9th INTERNATIONAL CONFERENCE ON
ENVIRONMENTAL ENGINEERING AND MANAGEMENT
Circular Economy and Environmental Sustainability
6 - 9 September 2017, Bologna, Italy

Municipal wastewater treatment to deliver circular economy in the water sector

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[5] Coordinator of the Horizon2020 "ENERWATER", University of Santiago de Compostela

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Outline

- Is (waste)water management central for circular economy?
- The pathways and the eco-innovations…at different TRLs
  - Energy pathway
  - Water pathway
  - Materials pathway
    - Nutrients
    - Organics (cellulose, biopolymers, proteins, methane)
- The value chains, the barriers and the key enabling strategies/solutions
- Discussion…and conclusion

Water in the Sustainable Development Goals: water challenges one of the top priorities for humankind

- At the global level, water has never been so visible. That it is listed as one of the 17 top priorities for humanity is a significant moment.
- **It presents an opportunity for a breakthrough**. Not just to accelerate the unfinished task of universal access to safe water and sanitation; but to **transform the water sector to become sustainable, resilient and a driver of the circular economy**.

Source: IWA, 2016

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From SDG to …business as usual…

Worldwide, the annual capital expenditures on water and wastewater infrastructure by utilities have been estimated at US$ 100 billion and US$ 104 billion, respectively

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UN WATER

Report

The United Nations World Water Development Report 2017

WASTEWATER
THE UNTAPPED RESOURCE

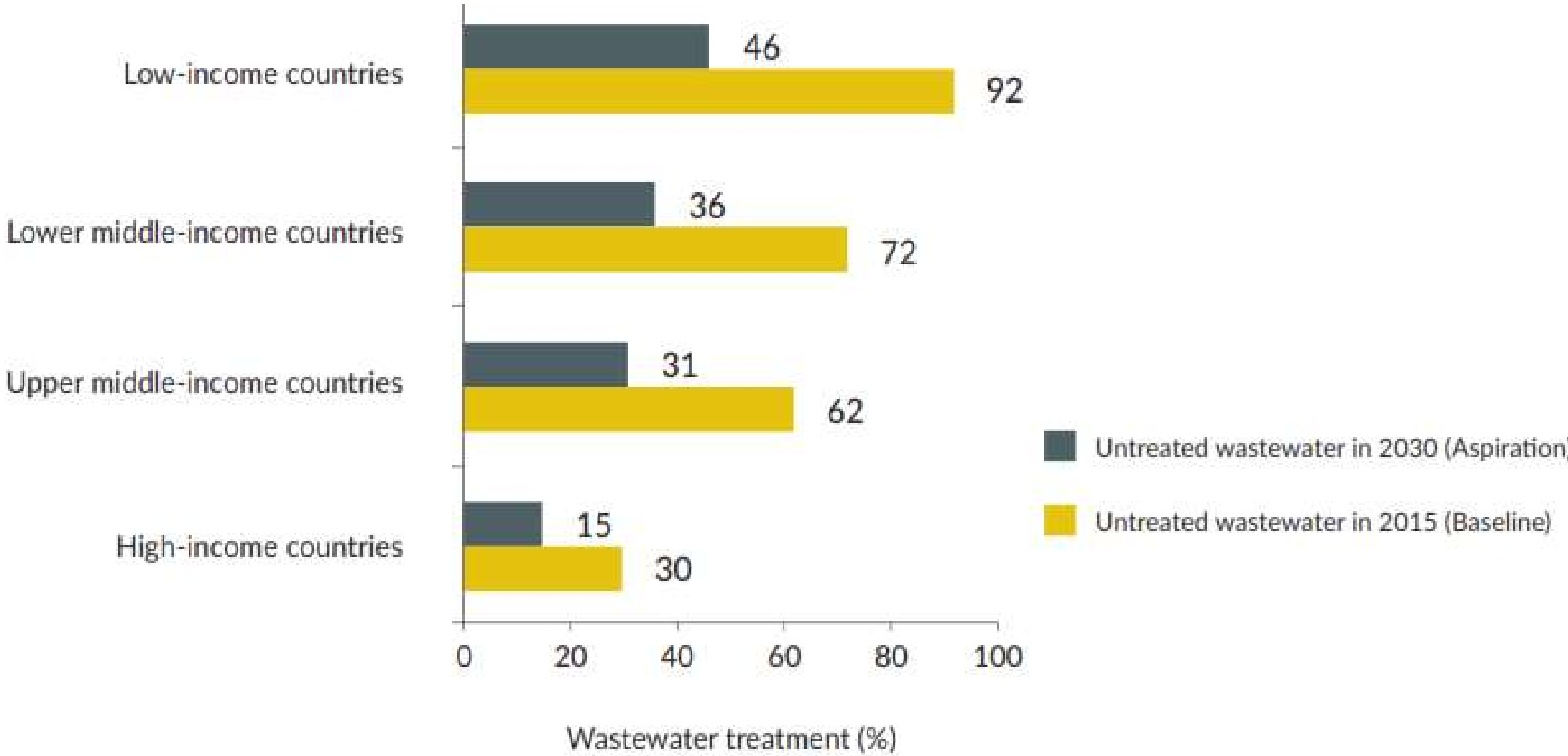
WWDR
2017

Framing wastewater management from a resource perspective

Resources in excreta and wastewater	Resource management options	Technical system options	Multiple potential benefits
Water	Water reuse and recycling Potable and non-potable water / industrial use / recharge of water bodies	Centralized vs decentralized	Health protection
Nutrients	Combined water and nutrient reuse Agricultural irrigation / forestry irrigation / aquaculture	Waterborne vs non-waterborne excreta management	Environmental protection
Energy content	Nutrient reuse or combined organic matter/nutrient reuse Solid and liquid fertilizer and soil conditioner for agriculture and forestry	Separate greywater management	Livelihoods
Organic matter	Energy generation Biogas generation / incineration / Biomas production	Sludge management	Gender equity
Other	Ecosystem services i.e. constructed wetland	Off-site vs on-site treatment	Water security
	Other outputs i.e. protein feed for livestock / building material	Wastewater treatment	Food security
		Excreta and sludge treatment	Energy security
			Climate mitigation and adaptation

Andersson et al. (2016) in WWRR2017

However, still long way to go



Is water central in the “Circular Economy Package”?

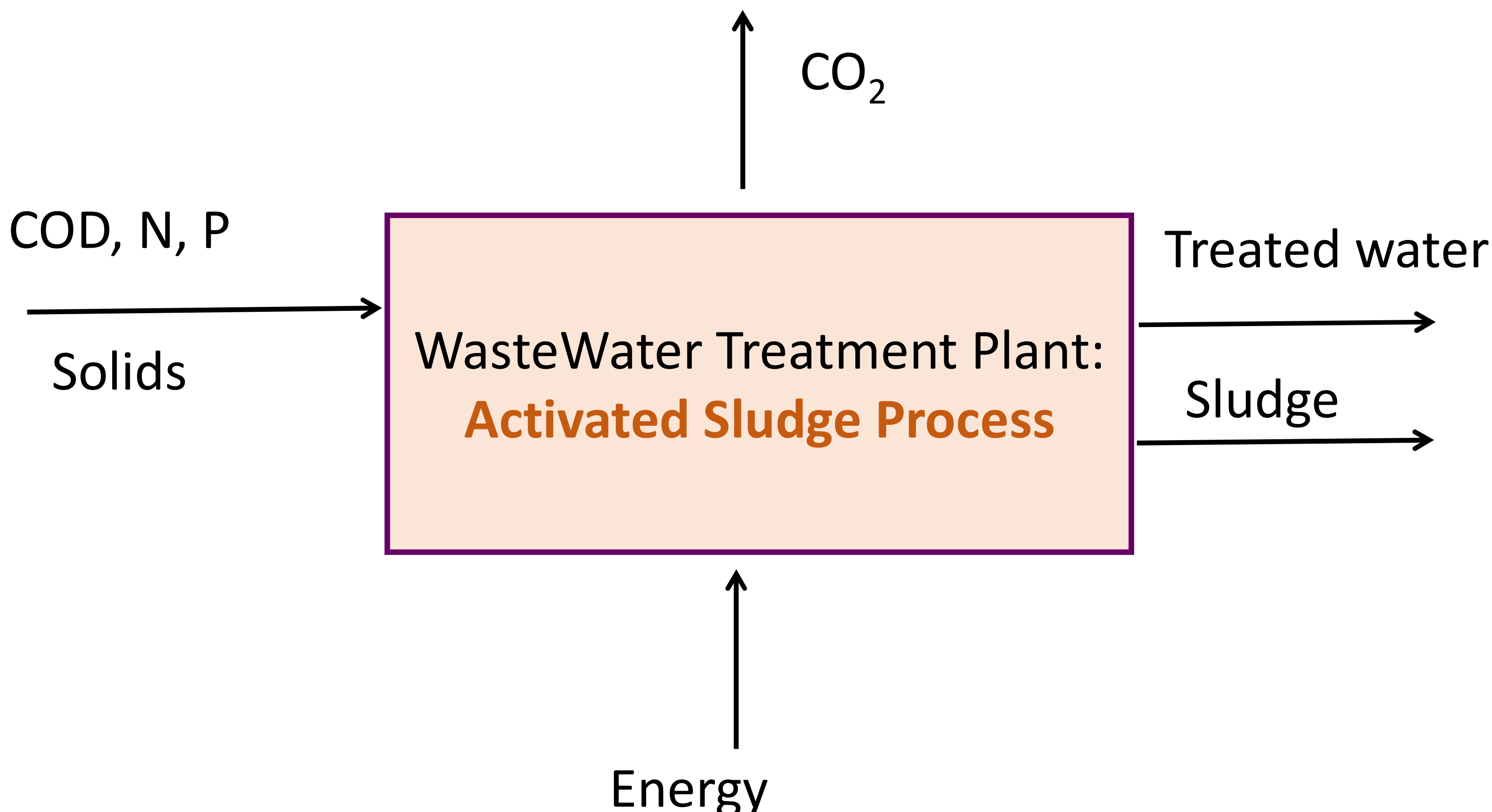
Circular Economy Package mainly aim at <u>facilitating water reuse</u> - this will include a legislative proposal on **<u>minimum requirements for reused water, for example for irrigation and groundwater recharge</u>**

Source: https://www.eip-water.eu/water-%E2%80%9Ccircular-economy-package%E2%80%9D

What about R&D&I in EU?

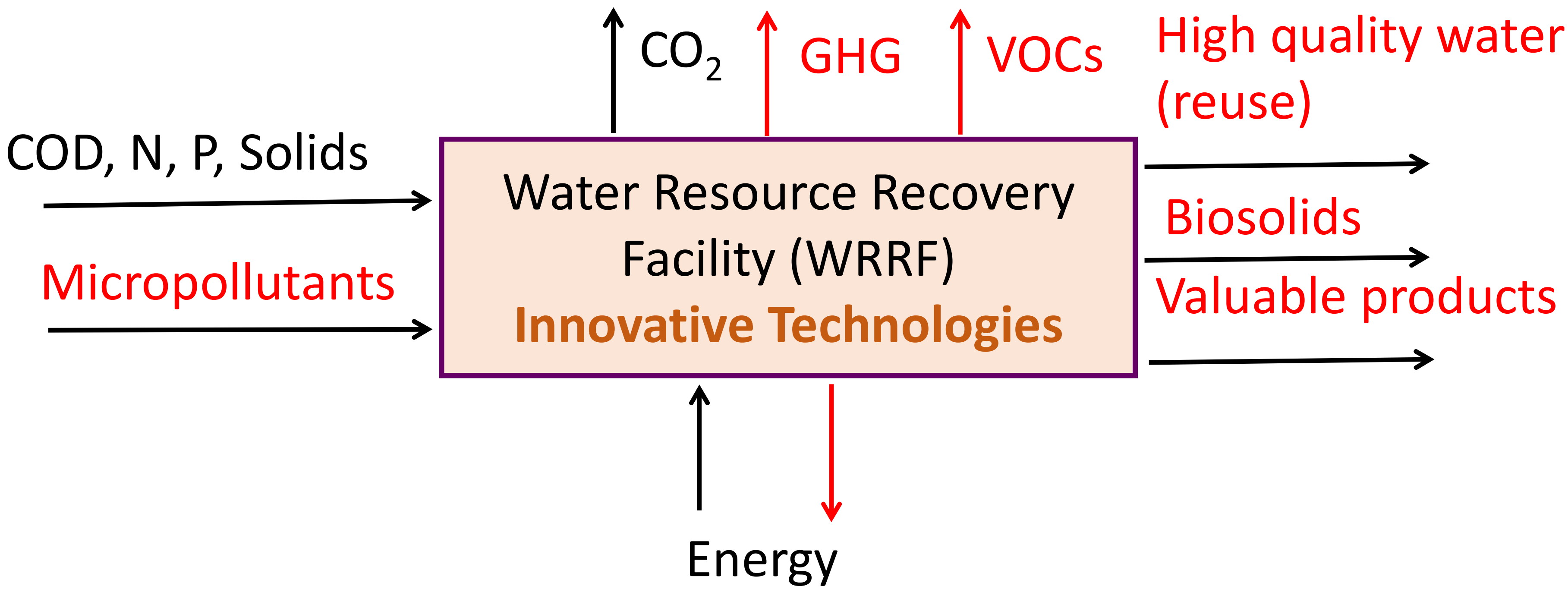
- **H2020 WATER INNOVATION: BOOSTING ITS VALUE FOR EUROPE (2014-2015):** Need of scale-up to demo, first application and market replication
- **H2020 WATER IN THE CONTEXT OF CIRCULAR ECONOMY (2016-2017)**: recovery and (re)use of nutrients and large demos for alternative water source, use and reuse

Current wastewater treatment:
Is this right for the next 100 years?



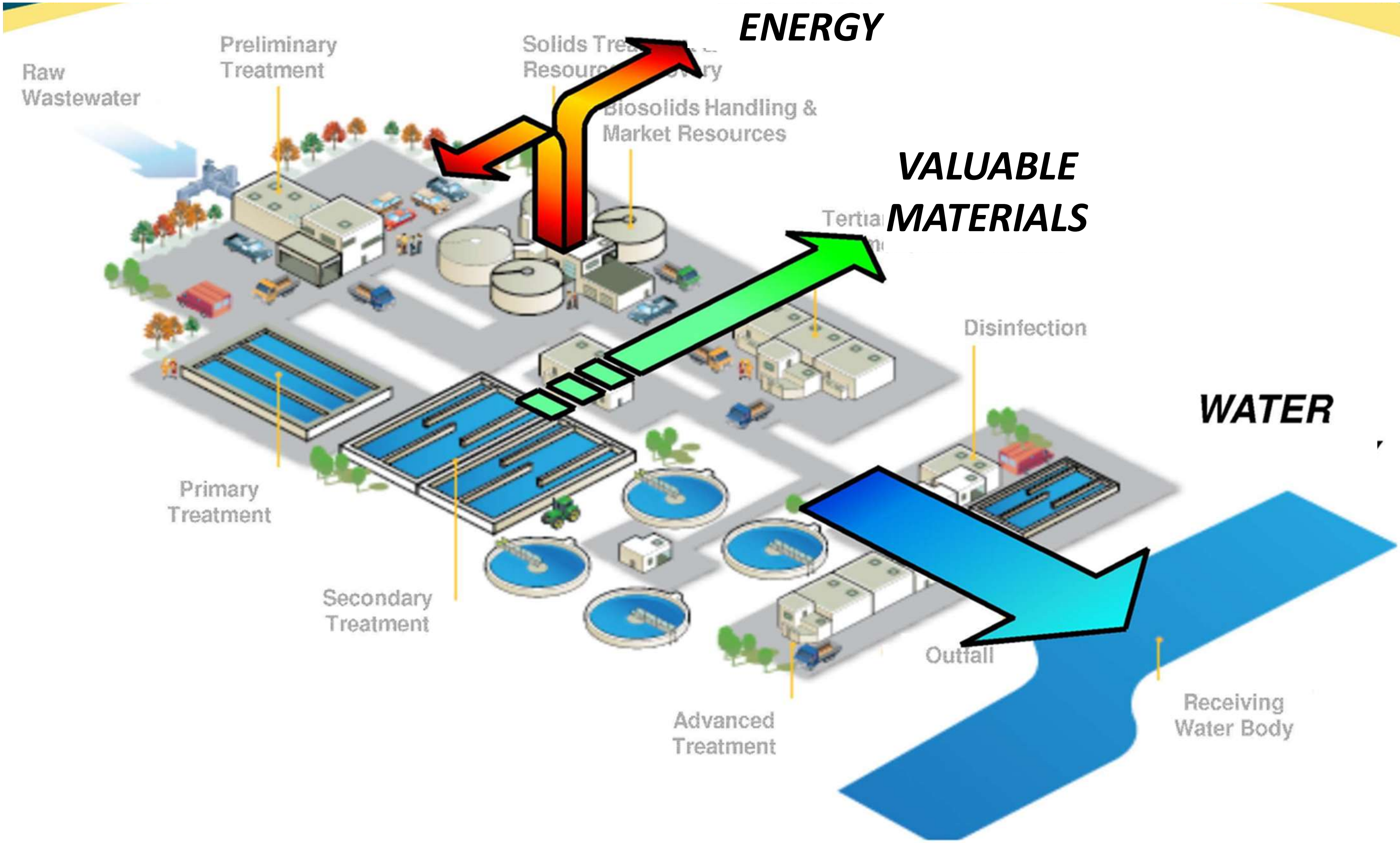
Courtesy: Juan Lema (Water_2020)

We want to move from WWTP to WRRF, how and when?



Courtesy: Juan Lema (Water_2020)

THREE MAIN PATHWAYS TO DELIVER CIRCULAR ECONOMY



Today's analysis: according to the Technology Readiness Level

TRL 0: **Idea**. Unproven concept, no testing has been performed.

TRL 1: **Basic research.** Principles postulated and observed but no experimental proof available.

TRL 2: **Technology formulation**. Concept and application have been formulated.

TRL 3: **Applied research**. First laboratory tests completed; proof of concept.

TRL 4: **Small scale prototype** built in a laboratory environment ("ugly" prototype).

TRL 5: **Large scale prototype** tested in intended environment.

TRL 6: **Prototype system** tested in intended environment close to expected performance.

TRL 7: **Demonstration system** operating in operational environment at pre-commercial scale.

TRL 8: **First of a kind commercial system**. Manufacturing issues solved.

TRL 9: **Full commercial application**, technology available for consumers.

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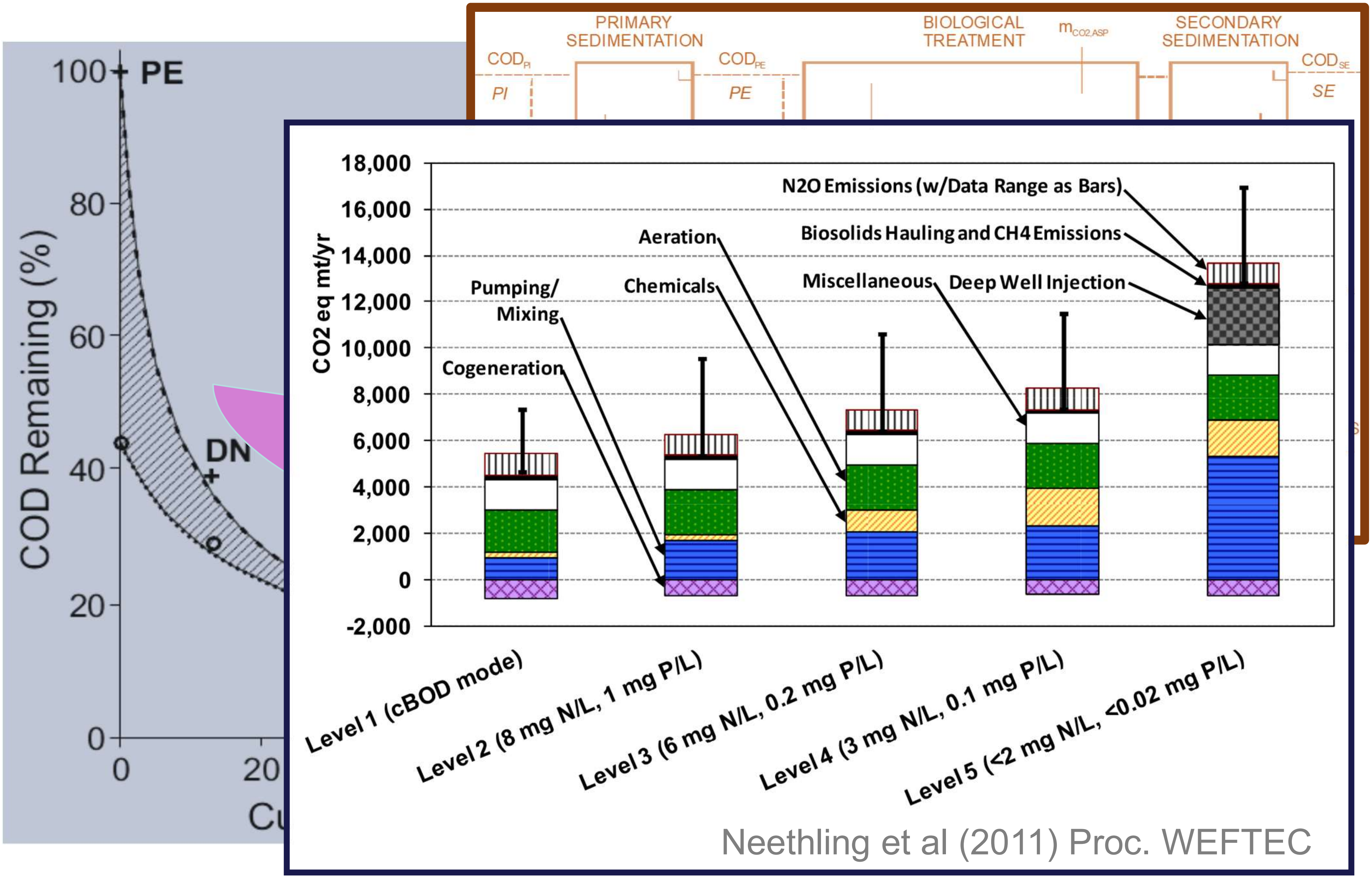
The ENERGY PATHWAY
(to deliver circular economy)

Current TRL = 8-9

but
WATER-ENERGY-CARBON NEXUS!

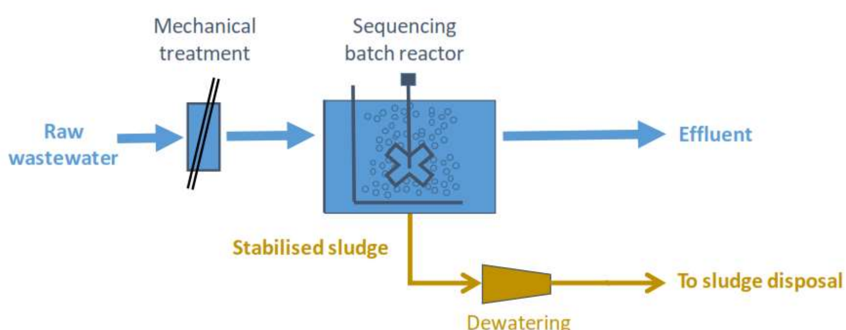
Case Study:
Energy and Carbon footprint vs. Product Water Quality

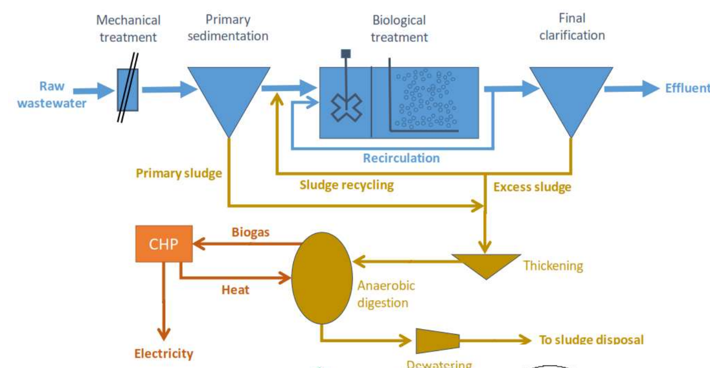


Neethling et al (2011) Proc. WEFTEC

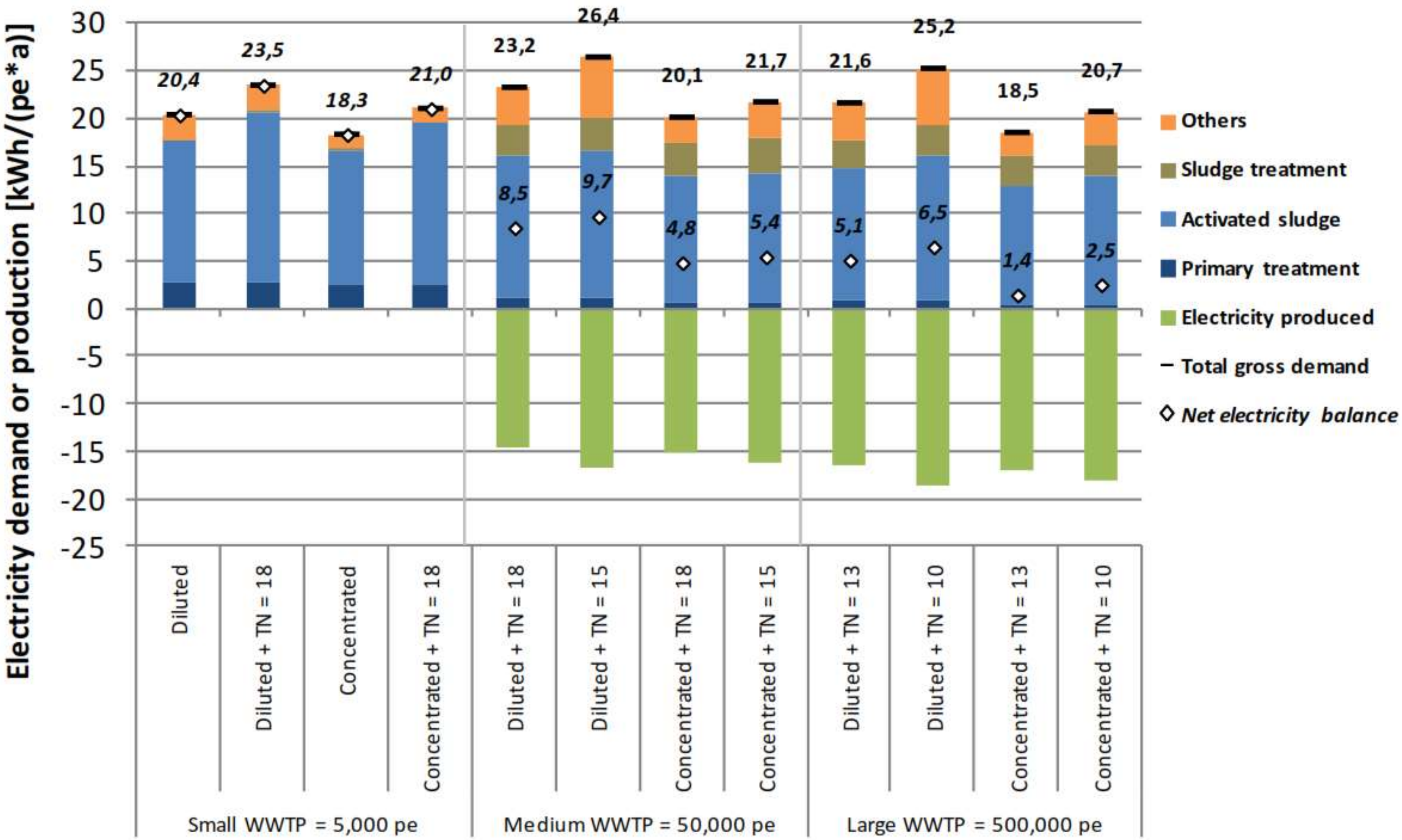
Reference conventional European WWTP

Stage	Small WWTP	Medium WWTP	Large WWTP
Size	5'000	50'000	500'000
Primary treatment	Mechanical	Mechanical + sedimentation	Mechanical + sedimentation
Biological treatment	Sequencing batch reactor (SBR)	Continuous activated sludge with pre-denitrification[2]	Continuous activated sludge with pre-denitrification[2]
Sludge treatment	Simultaneous aerobic stabilisation and dewatering	Thickening + anaerobic digestion[1] + dewatering	Thickening + anaerobic digestion + dewatering
Biogas valorisation	-	CHP[1]	CHP

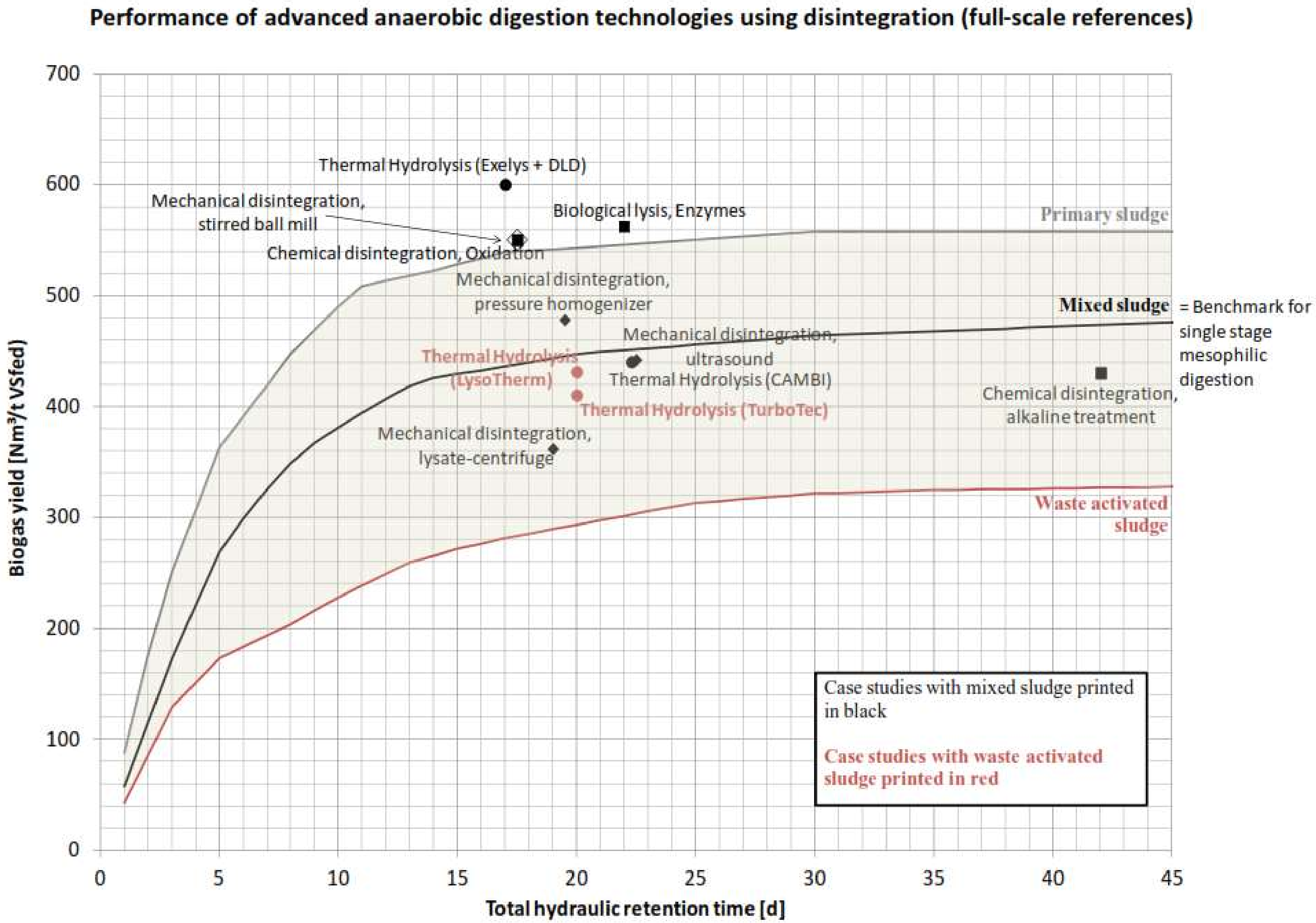




Energy positive is not possible in conventional WWTPs



Full scale performances of enhanced anaerobic digestion (1)



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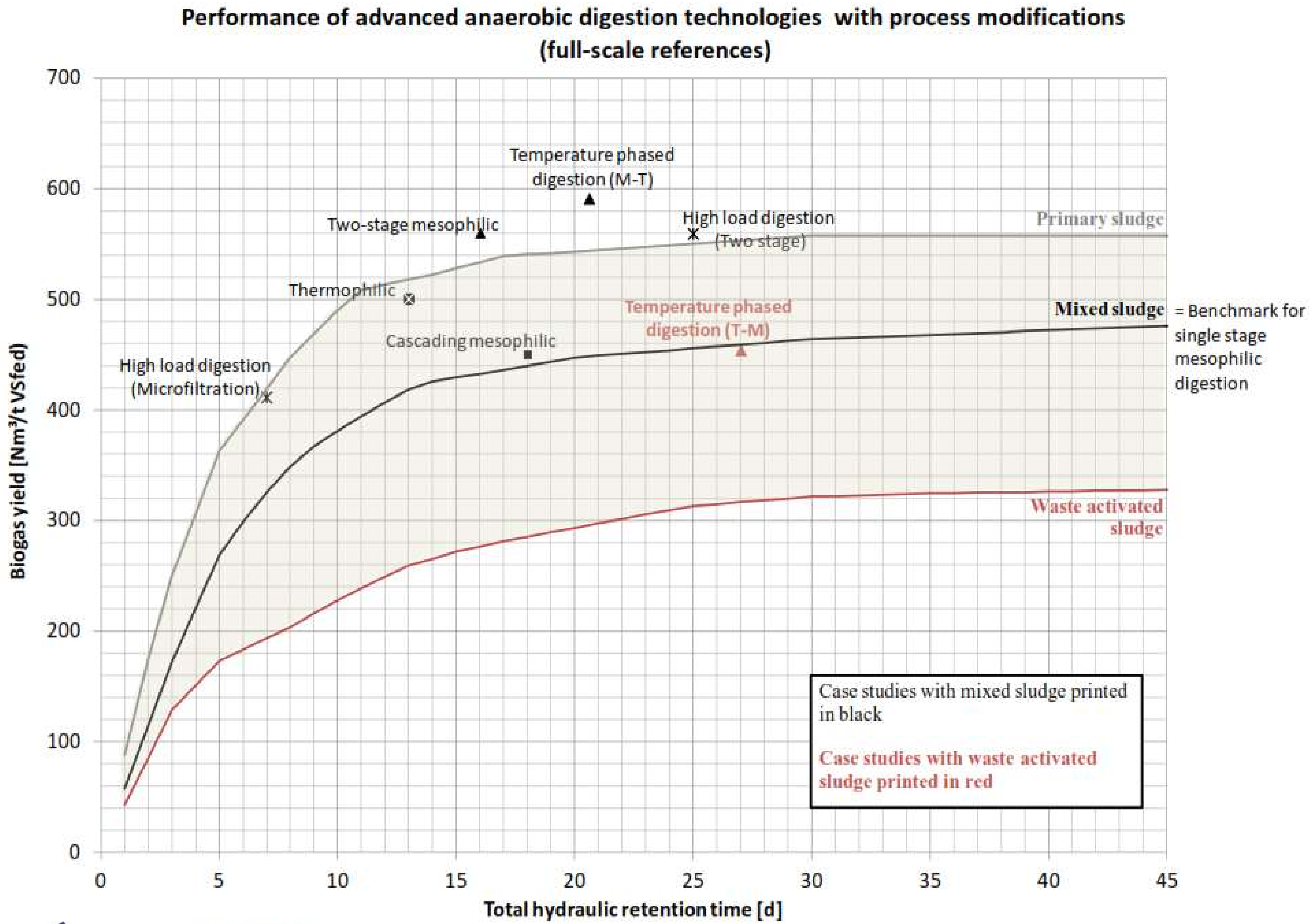
Full scale performances of enhanced anaerobic digestion (2)



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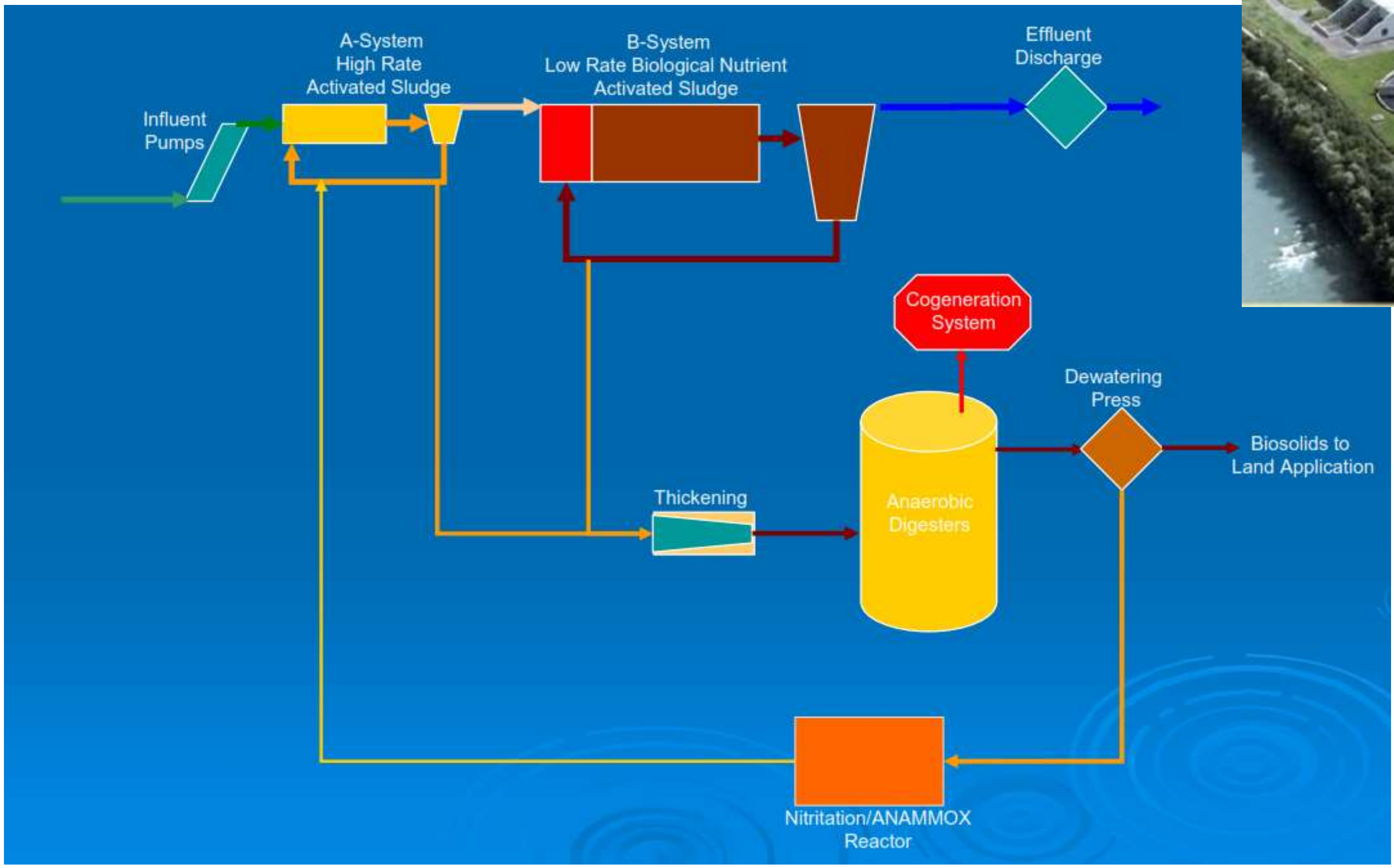
Energy positive in full scale: how?

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

Strass WRRF: energy positive since 2005



The A-stage

- High Rate Activated Sludge

0.5 h HRT; 12-18 h SRT

Particulate, Colloidal & SOLUBLE Organics

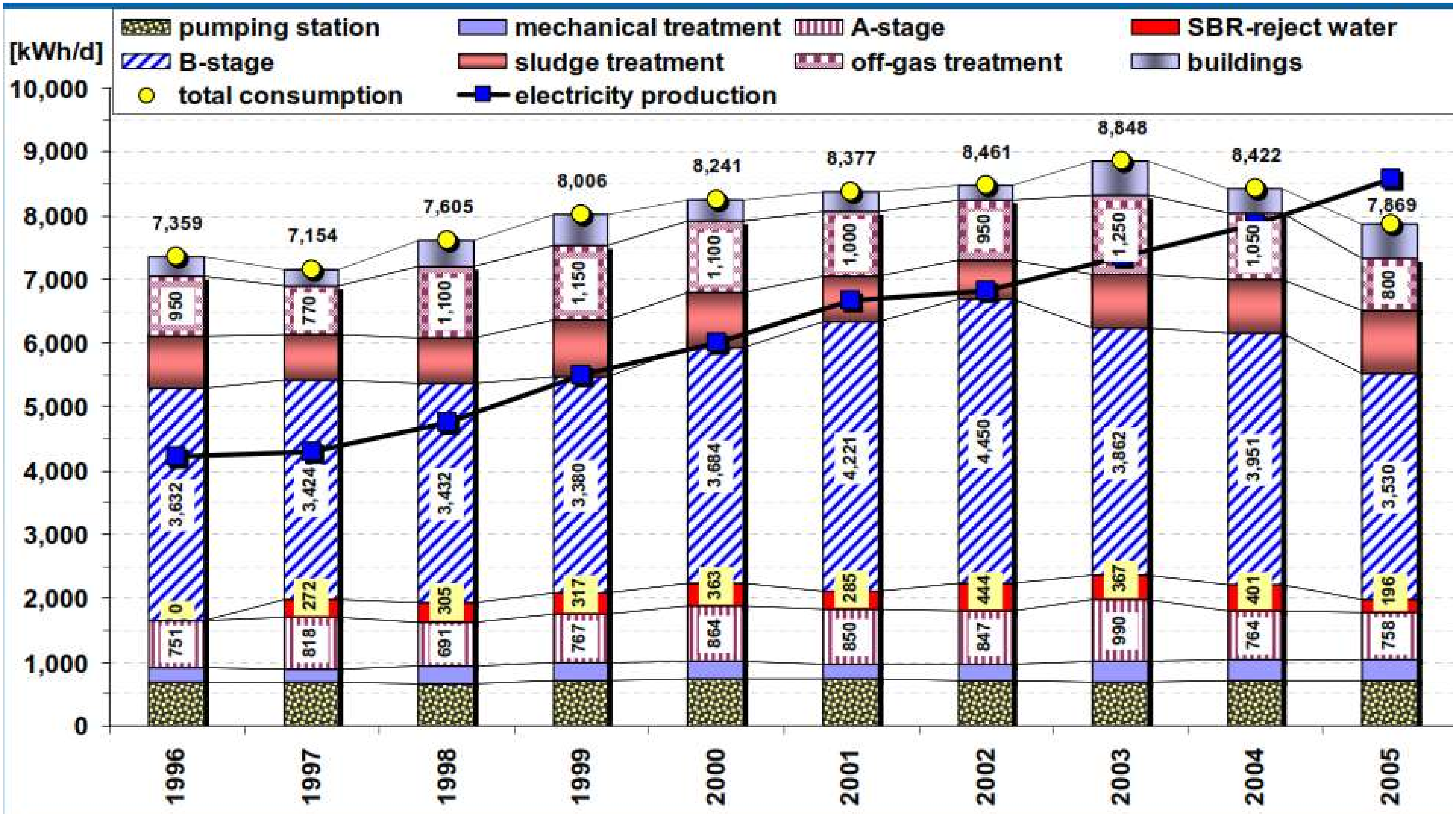
- Removal Without Chemical Addition

Rapid Transfer from Aerobic Conditions to

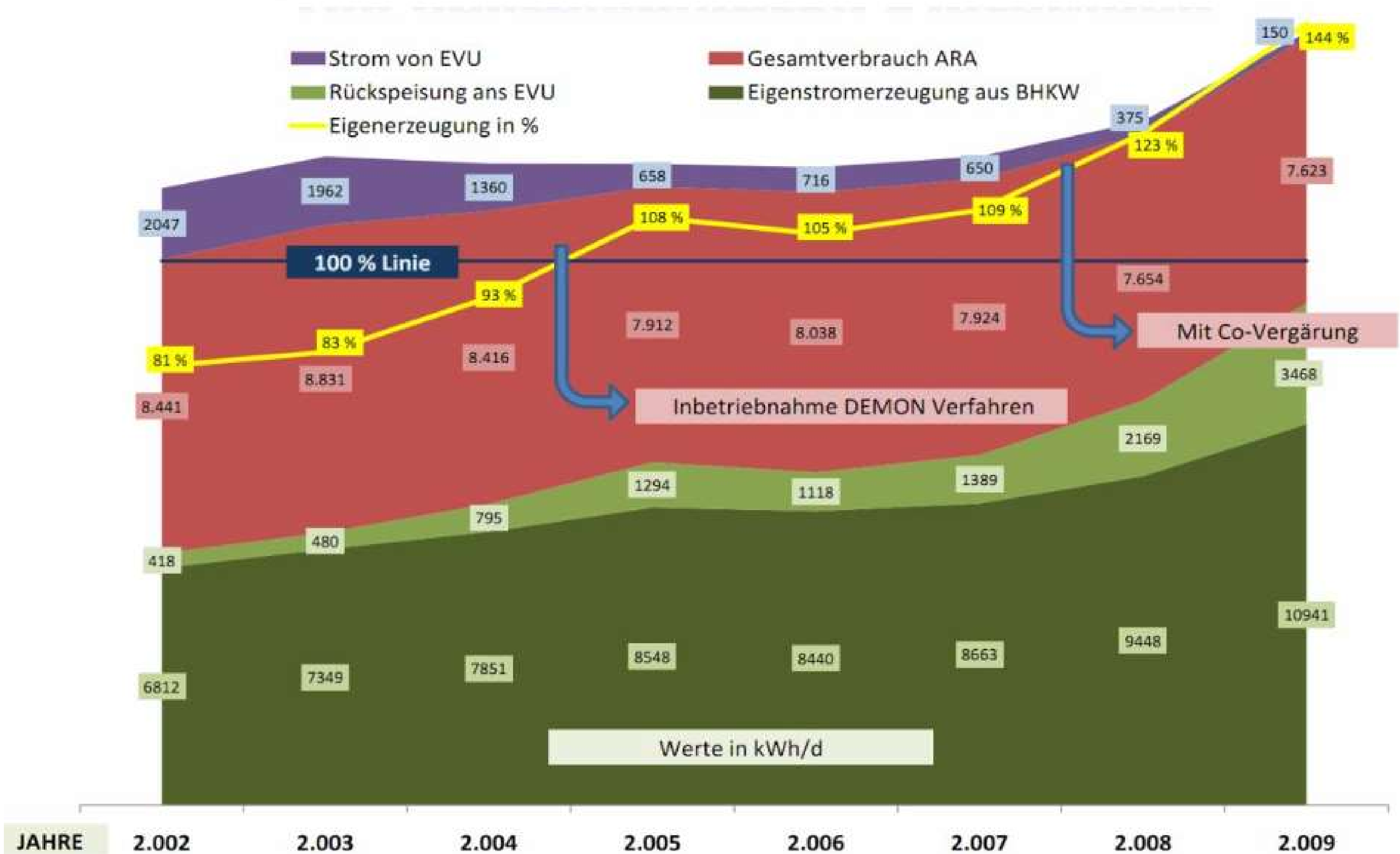
- Anaerobic Conditions for Rapid Thickening

Preserves Organics

Energy-positive in 2005



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



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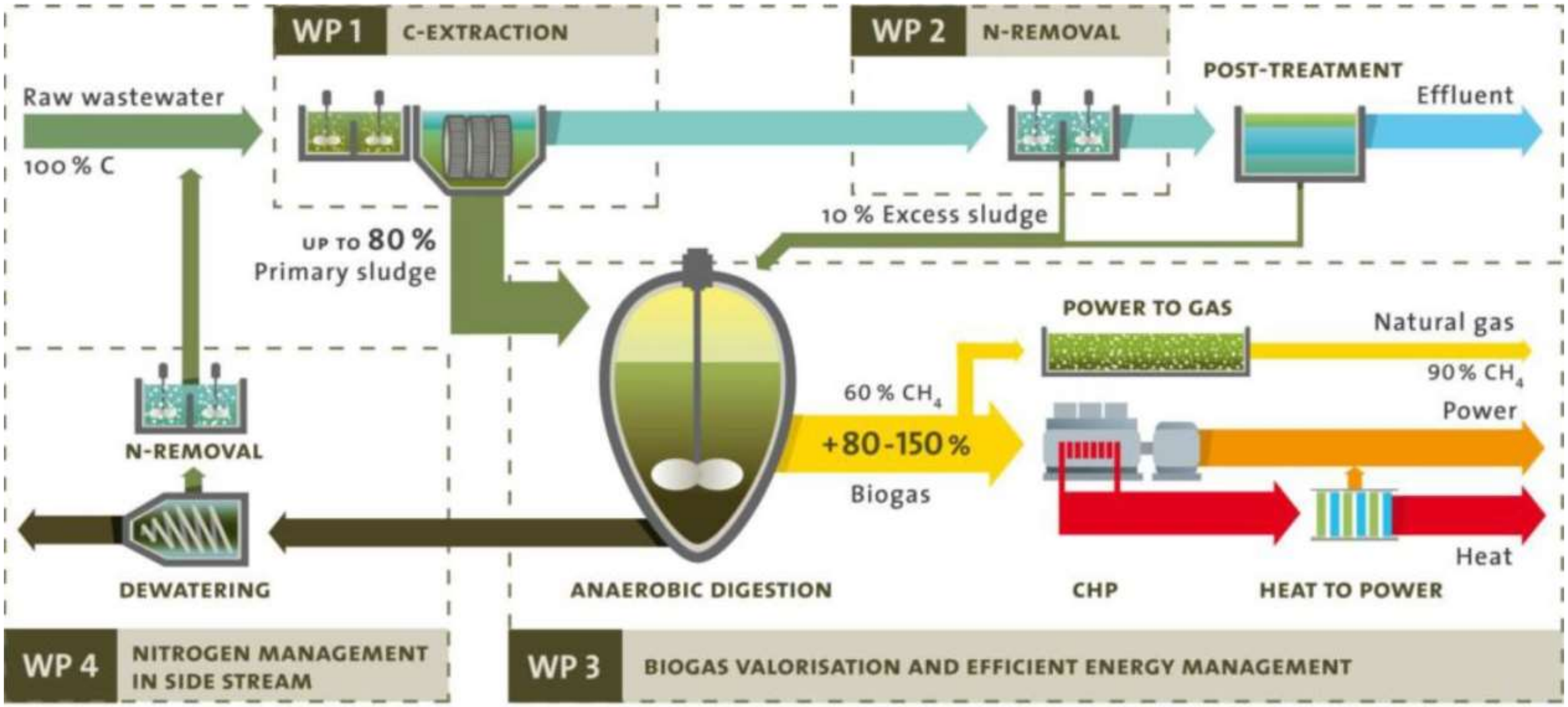
Energy positive evolution: H2020 POWERSTEP



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

The WATER PATHWAY
(to deliver circular economy)

TRL = 8-9

but, again,
WATER-ENERGY-CARBON NEXUS!

Water Recovery
NEWater - Singapore

Five NEWater plants produce total of 550,000 m^3/d

Source: Mc Carty – IWA-AD13

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Orange County Water District 2008
Wastewater Reuse (190,000 m^3/d)

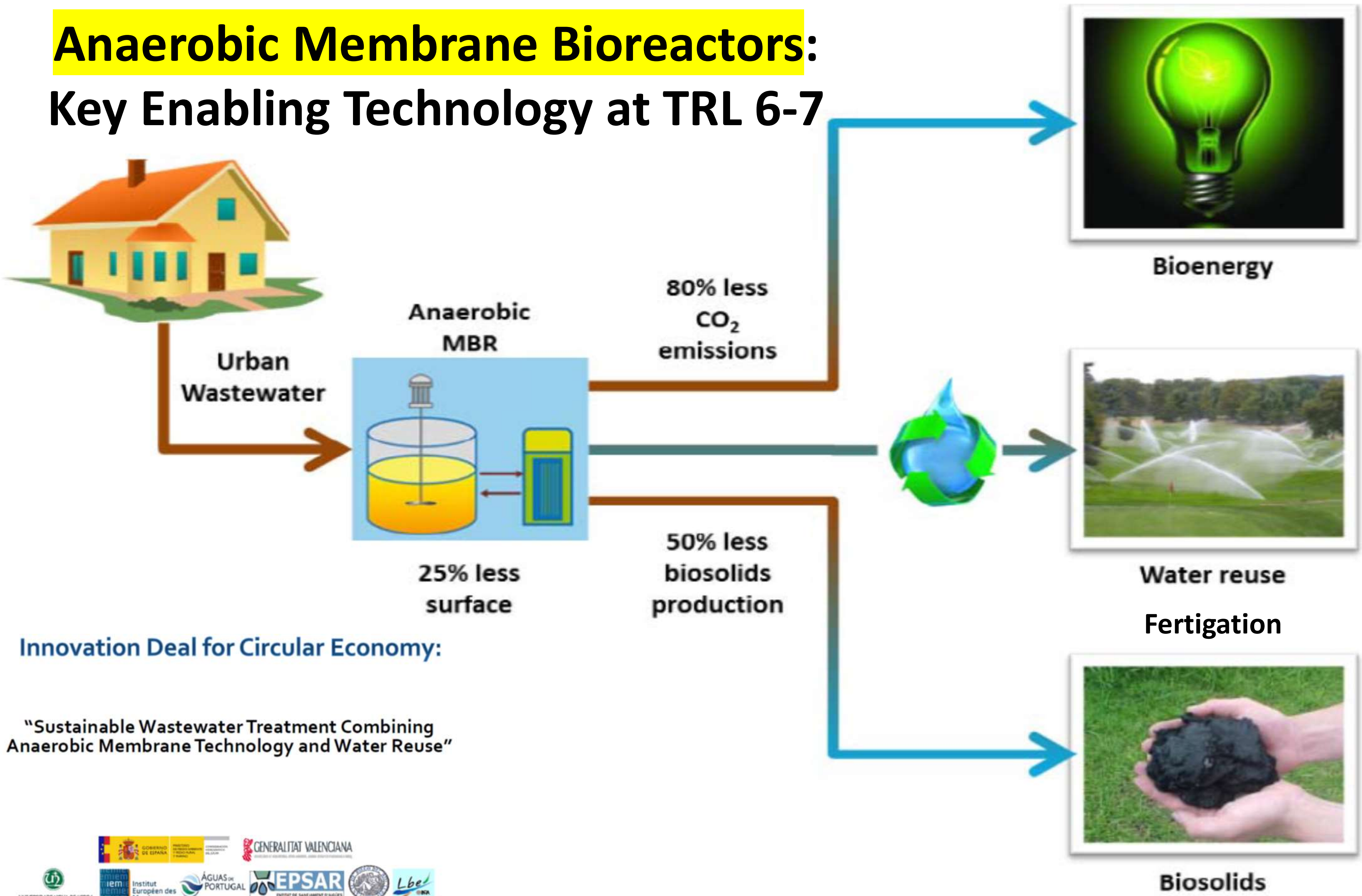
Source: Mc Carty – IWA-AD13

Innovation Deal for Circular Economy:

"Sustainable Wastewater Treatment Combining Anaerobic Membrane Technology and Water Reuse"

Anaerobic Membrane Bioreactors:

Key Enabling Technology at TRL 6-7

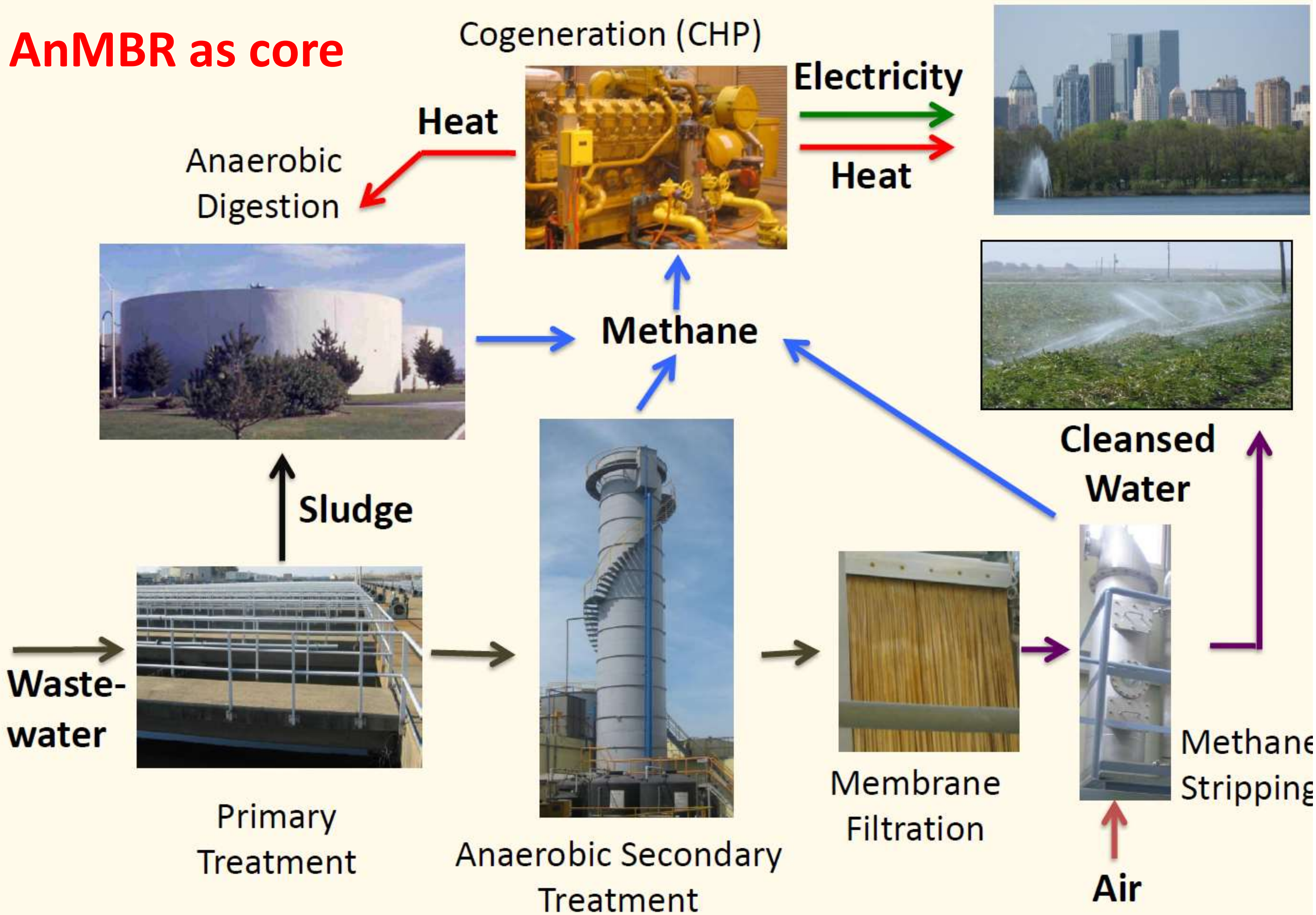


Innovation Deal for Circular Economy:

"Sustainable Wastewater Treatment Combining Anaerobic Membrane Technology and Water Reuse"

Source: Aurora Seco (2016)

AnMBR as core



McCarty, Bae, Kim, *Environ. Science & Tech.*, 45:7100 (2011)

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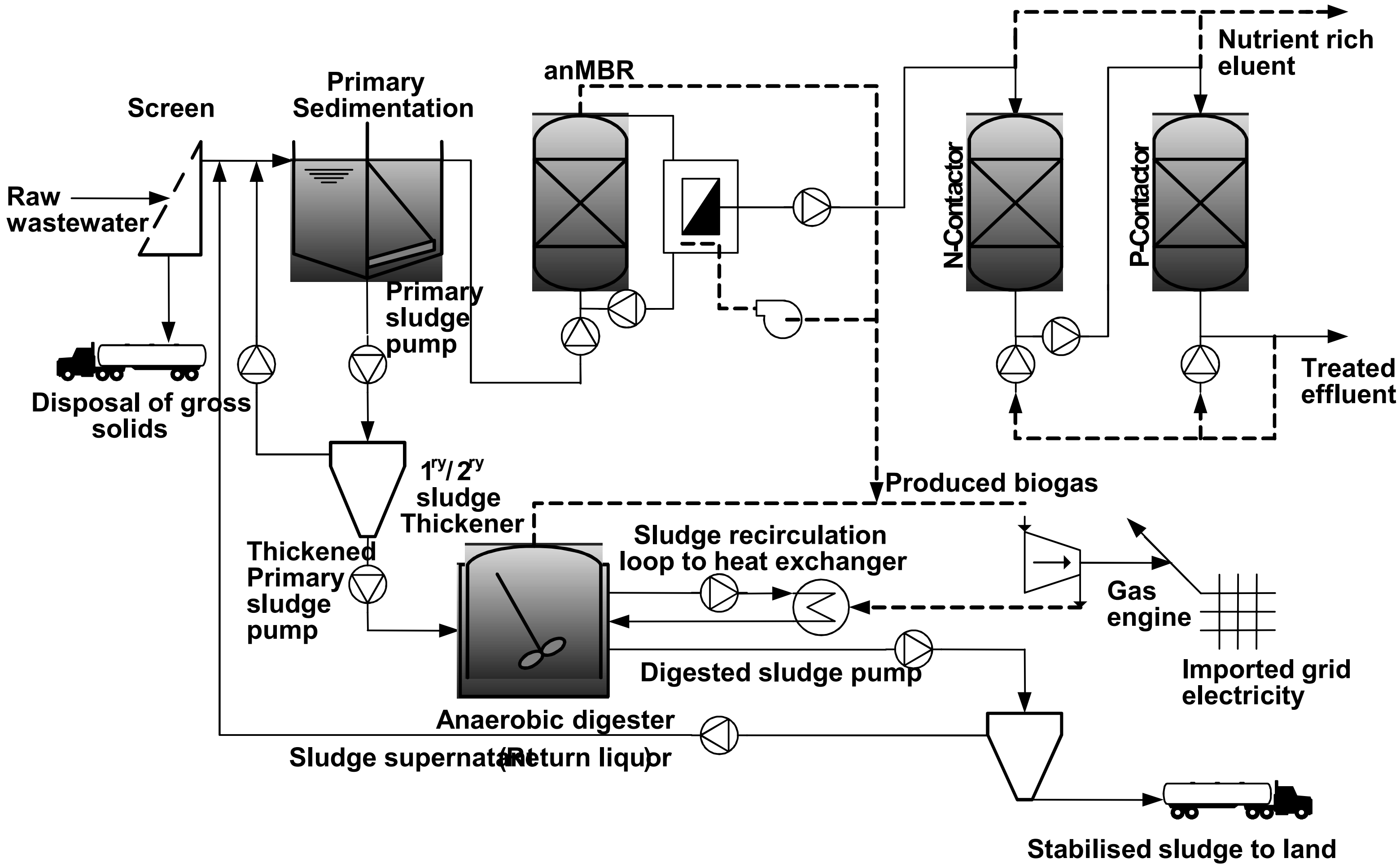
AnMBR central for energy positive and nutrient recovery (TRL = 5-6)



Source: Bruce Jefferson, 2016

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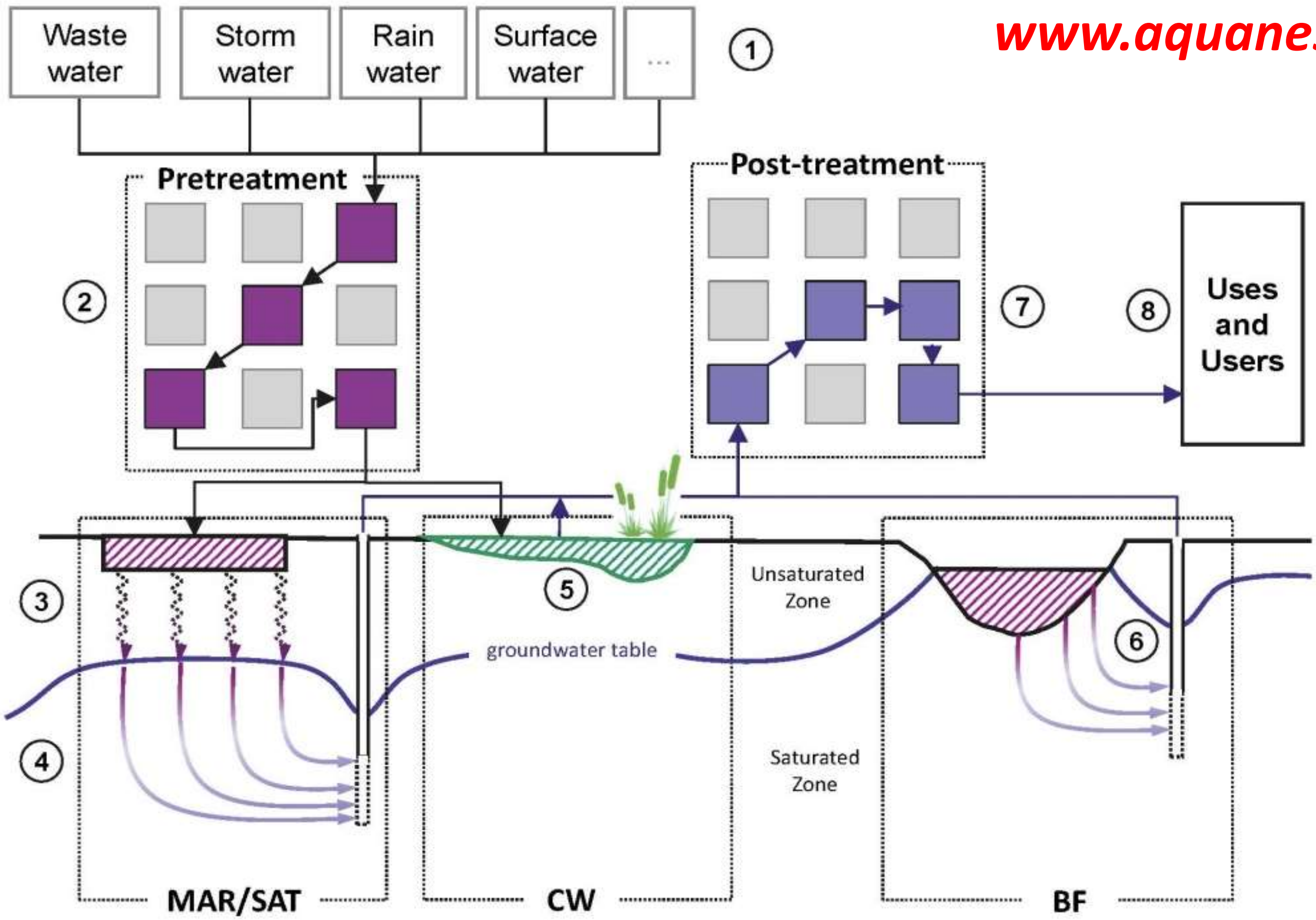
Evolution of water use and reuse: the H2020 AquaNES

www.aquanes.eu



Managed Aquifer Recharge

Constructed wetland

Bank Filtration

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The MATERIALS PATHWAY
(to deliver circular economy)

Phosphorus = TRL 8-9
Other = TRL 4-7

but: social, market and regulatory barriers!

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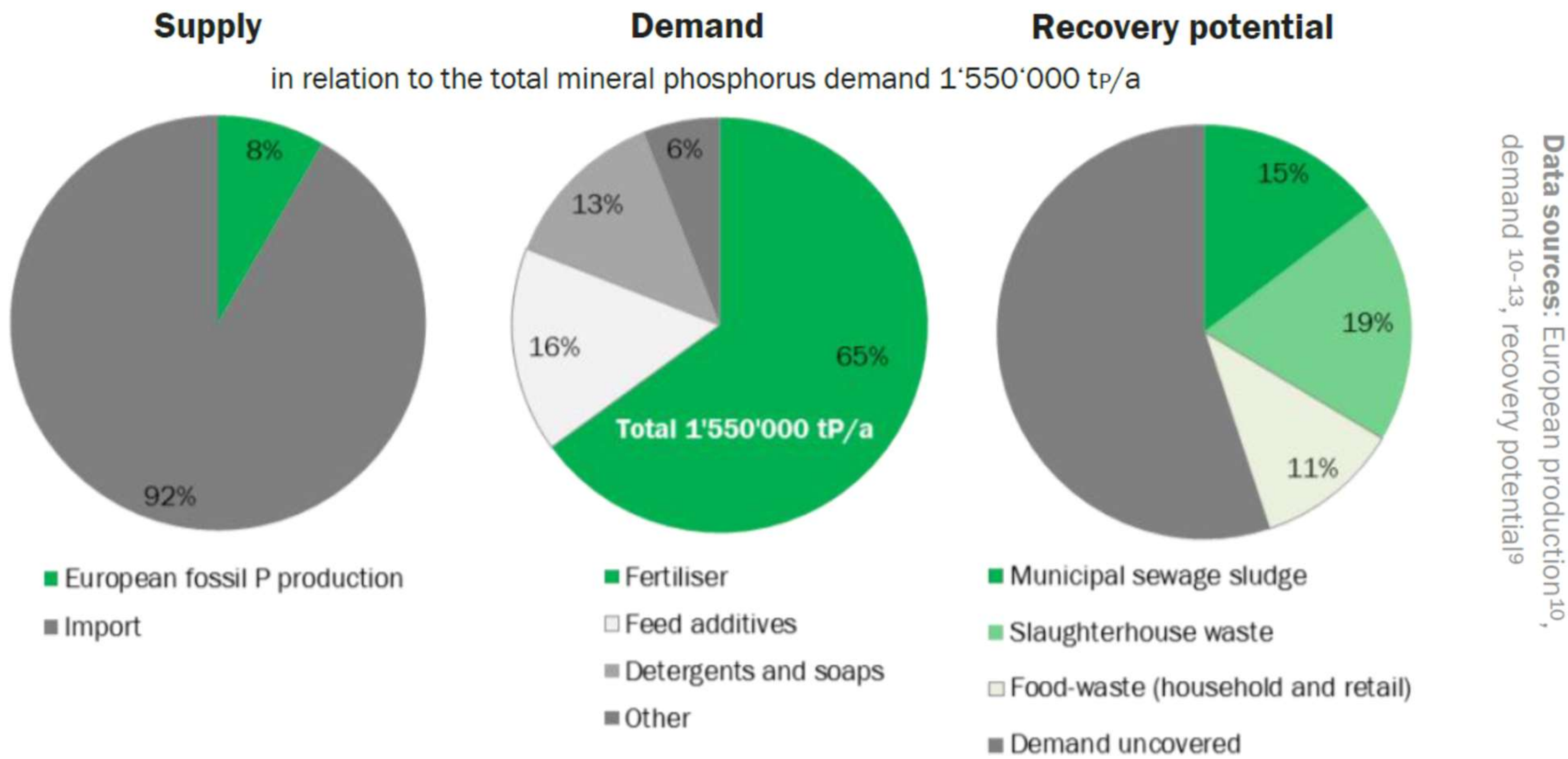
Phosphorus use in EU-27 in 2005



The lost P in the European wastewater stream could cover 15% of the European mineral phosphorus demand

Source: P-REX

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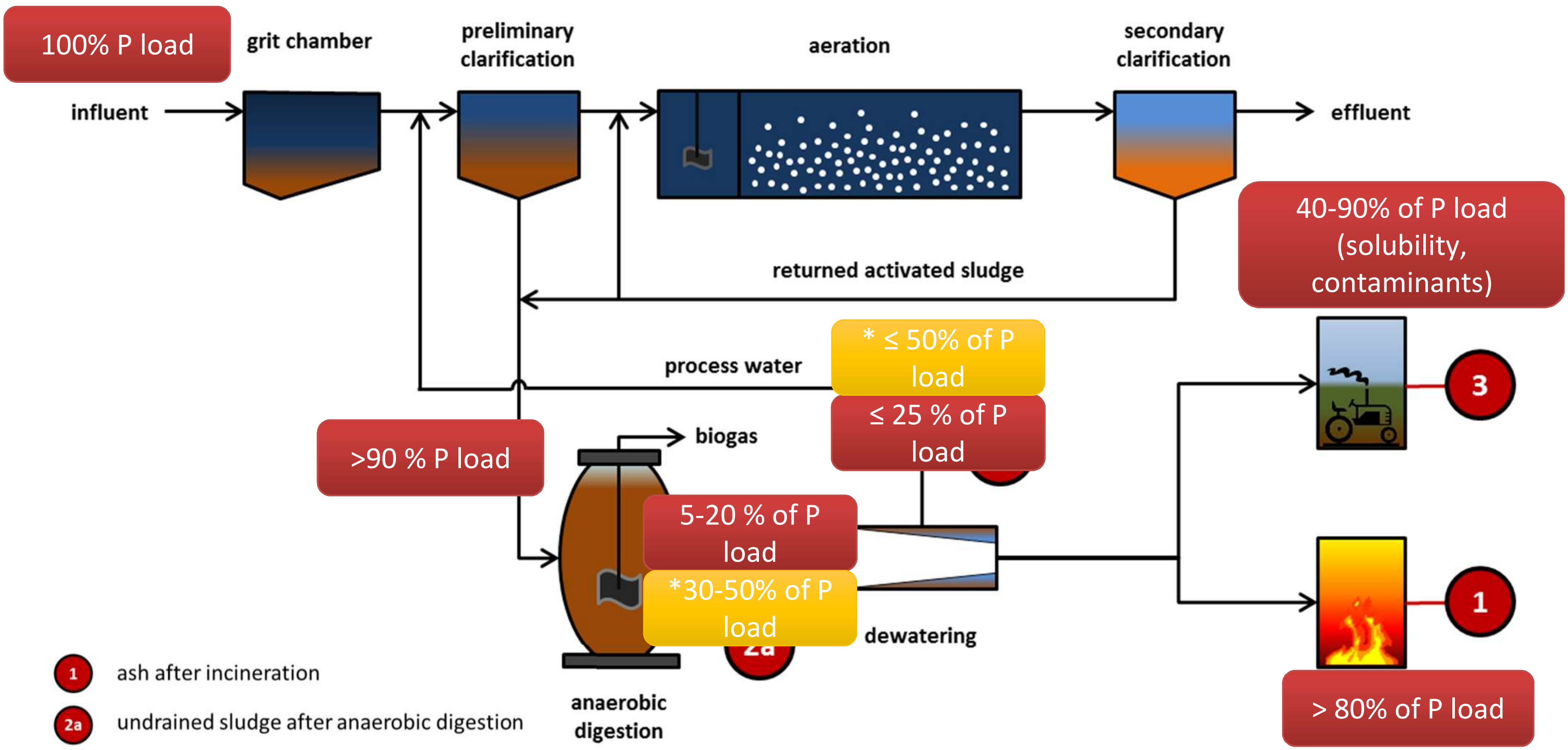
Hot spots for P recovery from municipal wastewater



1 ash after incineration

2a undrained sludge after anaerobic digestion

2b sludge liquor after dewatering

3 direct agricultural utilisation of dewatered sludge

*enhanced P dissolution

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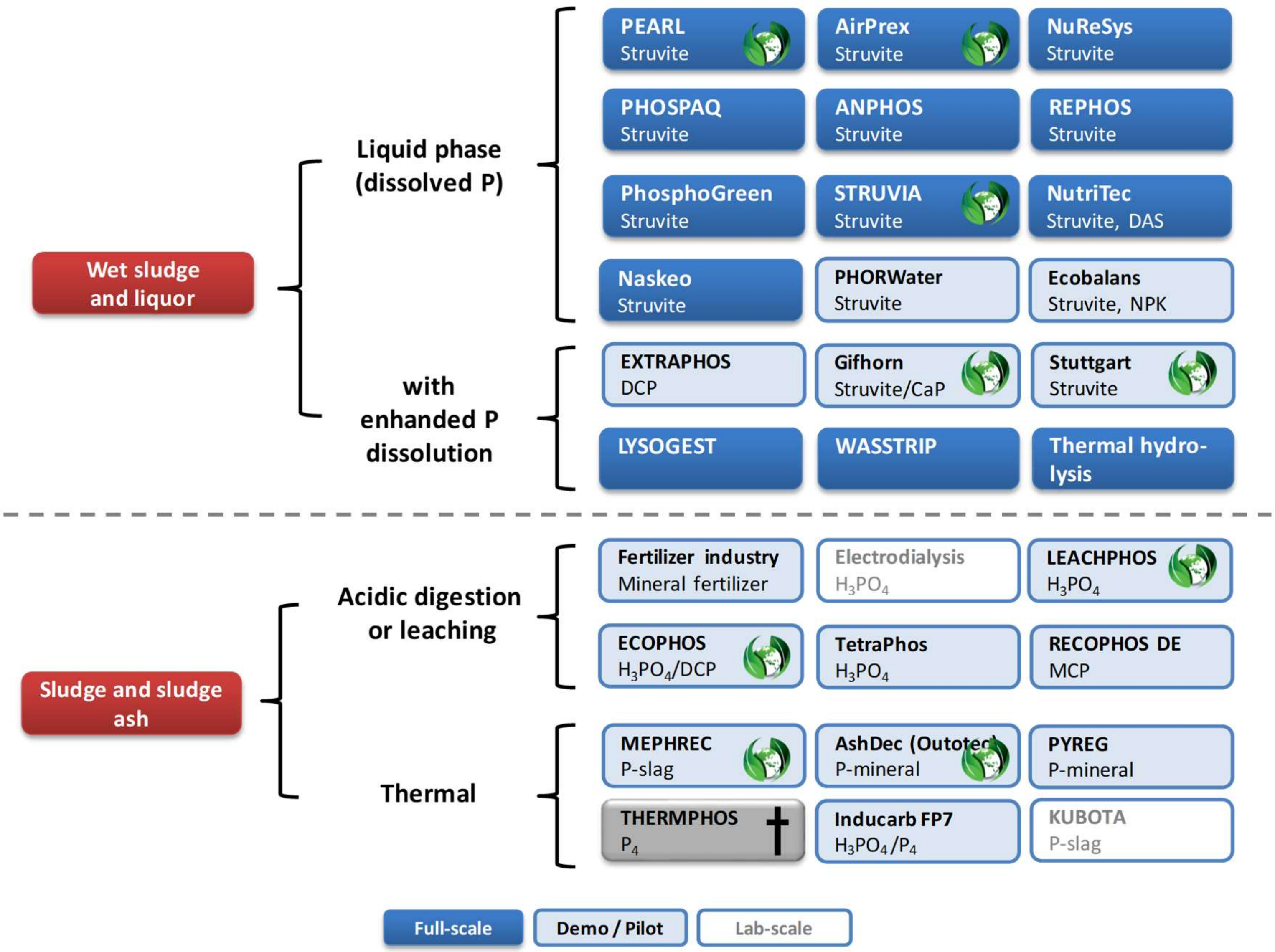
P recovery technologies



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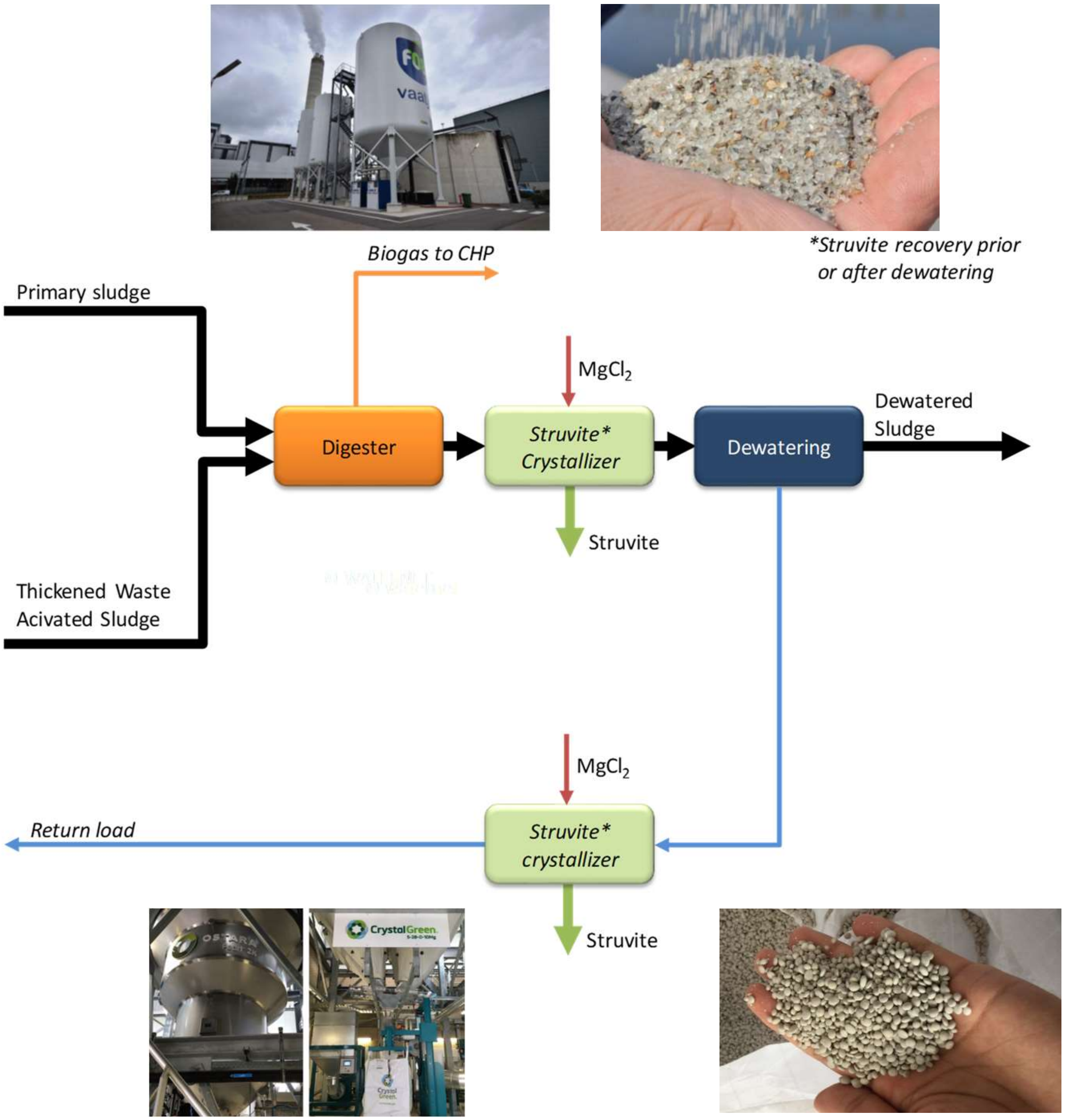
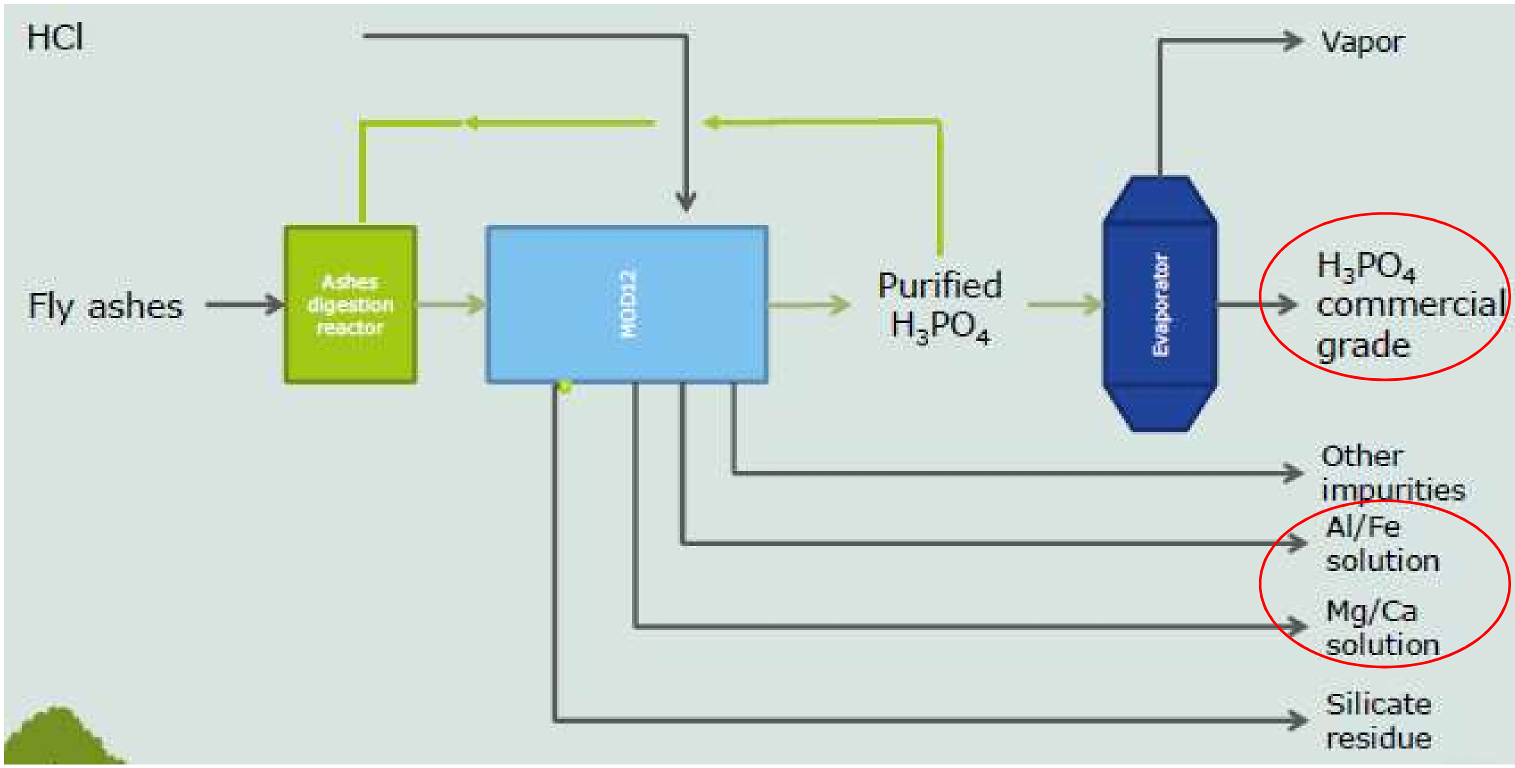


Source: P-Rex

P recovery from reject water: feasible only when
Enhanced Biological Phosphorus Removal is applied in mainline

Acid digestion of incineration ash and purification

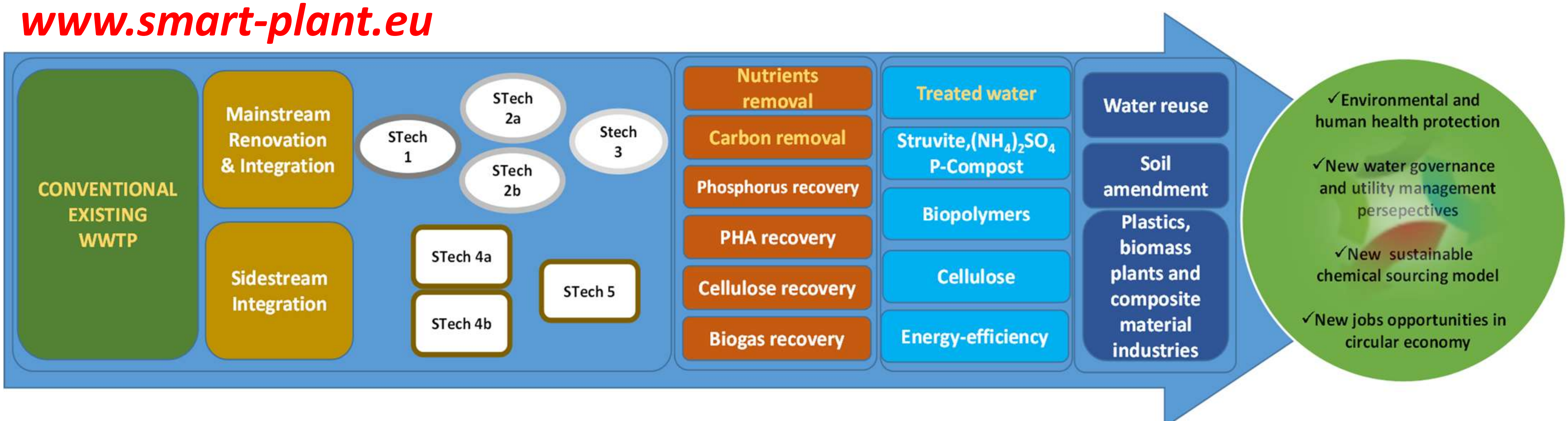


Source: ECOPHOS, R. de Ruiter 2014

- ✓ **Flexible low-grade inputs**
- ✓ **Commercial products (H_3PO_4)**
- ✓ **Commercial by-products (Metal salts)**
- ✓ **Independent from Fe/Al content**
- ✓ **First EU full-scale facility in Dunkerque (FR)**

Evolution of materials recovery and reuse : H2020 SMART-PLANT

www.smart-plant.eu



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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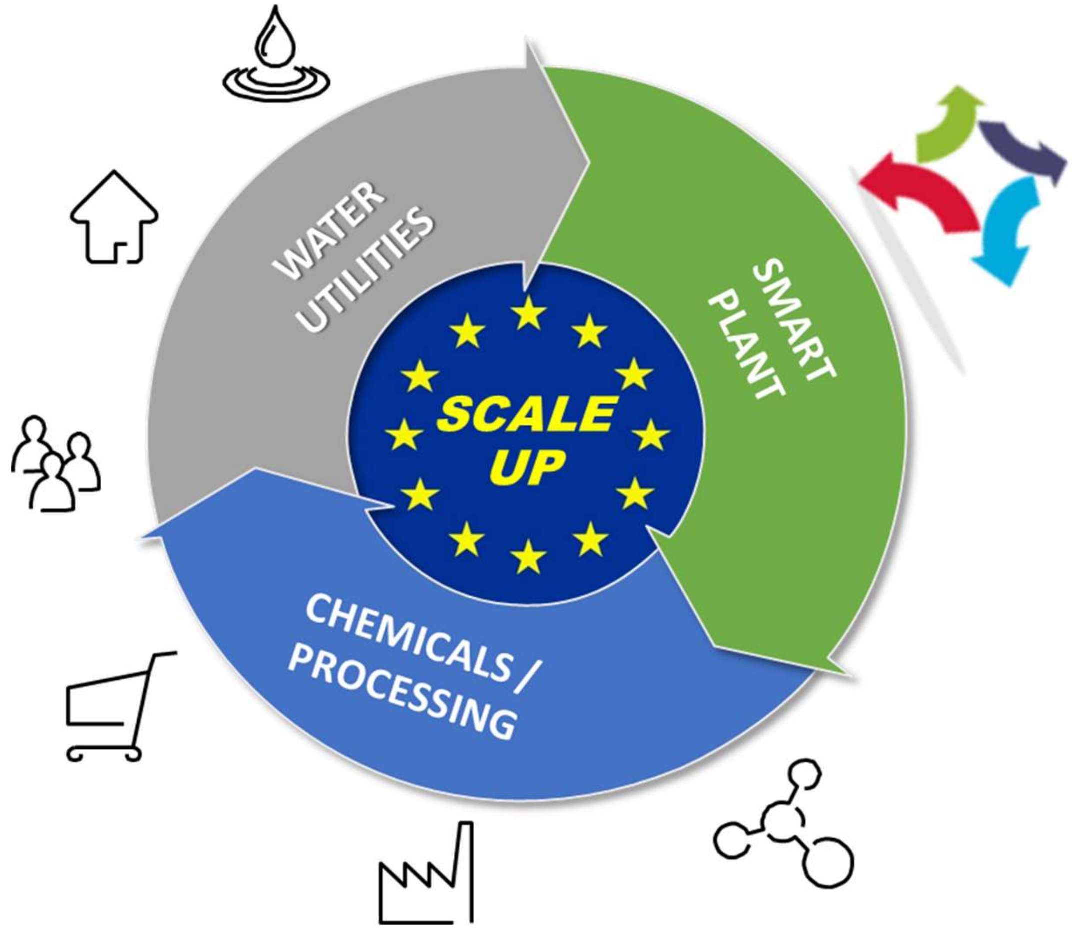
Demonstration of the full inter-sectorial value chain



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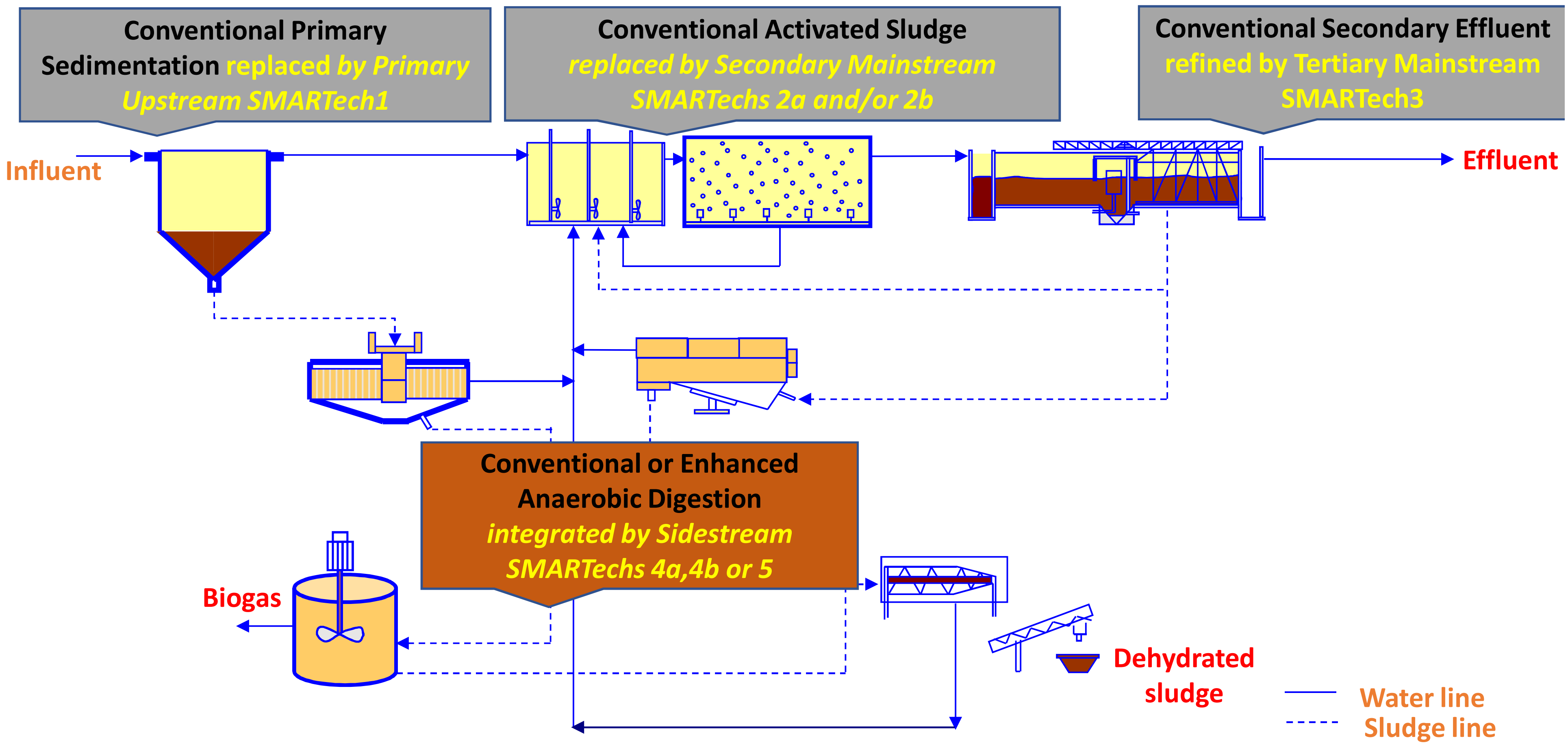
Energy efficiency is the water market entry strategy, materials recovery is the added value



The SMART-Plant integrated WRRFs

SMARTech	**Site**	Key enabling process(es)	**SMART-product(s)**
1	**Geestmerambacht (NL)**	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 (ES)**	Mainstream SCEPPHAR	**P-rich sludge, PHA**
3	**Cranfield (UK)**	Mainstream tertiary hybrid ion exchange	**Nutrients**
4a	**Carbonera (IT)**	Sidestream SCENA+conventional AD	**P-rich sludge, VFA**
4b	**Psyttalia (GR)**	Sidestream SCENA+enhanced AD	**P-rich sludge**
5	**Carbonera (IT)**	Sidestream SCEPPHAR	**PHA, struvite, VFA**
Downstream SMARTechA	**London (UK)**	Formulation of recovered cellulosic and PHA materials+extrusion	**Biocomposite (Sludge Plastic Composite – SPC)**
Downstream SMARTechB	**Manresa (ES)**	Dynamic composting of P-rich sludge using minerals as bulking agents; bio-drying of cellulosic sludge	**P-rich compost, enriched with minerals; fuel for biomass plants**

Want to know more on the SMARTechs and SMART business model?
Follow the session on Saturday!

Successful EU projects presentations

Saturday, 09.09.2017, 11:30 – 12:30, Complesso Terracini, Room TA-01
Chairperson: Prof.dr. Fabio Fava

Time	Title	Authors
11:30-12:30	Why and how to write ERC proposals?	**Prof. dr. Rainer Meckenstock** University of Duisburg-Essen, Germany
	CIRC-05-2016: "Unlocking the potential of urban organic waste (RES URBIS)"	**Prof. dr. Mauro Majone** University "La Sapienza", Rome, Italy
	WASTE-7-2015: "Ensuring sustainable use of agricultural waste, co-products and by-products (NoAW)"	**Prof. dr. Nathalie Gontard** INRA, Montpellier, France
	WATER-1b-2015: "Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants (SMART-plant)"	**Prof. dr. Francesco Fatone** Università Politecnica delle Marche, Ancona, Italy
	BBI VC3.F1 – 2014: "Flagship demonstration of an integrated biorefinery for dry crops sustainable exploitation towards biobased materials production (First2Run)"	**Dr. Giulia Gregori** Novamont, Italy

ICEEM 09

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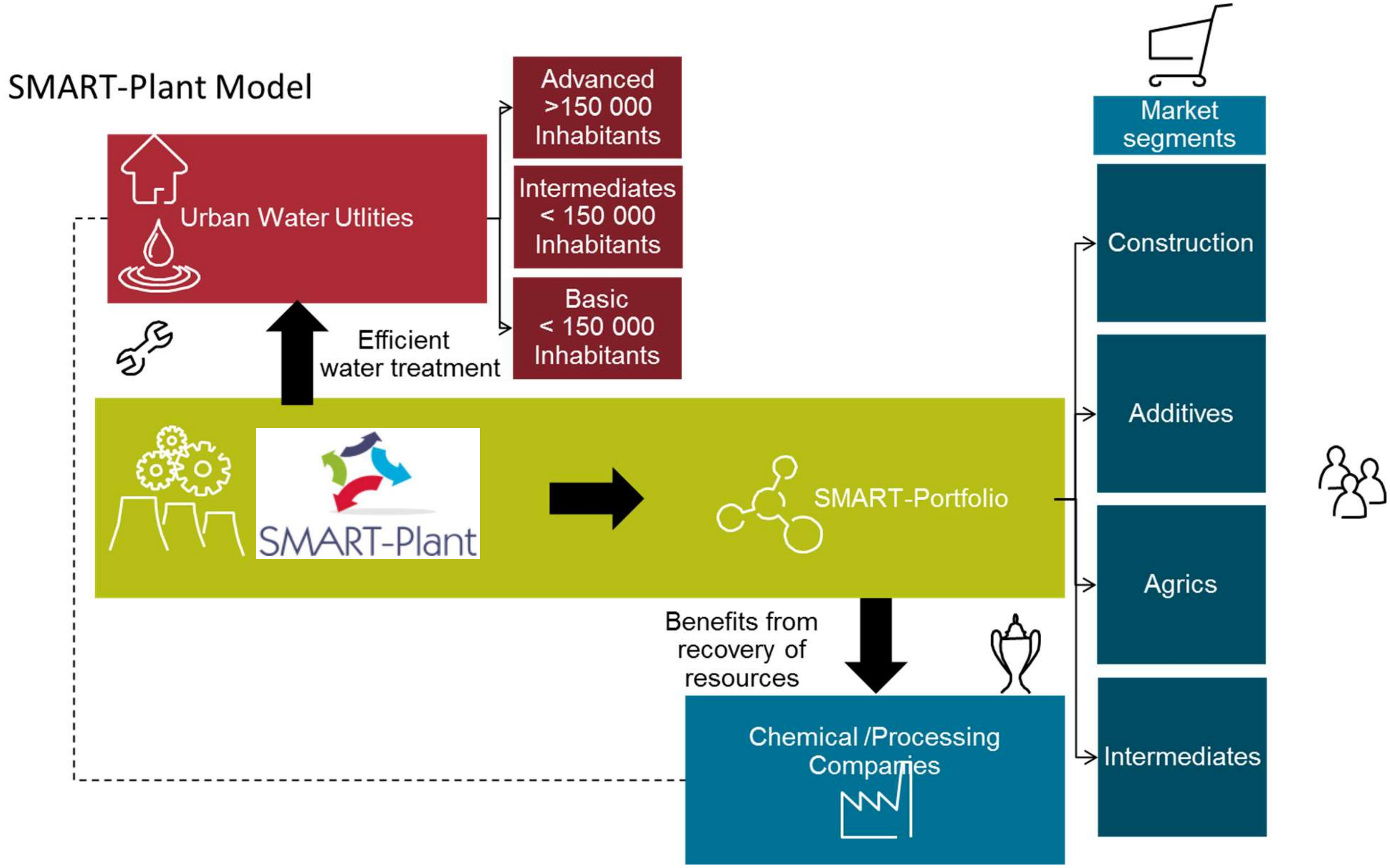
SMART-Plant Business plan and market deployment strategy



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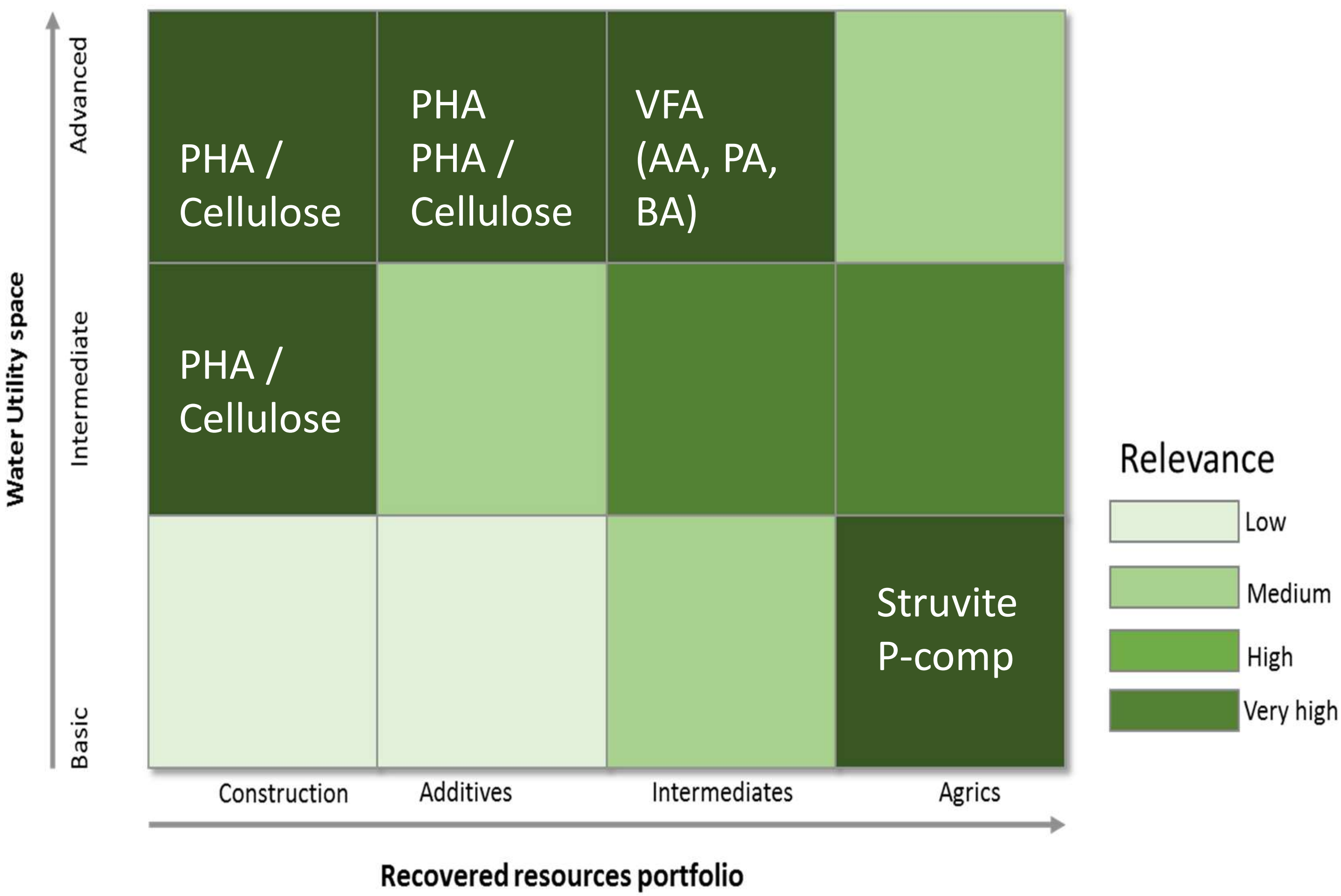
End use for recovered resources fit to water utility plants



Barriers…and solutions?

- No quality standard = **No market** → REACH? END OF WASTE?
- No quality standard = **No market** → CEN JWG11?
- No customer acceptance = **No market** → Incentive-based policy? Impact on water pricing?
- No competitive price = **No market** → (for instance) use of PHA-rich sludge?
- No utility interest = **No market** → energy efficient integration of WWTP (to WRRF)?
- No regulation = **No market** → Innovation deal?

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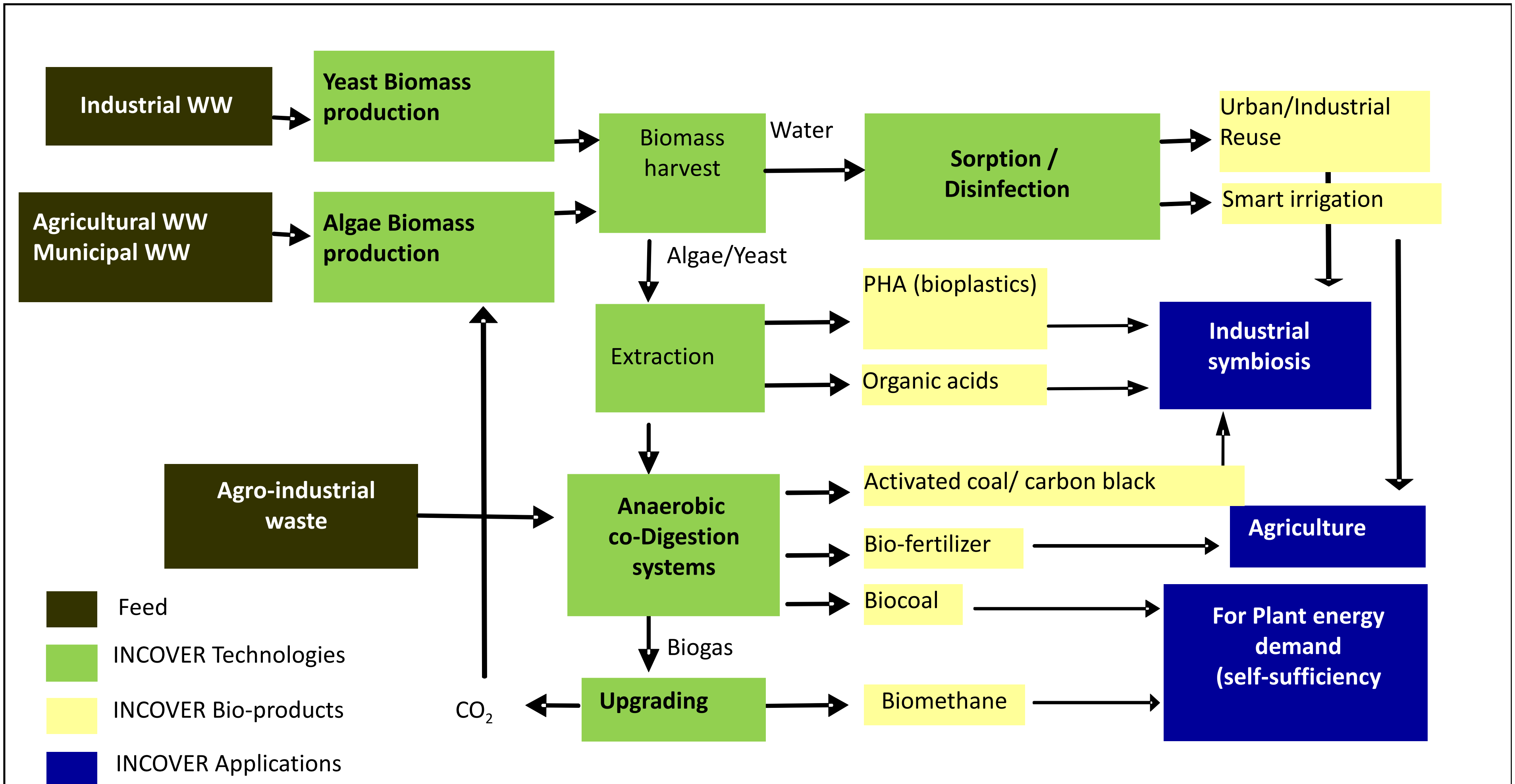
Algae based solutions? The H2020 INCOVER

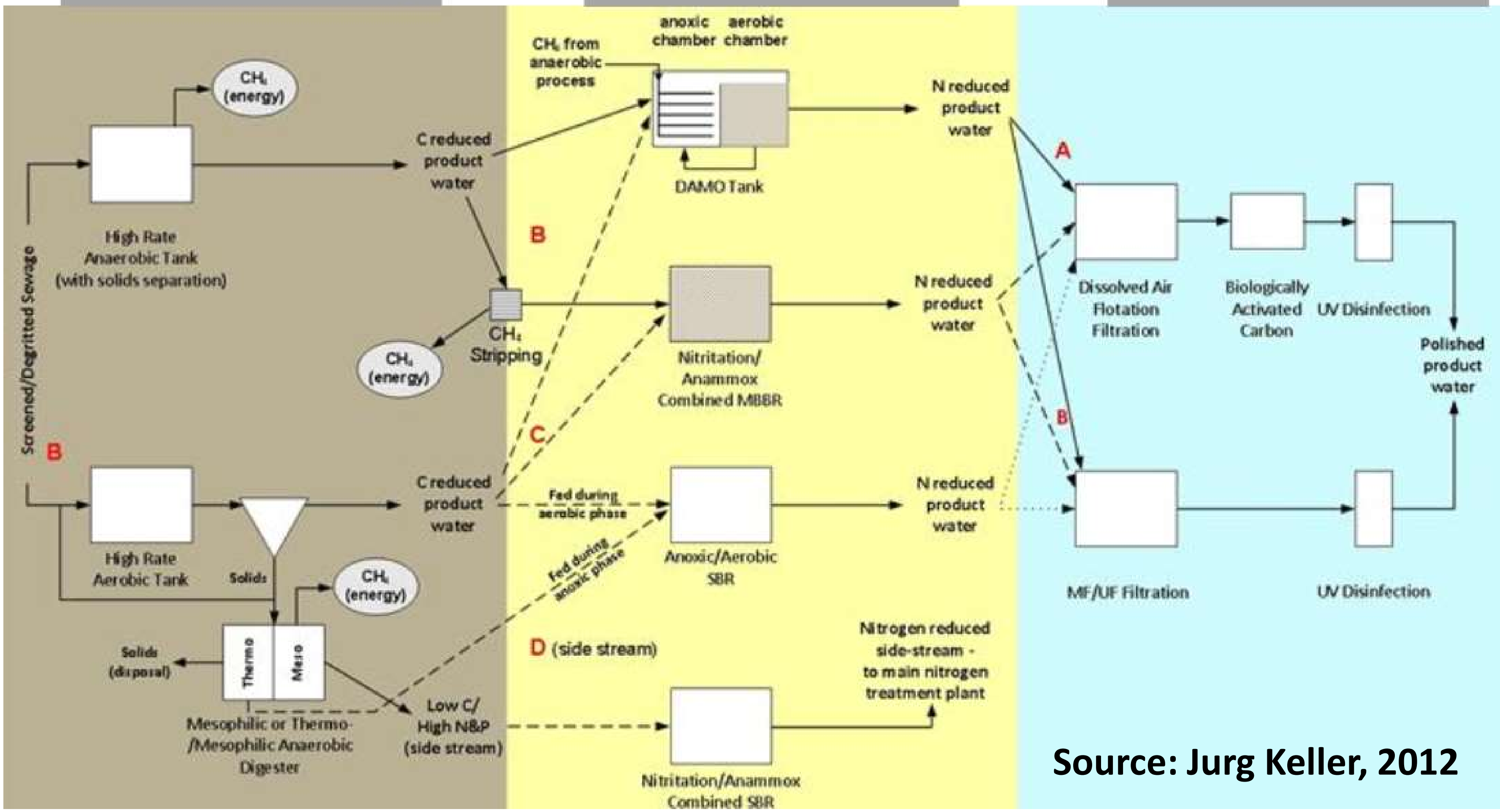


INNOVATIVE CONCEPTS
(to deliver circular economy)

at TRL 3-6

Conceptual overview of different combinations

Stage 1	**Stage 2**	**Stage 3**
Carbon Removal Nutrient Recovery	**Nitrogen Removal**	**Water Polishing/ Disinfection**



Source: Jurg Keller, 2012

The key potential alternatives

Stage 1

- Anaerobic membrane bioreactor (AnMBR)
- Granular high rate anaerobic (UASB/IC, EGSB, Baffled Anaerobic Reactor)
- High-rate aerobic (activated sludge) process
- Temperature phased anaerobic digestion (TPAD)

Stage 2

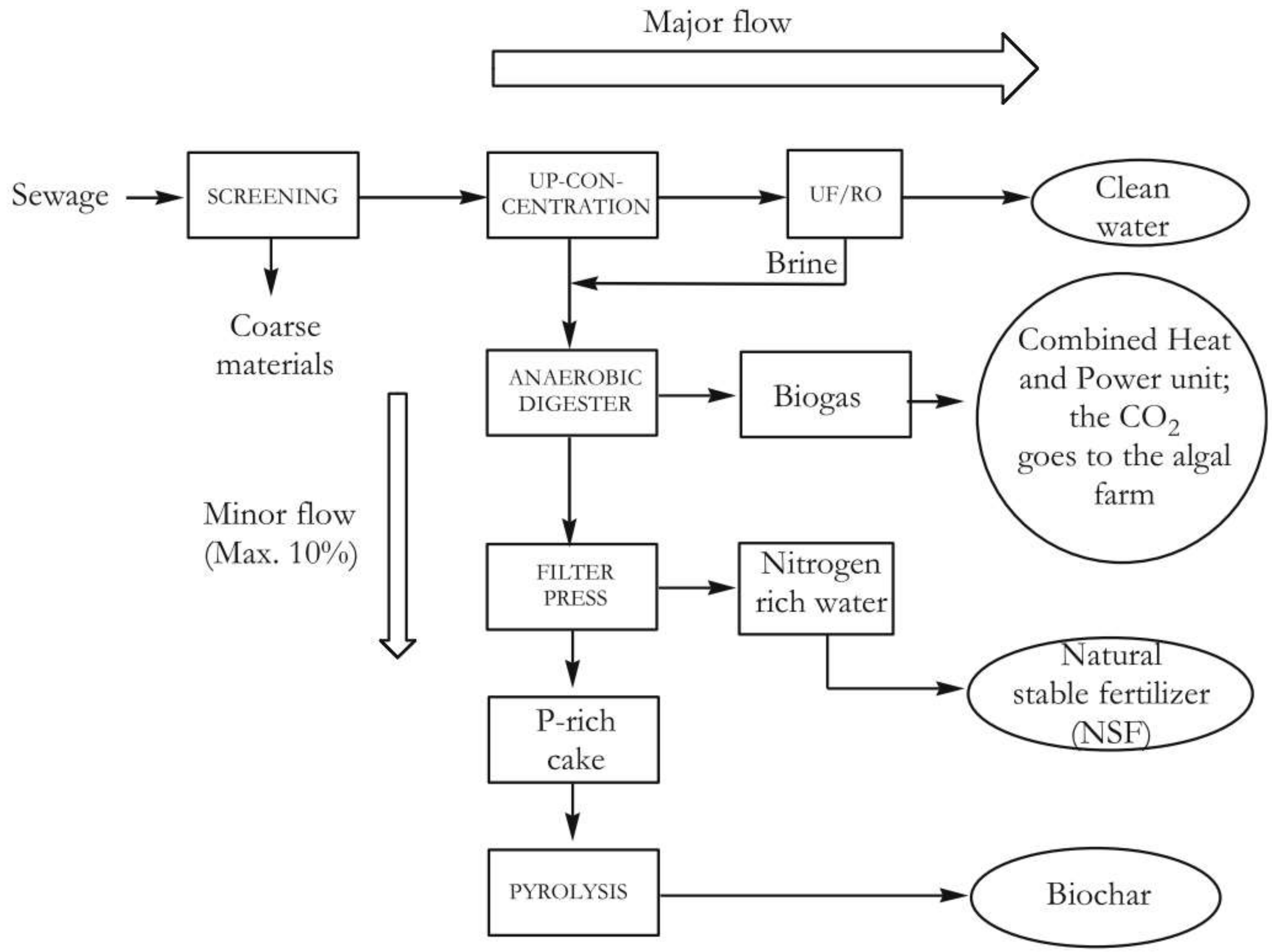
- Nitritation/anammox combined Moving Bed Biofilm Reactor
- Nitritation/anammox combined Sequencing Batch Reactor
- Denitrifying anaerobic methane oxidation (DAMO)

Stage 3

- Biologically activated carbon (BAC)
- Low pressure (membrane) filtration

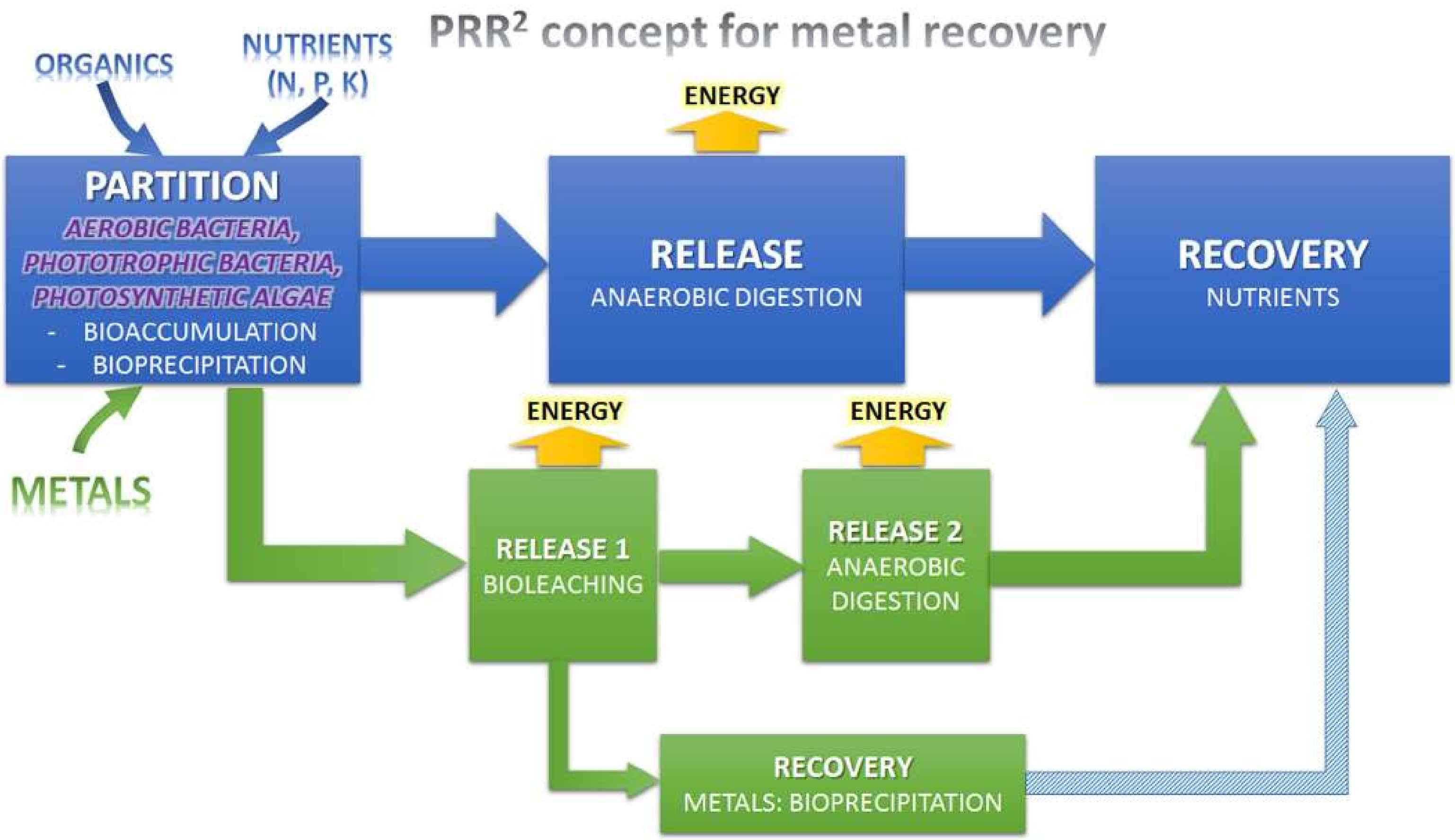
Source: Jurg Keller, 2012

Partition-Release-Recover Concept



Verstraete et al., 2009

Partition-Release-Recover^2 Concept



Batstone et al., 2015

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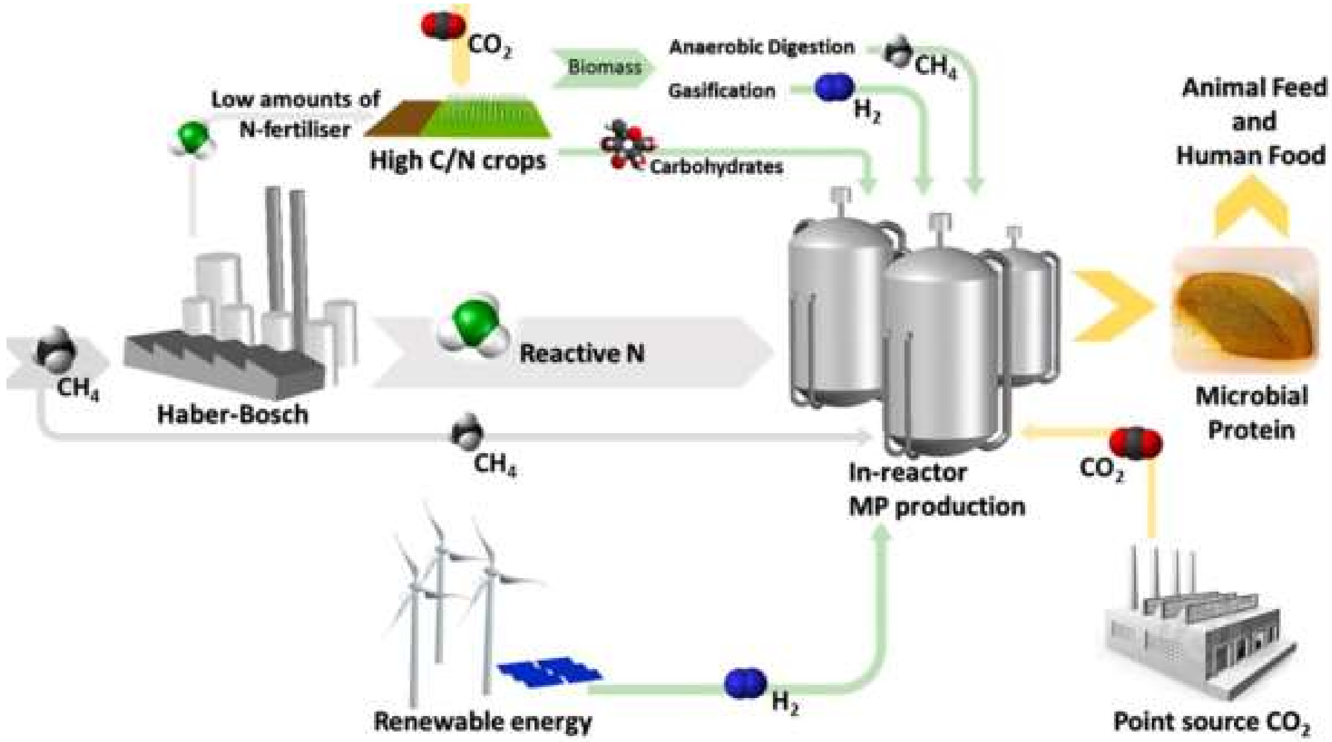
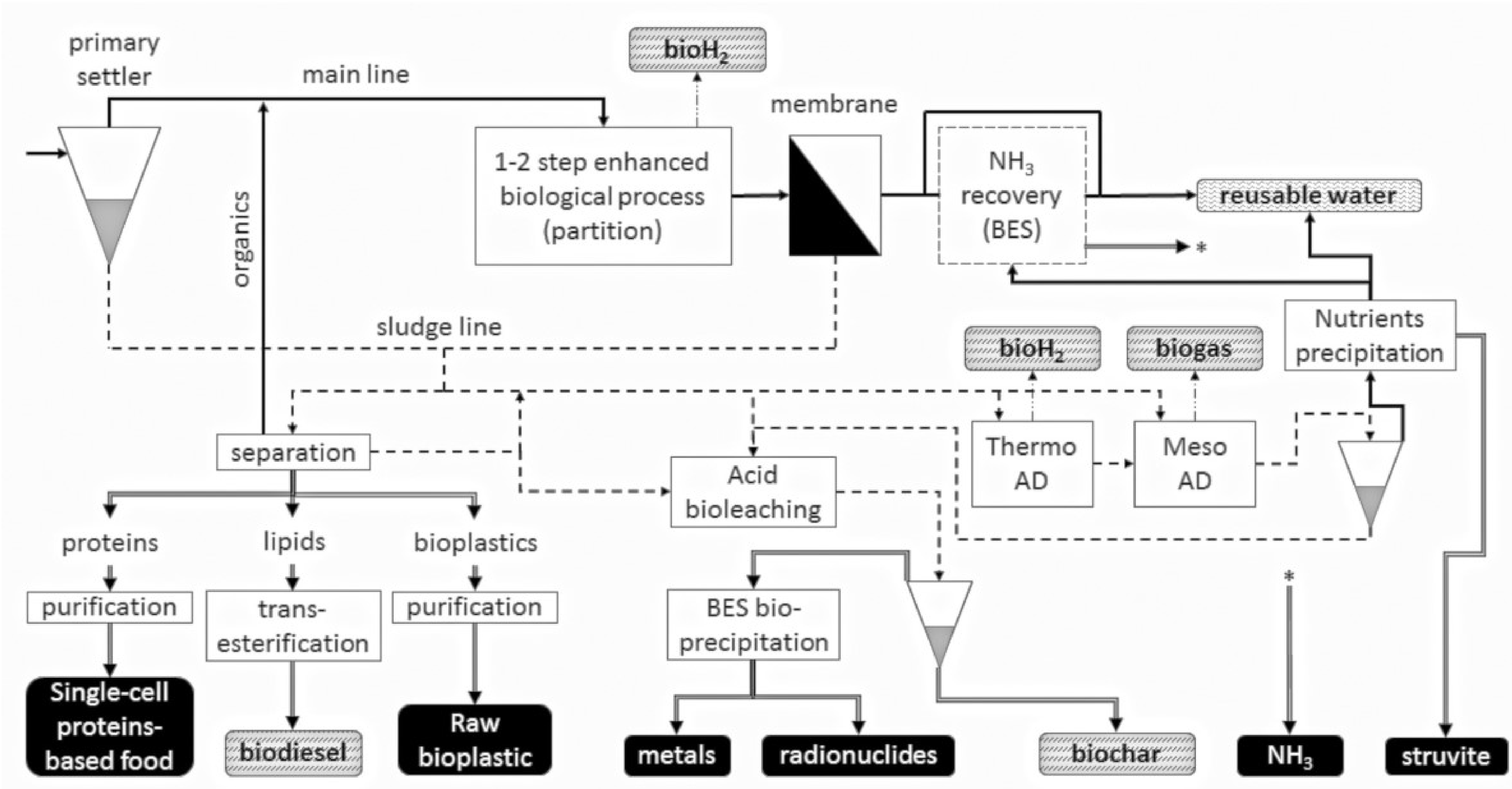
Nitrogen recovery: Verstraete plenary



- Only 30% of nitrogen ending up in the plant due to dissipation via run-off and volatilisation
- transforming plant protein into animal protein adds additional conversion losses
- In total, only around 17% of the total fertilizer-nitrogen is retained in vegetable and meat protein with the rest being dissipated
- Used nitrogen can be recovered and harvested as microbial protein from waste streams (close to 100% recovery)

Conceptual overview of different biological technologies applied in wastewater treatment for energy and resource recovery



Puyol et al., 2017

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Thank you for your time and attention

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