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European Union European Regional Development Fund
REEF 2W

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Brussels, 06/June/2019

Energy and material recovery and reuse in municipal wastewater systems

Francesco Fatone

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Contents of the presentation

- The framework: **circular economy** and **water-energy-carbon-food nexus in water systems management**
- **Standardization of energy audit**: the H2020 ENERWATER
- **Energy pathway to deliver CE** in full scale and H2020 IA
- **Energy-efficient materials pathway**: H2020 SMART-Plant
- Brief outlook: **«Water reuse – energy» nexus** in H2020 DWC and HYDROUSA project

Water & Circular Economy Principles

- Principle 1: **Design out waste externalities**
- Principle 2: **Keep Resources in Use**
- Principle 3: **Regenerate Natural Capital**

McArthur Foundation et al., 2018

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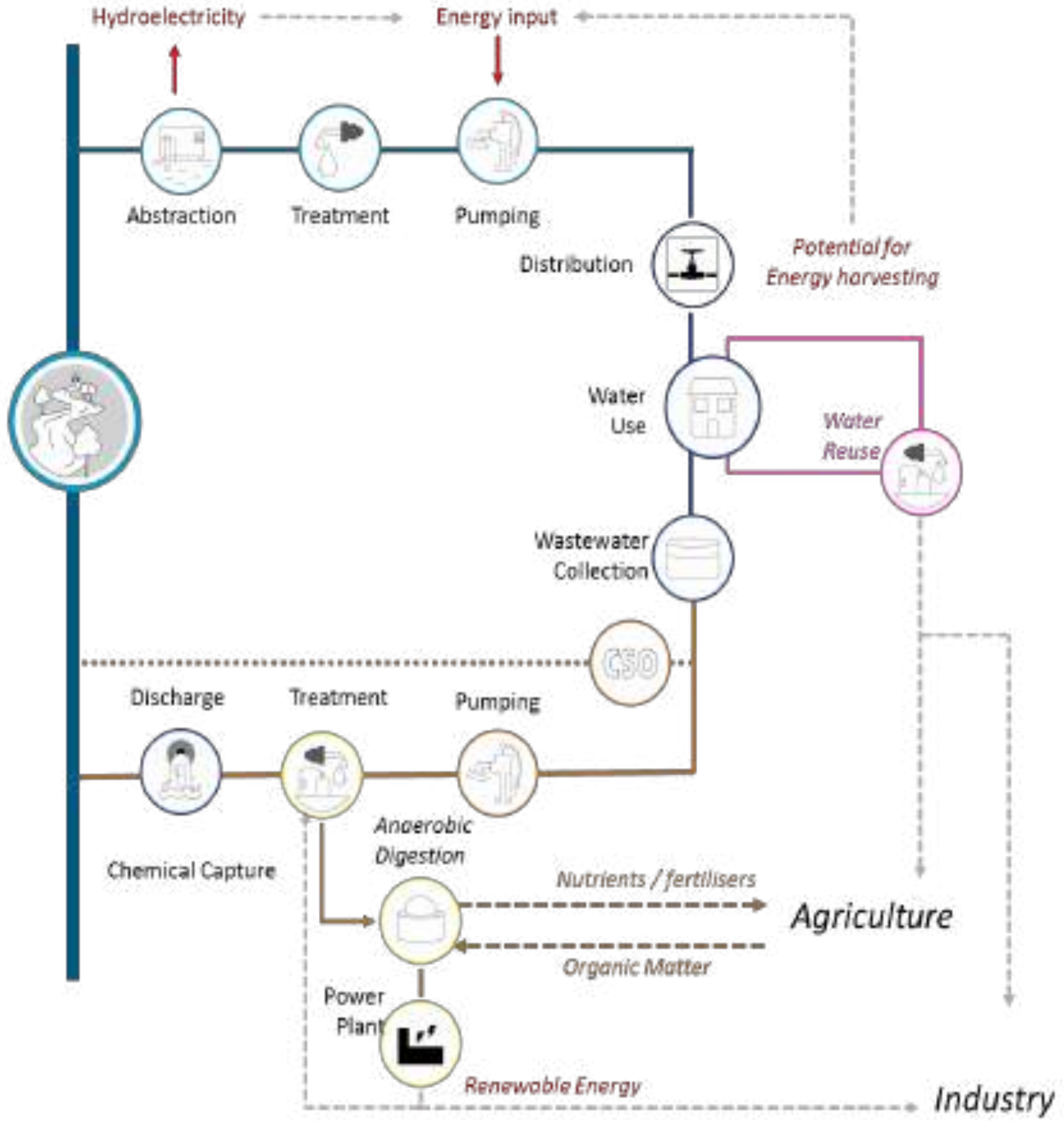
Opportunity

Holistic view of multiple Circular Economy opportunities across a municipal water system



McArthur Foundation et al., 2018

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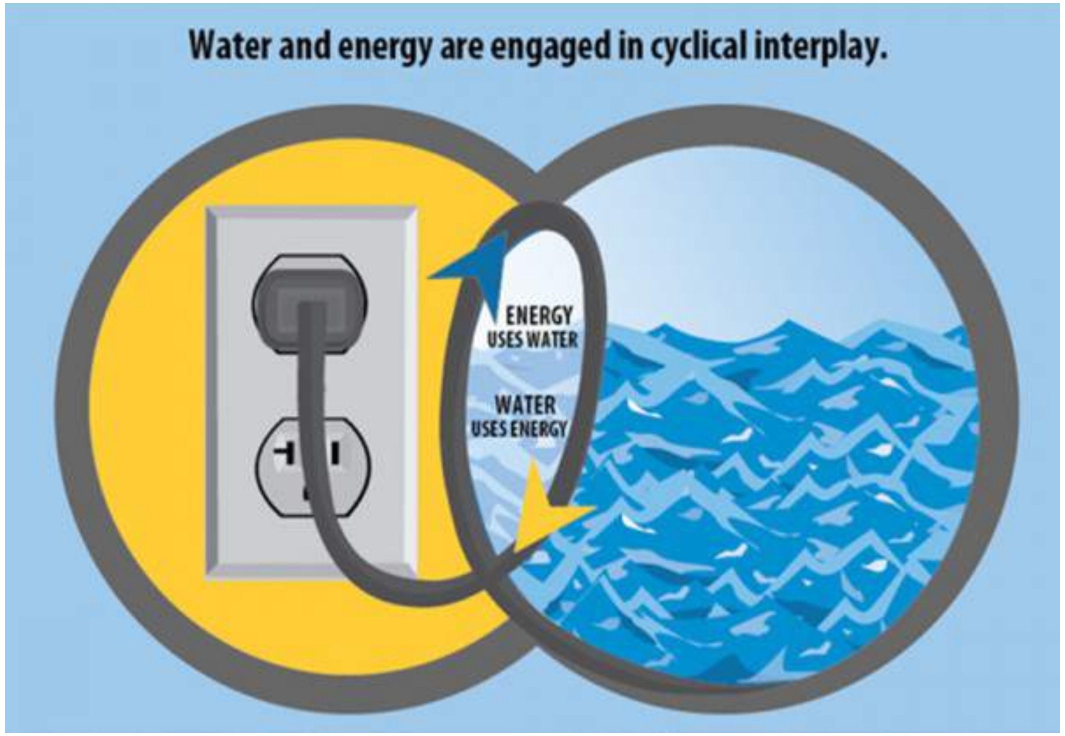
Energy and water are highly interconnected

0.33*

m^3/kWh

water demand for energy production



1.78*

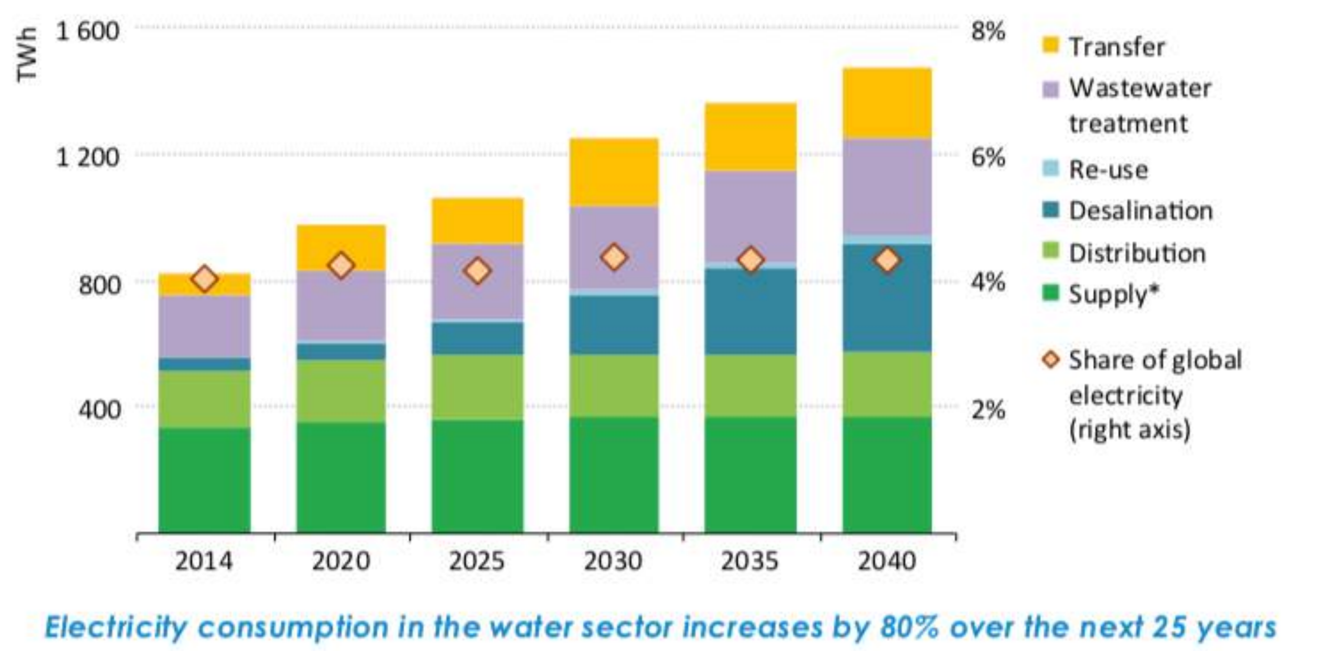
kWh/m^3

energy demand for domestic water use

* Including electricity, thermal energy and gas. Data from International Energy Agency (2016), own calculation.

Courtesy from Stefano Longo (H2020 ENERWATER Consortium)

Energy and water are important demands set to increase

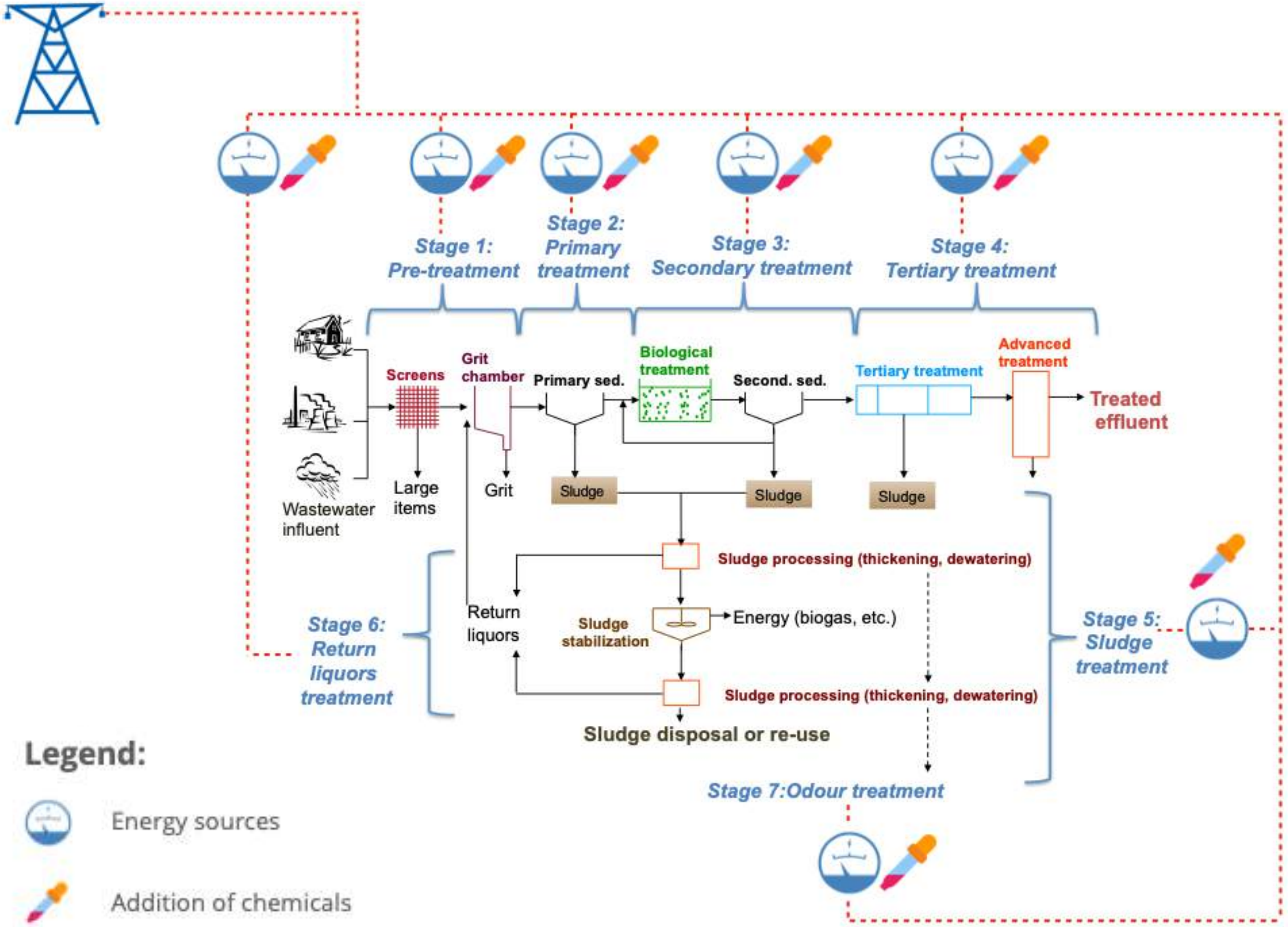


International Energy Agency (2016)

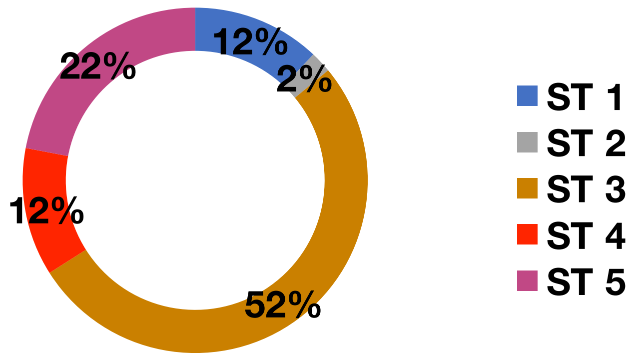
- About 800 TWh of electricity are consumed for the water cycle
- Equal to 4% of the global consumption
- 20-30% of electricity consumed in the water cycle is for wastewater treatment
- Electricity consumption is set to increase due to:
  - increasing number of people who have access to water
  - increasing effluent requirements

Courtesy from Stefano Longo (H2020 ENERWATER Consortium)

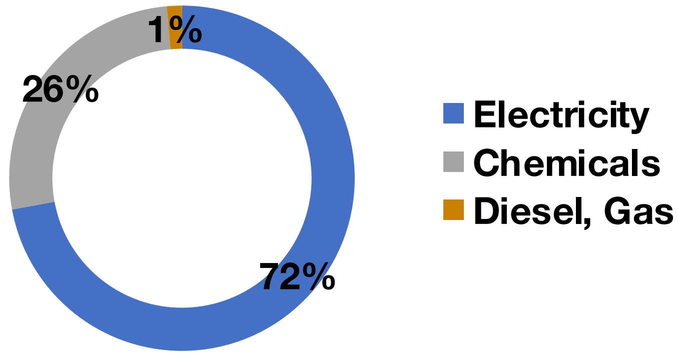
WWTP energy footprint



Where?



What type?



Courtesy from Stefano Longo (H2020 ENERWATER Consortium)

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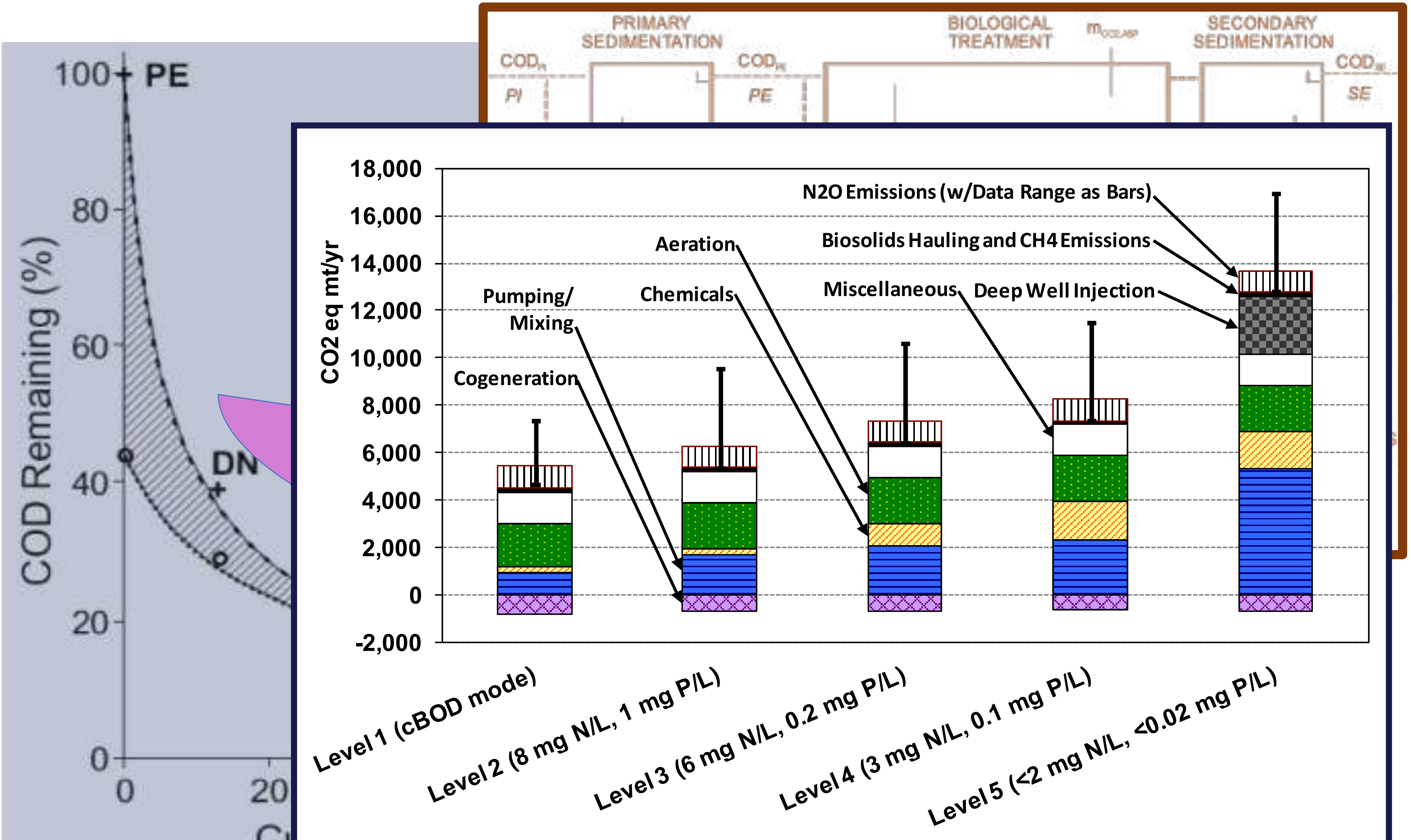
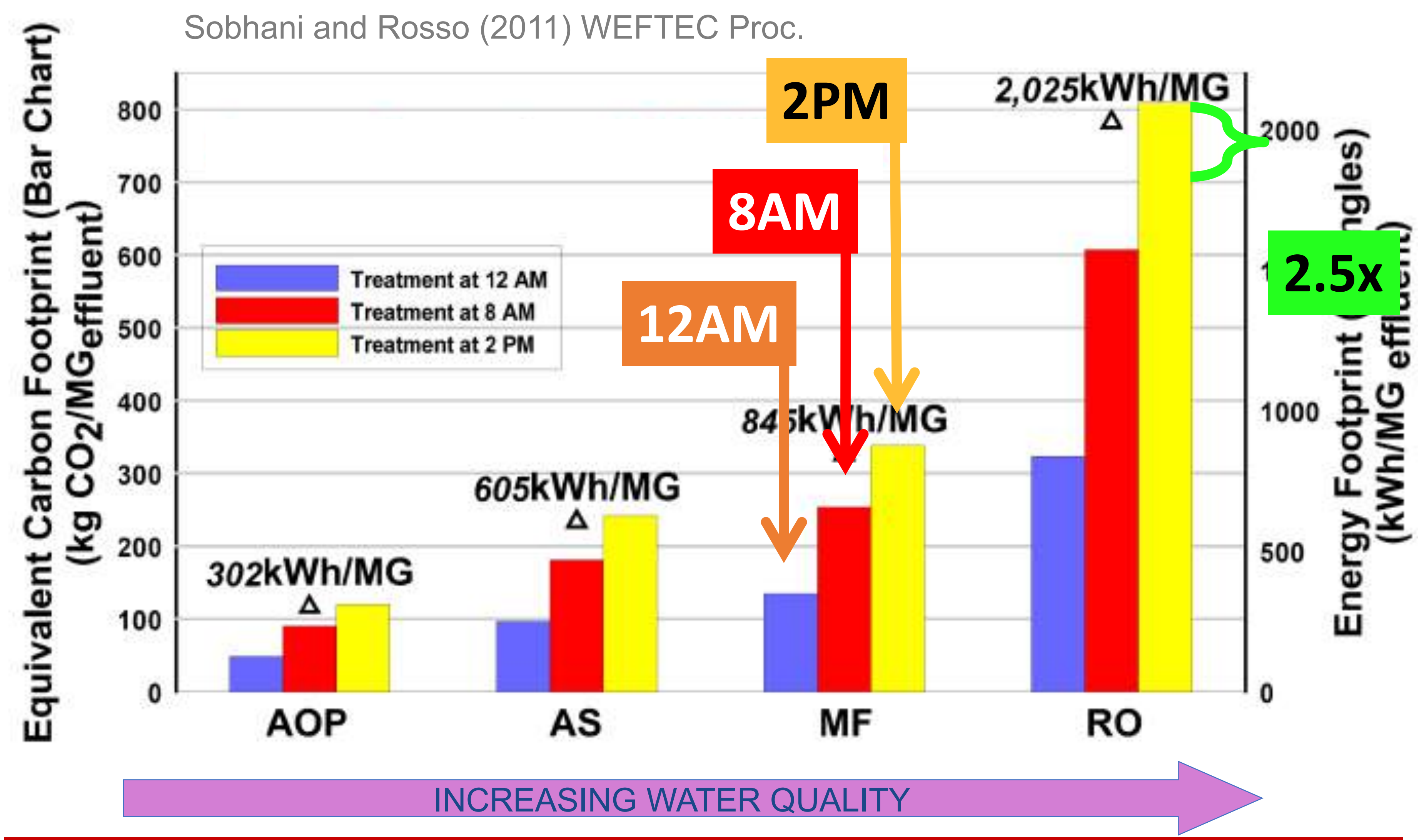
Case Study:
Energy vs. Product Water Quality



Neethling et al (2011) Proc. WEFTEC

Energy Intensity in Water Reuse



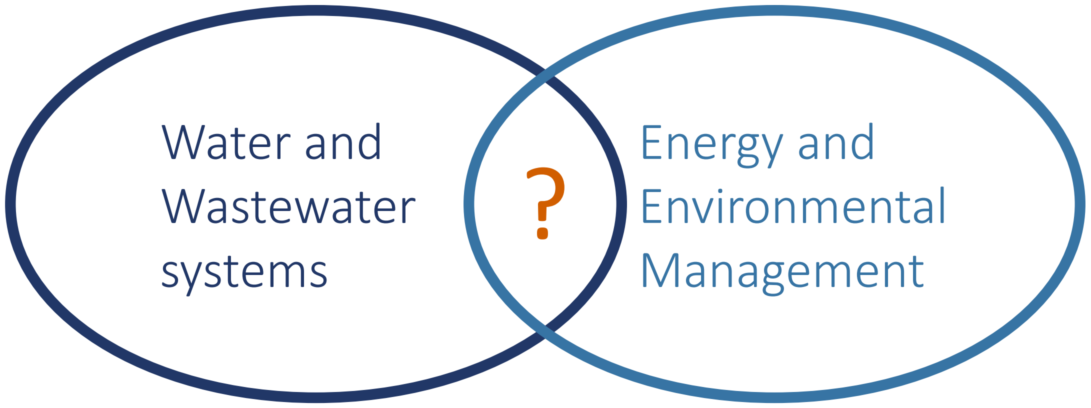
NORMALIZED METRICS DO NOT NECESSARILY REFLECT ACTUAL IMPACT

The water-energy policy context

EU Energy Efficiency Directive (EED)

- Under the EED all EU countries are required to use energy more efficiently at all stages of the energy chain from production to final consumption
- The EED establishes a set of binding measures to help the EU reach its 20% energy efficiency by 2020.
- Big enterprise (including water utilities) are obliged to carry out energy audit. However, EED and its transposition do not imposes a specific regulation for the water sector

There no exist energy efficiency standards in WWTP



Wastewater treatment
(EN 12255-1-16)
Drinking water
(ISO 24510:2007)
Water re-use
(ISO/AWI 20468)

Energy audit
(EN 16247-1-3:2012-2015)
Energy management
(EN ISO 50001:2011)
Energy efficiency
(EN 16212:2012)
Life cycle assessment
(ISO 14040:2006-14044:2006)
Greenhouse gases
(ISO 14064-1-2:2006)

Courtesy from Stefano Longo (H2020 ENERWATER Consortium)

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How to define energy efficiency in WWTPs?

Energy efficiency = relationship between the production of a service or good and the consumption of energy

Input → Energy (electricity, diesel, gas, chemicals)

―――――

Output → Good or service (pumping, TS removal, nutrient removal, pathogen removal, sludge handling etc.)

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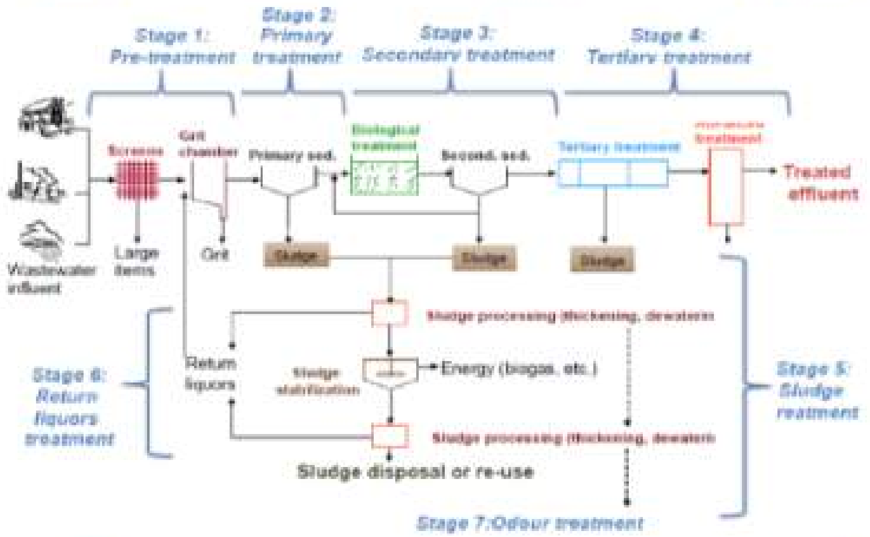
ENERWATER methodology: overview

Check the energy consumption and determine the KPIs

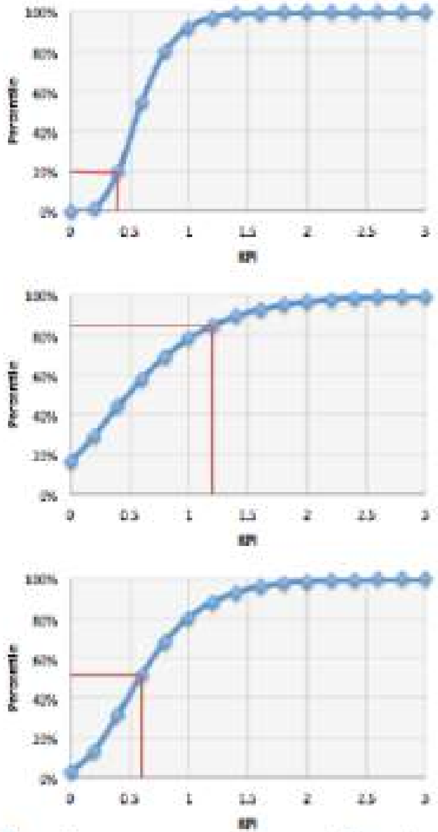
$KPI_1 = \frac{kWh}{m^3 \text{ of water treated}}$ $KPI_2 = \frac{kWh}{\text{kg solids removed}}$ $KPI_3 = \frac{kWh}{\text{kg pollutant removed}}$ $KPI_4 = \frac{kWh}{(m^3 \cdot \text{log reduction of pathogens})}$



$KPI_6 = \frac{kWh}{\text{kg nitrogen removed}}$ $KPI_7 = \frac{kWh}{\text{kg volatile organic compound}}$ $KPI_5 = \frac{kWh}{\text{kg sludge treated}}$

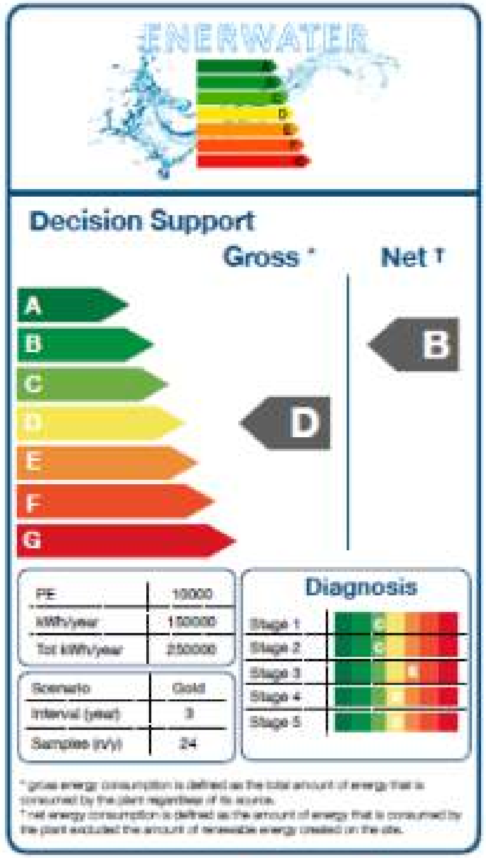
WWTP divided into functions -> a KPI is associated to each function performance

Compare vs other WWTPs



Assign a percentile to each KPI with a 600 WWTPs database

Get the energy label



Diagnosis of inefficient processes. Communication through the energy label

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ENERWATER methodology: Define

There is a clear need to establish suitable KPIs within the WWTP that allow a comparable, realistic and universal form of reporting the energy data.

STAGE	FUNCTION	KPI
STAGE 1	Pumping	kWh/m^3
STAGE 2	Solid removal	$kWh/kg\ TSS_{removed}$
STAGE 3	Pollutants removal	$kWh/kg\ TPE_{removed}$ *
STAGE 4	Pathogens removal	$kWh/Log_{\ reduction}*m^3$
STAGE 5	Sludge handling	$kWh/kg\ TS_{processed}$

* kgTPE (total pollution equivalent) = kgCOD+20 kgTN+100 kgTP
Benedetti et al. 2008

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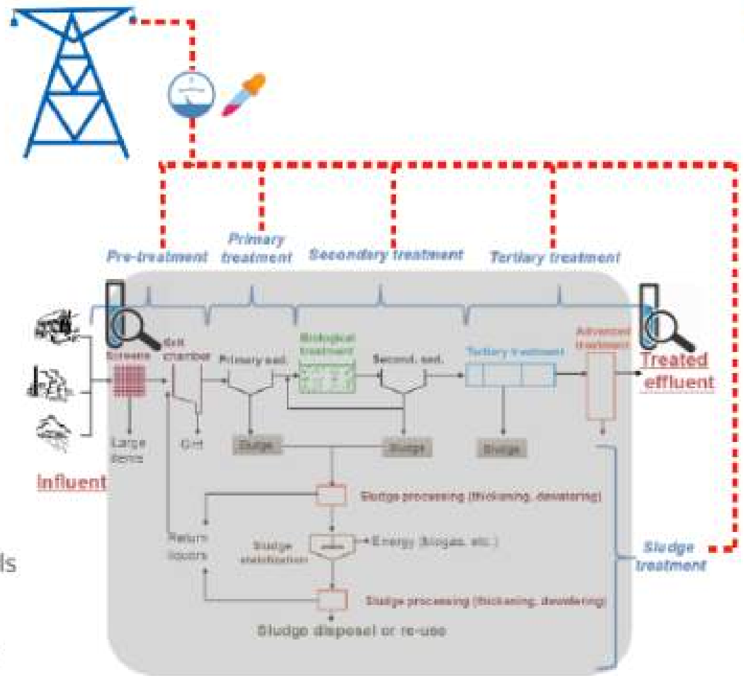
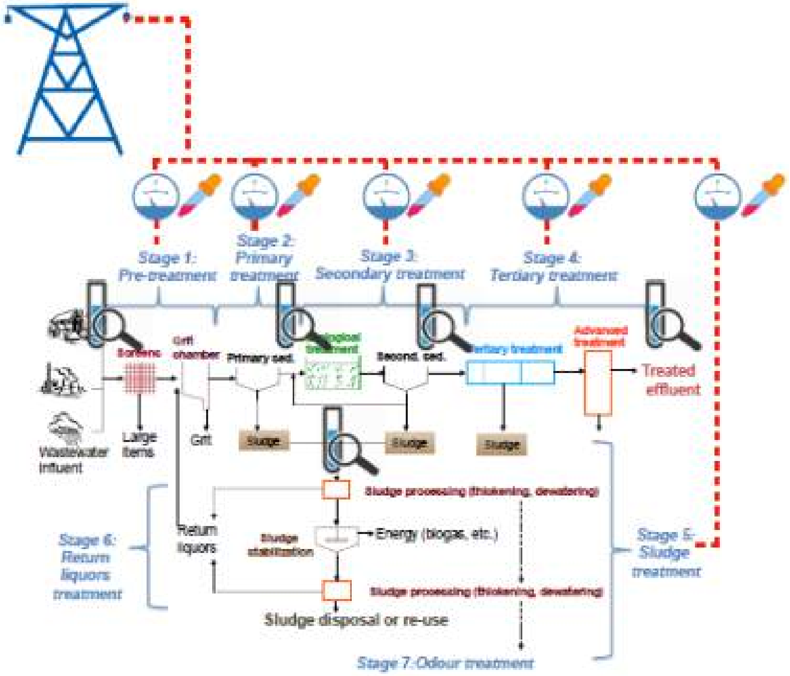
ENERWATER: Rapid audit and decision support

Rapid Audit



Decision Support



Legend:

- Energy sources
- Addition of chemicals
- Sampling + analysis

	Rapid Audit	Decision Support
Energy consumption data	- Aggregated energy consumption from energy bills	- Disaggregated online data from energy meters on site
Operational data	- Routine influent/effluent analyses	- Per section influent/effluent analyses
Objective of the analysis	- Energy benchmarking	- Energy benchmarking - Diagnosis

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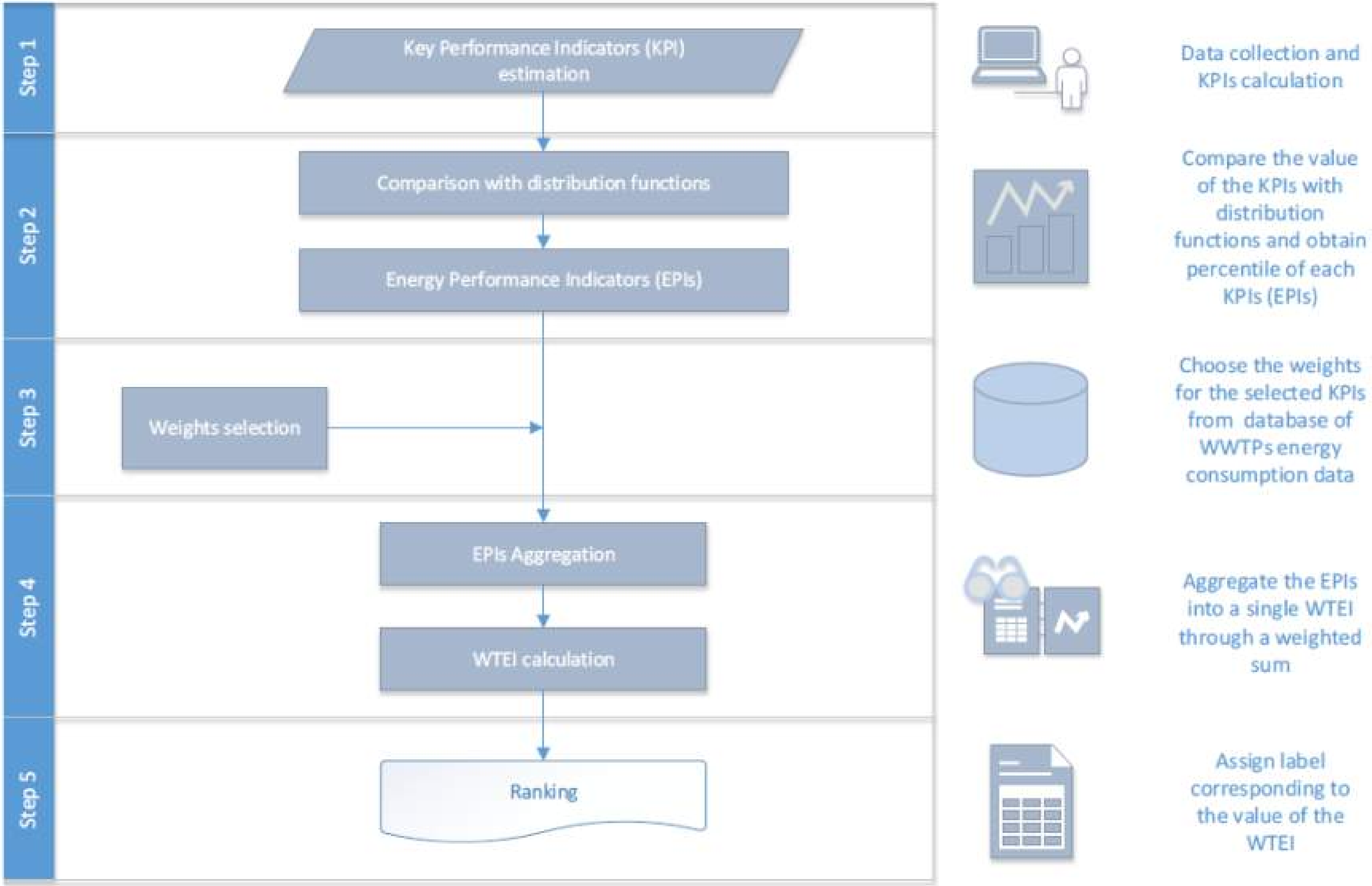
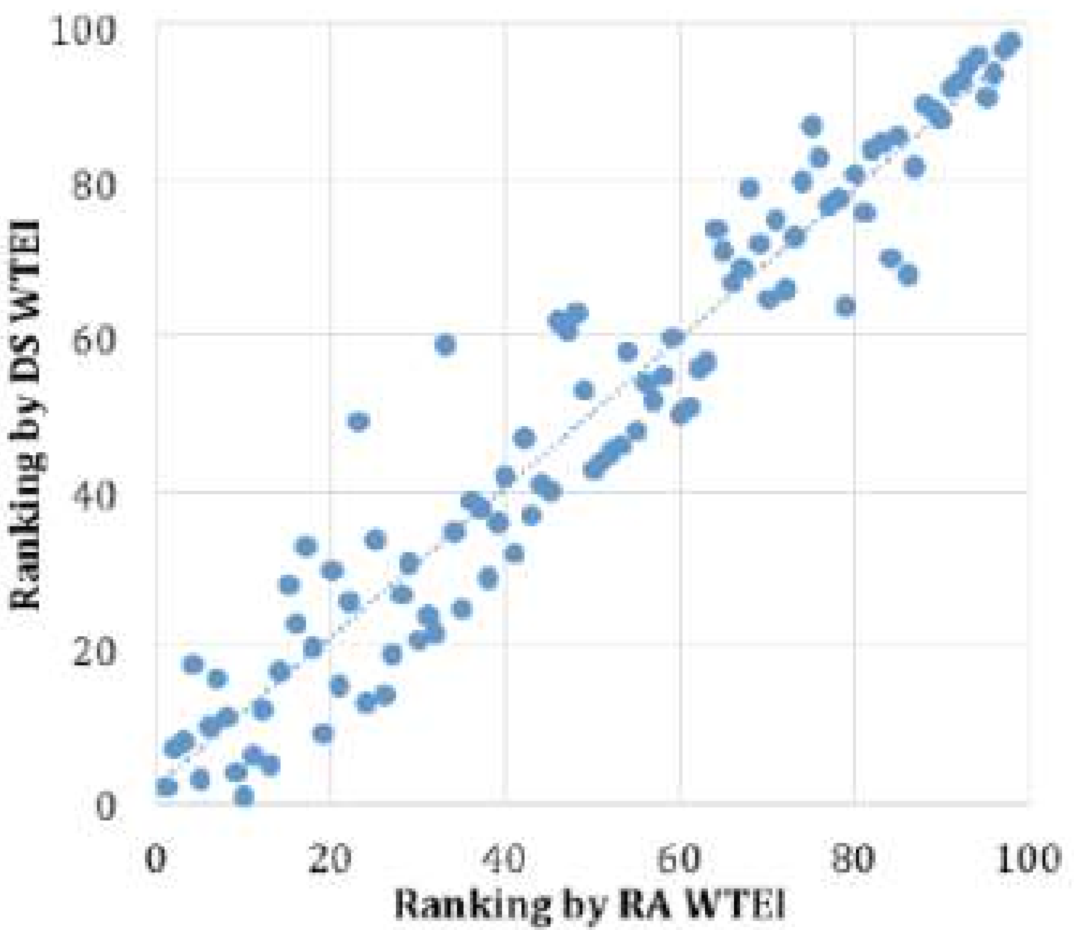
Water Treatment Energy Index (WTEI) calculation

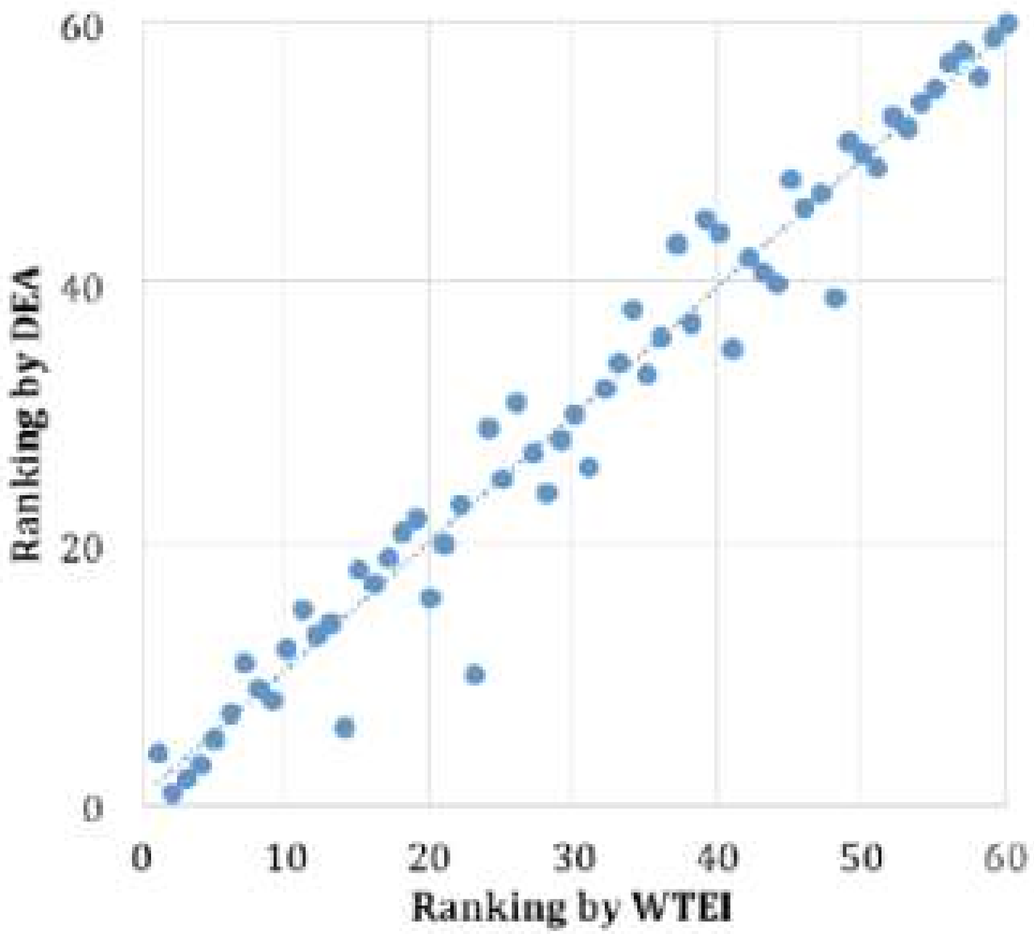


Data validation

Internal validation: RA vs DS



External validation: ENERWATER vs DEA



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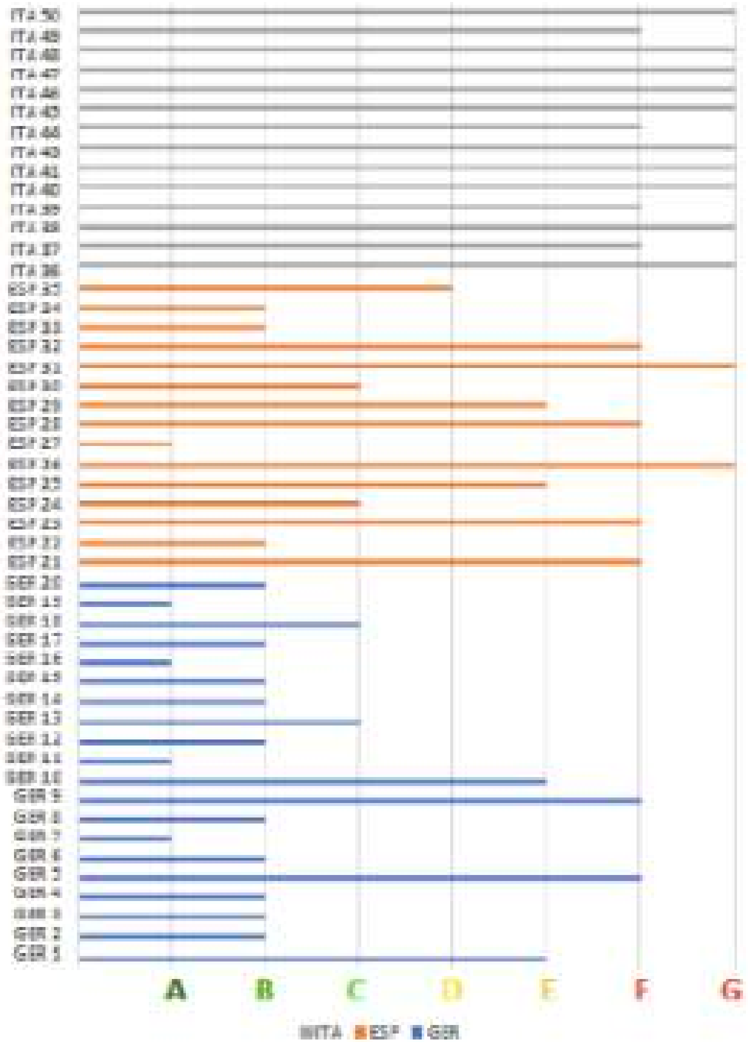
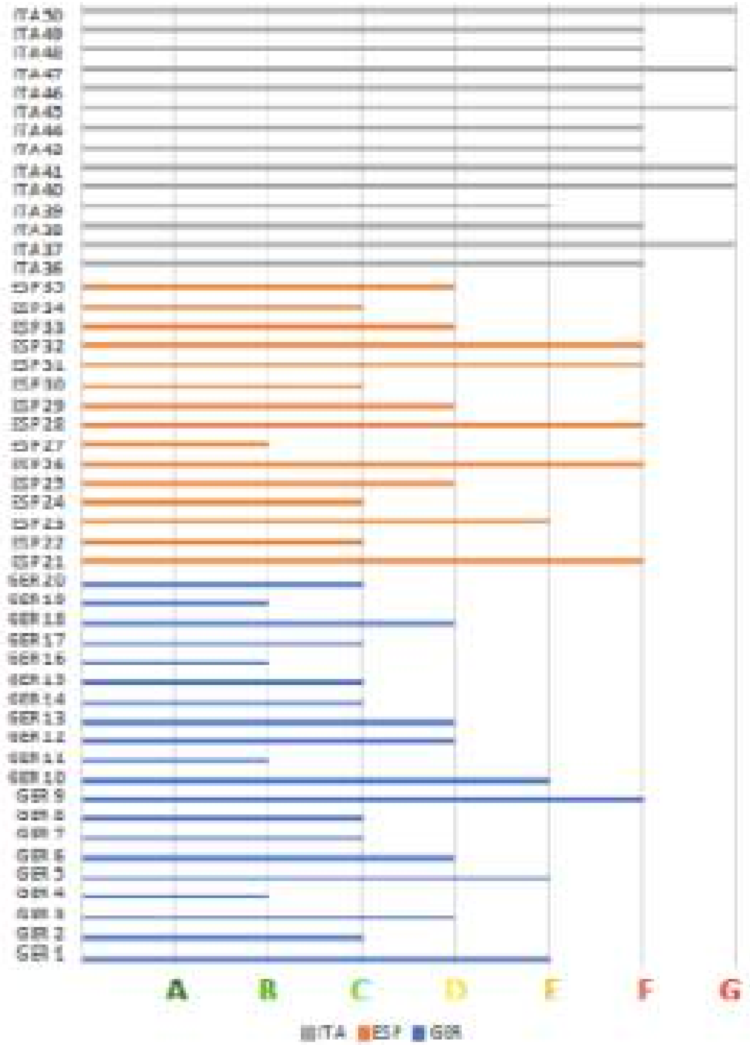
ENERWATER results

Rapid audit



Decision support



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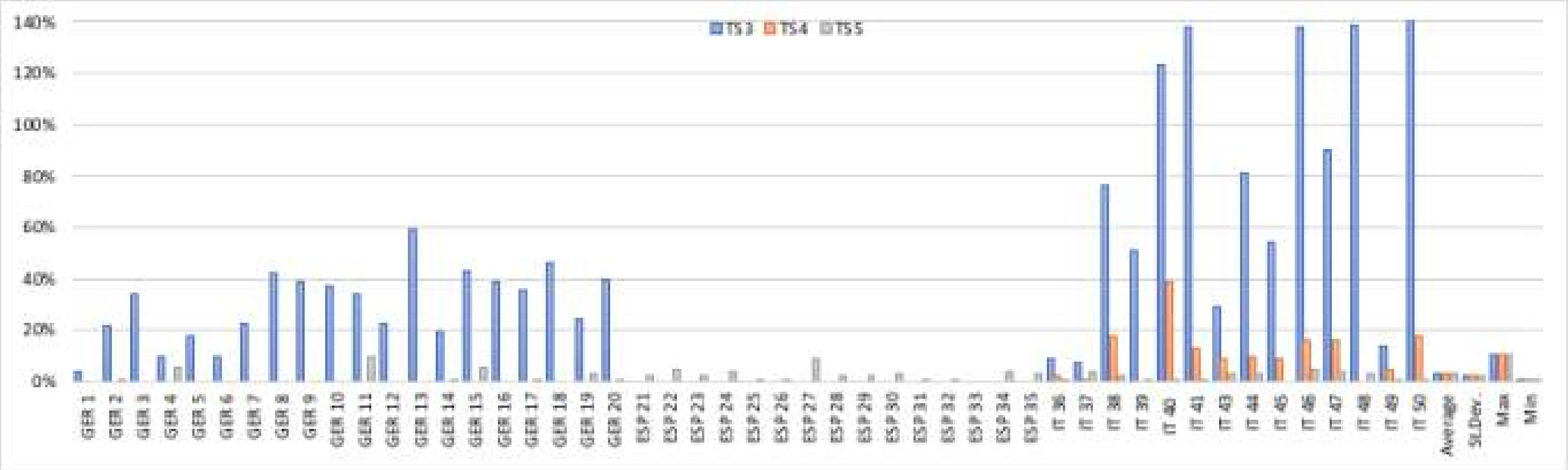
What we did expect/know:
consumptions along the treatment stages

Energy demand distribution					
	TS1	TS2	TS3	TS4	TS5
Average	10%	0%	73%	3%	13%
St.Dev.	9%	1%	18%	5%	18%

Relative importance of a stage on total energy demand

Treatment Stage	Average	Min	Max	St. Dev.
Stage 1	0.114	0.069	0.239	0.046
Stage 2	0.015	0.005	0.081	0.017
Stage 3	0.490	0.268	0.624	0.096
Stage 4	0.123	0.047	0.249	0.042
Stage 5	0.258	0.112	0.540	0.097

What many do NOT know/expect: impact of chemical energy demand on the rest of energy consumption



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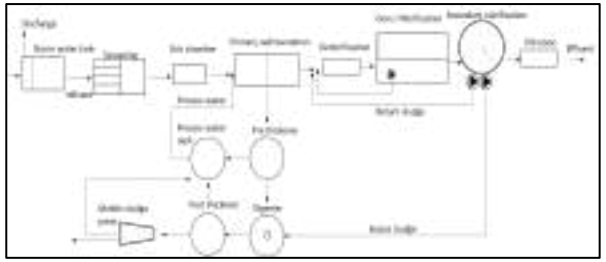
ENERWATER decision support: example process and equipment optimization



1

1- Current conditions are audited

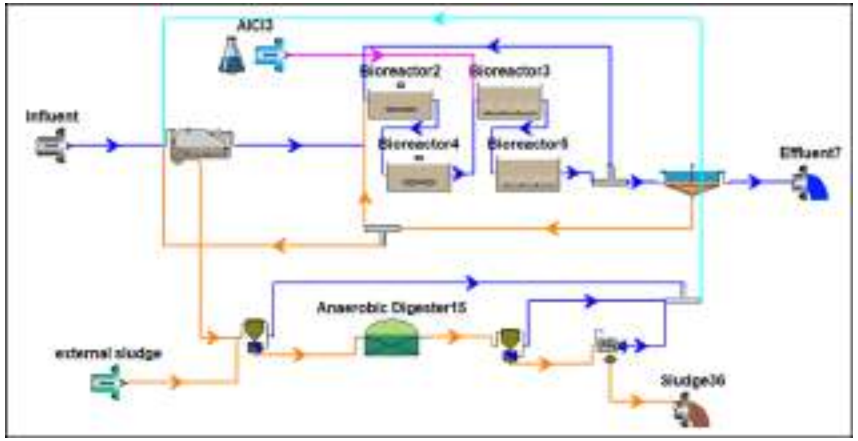
2

2- Equipment changes/revamping are identified and prioritized

Energy consumption Treatment stage 3 (kWh/d)	Total	Agitators	Recycling pump	Blower 1	Blower 2	Blower 3	Ground water pump	Second clarifica groundv pump
Before revamping	775	224	95	123	95	62	6	
After revamping	**460**	**46**	**47**	191			6	

2

2- Process changes are identified and prioritized



3

3- Energy efficiency improvement are verified

4

4- Impacts are verified and optimal parameters are applied

Rapid audit		Pre-revamping	Post-revamping
KPI1	kWh/m3	0.731	0.527
KPI2	kWh/TPE	0.523	0.392
KPI3	kWh/LogRed*m3		
KPI4	kWh/kgTSproc	3.371	1.944
	WTEI	0.721	0.481
	Label	*F*	*E*
Decision Support			
KPI1	kWh/m3	0.176	0.176
KPI2	kWh/TSrem		
KPI3	kWh/TPE	0.342	0.202
KPI4	kWh/LogRed*m3		
KPI5	kWh/TSE	0.066	0.058
Label Stage 1		G	G
Label Stage 2			
Label Stage 3		*F*	*D*
Label Stage 4			
Label Stage 5		A	A
	WTEI global	0.471	0.344
	Label global	*E*	*D*

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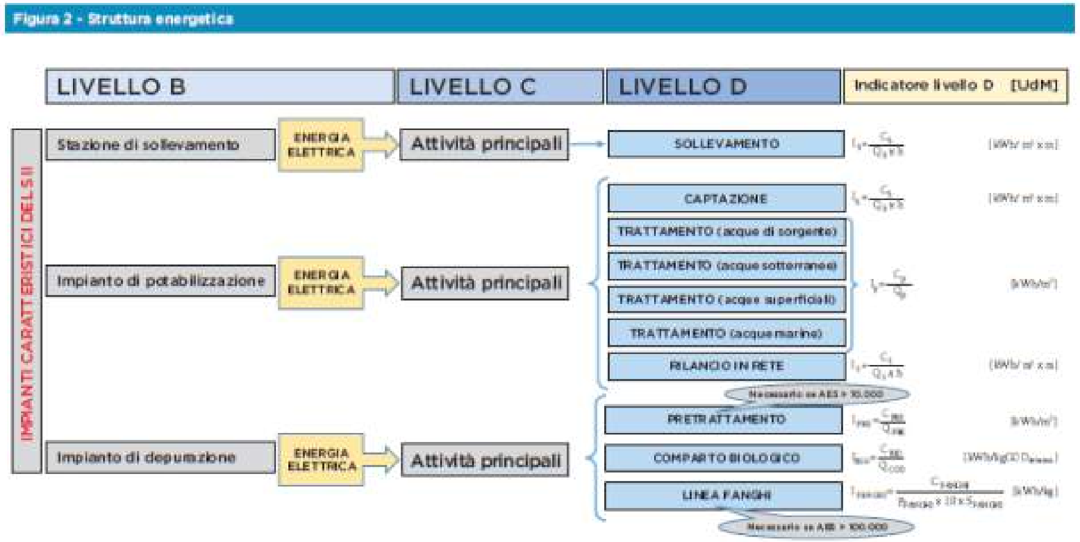
Focus On

Linea Guida per l'Esecuzione della Diagnosi Energetica ai sensi dell'articolo 8 del d.lgs 102/2014

a cura del Settore Acqua Utilitalia

Servizio Idrico Integrato

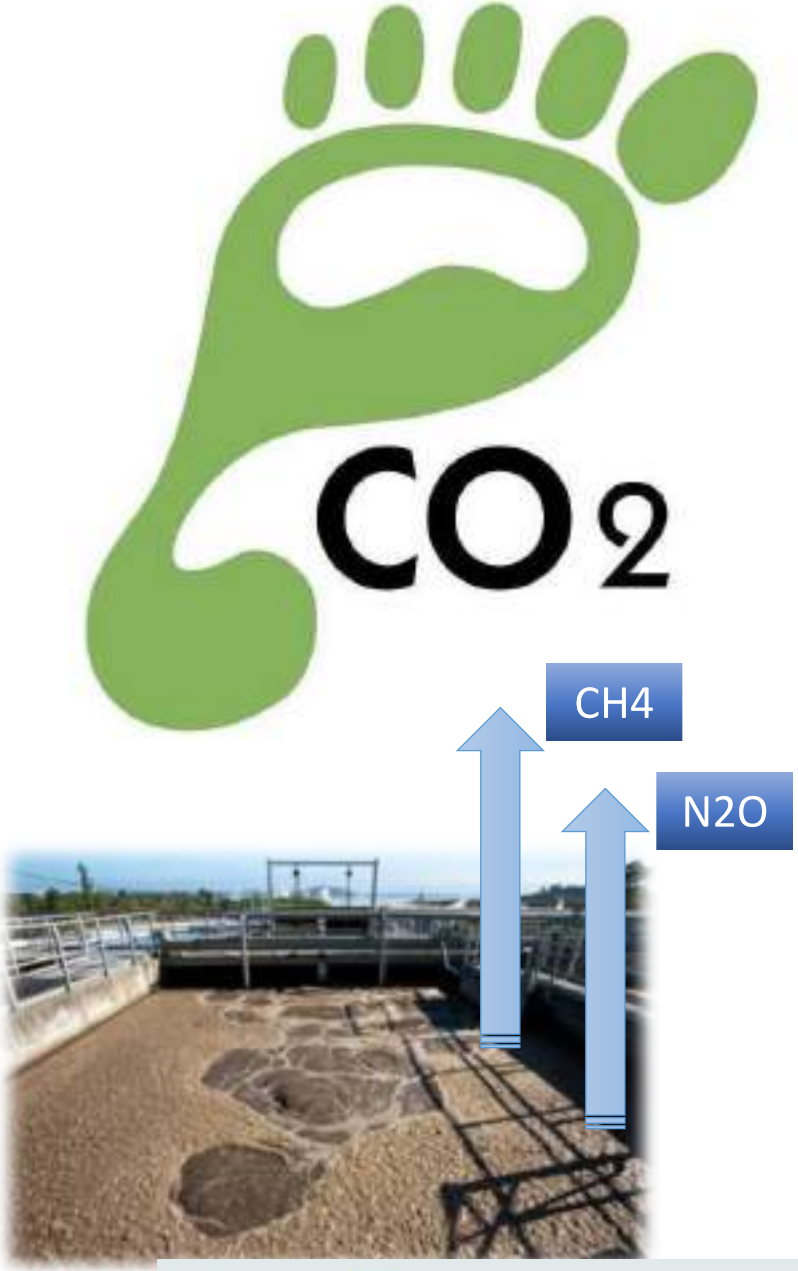


UTILITALIA
imprese acqua ambiente energia

FUTURE:

Better interface with national associations guidelines

ENERGY STAR



*Delibera **ARERA 917/2017/R/idr** in relazione alla Regolazione della Qualità Tecnica del Servizio Idrico Integrato* (RQTI)

(Entrata in vigore il 1 gennaio 2018)

*«Ad integrazione del macro-indicatore **M5** (smaltimento fanghi in discarica) […] si considera l'indicatore **G5.3** denominato "<u>Impronta di carbonio del servizio di depurazione</u>", valutato in accordo alla norma UNI EN ISO 14064-1 e misurato in termini di tonnellate di CO2 equivalente".*

<u>Scope 1:</u>
<u>Emissioni dirette correlate ai processi</u>

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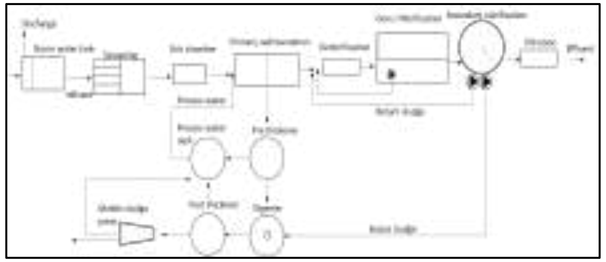
ENERWATER decision support:
example process and equipment optimization



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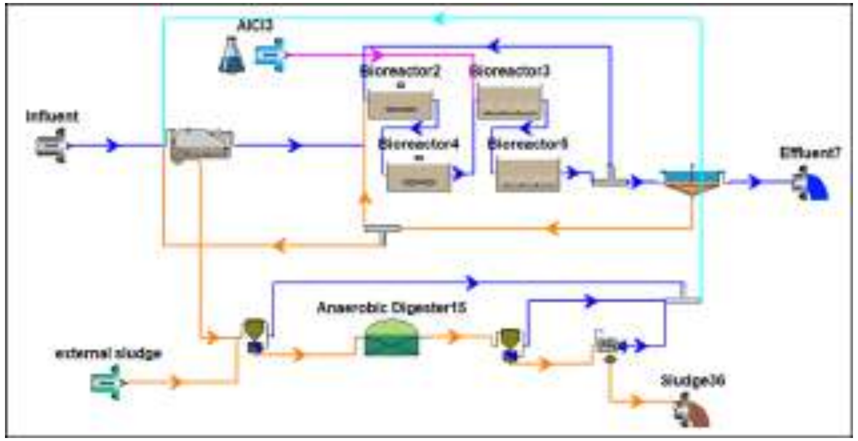

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Label Stage 4			
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	Label global	***E***	***D***

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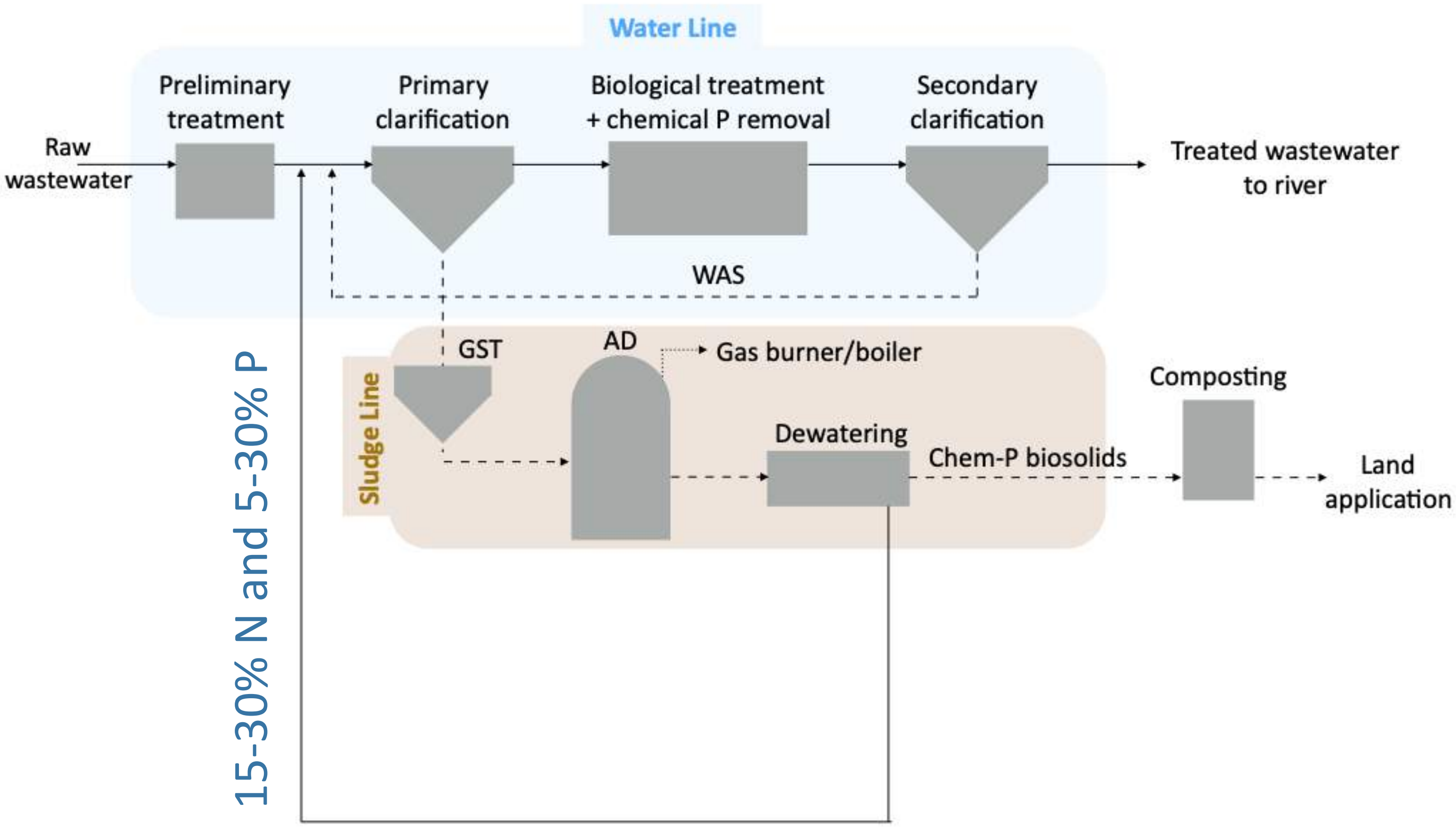
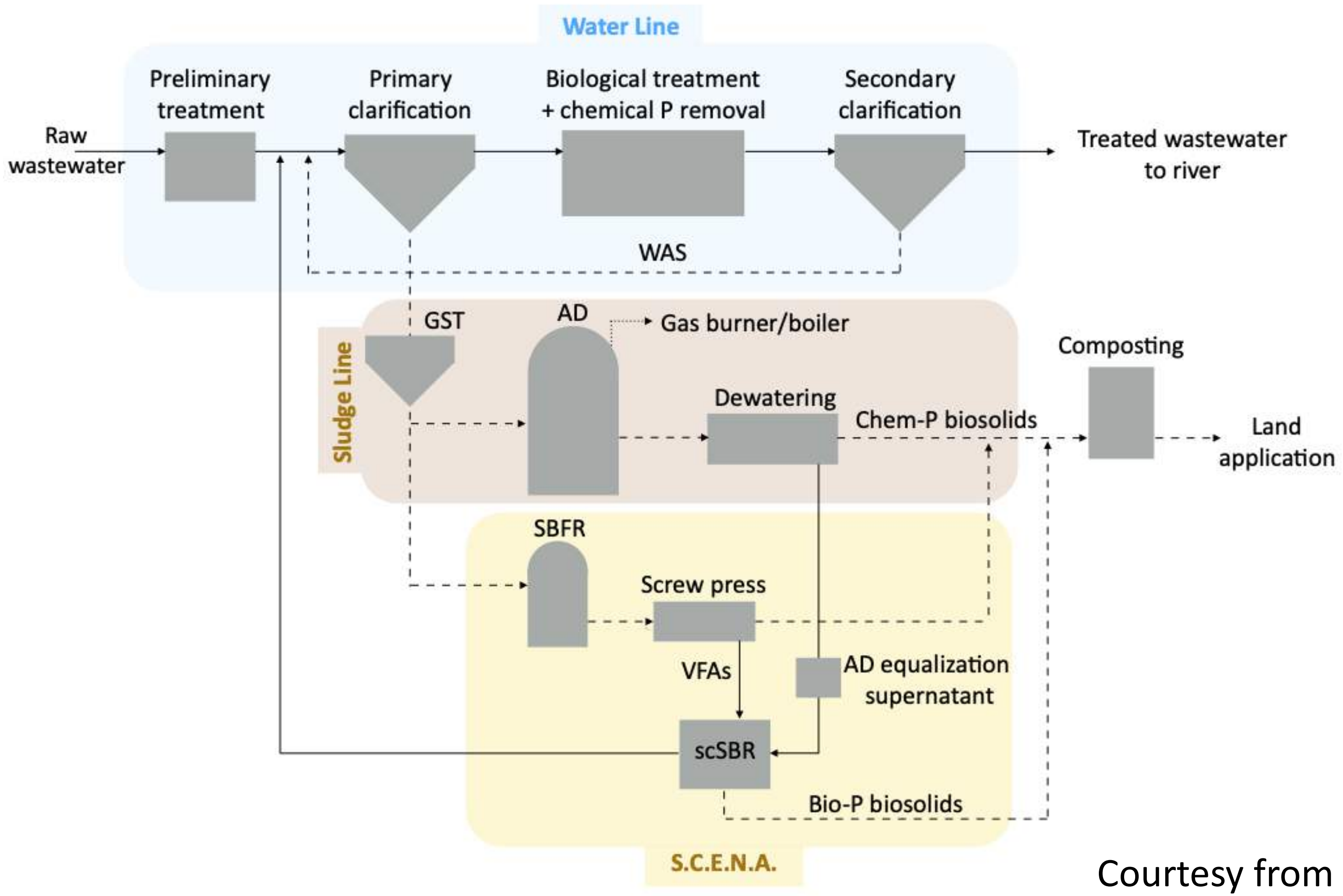
Example: reject water treatment by SCENA system in Carbonera WWTP



Courtesy from Stefano Longo (H2020 ENERWATER Consortium)

Example: reject water treatment by SCENA system in Carbonera WWTP



Scenarios under analysis:

- **Sc. 0 = Old configuration**
- **Sc. 1 = Sc. 0 + SCENA**
- Sc. 2A = Sc. 1 + dynamic thickening
- Sc. 2B = Sc. 1 + chemically assisted I SED
- Sc. 2C = Sc. 1 + rotating belt screen

Indicators:

- Global Warming Potential (GWP)
- Eutrophication Potential (EP)
- Net Present Value (NPV)

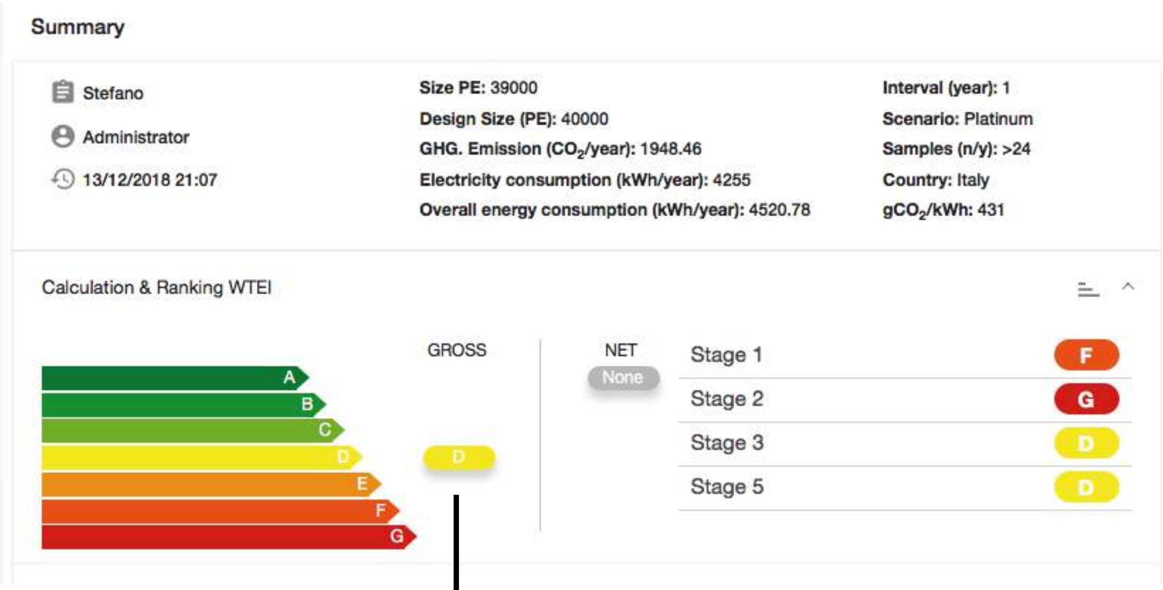
Functional Unit:

- kgPO4eq. removed

Courtesy from Stefano Longo (H2020 ENERWATER Consortium)

What about ENERWATER?

Before SCENA



WTEI = D = 0.42

After SCENA

WTEI = D = 0.35;

C ≤ 0.33

Courtesy from Stefano Longo (H2020 ENERWATER Consortium)

Future: water-energy nexus and regulation interface

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Recommendations for a FUTURE directive

What is needed:

- Harmonization with national guidelines
- Elevate the ENERWATER methodology to the CEN/TC 165 for discussion and potential translation into a European standard → **IN PROGRESS !**
- More public stakeholders, authorities and officers within the discussion
- Stakeholders, mostly representing water utilities, have expressed concern and scepticism on the possibility of new regulation on wastewater treatment efficiency

IT IS OUR RECOMMENDATION THAT THE CURRENT DIRECTIVE 2012/27/EU REMAINS AS THE MAIN REGULATORY INSTRUMENT ON ENERGY EFFICIENCY OF WWTPS UNTIL A CLEAR EVALUATION OF ITS EFFECTS AND SHORTCOMINGS CAN BE CARRIED OUT. THE STANDARDISING ACTIVITIES DEVELOPED IN THE FRAMEWORK OF THIS PROJECT CAN BE USED BY PUBLIC OFFICIALS AS INSTRUMENTS TO INCLUDE ENERGY EFFICIENCY CRITERIA IN PUBLIC TENDERS AND, IF REQUIRED IN THE FUTURE, CAN BE USED AS A STARTING POINT TO REACH A WIDE CONSENSUS IN A DETAILED DEFINITION OF WWTP ENERGY EFFICIENCY, ITS ESTIMATION AND OBJECTIVES. THE COLLECTION AND OPEN PROVISION OF DATA ON THE PERFORMANCE OF WWTPS IS, NOTWITHSTANDING, AN ACHIEVABLE GOAL THAT SHOULD BE ASSUMED BY WATER AUTHORITIES.

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Once we audit well…we can improve much…and become energy positive

HOW?

Next slides

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Energy positive in full scale: how?

- Upstream diversion of more carbon to anaerobic digestion
- Separate short-cut treatment of the reject water
- Energy-efficiency in the mainline (e.g. short-cut (via-nitrite) processes)

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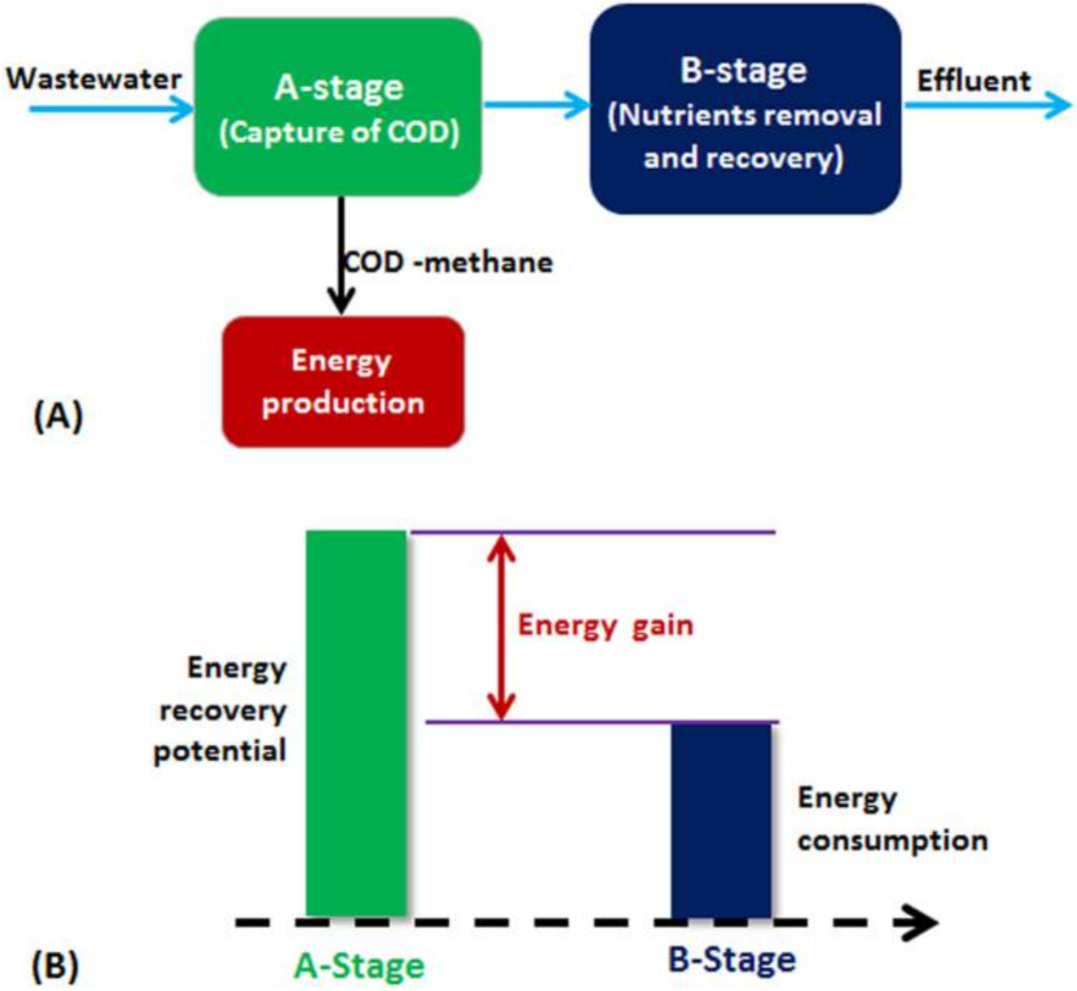
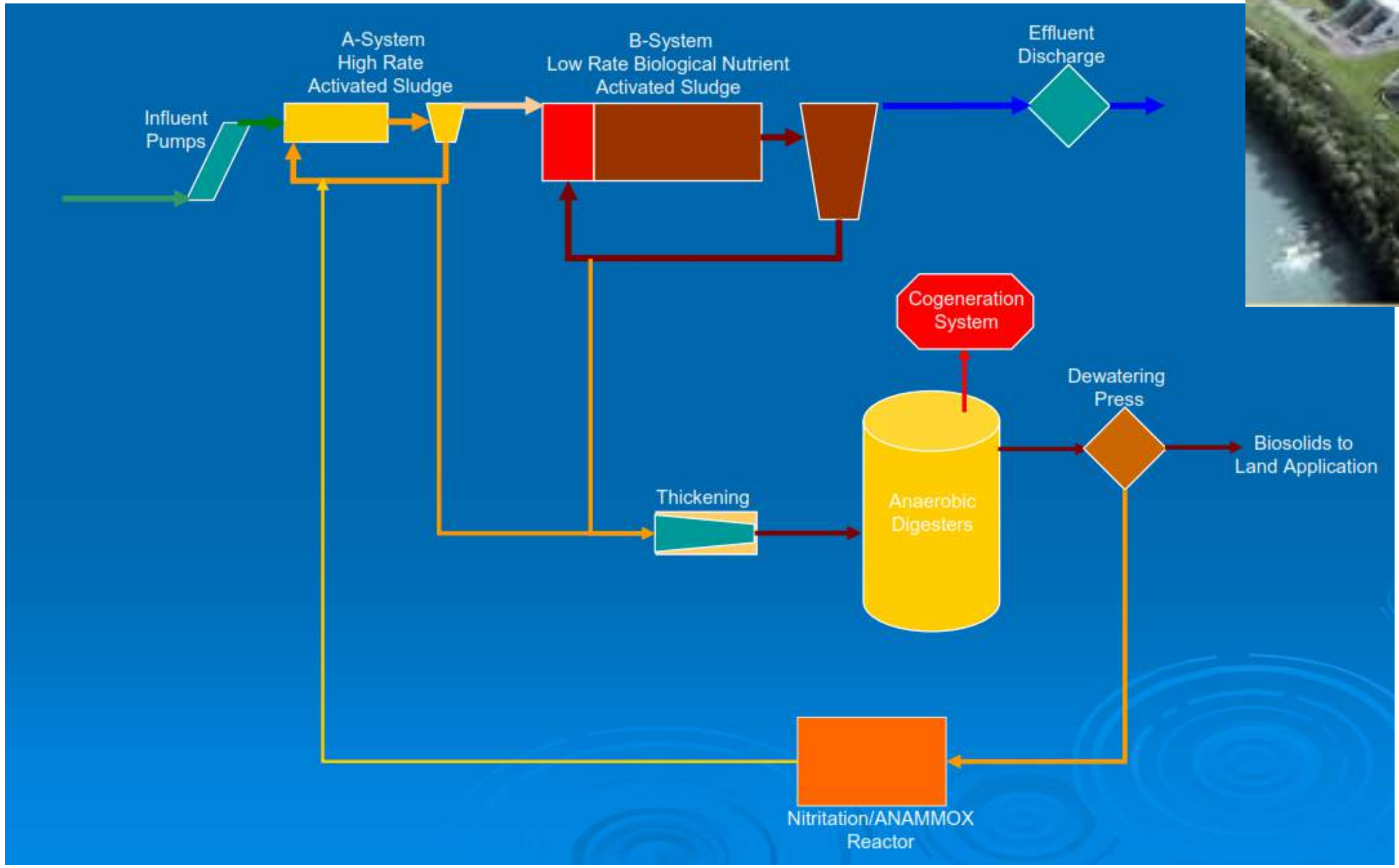
The A-B schemes

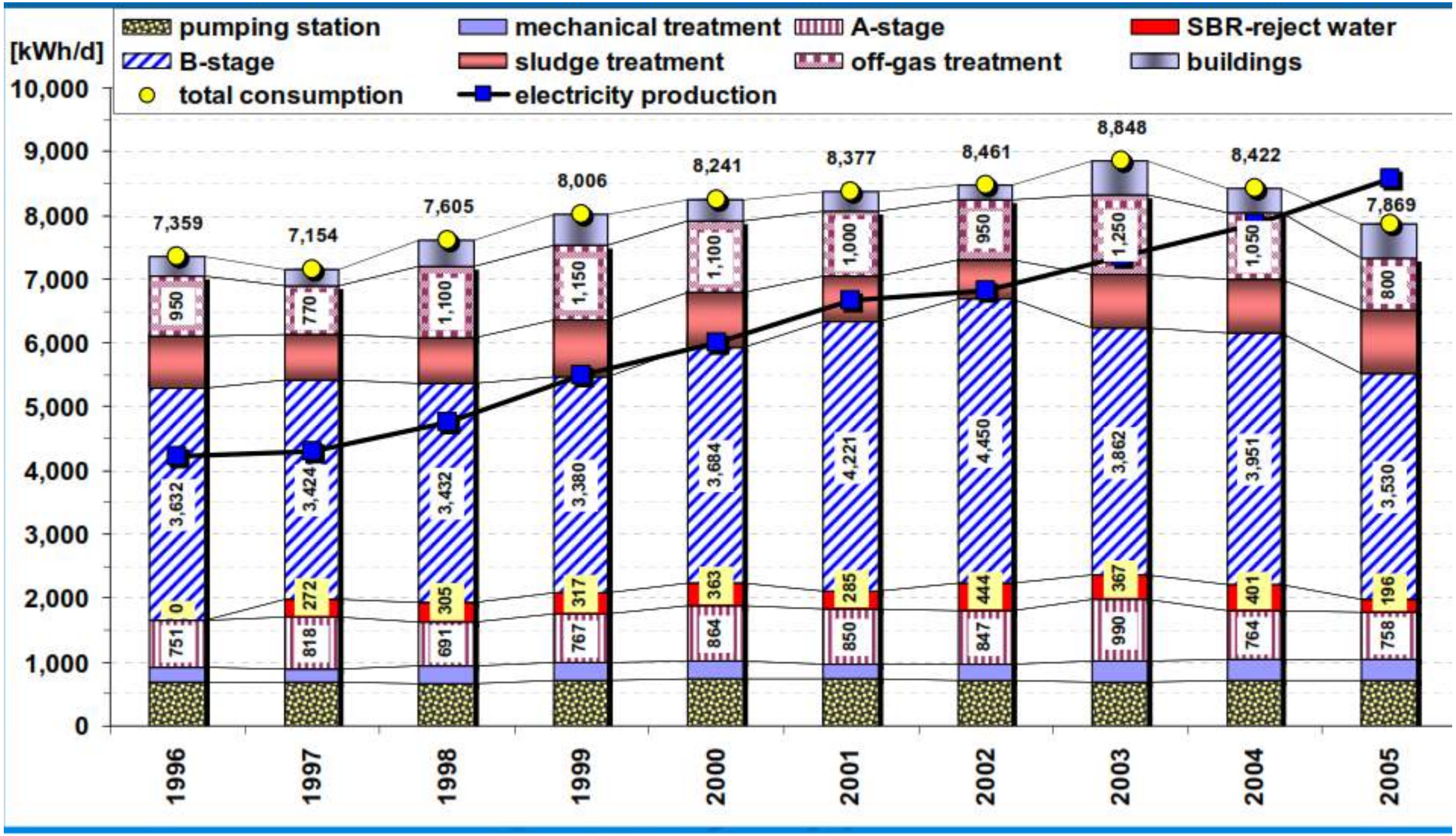


Strass WRRF: energy positive since 2005

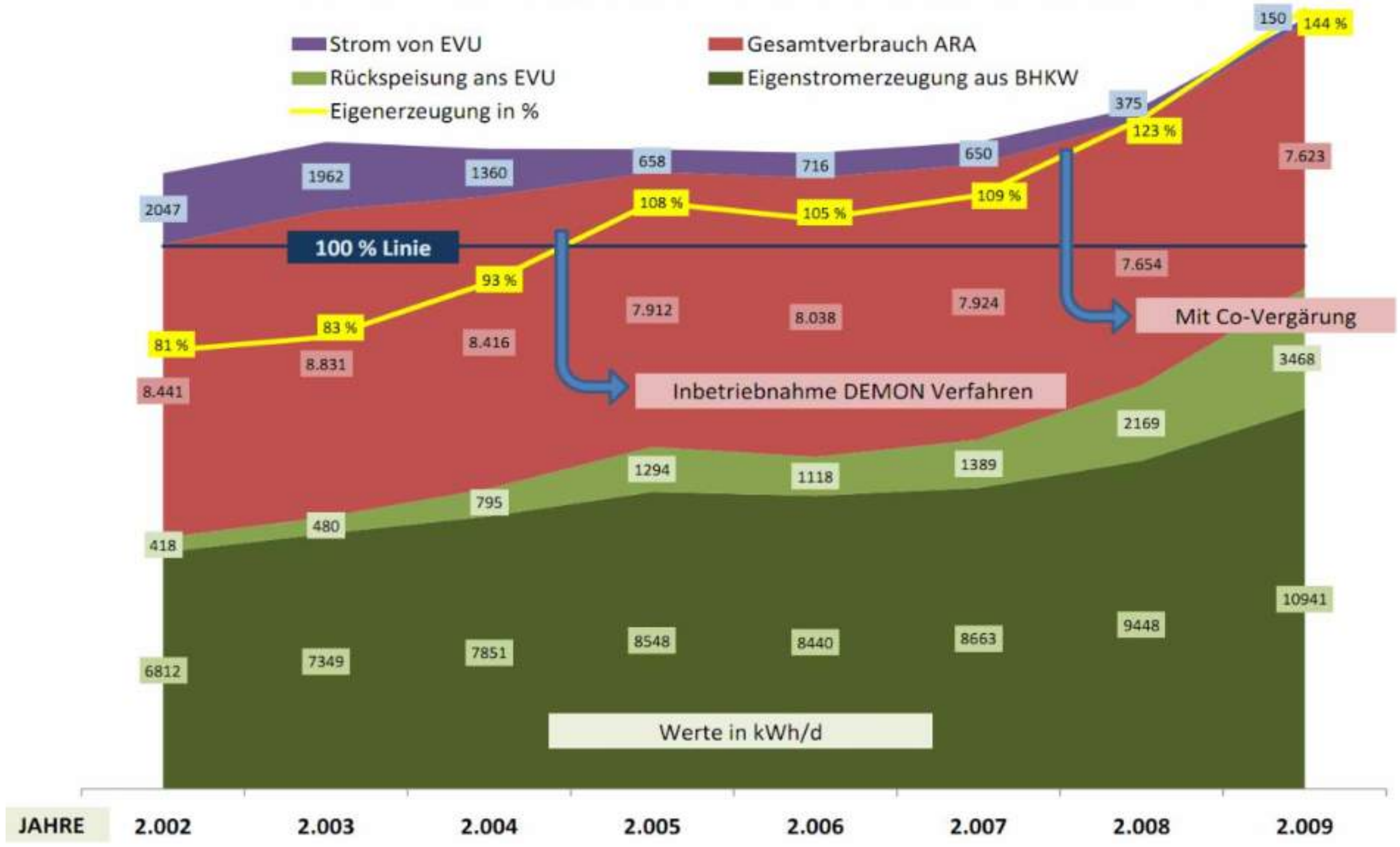


Source: Wett et al.

Energy-positive in 2005



120%-140% positive by co-digestion of sewage sludge and organic waste



What about the final sludge/digestate disposal? Composting and Agriculture ? Incineration ?

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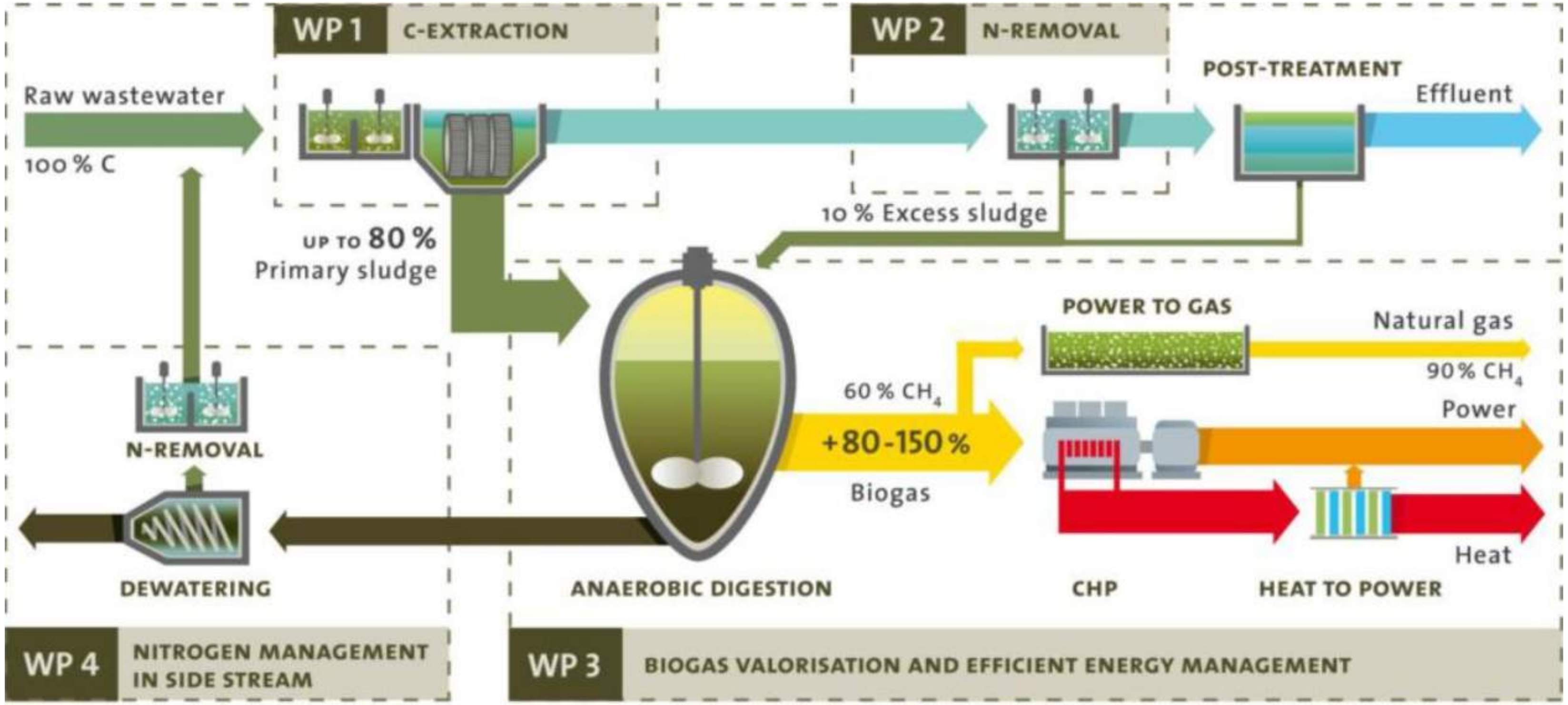
Energy positive evolution: H2020 POWERSTEP



POWERSTEP modules ***www.powerstep.eu***

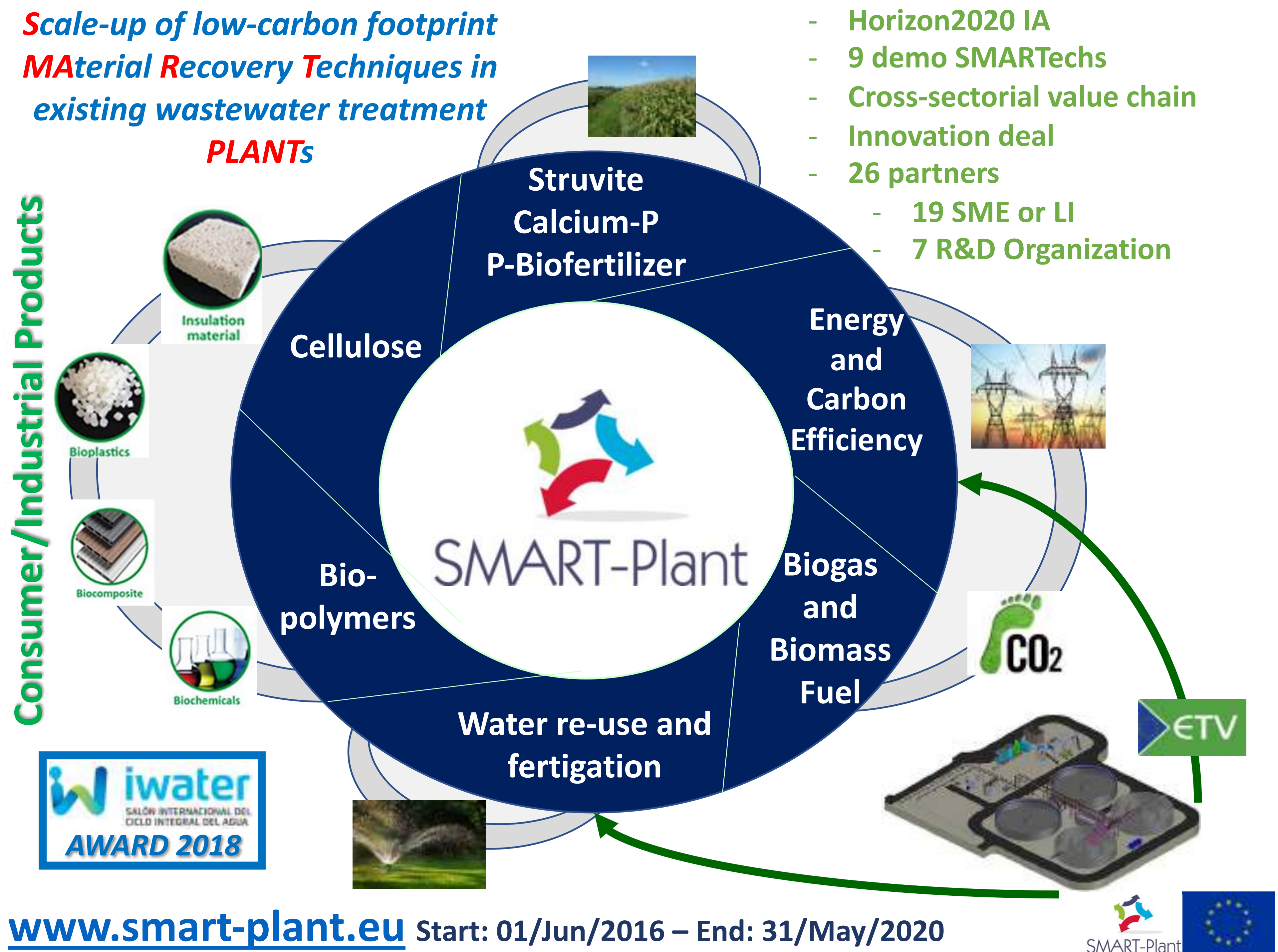
1- in mainline WWTP for A-stage (C extraction)

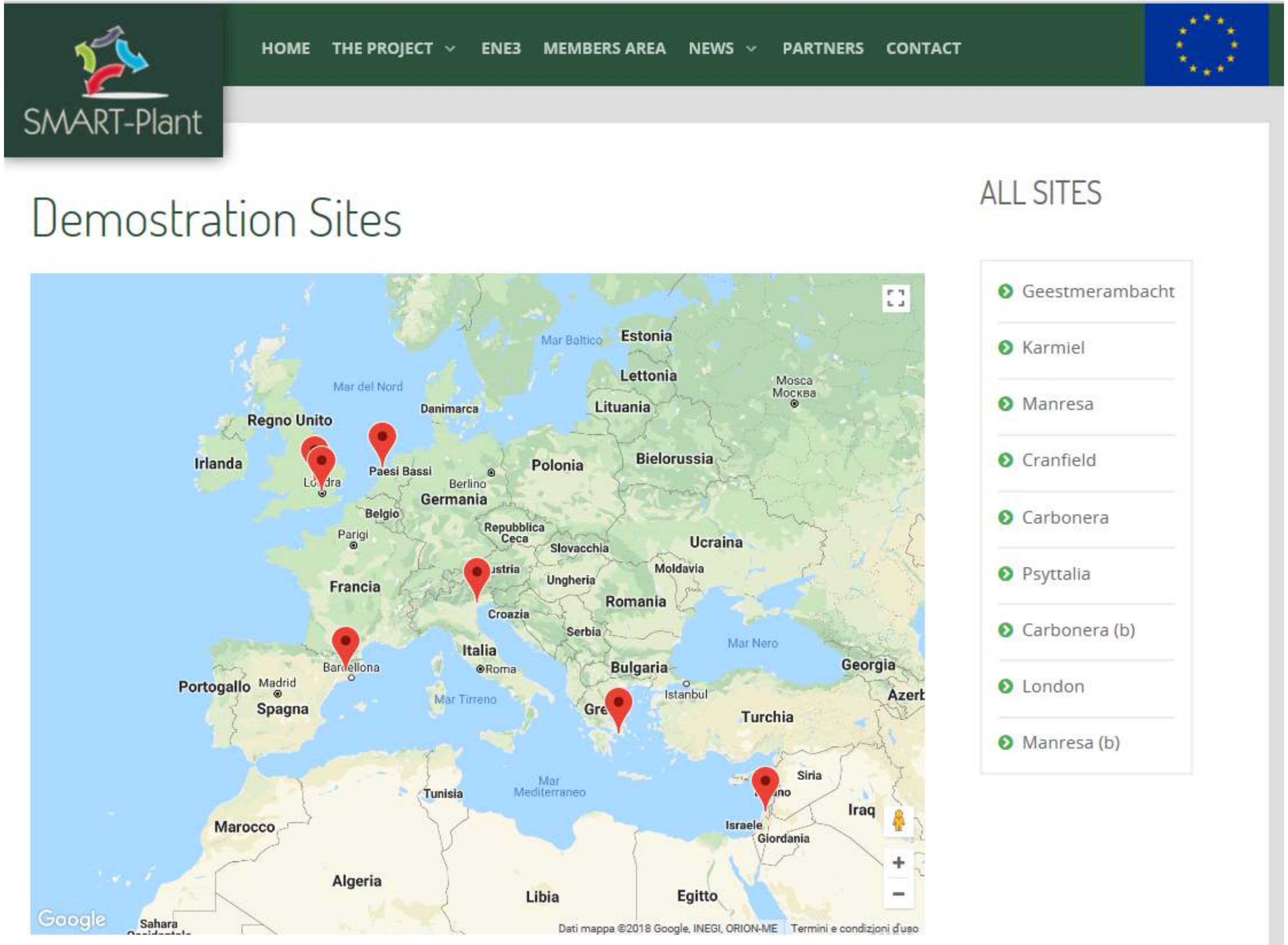
2- in mainline WWTP for B-stage (N removal)

3- reject water for N- removal or N-recovery

4- for best biogas valorisation

New frontier: energy- and carbon-efficient materials recovery and reuse


Scale-up of low-carbon footprint MAterial Recovery Techniques in existing wastewater treatment PLANTs
- Horizon2020 IA
- 9 demo SMARTechs
- Cross-sectorial value chain
- Innovation deal
- 26 partners
- 19 SME or LI
- 7 R&D Organization
Consumer/Industrial Products
Insulation material
Bioplastics
Biocomposite
Biochemicals
Struvite
Calcium-P
P-Biofertilizer
Cellulose
Energy and Carbon Efficiency
Biogas and Biomass Fuel
Water re-use and fertigation
Bio-polymers
SMART-Plant
CO_2
ETV
iwater
SALÓN INTERNACIONAL DEL CICLO INTEGRAL DEL AGUA
AWARD 2018
www.smart-plant.eu
Start: 01/Jun/2016 – End: 31/May/2020



http://smart-plant.eu/index.php/map

SMARTechs integrated in existing WWTPs (revamped/upgraded to WRRFs)


SMARTech1 - Geestmerambacht WWTP (NL)


SMARTech2a – Karmiel WWTP (IL)


SMARTech2b and Downstream SMARTech B - Manresa WWTP (Spain)


SMARTech3 – WWTP at Cranfield University (UK)


SMARTech 4a and SMARTech 5 Carbonera WWTP (Italy)


SMARTech 4b - Psyttalia WWTP (Greece)

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ACHIEVEMENTS OF SMART-PLANT

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

Demos commissioned: June 2017 – Long-term validation: May 2019

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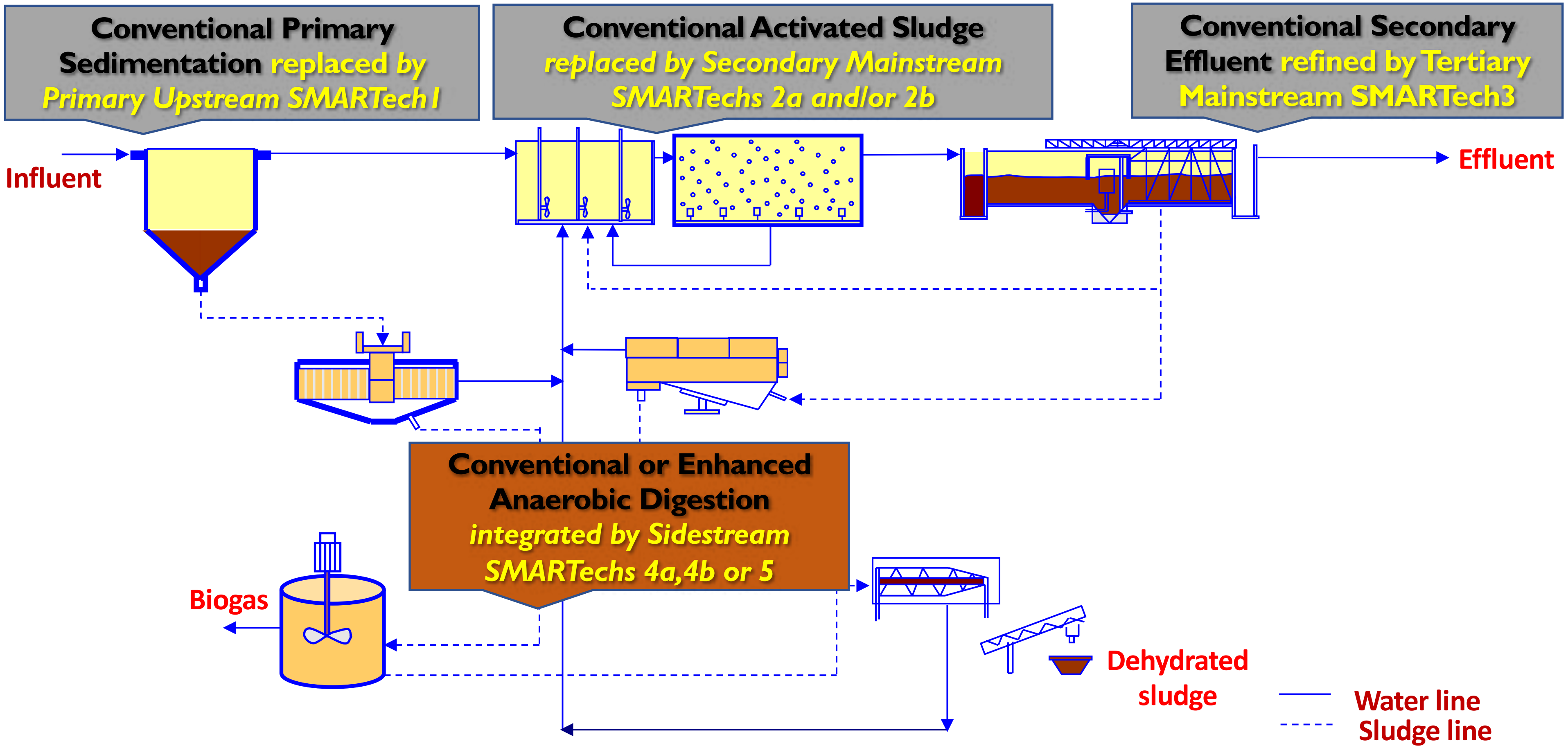
SMART-Plant approach and SMARTechs



CURRENT ACHIEVEMENTS OF THE PROJECT:

Energy and Carbon-Efficient Valuable Materials Recovery in SMART-Plant demos

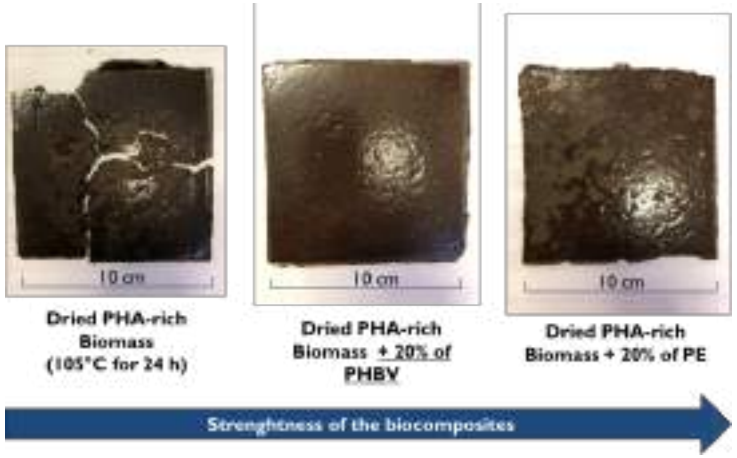
- 350-400 kg Cellulose per week;
- 1,0-1,2 kg PHA per day;
- > 250-300 g Struvite per day;
- 2000-3000 Liters of biogas per day;
- 60% of P recovered as $CaPO_4$ from the tertiary treatment;
- 15-20 kg of P-rich sludge, 60-65 gP/kgTS
- > 10 kg BioFertilizers per day;
- **10-30% Energy Efficiency;**
- **10-50% Carbon Efficiency;**

Closed value chain with validated technologies and marketable industrial/consumer products

Industrial production of lignocellulosic PHA biocomposites

Post-processing of recovered cellulose in mortars and concrete

Pilot-scale production of biocomposites from raw PHA-rich biomass



Production and testing of phosphorus bio-fertilizers and biomass fuels

Focus on cellulose recovery…and value chain!!!

Recell®

Product description Recell®
Tertiary cellulose fiber produced for the industry.

Safety & Health
This document provides a short view of the extended MSDS. Read the full MSDS before working with the product.

CAS-No.	9004-34-6
REACH-No.	Do not require registration
Cellulose	100% recycled product
Toxic properties	None
Fire Hazardous	Yes

Handling
Take care of dust formation when handling the dry fluff cellulose. Avoid inhaling. It is recommended to use protective measures (PBMs) for eye protection, skin protection, body protection and respiratory protection. The product is microbiologically comparable to the market product, only due to the pilot installation it cannot be guaranteed. This should be taken into account when processing the product. It is recommended to wash hands after using the product.

Shelf life: Minimum 1 year, provided the products are stored in a dry, cool and in the delivered intact packaging.

Physical properties	
Appearance	fibre fluff
Cellulose content	60 - 80 %
Hemicellulose/Lignin	10 - 15 %
Ash	5 - 15 %
Organic residue	5 - 10 %
pH	5 - 8
Dry matter	> 90%
Odour	Neutral
Colour	Light grey
Brightness	> 50%
Loose density	50 - 80 kg/m3

Number	Weight	Volume	Date production	Productionlocation	Operator
....	....	....	....	....	....

For more information:

Cellvation B.V.
Agora 4, 8934 CJ Leeuwarden
Postbus 7560, 8903 JN Leeuwarden
The Netherlands
T: + 31 6 47 18 73 88
Email: Info@cell-vation.com
www.cell-vation.com

Cellvation

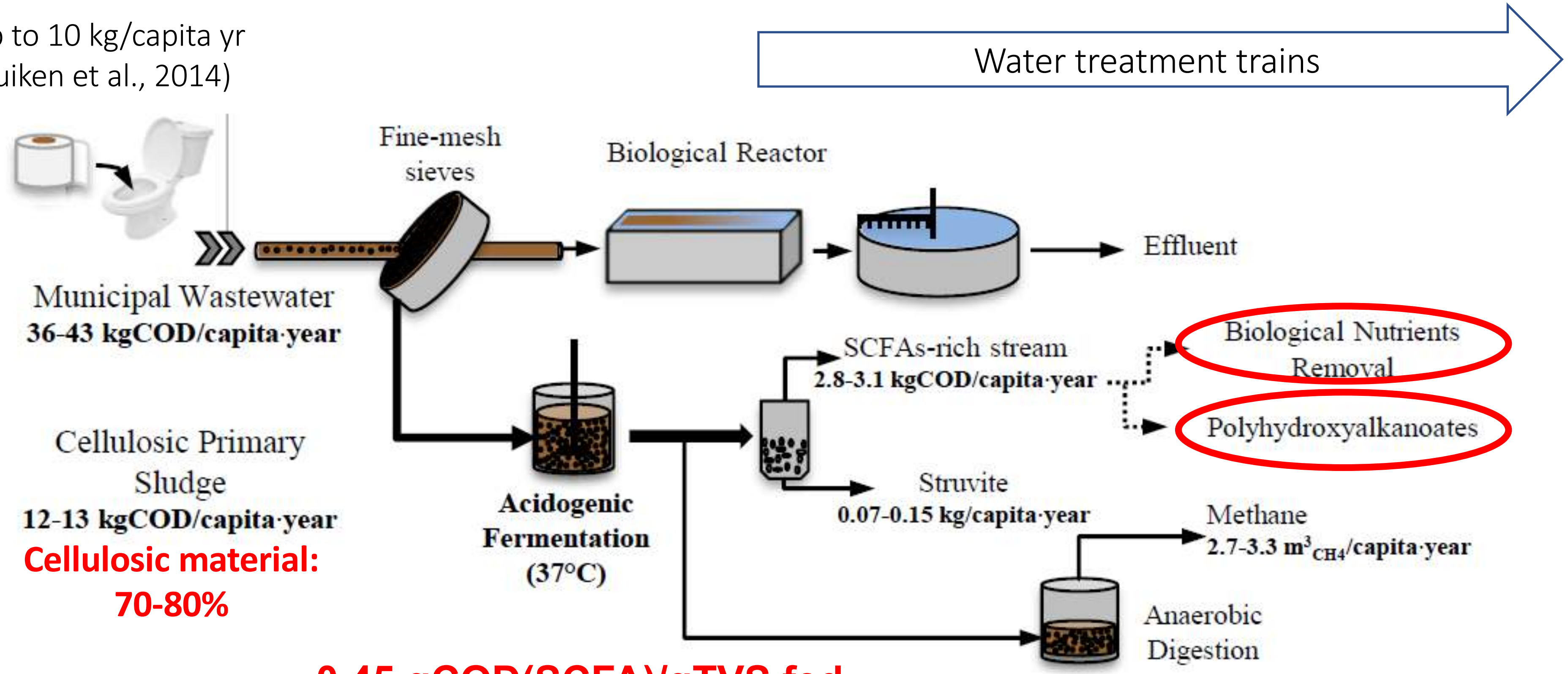
SMART-Plant

The main advantages delivered to the water utilities adopted are:

1. Reduction of sewage sludge by 6% to 20%
2. Consequent increase of 20% of plant capacity
3. Energy savings of 4-6% of the plant total energy consumption or 10-15% on energy required for aeration
4. Recovery of materials

More value?
Biorefinery of Cellulosic Primary Sludge (CPS)

Up to 10 kg/capita yr
(Ruiken et al., 2014)



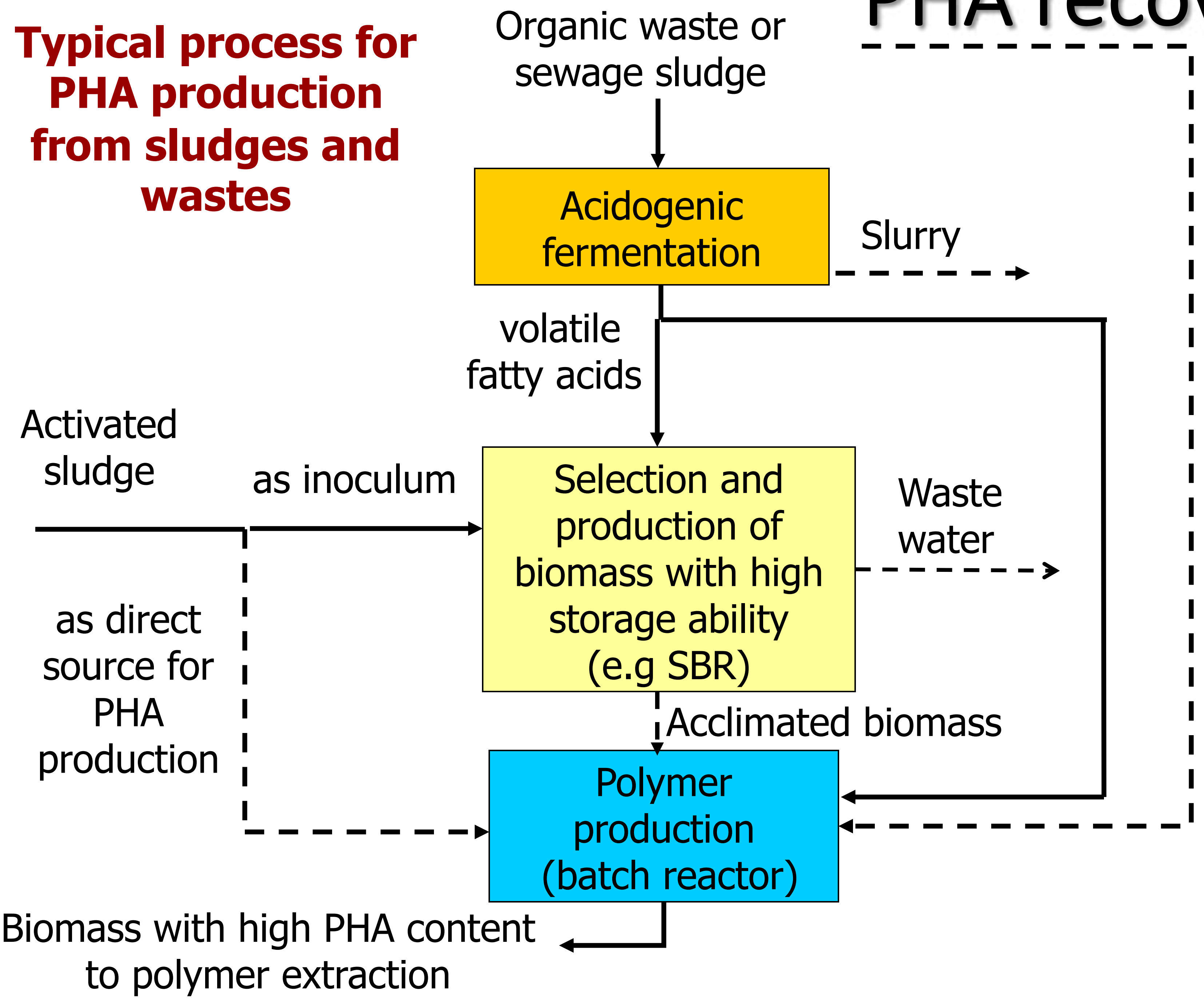
Cellulosic material: 70-80%

0.45 gCOD(SCFA)/gTVS fed
(45-50% HAc;
30-35% HPr)

Water Research, Crutchik et al., 2018

PHA recovery

Typical process for PHA production from sludges and wastes



The «short-cut» innovation in SCEPPHAR:

- Integrate the via-nitrite nitrogen removal with the PHA recovery → major interest of the water utility
- Adopt anoxic (via-nitrite) conditions to optimize energy consumptions
- Phosphorus (struvite) recovery even to support the balance of nitrogen and phosphorus to the PHA recovery

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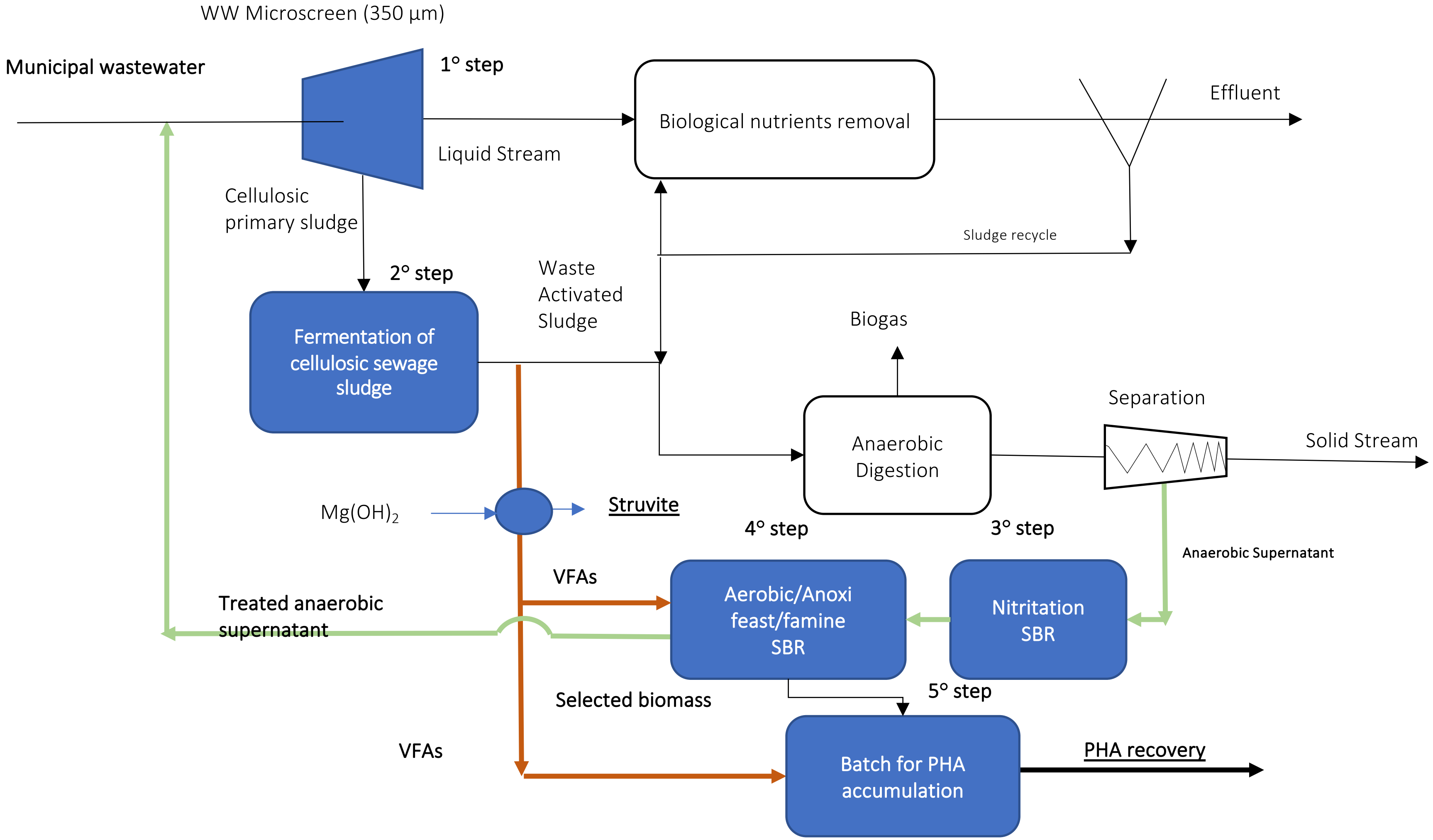
Sidestream S.C.E.P.P.H.A.R.: Short-Cut Enhanced Phosphorus and PHA recovery (Smartech 5)



10%-30% energy saving compared to completely aerobic proceses

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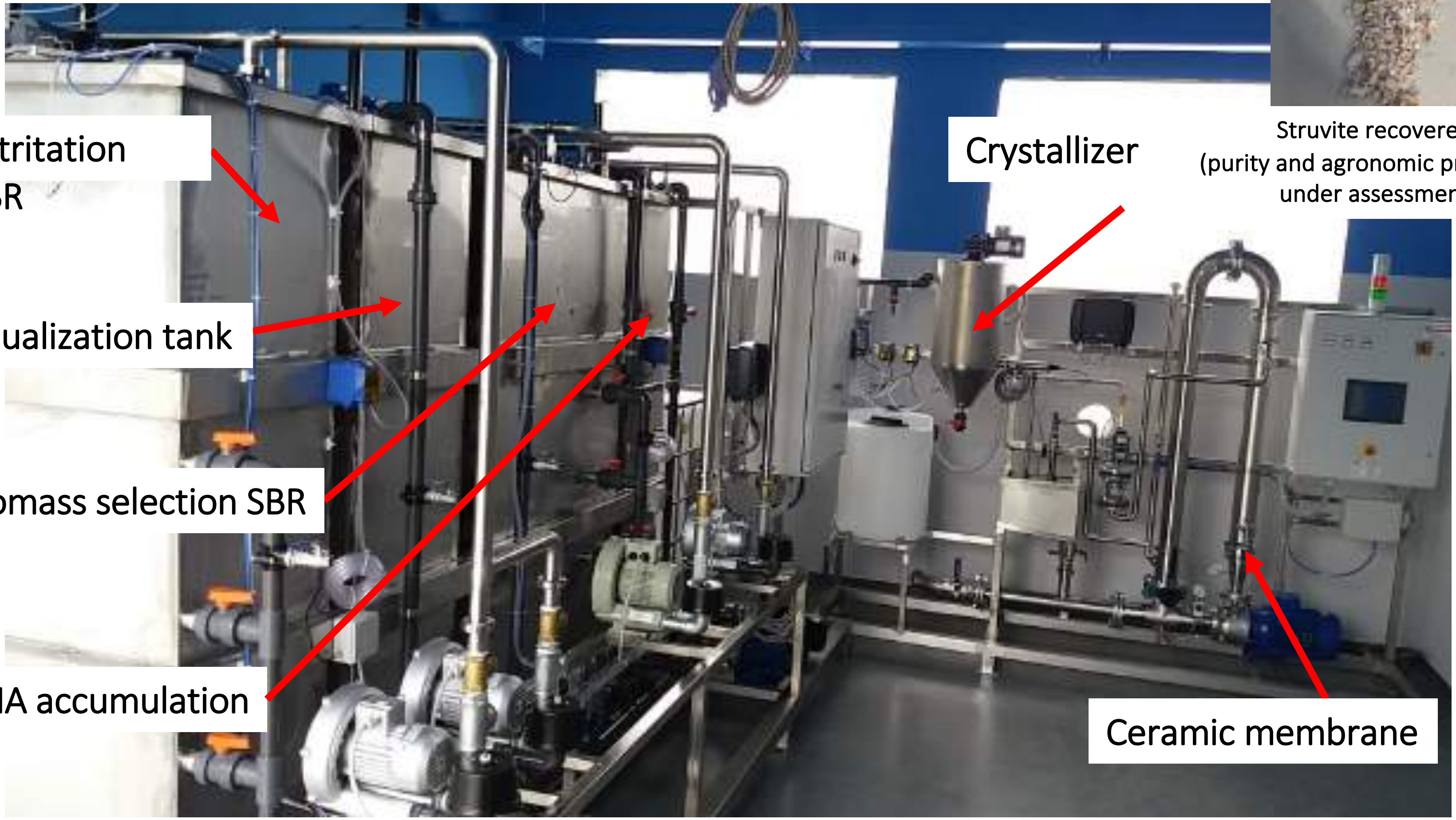
SCHEPPHAR: Short-Cut Enhanced P and PHA Recovery

Struvite recovered
(purity and agronomic properties under assessment



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Verification procedure for energy and carbon efficiency KPI

Timeline

- ✓Contact phase with Verification Body
- ✓Quick-Scan (QS) eligibility assessment
- ✓Verification proposal
- ✓Offer and contractual agreement
- ✓Specific verification protocol phase (*starting*)
- →Testing
- →Verification
- →Reporting and publication

ETV

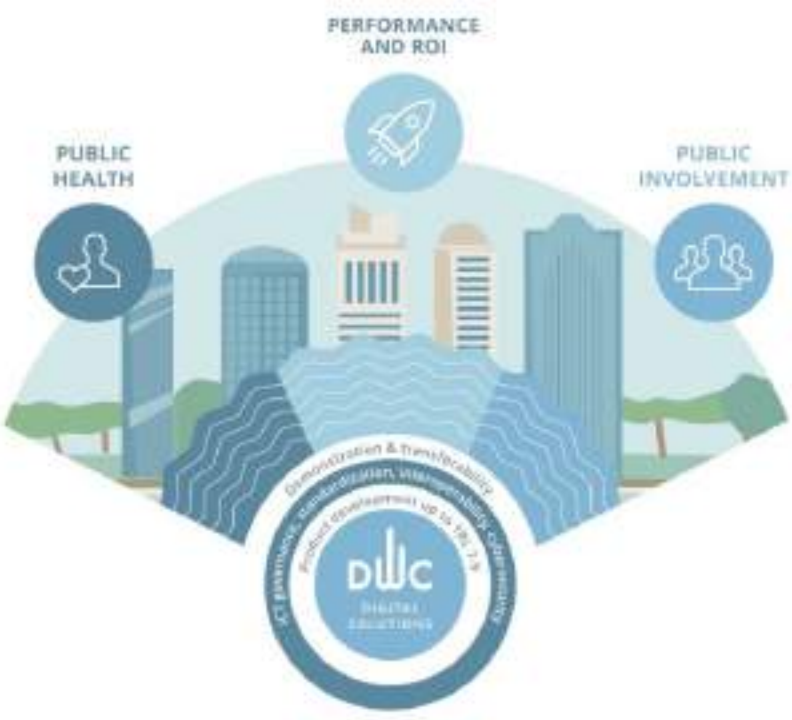
Are H2020 Innovation Actions inspiring a change?
Is there a market ready?

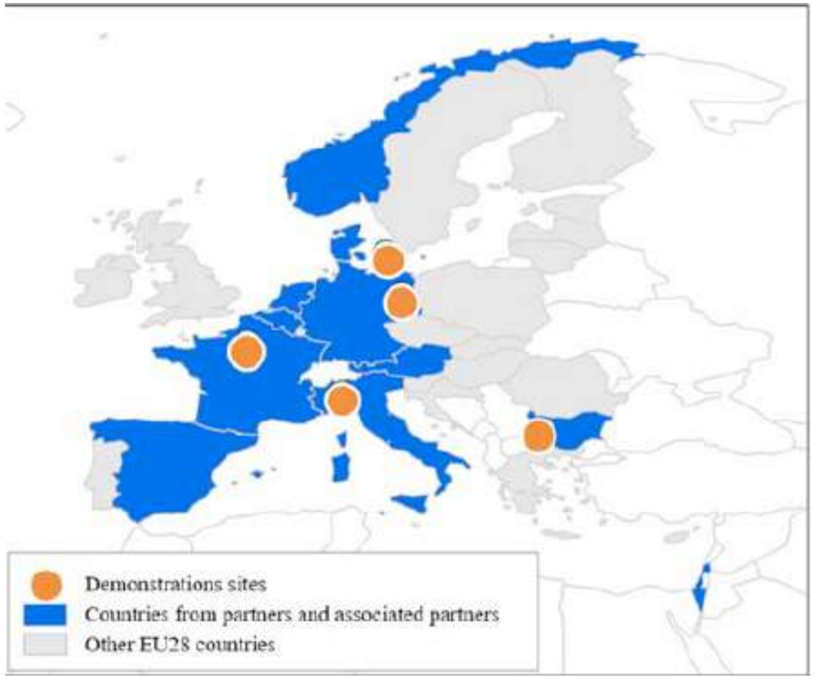
Only in Italy: > 4 WWTPs are going to apply SMARTechs in 2018-2019

ALTO TREVIGIANO SERVIZI

Digital.water.city:

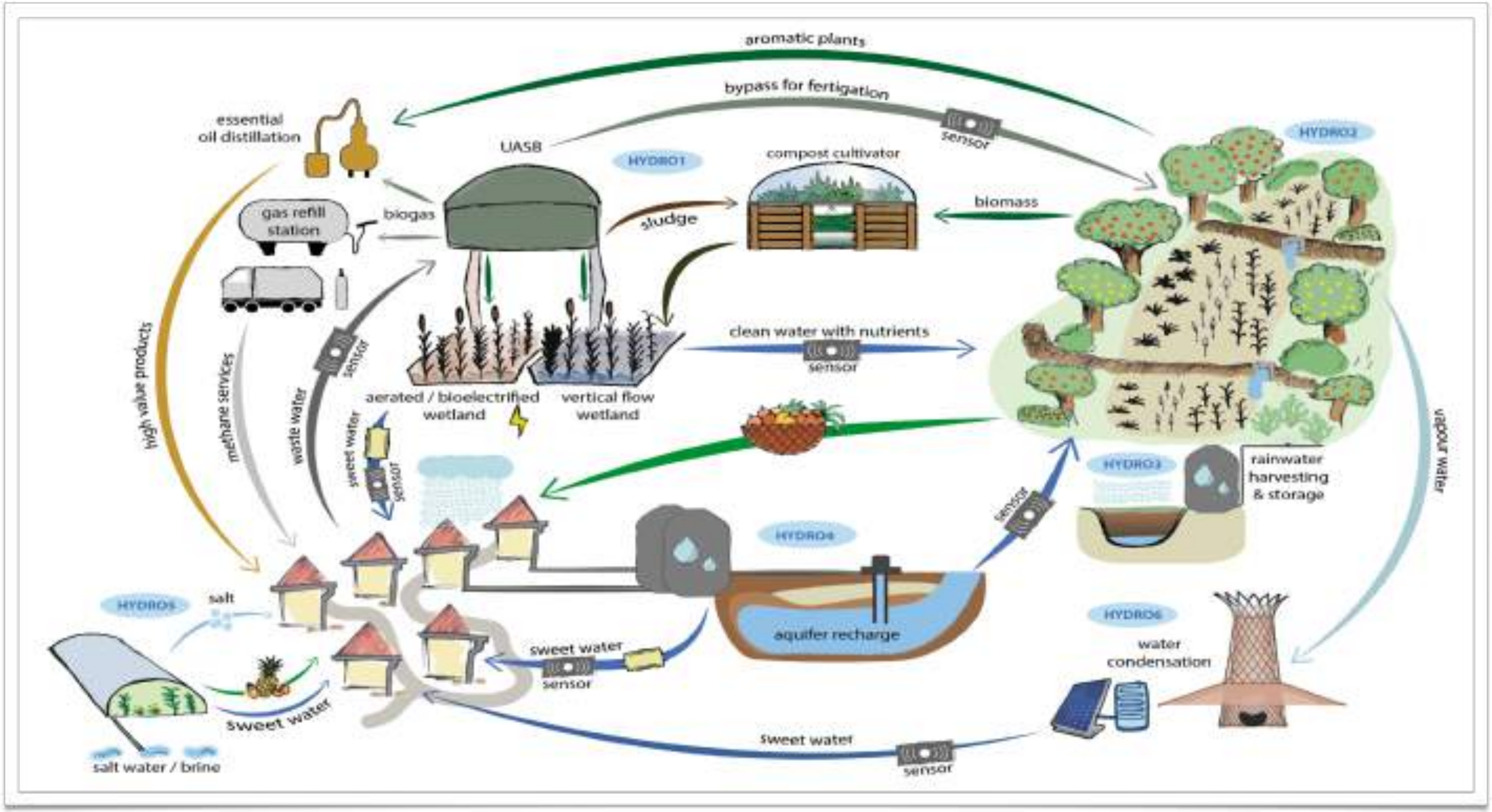
Leading urban water management to its digital future



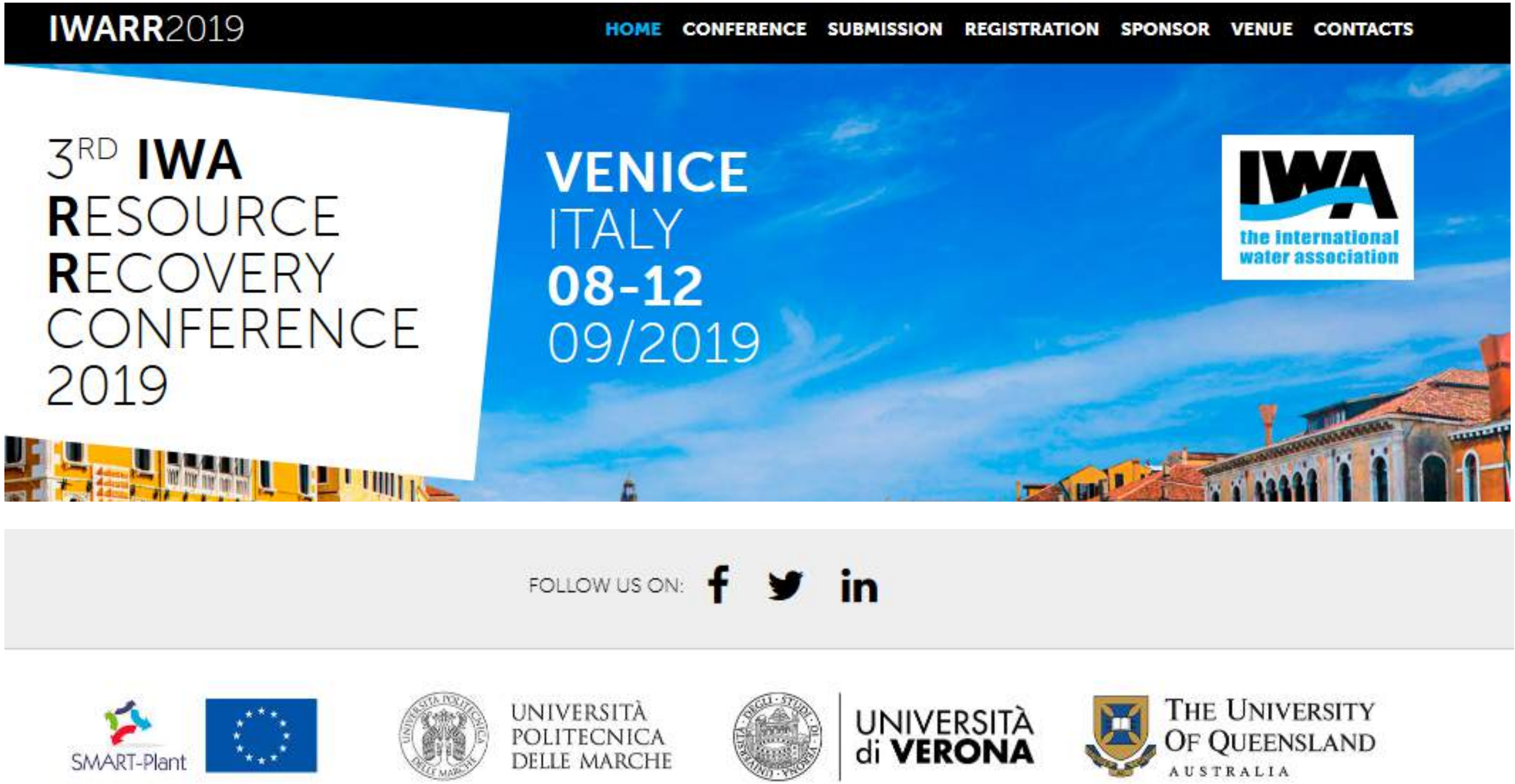


Water reuse – enregy nexus inside an Agricultural Protected Area

CLOSING WATER LOOPS IN HYDROUSA



Thank you and…see you in Venice!



https://www.iwarr2019.org/

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SMART-Plant DWC Digital Water City HYDROUSA

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