From Wastewater Treatment Plants Towards Water Resource Recovery Facilities

- ***Technologies***
- ***Potentials***
- ***Bottlenecks***

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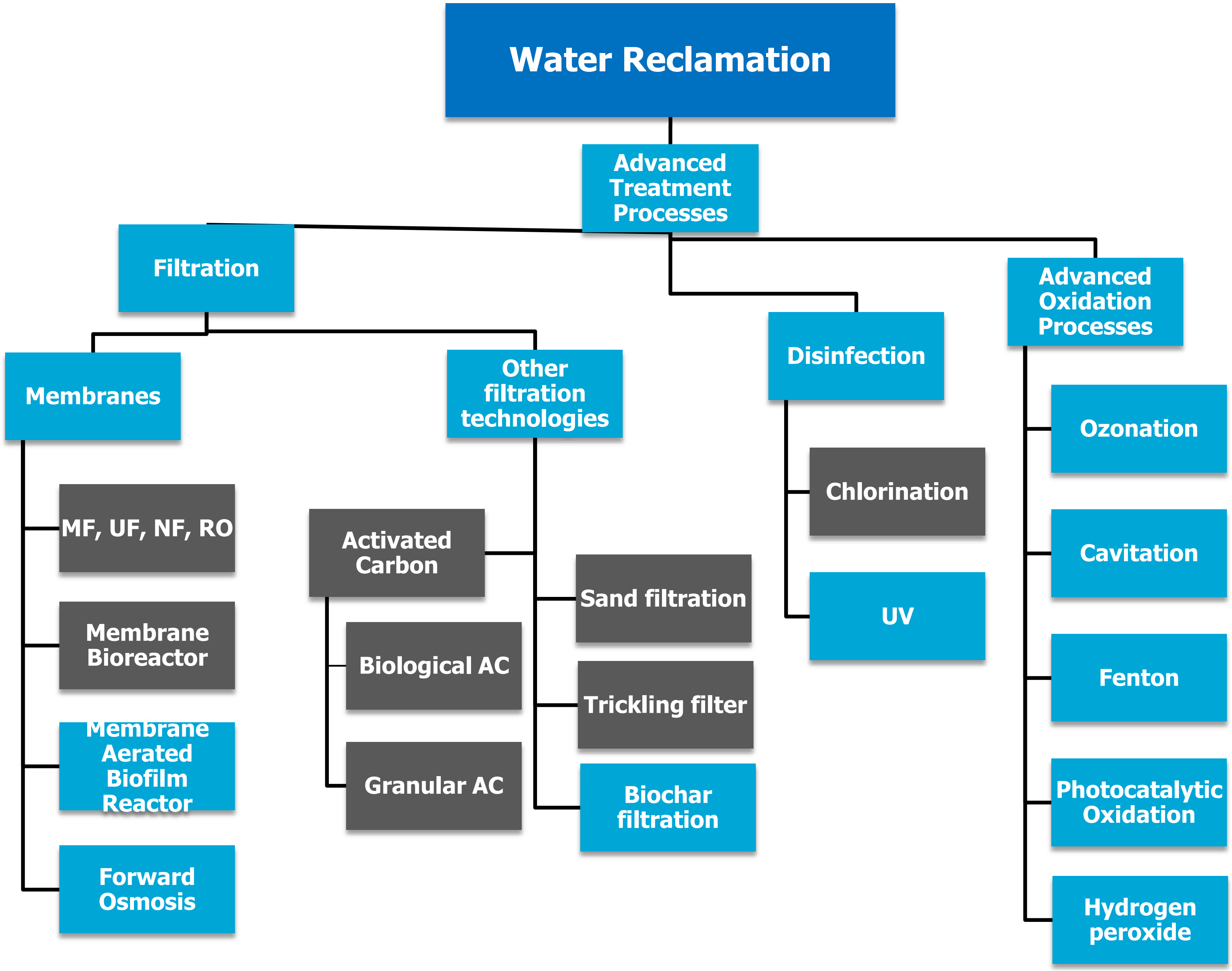
Water Reclamation
Advanced Treatment Processes
Filtration
Membranes
MF, UF, NF, RO
Membrane Bioreactor
Membrane Aerated Biofilm Reactor
Forward Osmosis
Other filtration technologies
Activated Carbon
Biological AC
Granular AC
Sand filtration
Trickling filter
Biochar filtration
Disinfection
Chlorination
UV
Advanced Oxidation Processes
Ozonation
Cavitation
Fenton
Photocatalytic Oxidation
Hydrogen peroxide

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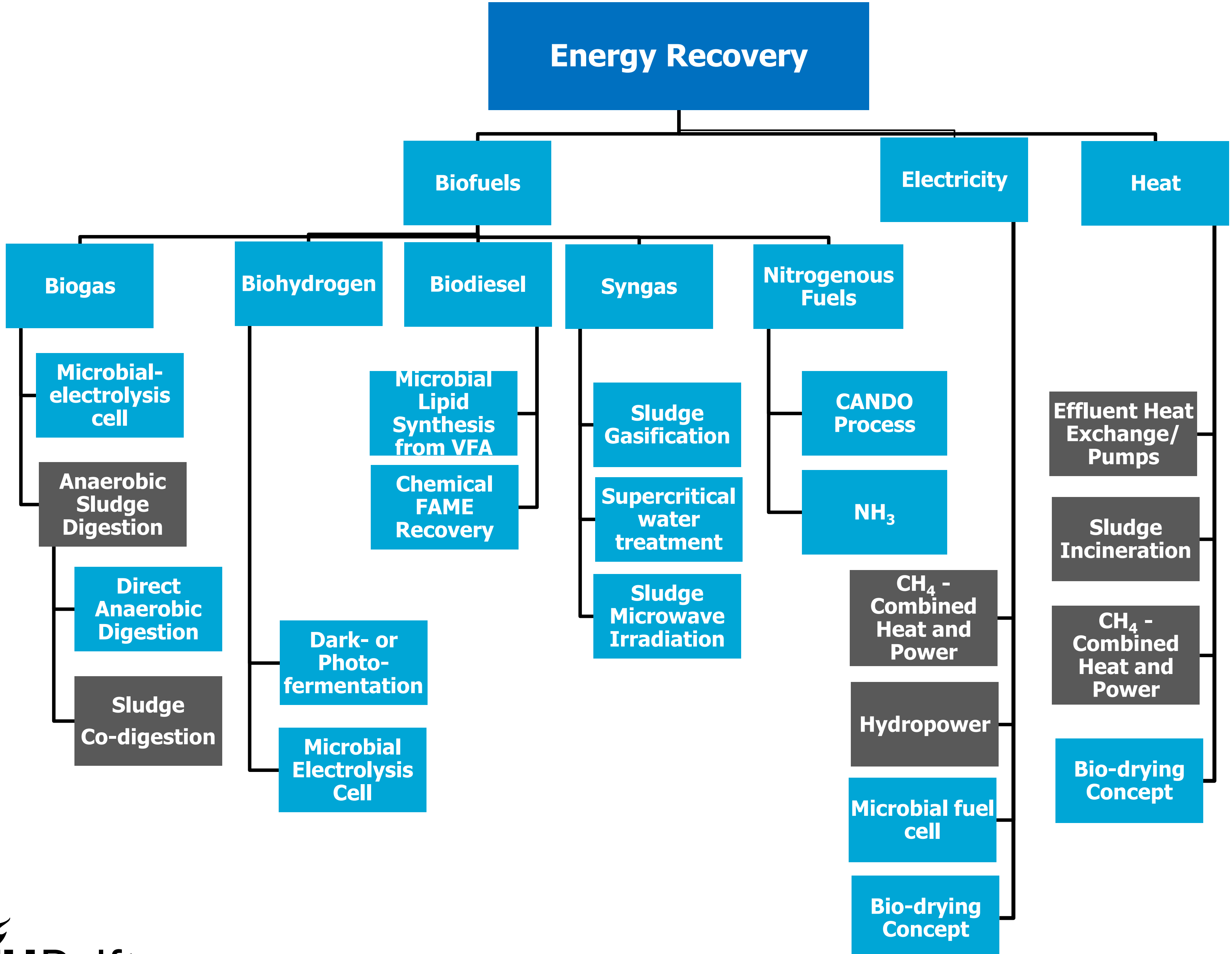
Energy Recovery
Biofuels
Electricity
Heat
Biogas
Biohydrogen
Biodiesel
Syngas
Nitrogenous Fuels
Microbial-electrolysis cell
Anaerobic Sludge Digestion
Direct Anaerobic Digestion
Sludge Co-digestion
Dark- or Photo-fermentation
Microbial Electrolysis Cell
Microbial Lipid Synthesis from VFA
Chemical FAME Recovery
Sludge Gasification
Supercritical water treatment
Sludge Microwave Irradiation
CANDO Process
NH_3
CH_4 - Combined Heat and Power
Hydropower
Microbial fuel cell
Bio-drying Concept
Effluent Heat Exchange/ Pumps
Sludge Incineration
CH_4 - Combined Heat and Power
Bio-drying Concept

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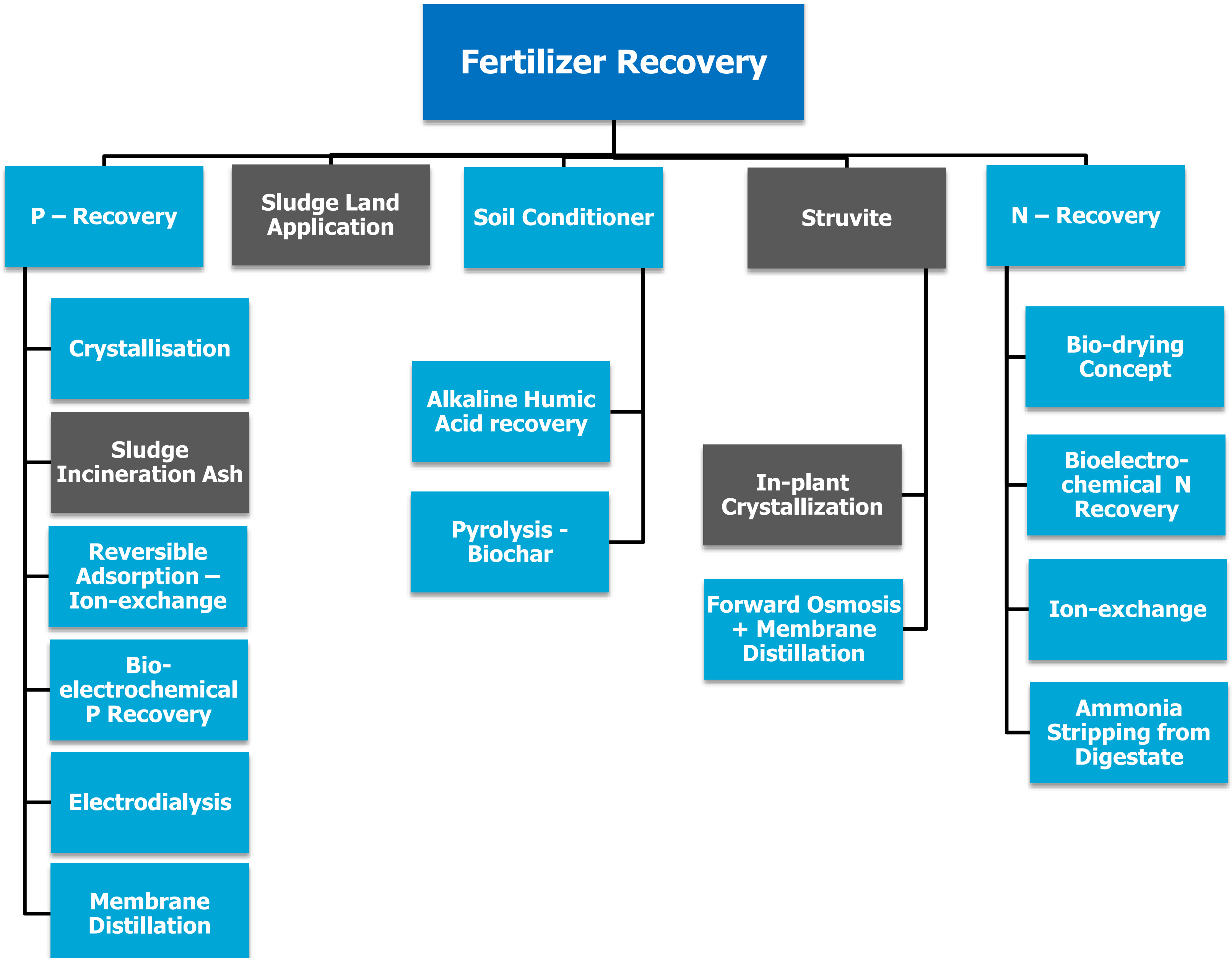
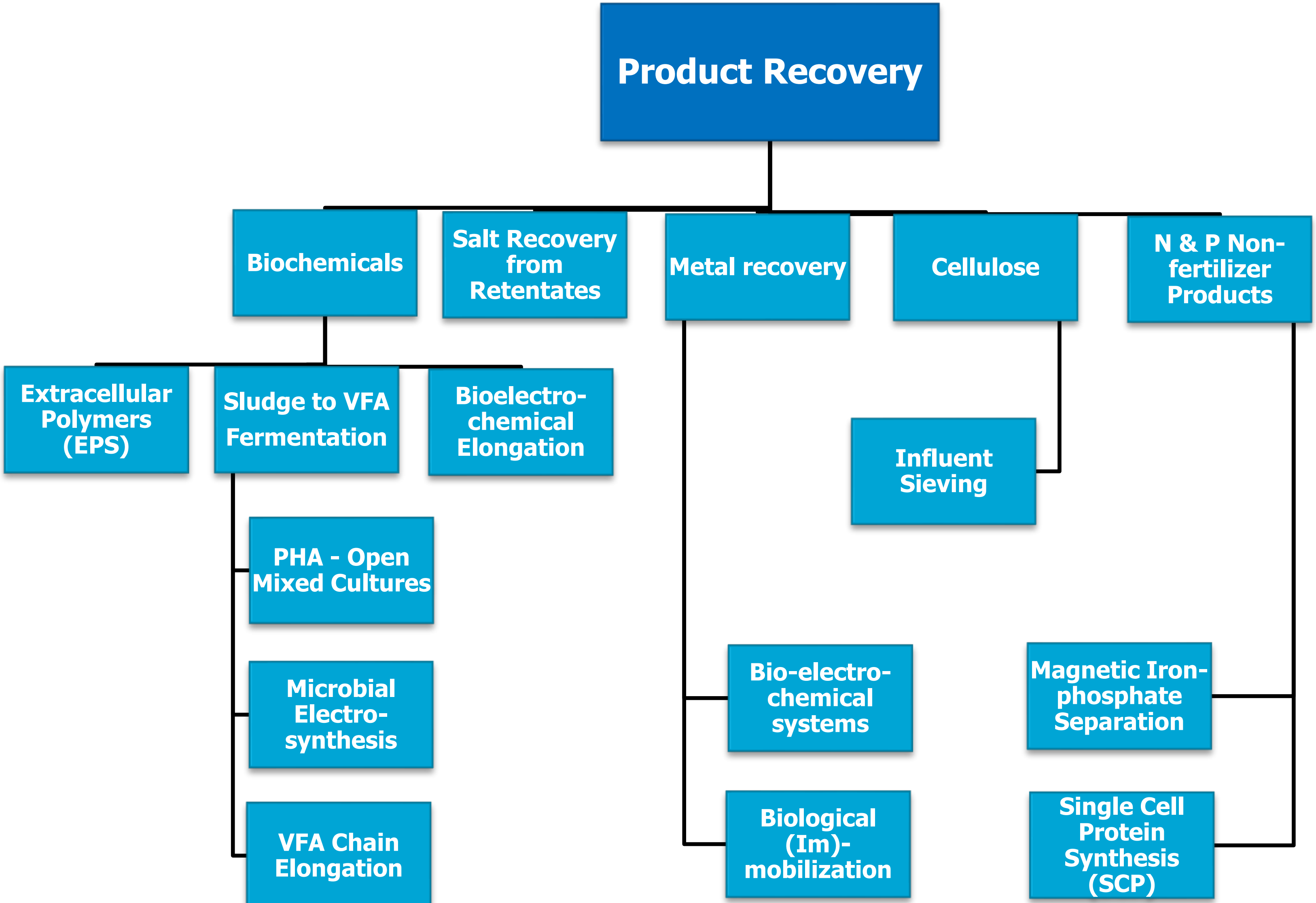

Fertilizer Recovery
P – Recovery
Sludge Land Application
Soil Conditioner
Struvite
N – Recovery
Crystallisation
Sludge Incineration Ash
Reversible Adsorption – Ion-exchange
Bio-electrochemical P Recovery
Electrodialysis
Membrane Distillation
Alkaline Humic Acid recovery
Pyrolysis - Biochar
In-plant Crystallization
Forward Osmosis + Membrane Distillation
Bio-drying Concept
Bioelectro-chemical N Recovery
Ion-exchange
Ammonia Stripping from Digestate


Product Recovery
Biochemicals
Salt Recovery from Retentates
Metal recovery
Cellulose
N & P Non-fertilizer Products
Extracellular Polymers (EPS)
Sludge to VFA Fermentation
Bioelectro-chemical Elongation
Influent Sieving
PHA - Open Mixed Cultures
Microbial Electro-synthesis
VFA Chain Elongation
Bio-electro-chemical systems
Biological (Im)-mobilization
Magnetic Iron-phosphate Separation
Single Cell Protein Synthesis (SCP)

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Economic bottlenecks

Bottleneck	Examples
Process costs	• P: Ash-P recovery requires specialised expensive sludge incinerator • Water: Disposal costs of membrane brines
Resource quantity	• Struvite: Only solubilized P fraction in side stream is recovered • N: Low N concentrations may make NH_4 recovery uneconomical
Resource quality	• VFA: Product spectrum is hard to control • Cellulose: Impurities in sieved fibres
Market value & Competition	• CH_4/electricity: Very low market value • N,P: Industrial bulk nutrients are cheaply available • P: Manure abundantly available in livestock intensive regions
Utilization & Applications	• PHA: New utilization routes have to be found • Cellulose fibres " "
Logistics	• Water: Temporal and spatial variability of demand and supply • Water: Topographical location of WWTP may require uphill pumping • CH_4: Pressurizing and transporting if no grid is connected

Environment & health bottlenecks

Bottleneck	Examples
Emissions & Health risks	• Water: Harmful by-products from chemical biocides in tertiary treatment • Water: Plant or soil contamination due to wastewater irrigation • CH_4: Unheated digesters may promote emissions of solubilised CH_4 • Struvite: Possible contaminations with micropollutants/heavy metals

Society & policy bottlenecks

Bottleneck	Examples
Acceptance	• Water: Reuse can hardly be implemented without social acceptance • SCP: Negative perception of faecal matter as source for feed/food
Policy	• Struvite: Missing legislation for field application • SCP: EU forbids the use of protein produced from faecal substrate • Water: Governmental incentives needed to make WR financially attractive

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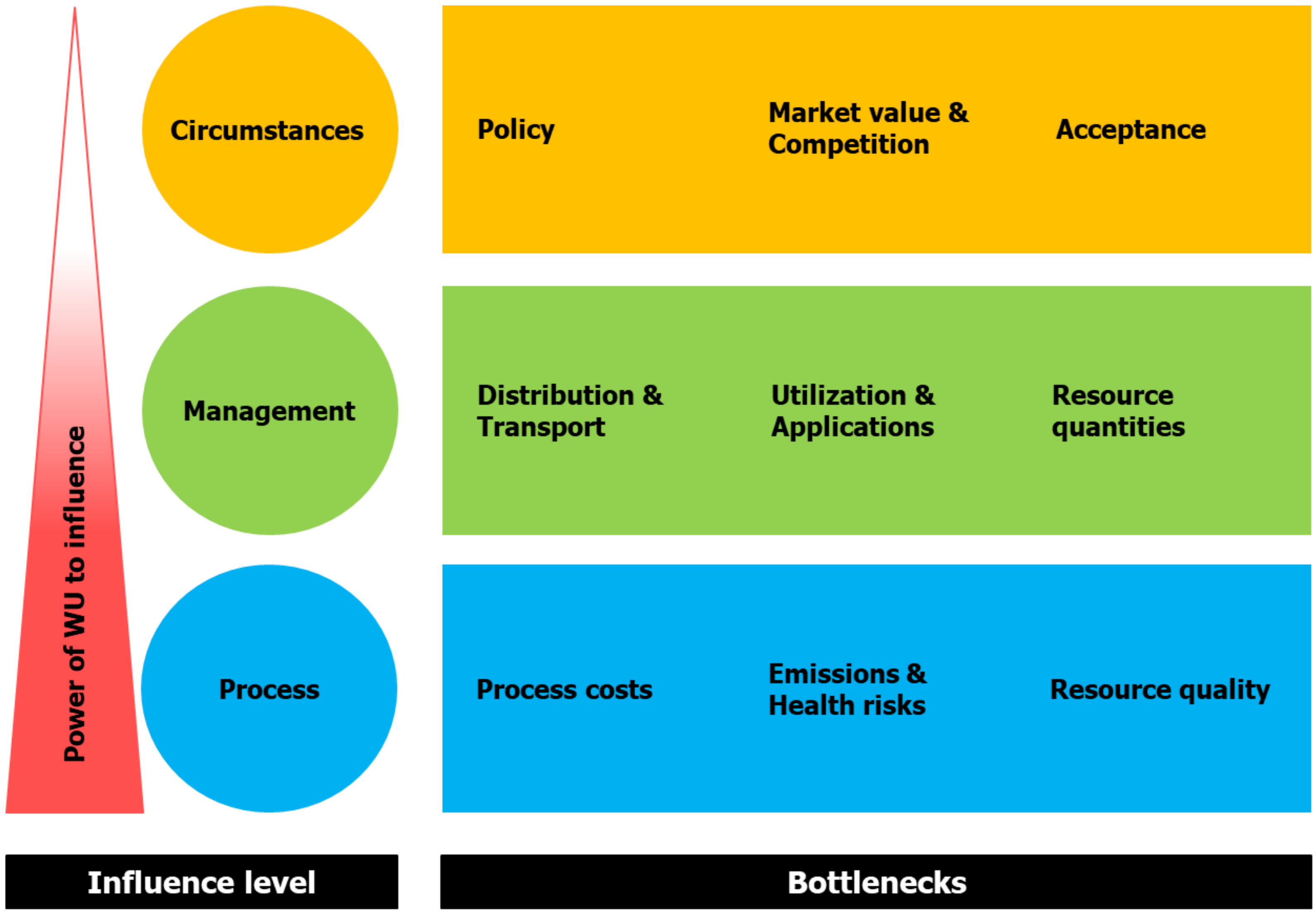
Role of water utilities



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Role of water utilities

Decision making beyond costs and effluent quality:

- **Switch paradigm from treatment to recovery**
- **From budget receiver to value chain developer**
- **Find niche applications with unique selling proposition**
- **Find partners in a value chain to share financial risks**
- **Invest in R&D**
- **Collaborate to make use of economy of scale (e.g. P)**

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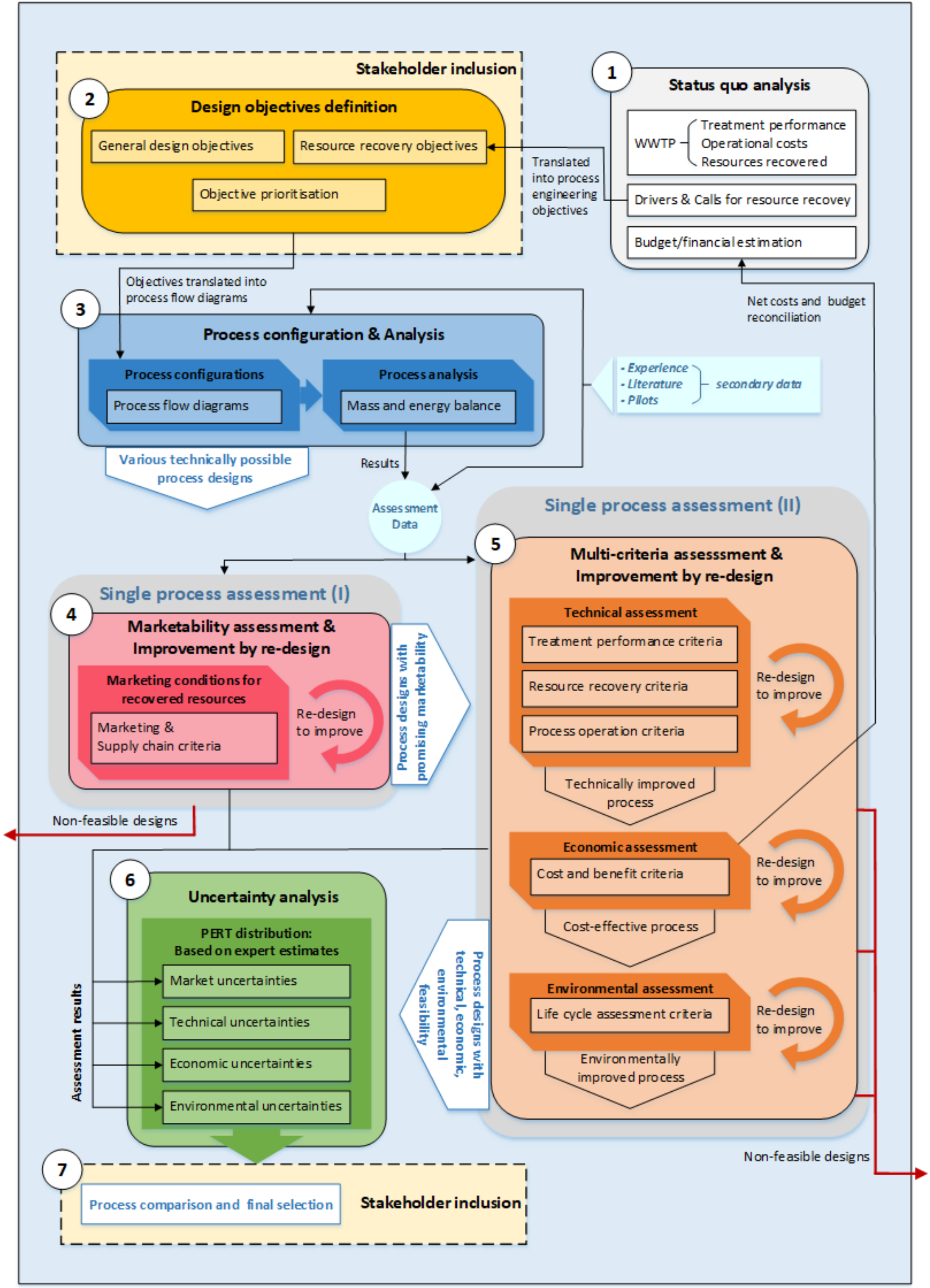
Process design framework

Objectives

1. Consider RR from early stage
2. Strategically plan WRRFs
3. Provide criteria to assess:

   Marketability
   Technical performance
   Costs & Benefits
   Environmental impacts



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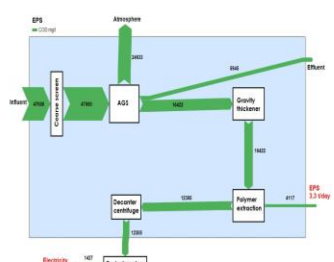
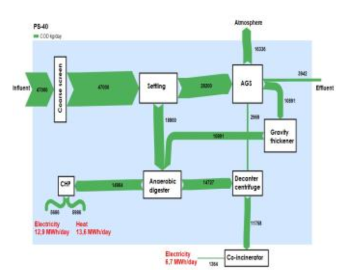
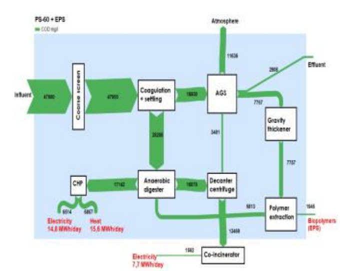
Mass & energy balances

A great tool to predict at an early stage what a process can do

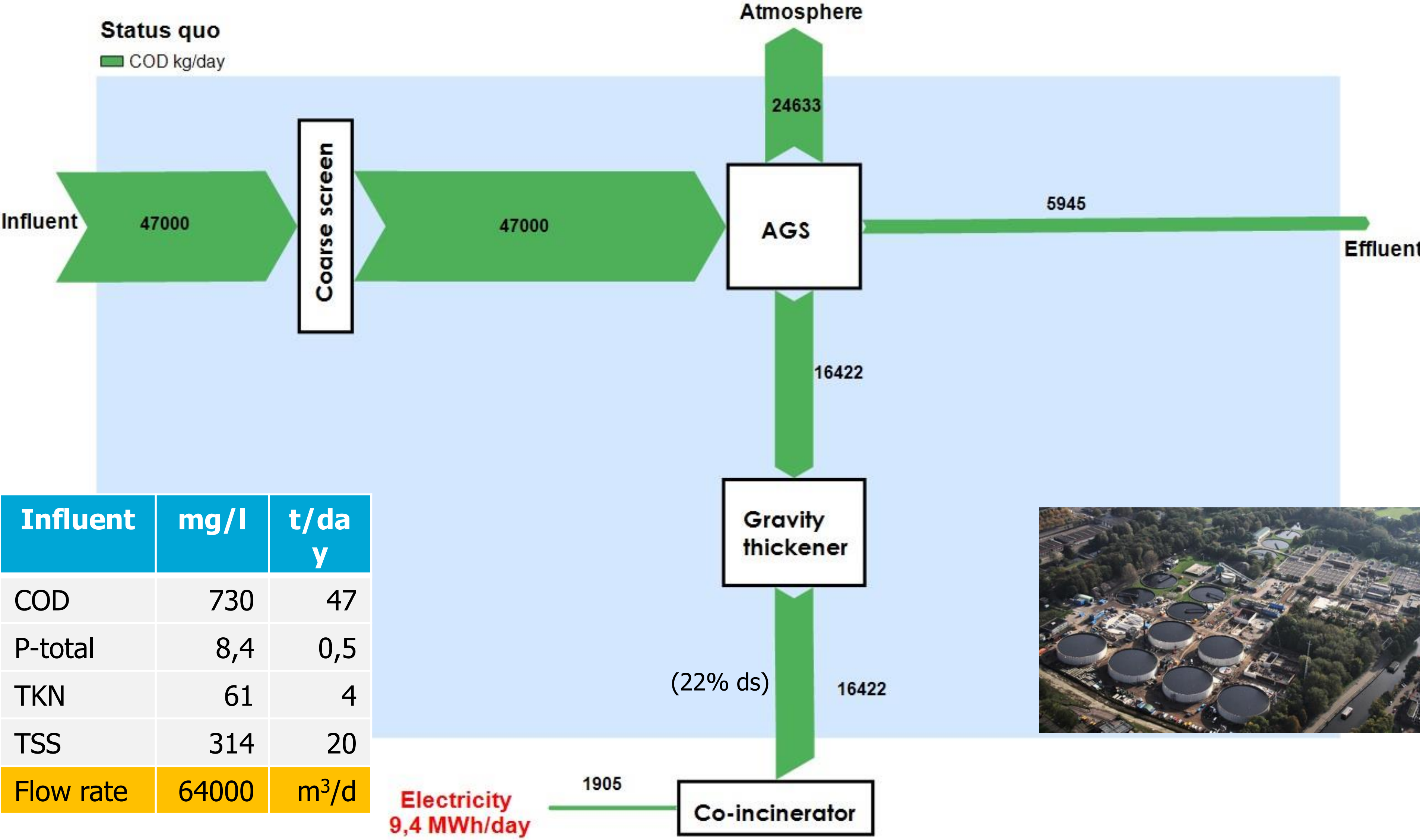
- Only data is needed
- Model COD, P, flows
- Quantify recoverable resources trade-offs
- Supports technical, economic, environmental analysis
- Predict weaknesses of a process





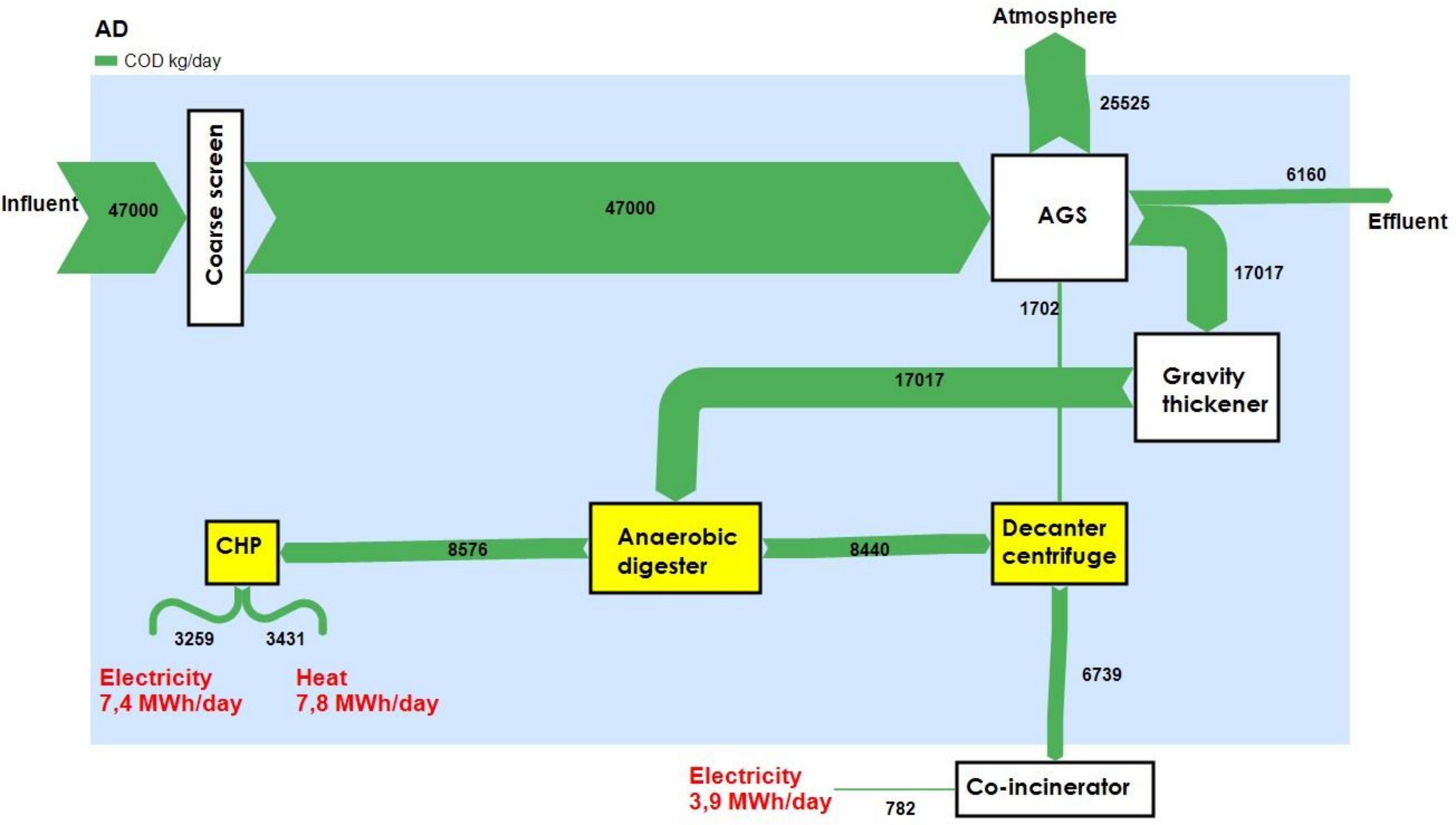


Utrecht (NL) NEREDA®
COD kg/day

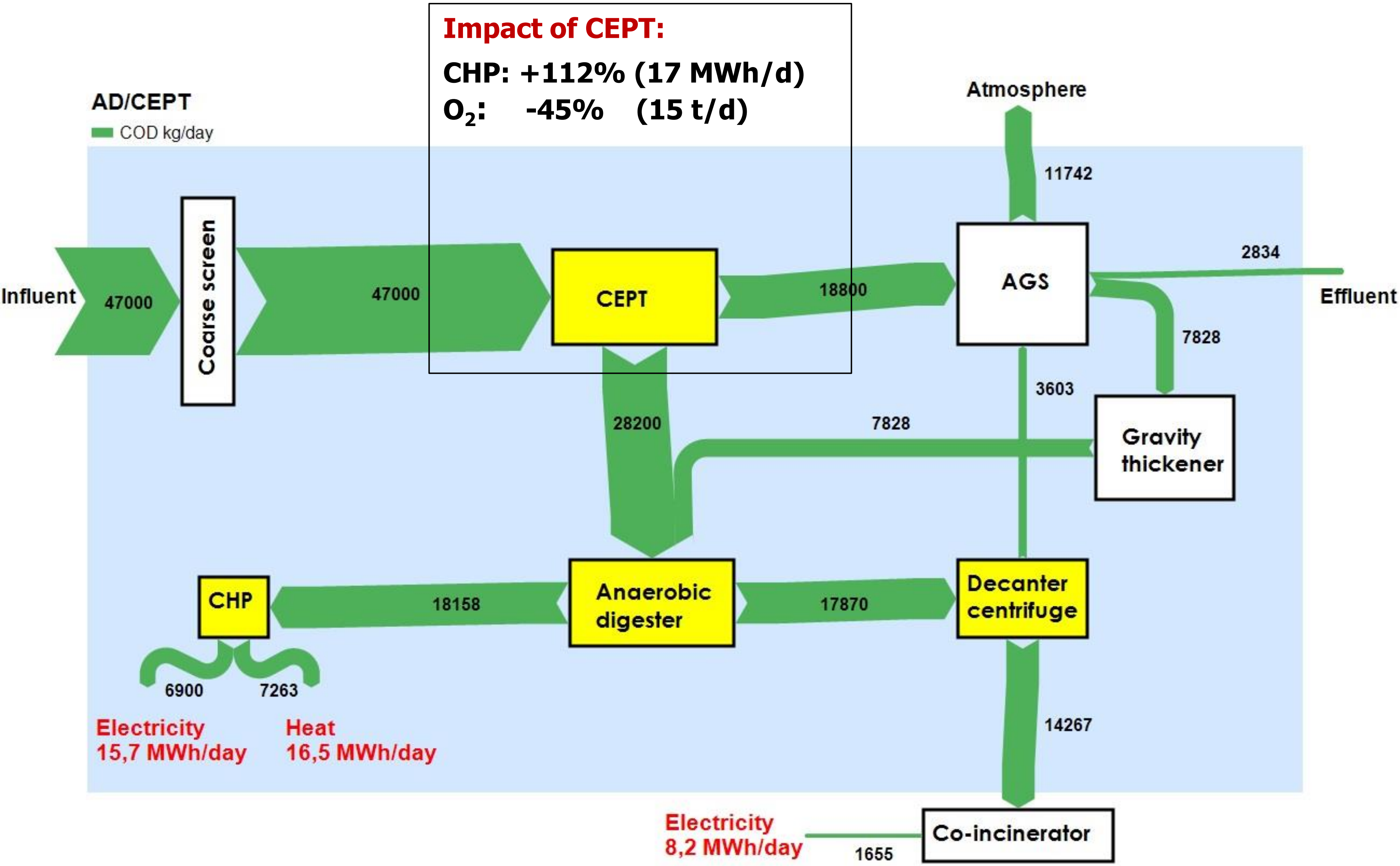


Influent	mg/l	t/day
COD	730	47
P-total	8,4	0,5
TKN	61	4
TSS	314	20
Flow rate	64000	m^3/d

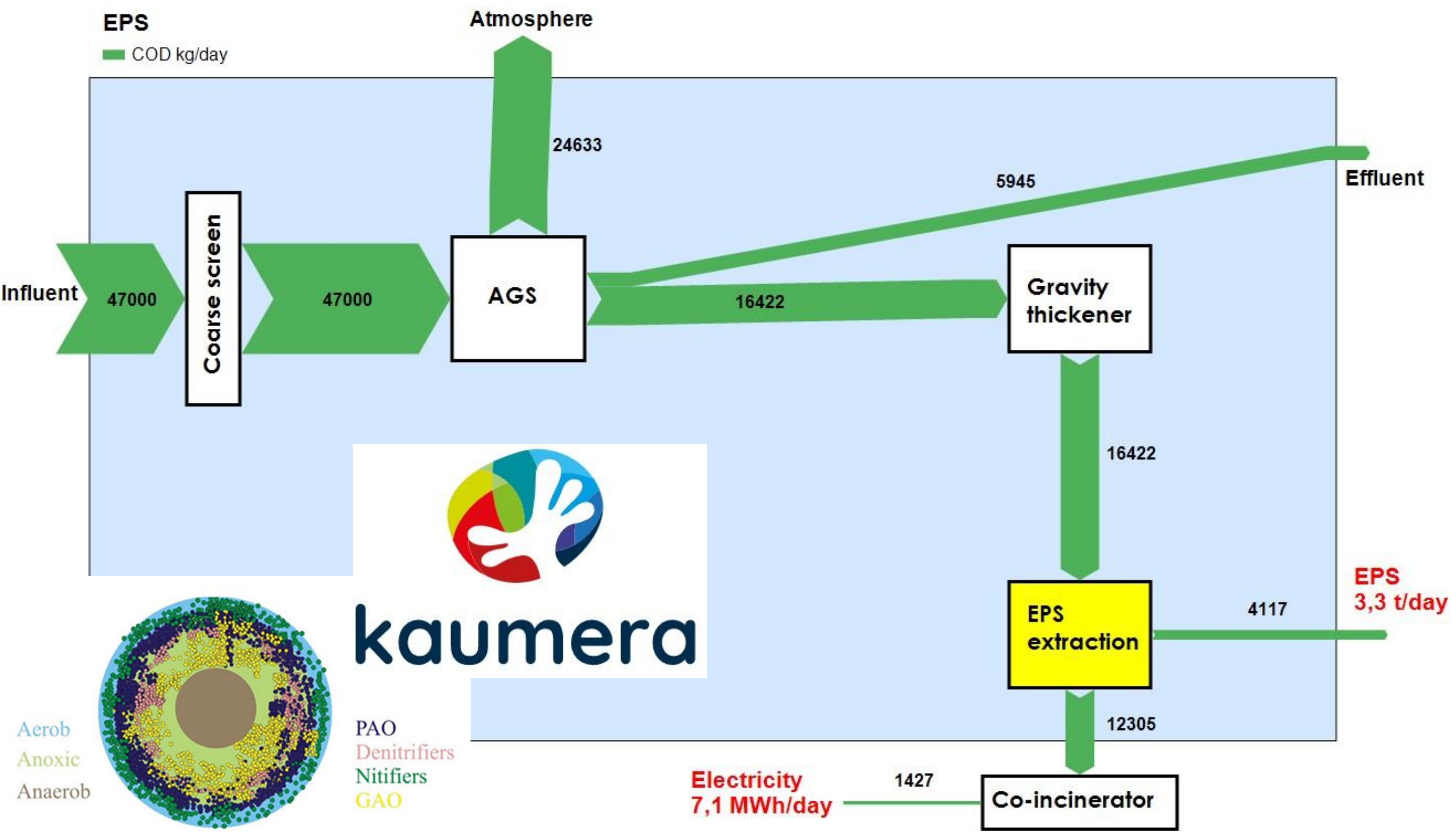
Energy recovery integration
COD kg/day



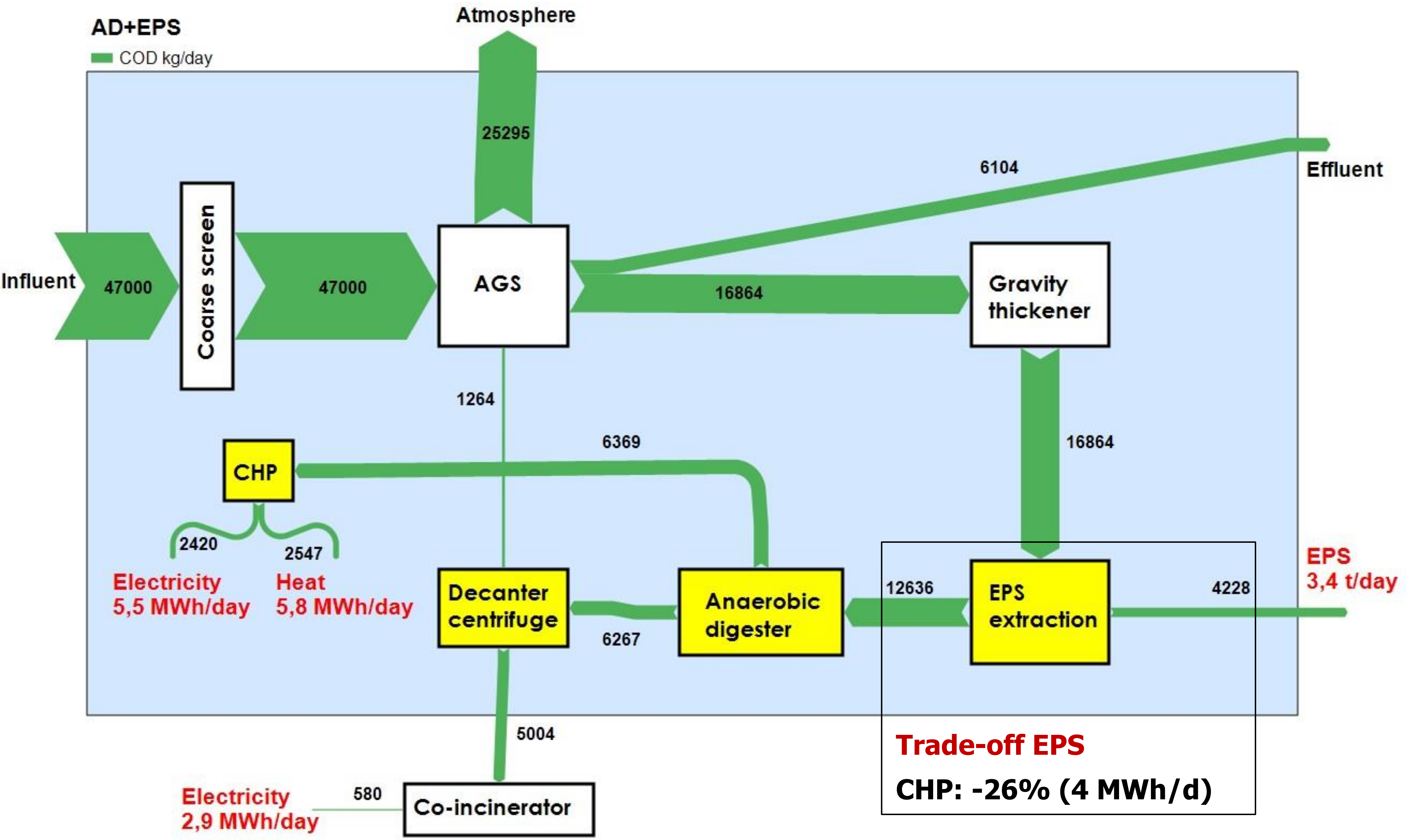
Maximised energy recovery integration
COD kg/day



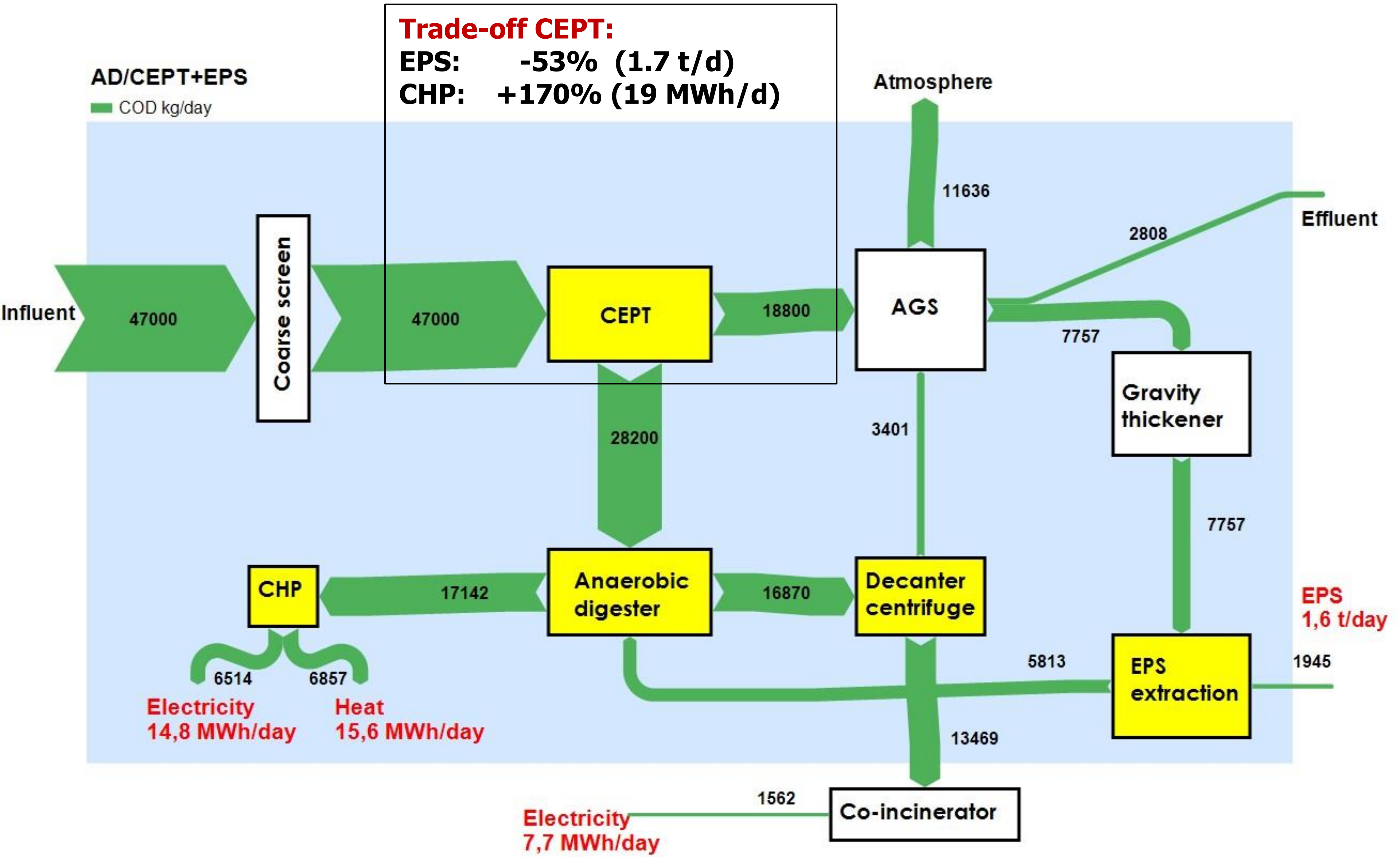
Polymer recovery integration
COD kg/day



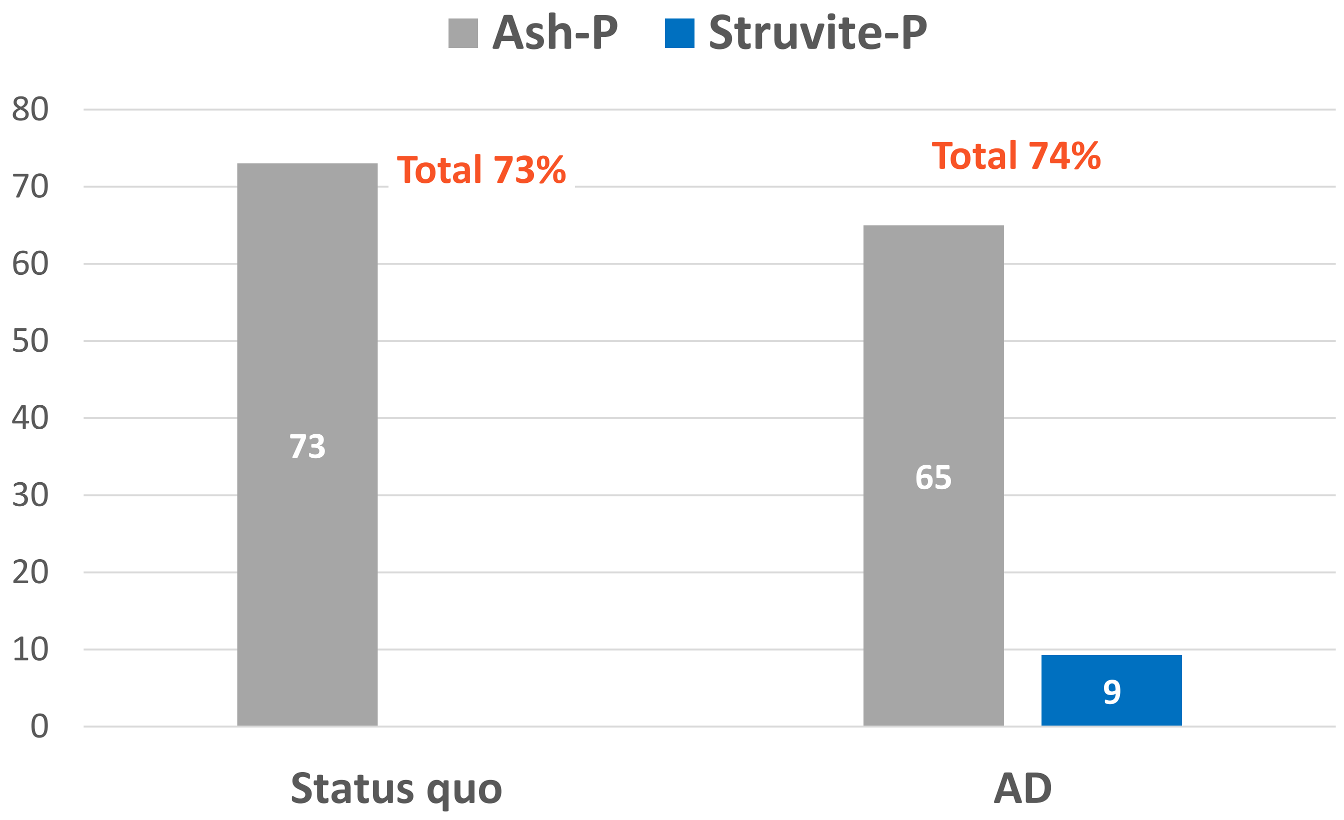
Polymer recovery integration
COD kg/day



Polymer recovery integration COD kg/day



Influent-P recovery rates (%)



Struvite recovery is questionable if ash-P recovery is possible

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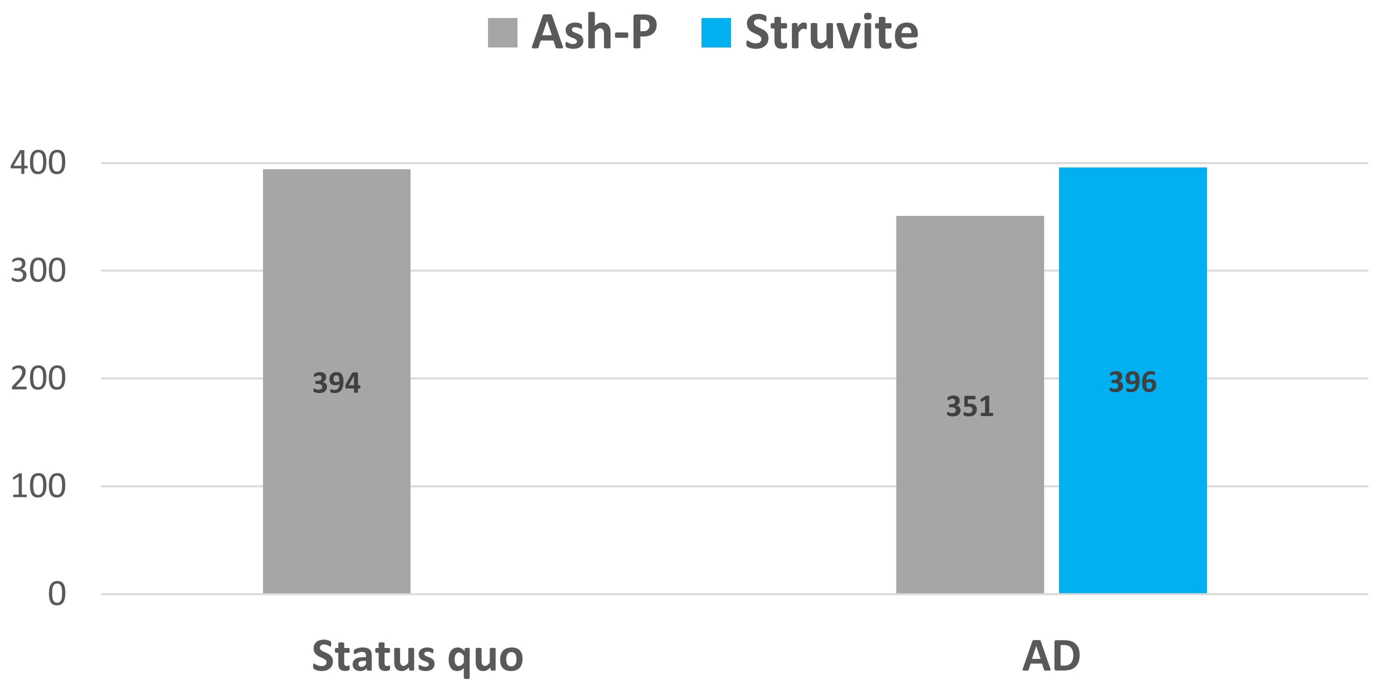
Product quantities:
Ash-P & Struvite (kg/day)



Struvite recovery

Pros

- Clogging prevention
- Revenues for water utility

Cons

- Low influent-P recovery rate (side stream)
- Only slightly increase of total P recovery
- 1kg dissolved P requires 0,8kg Mg
- Ash-P recoverable in bulk (centralised P recovery)

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Process design

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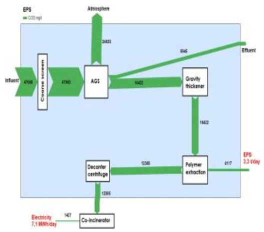
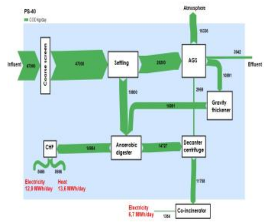
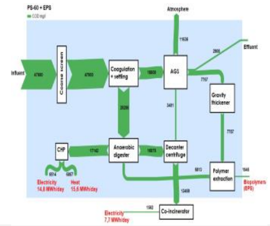


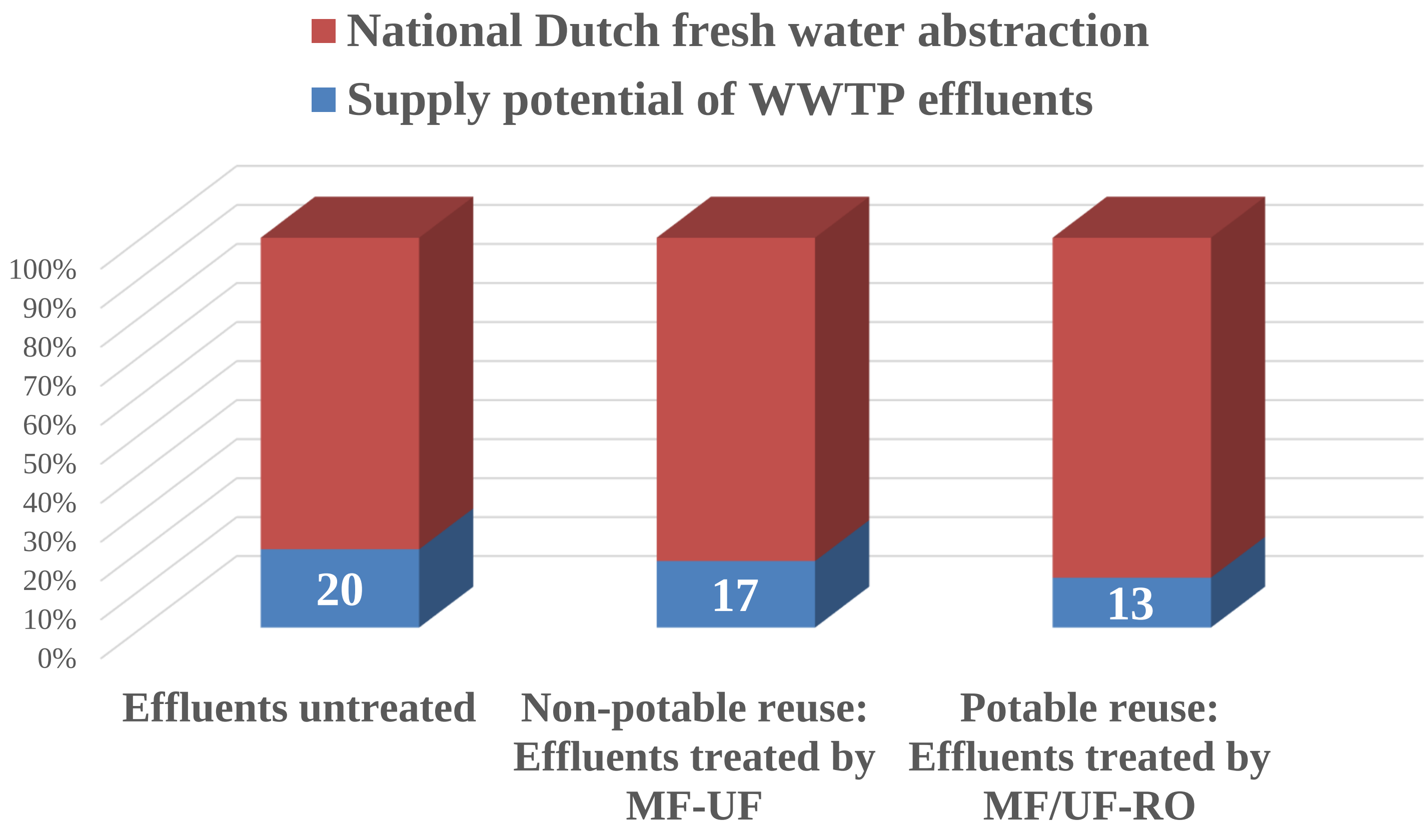




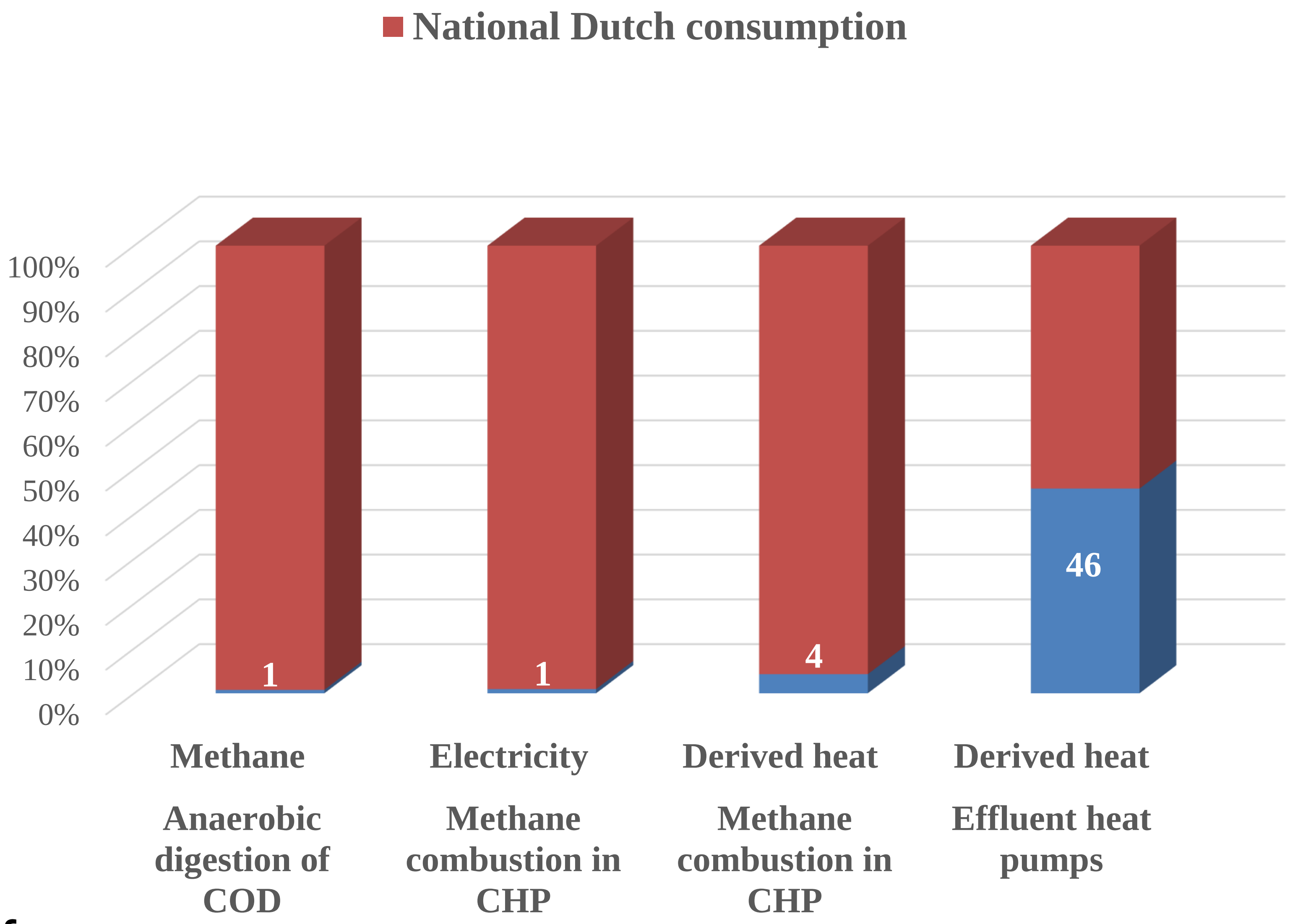
Marketability and supply chain assessment criteria

Applications	Exploring applications and utilization routes for recovered resources
Monetary value	Estimating the market prize of recoverable resources and applications
Demand analysis	Quantifying and localising demands for recoverable resources
Logistics	Analysing distance, topography, and transport possibilities of recoverable resources to reach customers
Legal situation	Analysing regulations and policies that support or hinder the recovery of a resource
Political support	Analysing available subsidies, or political bias for investing in a recovery route
Acceptance	Estimating the consumer perspective and acceptance for resources recovered from municipal wastewater

Water reuse: Supply potential Netherlands



Energy recovery: Supply potential Netherlands



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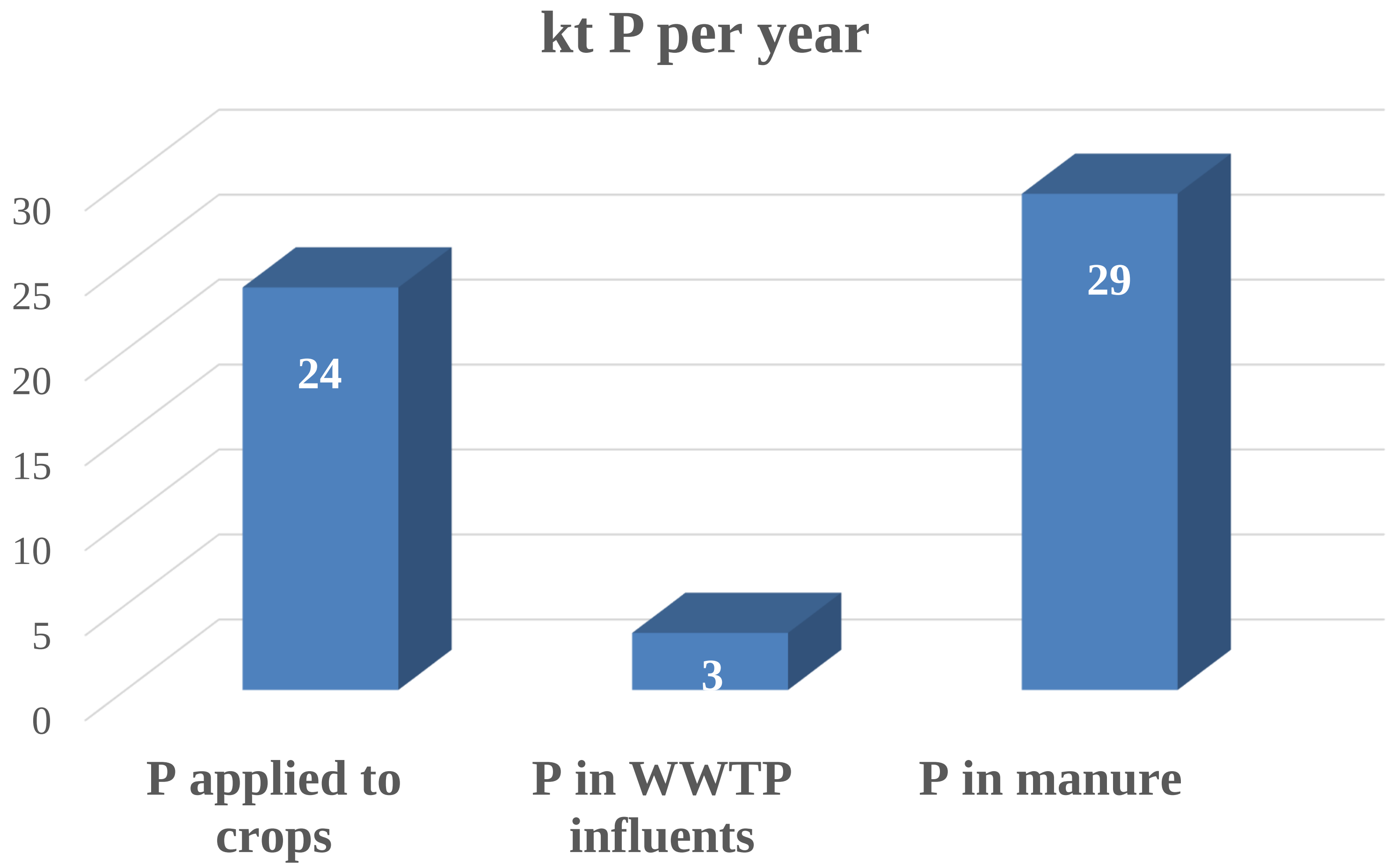
P recovery: Supply potential Flanders (Belgium)



Calculated based on *Coppens et al. 2016*

Conclusion

Future: Water resource recovery facilities?

The technology is ready, but are we?

- **Many technologies available but many bottlenecks too**
- **Extension of traditional responsibilities of utilities is required**
- **Pro-active value chain development required**
- **Mass-energy balances can help in decision making**
- **Necessity to include marketability in process design decisions**
- **Water is the most precious resource in wastewater**

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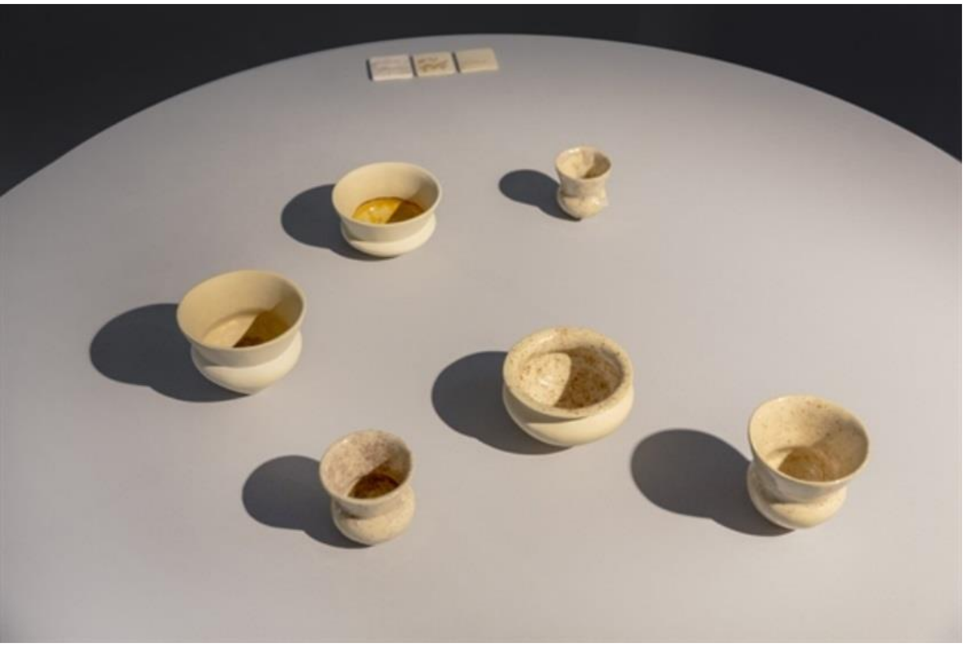
EPS polymers



Thank you!

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