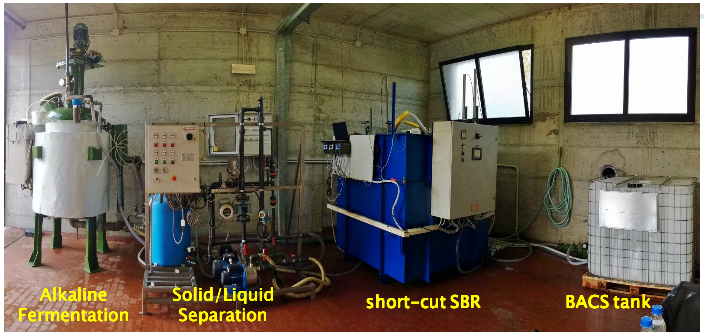
THE S.C.E.N.A. PILOT SCALE SYSTEM



0,5 m³ for mixed sludge (primary and secondary)

3 m³ SBR reactor to treat supernatant using via-nitrite process

UF membrane filtration skid

START-UP
NOVEMBER 2013

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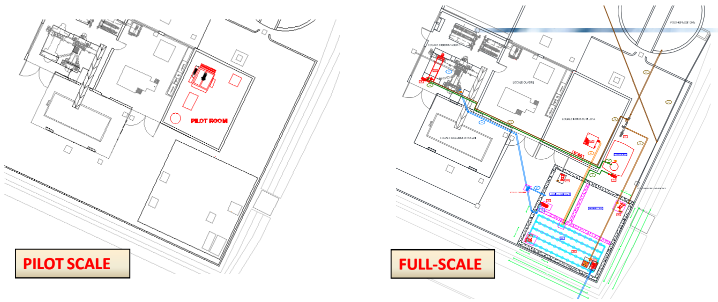
S.C.E.N.A. FULL SCALE



	VOLUME	TANK
STORAGE/EQUALIZATION SUPERNATANT	40 m³	Ex Storage of Liquid Waste
scSBR BIOLOGICAL PROCESS	70 m³	Ex Storage of Liquid Waste
FERMENTER FOR BACS PRODUCTION	50 m³	Ex Storage of Liquid Waste
BACS STORAGE	10 m³	External tank

SUPERNATANT TREATING ON S.C.E.N.A. FULL - SCALE	
m3/d	65
kgN / d	35 - 50
Kg P / d	3 - 5

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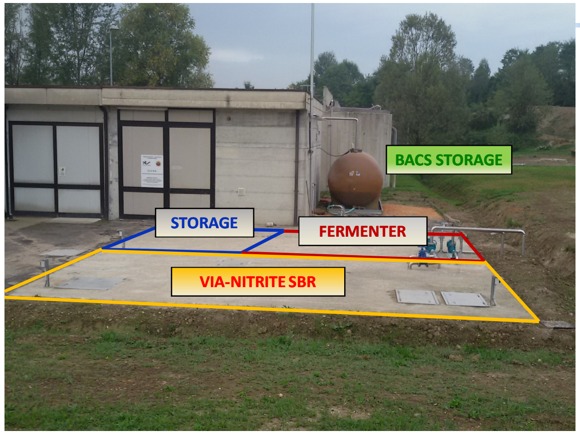
S.C.E.N.A. FULL SCALE



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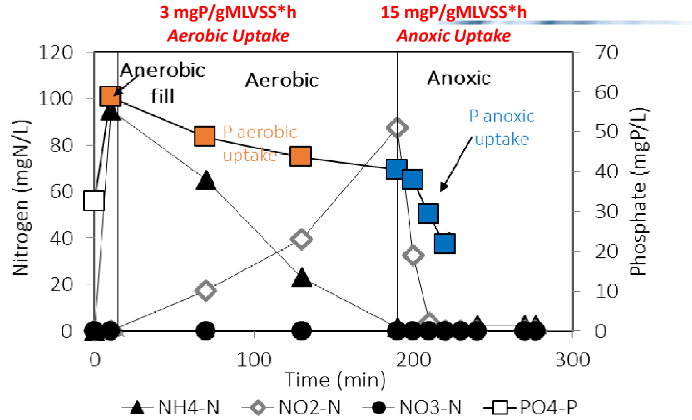
S.C.E.N.A. NITROGEN & PHOSPHORUS REMOVAL CYCLE



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SPECIFIC O&M COSTS FOR REJECT WATER TREATMENT BY SCENA

Load= 35 kgN/d									€/kgN rem ...+ Prem
ENERGY CONSUMPTION						kWh/d	130		0,72
STORAGE SUPERNATANT						kWh/d	9	7%	0,05
Storage mixer	kW	1,5	h/d	6	kwh/d	9		7%	0,05
SBR						kWh/d	56	43%	0,31
Filling pump	kW	1,3	h/d	0,6	kwh/d	0,78		0,6%	0,00
Discharge pump	kW	1,3	h/d	0,6	kwh/d	0,78		0,6%	0,00
Mixer SBR	kW	1,5	h/d	6,3	kwh/d	9,4		7,2%	0,05
Air Blower	kW	3,0	h/d	15,1	kwh/d	45,4		34,8%	0,25
FERMENTER						kWh/d	48	37%	0,26
Fermenter Mixer	kW	2,5	h	6	kwh/d	15		11,5%	0,08
Heating System	kW	5,5	h	24	kwh/d	33		25,3%	0,18
S/L SEPARATOR						kWh/d	17	13%	0,09
Sludge load pump	kW	0,4	h/d	6	kwh/d	2,4		1,8%	0,01
Screw Press	kW	0,37	h/d	6	kwh/d	2,22		1,7%	0,01
Bacs pump to storage	kW	4	h/d	2	kwh/d	8		6,1%	0,04
Poly pump	kW	0,4	h/d	6	kwh/d	2,4		1,8%	0,01
BACS dosage pump	kW	1,5	h/d	1,3	kwh/d	2		1,5%	0,01
POLYELECTROLYTE DOSAGE						kg/d	8,5		0,4
Dosage solution poly-water	lt/h	270	h/d	6	lt/d	1620			
Dosage poly	% vol	0,5%	kg/l	1,05	kg/d	8,51			
SLUDGE PRODUCTION						tonn/d	0,07		0,17
PERSONELLE									0,21
MAINTENANCE									0,10

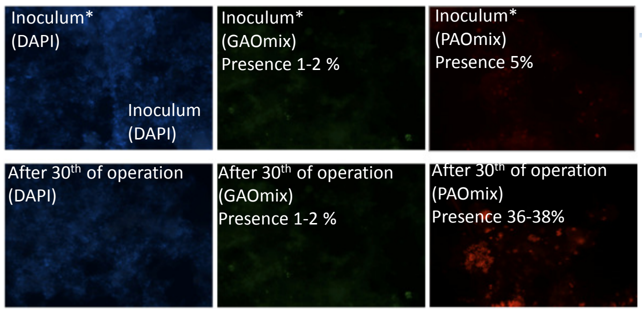
Carbonera WWTP
3,4 €/kgN rem
OPEX – 53%

1,61 €/kgN rem...+ Prem

Optimizing at 50 kgN/d → 1,1 - 1,3 €/ kgN rem...+ Prem

Investment PBP – 4-5 years

Selective pressure of nitrite and BACS



The quantification was performed using the software Jmage
* Activated sludge of Treviso WWTP.

We observed the predominance of the coccus morphology (not rod morphology) that shows the presence of nitrite-DPAO versus nitrate-DPAO (Guisasola et al., 2009; Carvalho et al.2007)

What about the selection of PHA accumulating bacteria?

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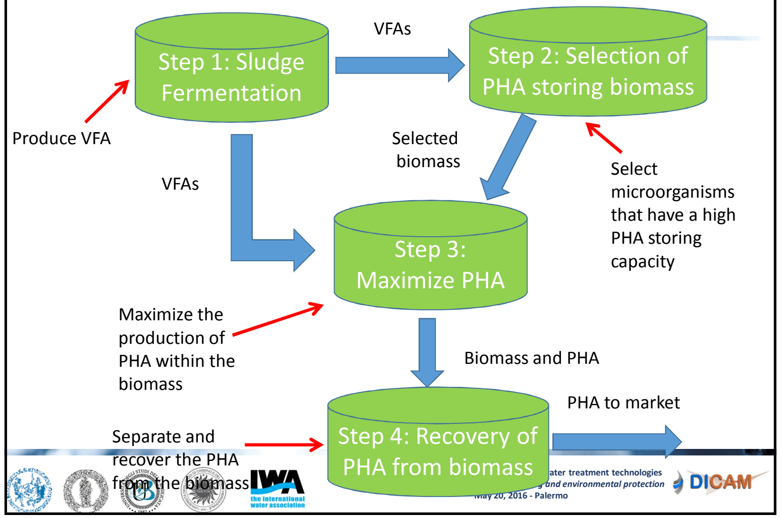
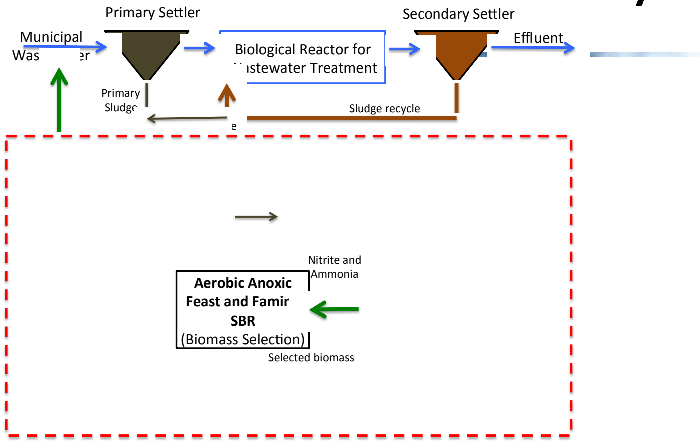
Typical steps involved in PHA production in WWTPs



Short-Cut Enhanced PHA Recovery



Frison et al., Environmental Science and Technology, 2015

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The main stages of the SCEPHAR system

VFAs production from primary sludge
Fermentantion and
Ultrafiltration with tubular membrane

Sequencing batch reactor
26 L reaction volume
Biomass enrichment

Batch PHA accumulation
Pulse manual feeding - through OUR control

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Operating parameters

vNLR (gN/m^3d)	**530±11**
Total vOLR ($gCOD/m^3d$)	1394±112
$vOLR_{VFA}$ ($gCOD_{VFA}/m^3d$)	1166±106
HRT (d)	0.8±0.1
COD/N ($gCOD_{VFA}$:gNH_4-N)	2.2±0.1
F/M ($gCOD_{VFA}$:gX_a)	0.37±0.07
Aerobic reaction time/Anoxic reaction time ratio	0.20
Feast/Famine ratio	0.13

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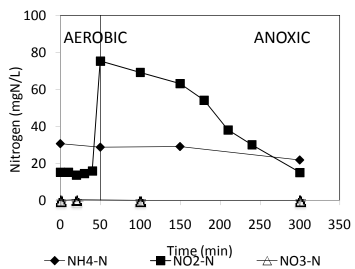
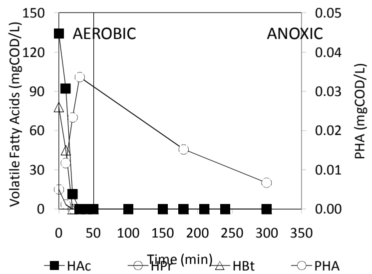
Enrichment of PHA-storing bacteria





<u>During the feast phase:</u>
-qVFA = 239 $mgCOD_{VFA}/gXa$ h
qPHA = 89 $mgCOD_{PHA}/gXa$ h
$Y_{PHA/VFA}$= 0.42 $gCOD_{PHA}/gCOD_{VFA}$

<u>Nitritation reactor + SBR enrichment biomass:</u>
vNLR up to 0.5 kgN/m^3d
Ed = 89%
En = 87 %

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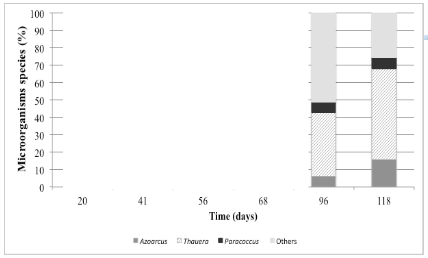
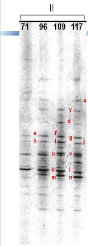
PHA accumulation

Parameter	Synthetic mixture of VFA	WSFL	SFL
Duration of accumulation	8.5	8.5	8.5
COD_{VFA}:NH_4-N:PO_4-P	100:0:0	100:7.8:0.06	100:9.7:2.1
Initial NH_4-N/ Final NH_4-N (mgN/L)	35.7/27.2	20.1/185.5	35.2/146.5
Initial PO_4-P/Final PO_4-P (mgP/L)	12.5/8.4	11.6/8.1	25.4/45.3
%PHAs (gPHA/gVSS x 100)	44±5%	21±2%	19±2%
HAc/HPr (gCOD/gCOD)	1.4	1.1	1.1
3HB (%)	60	57	56
3HV (%)	35	41	42
2HH (%)	5	2	2
$Y_{PHA/VFA}$ (gCOD/gCOD)	0.46±0.06	0.40±0.04	0.40±0.04
$Y_{X/VFA}$ (gCOD/gCOD)	0.26±0.02	0.25±0.09	0.23±0.06

Speciation of the microbial community





Very specific selective pressure on denitryfing and PHA storing strains:

- *Azoarcus olearius (enabling high PHA content)*
- *Thauera terpenica (enabling PHA with higher HV percentages)*

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Main properties of the biopolymers obtained with the different carbon sources after the accumulation tests

Carbon source	M_w (g/mol)	PDI (Mw/Mn)	T_g (°C)	T_{m1} (°C)	T_{m2} (°C)	ΔHm (J/g)	$T_{d\text{-}trans}$ (°C)
Synthetic mixture of VFA	$6.2x10^5$	1.30	-1.1	138	147	21	267
SFL	$6.5x10^5$	1.29	-0.5	136	144	24	275
WSFL	$7.4x10^5$	1.25	-1.6	141	153	27	276

M_w: average molecular weight, PDI: polydispersity index; M_n: molar number; $T_{d\text{-}trans}$: decomposition temperature (DSC analyses); T_g: glass-transition temperature; $T_{m1,2}$: melting temperature; $ΔH_m$: melting enthalpy.

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Comparison of the performance and energy consumption of SCEPPHAR with the complete aerobic PHA production process

Parameter	Unit	This study	Complete aerobic PHA production
Total PHA produced (60 %HB, 40% HV)	kgPHA/d	1.0	1.0
Total VFA needed (Selection and Accumulation)	kgCOD/d	16.5	16.5
Overall Yield of PHA production ($Y_{PHA/VFA}$)	kgCOD/kgCOD	0.11	0.11
Yield of oxygen consumption ($Y_{Oxygen/PHA}$)	kgO_2/kgCOD	106.2	165.1
Electrical energy consumption ($Y_{kwh/PHA}$)	kwh/kgCOD	23.6	36.7

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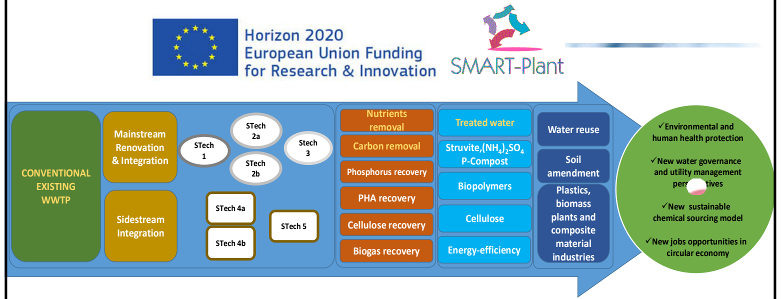
Where are we going?



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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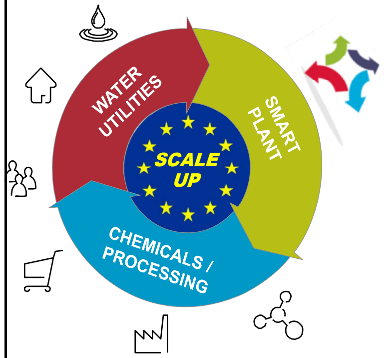

Partner n	Participant organisation name	Country
1 (Coordinator)	Università degli Studi di Verona	Italy
2	Università di Roma La Sapienza	Italy
3	Brunel University	UK
4	Cranfield University	UK
5	Universitat Autònoma de Barcelona	Spain
6	Universitat de Vic	Spain
7	National Technical University of Athens	Greece
8	Berlin Centre of Competence for Water	Germany
9	Biotrend S.A.	Portugal
10	Socamex S.A.	Spain
11	BYK Additives Ltd	Germany
12	SCAE	Italy
13	AGROBICS Ltd	Israel
14	Salsnes Filter A.S.	Norway
15	Instituto de Biologia Experimental e Tecnológica	Portugal
16	Athens Water Supply and Sewerage Company	Greece
17	Alto Trevigiano Servizi S.r.l.	Italy
18	Mekorot Water Company Ltd	Israel
19	Aiguas de Manresa S.A.	Spain
20	BWA B.V.	Netherlands
21	Execon-Partners Gmbh	Switzerland
22	SEVERN TRENT WATER Ltd	UK
23	Aktor SA	Greece
24	Vannplastics Ltd. (Ecodek)	UK
25	Wellness Smart Cities SLU	Spain

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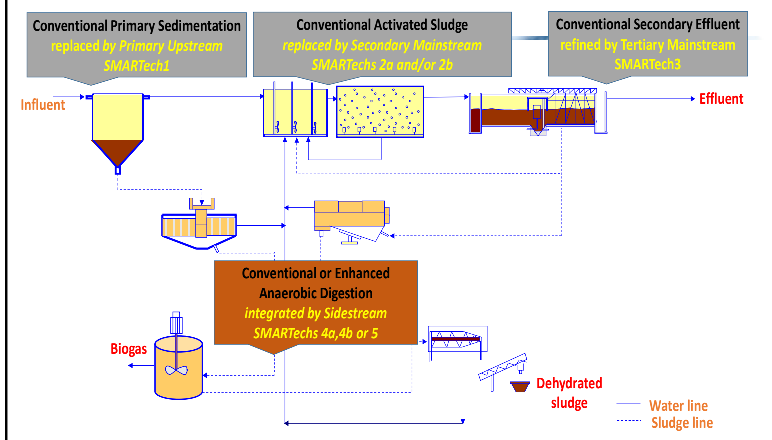

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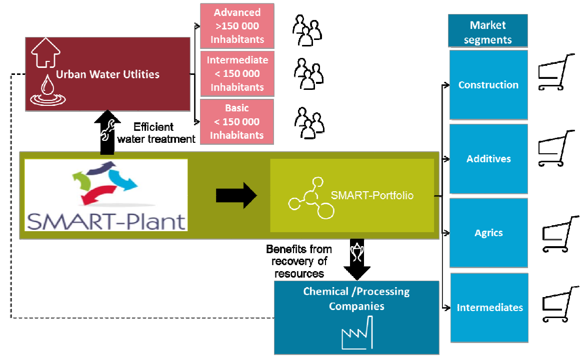
Where are we going?

Schematic view of SMART-Plant Model



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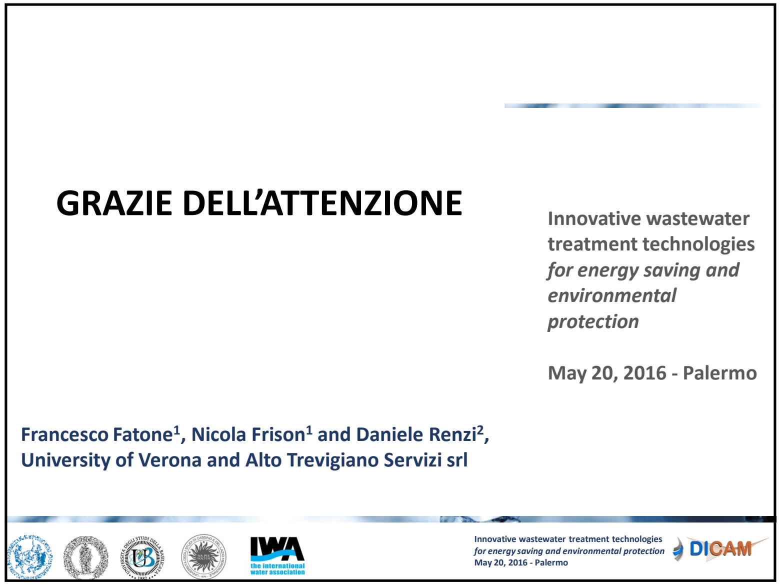
GRAZIE DELL'ATTENZIONE
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