A Systems Analysis of Wastewater Treatment Intensification

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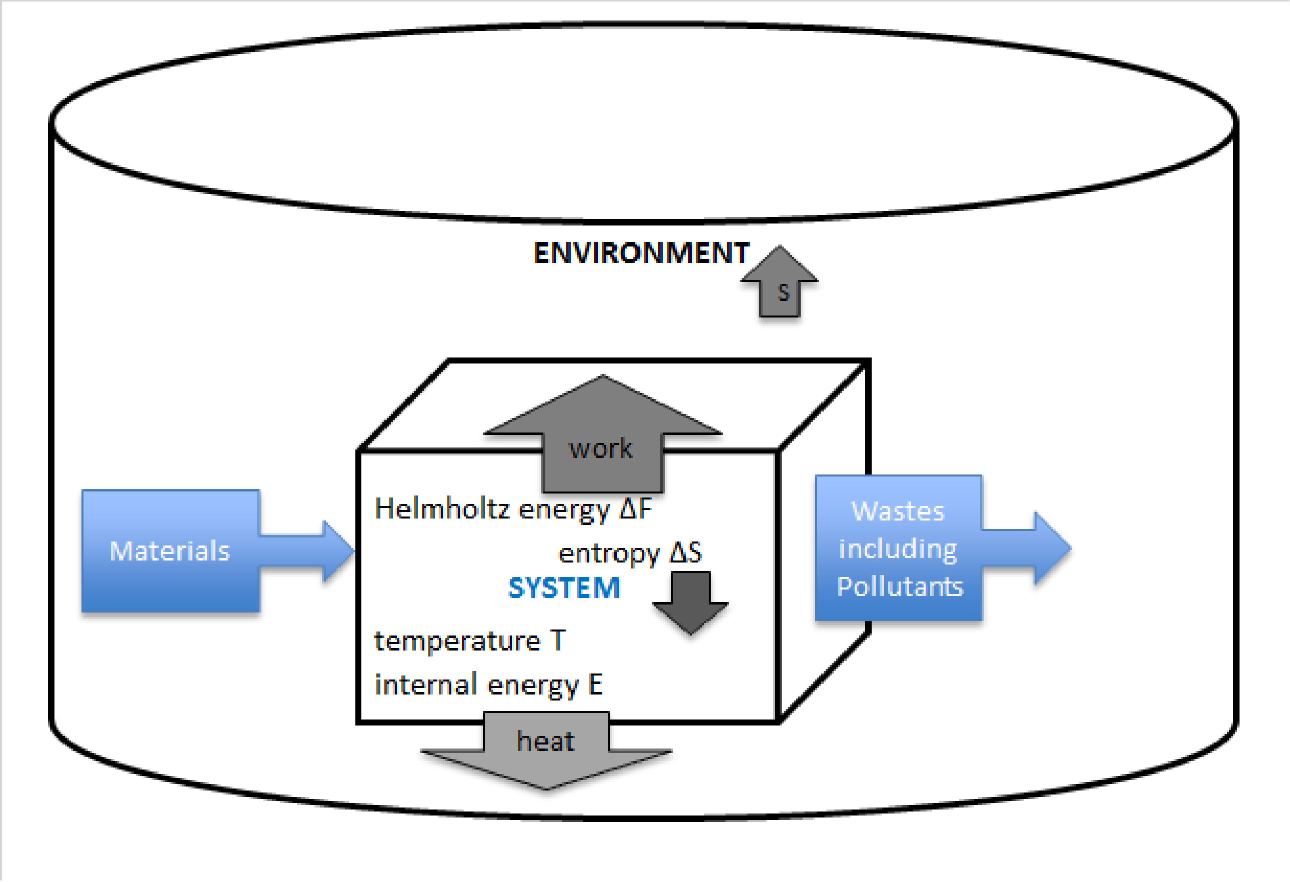
Stantec

Physical Description of Economic Production

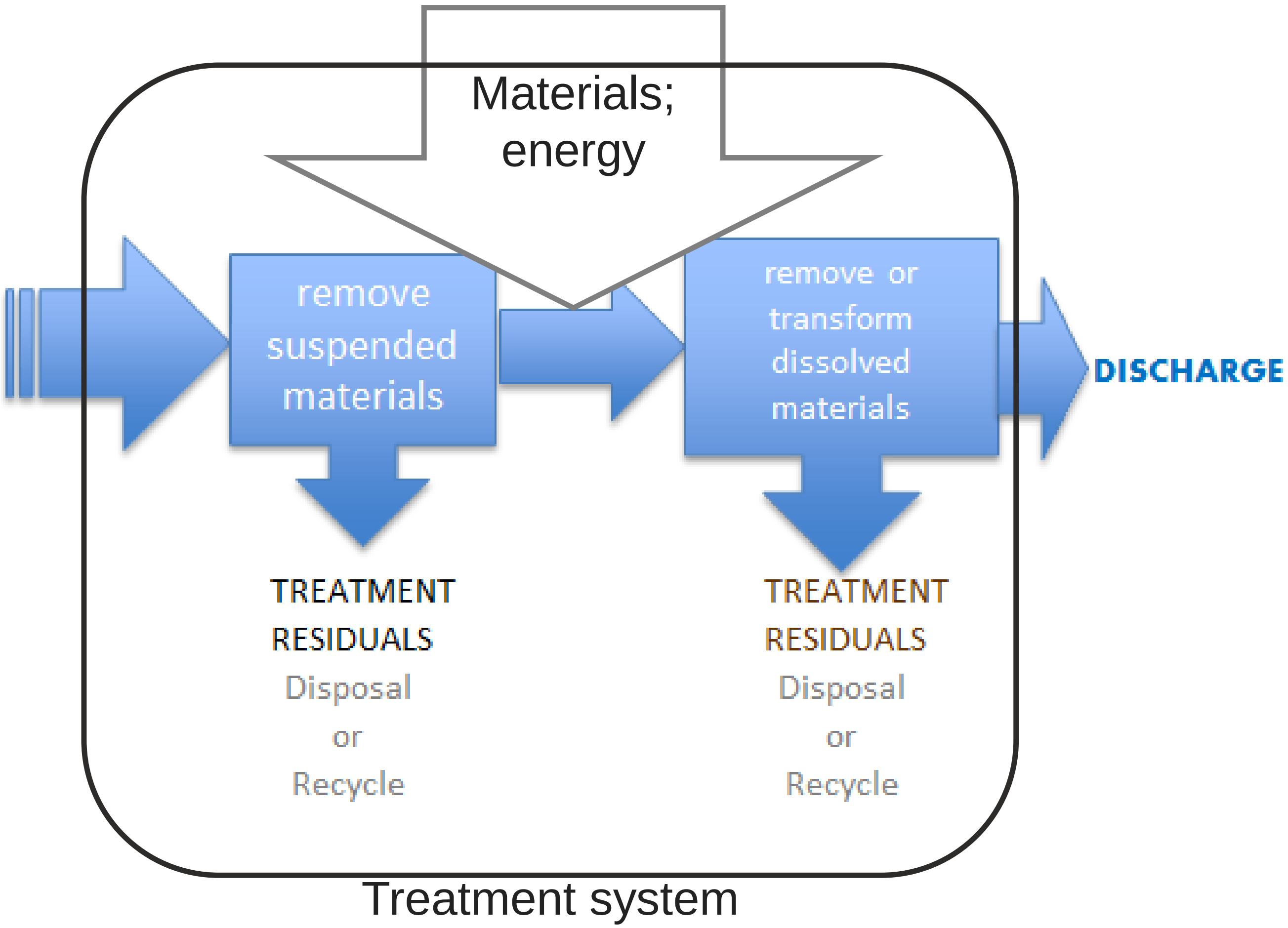


- ❑ All work is driven by free energy (exergy)
- ❑ Economic production requires work and products provided by labour, energy and materials, funded by capital

❑ Resource entropy consequences

- Increasing dissipation of materials into the environment (air, water and land)
- Decreasing quality of key resources as cost mechanism in market exhausts easiest to process (lowest cost) resources first- degrading natural capital
- Materials dissipated into the environment may erode habitat – reducing biodiversity and degrading natural capital
- Materials dissipated into the environment may pose risks to human health, requiring mitigation
- These downstream services for economic production (human health protection and environmental, hence natural capital protection) are provided by the **water industry**

Physical description of wastewater treatment; its ‘Intensification Needs’



❑ Wastewater Intensification NEEDS

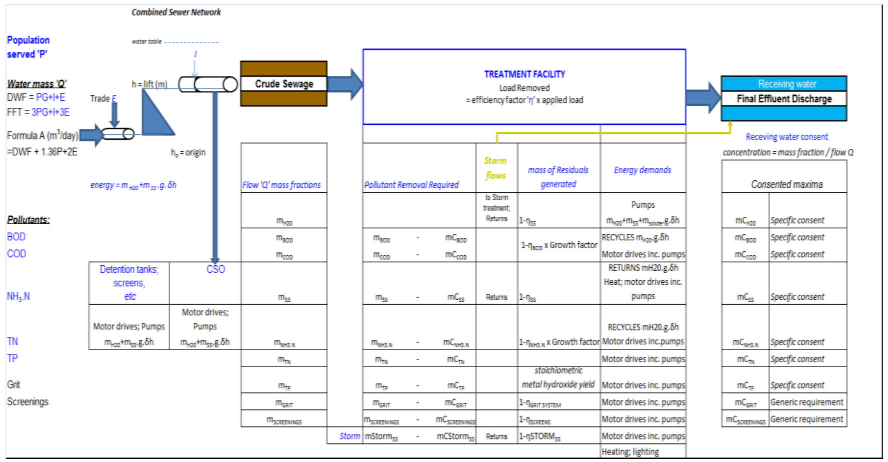
- Increased population ≡ increased **PROCESS CAPACITY** need
- Globally, bulk of increased in predominantly urbanized and hence large WwTW associated)
- Most of overall treatment work (that accomplished at large WwTW) will require small footprint (intensive) solutions

- Increased range of pollutant removal ≡ increased **PROCESS CAPABILITY** need

- **Affordability** = the need for Value for Money design solutions and operations; avoiding premature write off of existing assets, making operations Circular Economy thus requiring resource recovery (energy and materials) from residuals and whole-stream treatment

- **Climate change** and industrial change= increased **RESILIENCE**; needing adaptable technology and systems engineering approaches

- New Design Philosophy: **Systems Engineering**



Performance Resilience: the need for new capabilities to meet emerging performance and regulatory risks

❑ Operational Performance risks: Climate change

- ➢ Changing weather patterns
  - Dryer summers with more intense storms = increased foul flush risk
  - More intense loading evens on preliminary treatment
  - Increased peaking in crude sewage solids

- ➢ Marginal waste water temperature increases
  - Marginal gains for nitrification and BNR but marginal increases in septicity and hence odour risk and biodeterioration risks

❑ Microplastics

The resistance of non degradable plastics to biodegradation results in their accumulation in the environment. Microplastics are plastics of less than 5mm in size.

- Global production 322 million tonnes *per annum*. Main sources: tyres, synthetic materials, marine coatings, road markings, personal care products, city dust, losses during plastic production. Only 9% currently recycled

- Source controls: *e.g*. Microbeads: Cosmetic microplastics – now source controlled in UK but microbeads only 4% of total microplastic burden

❑ Xenobiotics:

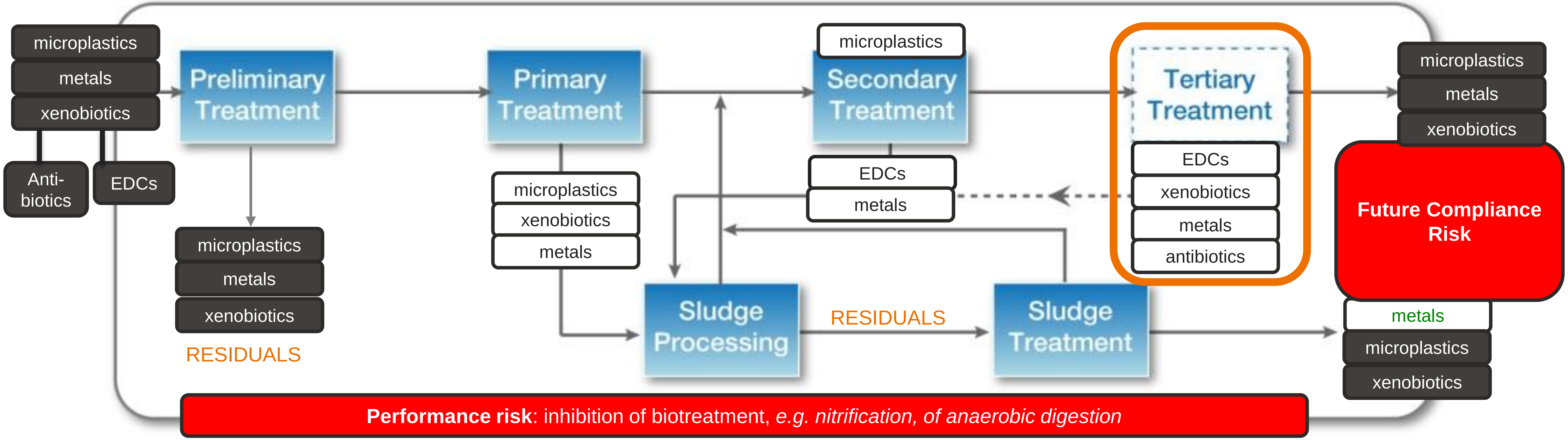
Xenobiotics are any chemicals present in an organism which are not naturally produced or naturally occur in an organism. Approximately 200,000 industrial chemical known.

- ➢ **Xenobiotic Operational Performance risks**
  - Inhibition of biotreatment reducing biotreatment efficiency
  - Current Highest Risks: Nitrification in aerobic biotreatment; methanogenesis in anaerobic biotreatment, CHP asset life (siloxanes)

Performance Resilience: The need for new treatment capabilities to meet Chemical Emerging Contaminants (CEC) Regulatory risks

- ❑ Xenobiotic Chemical Emerging Contaminants
  - **Halogenated compounds**
  - **Pesticides and Herbicides**
  - **Pharmaceutical and Personal Care Products (PPCPs), Antibiotics**
  - **EDCs (endocrine disrupting compounds)**
- ❑ Metals
- ❑ Nanoparticles

Capability: Wastewater Plant Treatment Activity and Emerging Risk Profile



Preliminary and PRIMARY TREATMENT

- ❑ Particulate flocculation and sedimentation
- ❑ Trapping/filtering particulates
- ❑ Adsorption of metals and particulates (also microplastics)

BIOLOGICAL TREATMENT

- ❑ Adsorption into floc of particulates, sorption of hydrophobic materials
- ❑ Biosorption of metals
- ❑ Role of EPS (biofilm & suspended): trapping particulates, biosorption

TERTIARY TREATMENT

- ❑ Adsorption biofilm of particulates, sorption of hydrophobic materials, biosorption
- ❑ Role of EPS
- ❑ Adsorption onto media
- ❑ Opportunity for most effective (least interfered with) downstream processing at lowest BOD/COD, N and P load burden

Performance risk

- ❑ Management measures
  - *e.g.* ASPs: Monitor OUR and compare to past trends; increase MLVSS & sludge age in AS when inhibited
  - *e.g.* Monitor rate of and level of CH_4 production versus trends, reduce MAD federate when inhibited

Future Regulatory Risks? Emerging Contaminants of Concern (CECs)

❑ Microplastics

Found in humans in 2018 - which is not really a surprise given their size, ubiquity and non-biodegradability. Health risk status currently unknown

❑ Xenobiotics – UK non-Compliant EQS CECs and other emerging CEC xenobiotics

- **Halogenated compounds**
- PFOA's (perfluoro-octanoic acid *e.g.* C8); PFOS's (perfluoro-sulphonic acids), Benzapyrene, Fluoranthene

- **Pesticides and Herbicides**
- Cypermethrin

- **Pharmaceutical and Personal Care Products (PPCPs), Antibiotics**
- VOCs:1,4 Dioxane (USA)
- Pharmaceutical emerging risks: Diclofenac, Ibuprofen, Ranitidine, Propanalol;
- Antibiotic emerging risks: Azithromycin, Clarithromycin, Erythromycin

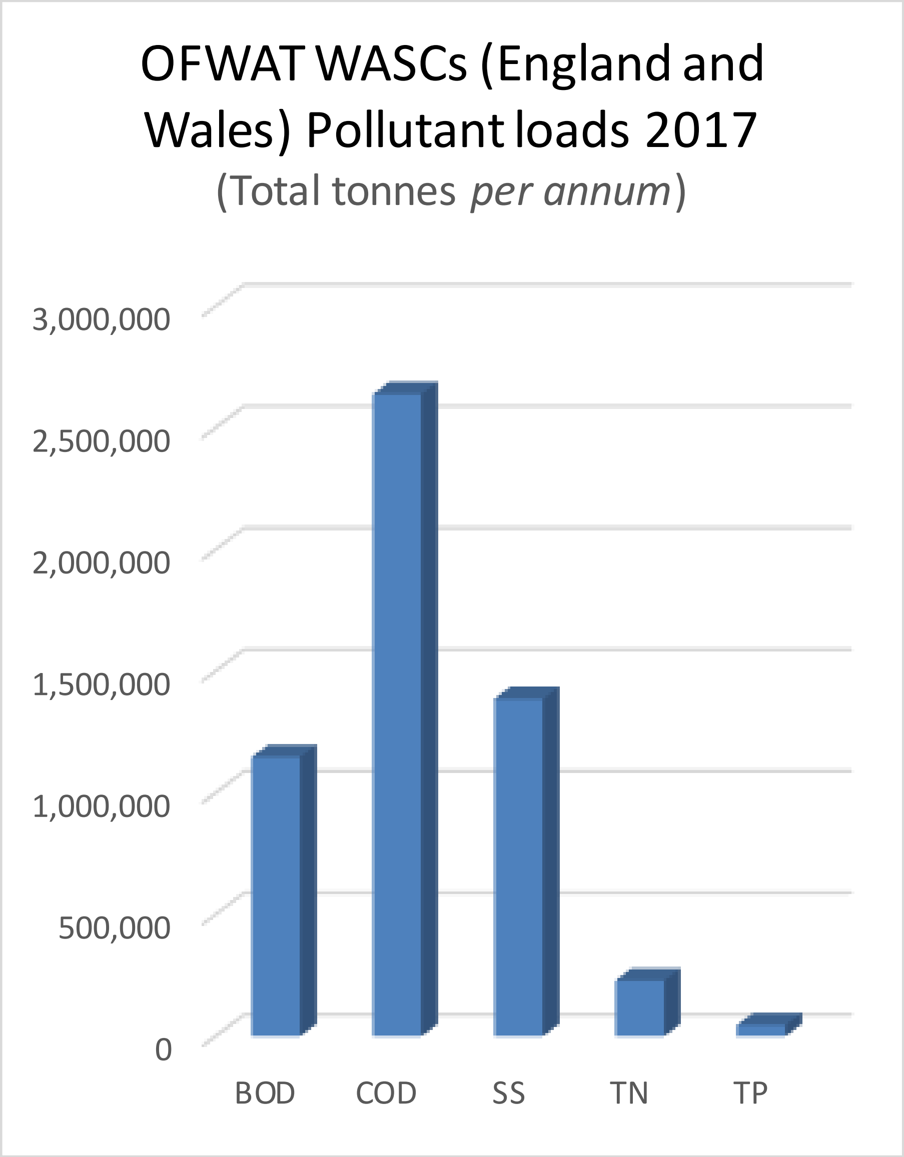
- **EDCs (endocrine disrupting compounds**
- Steroid emerging risk: Ethinyloestradiol (EE2); lesser risk: Oestrone (E1), Oestradiol (E2)

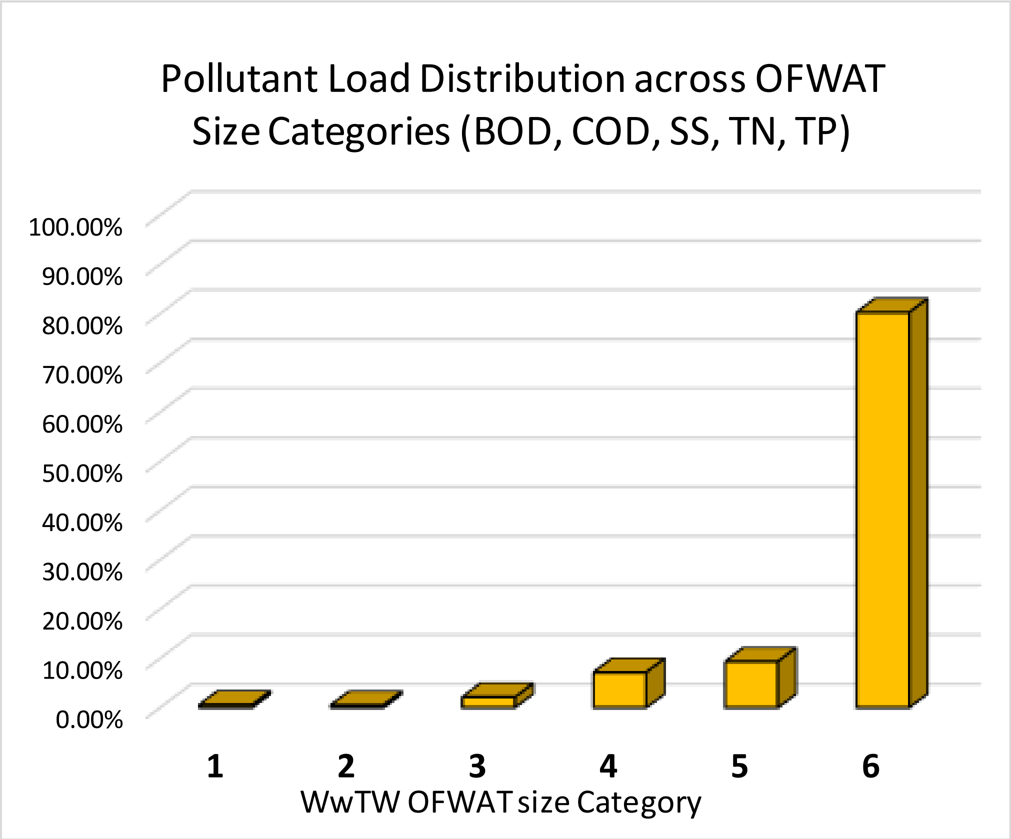
- **Other emerging CEC xenobiotics**
- Corrosion inhibitors: Benzotriazole, Tolyltriazole.

❑ **Nanoparticles**

- Metal nanoparticles include Zinc, Titanium, Silver. Pass into sludge. Effects on human health currently unknown

Wastewater Treatment Plant Work Profile: where to treat most intensively



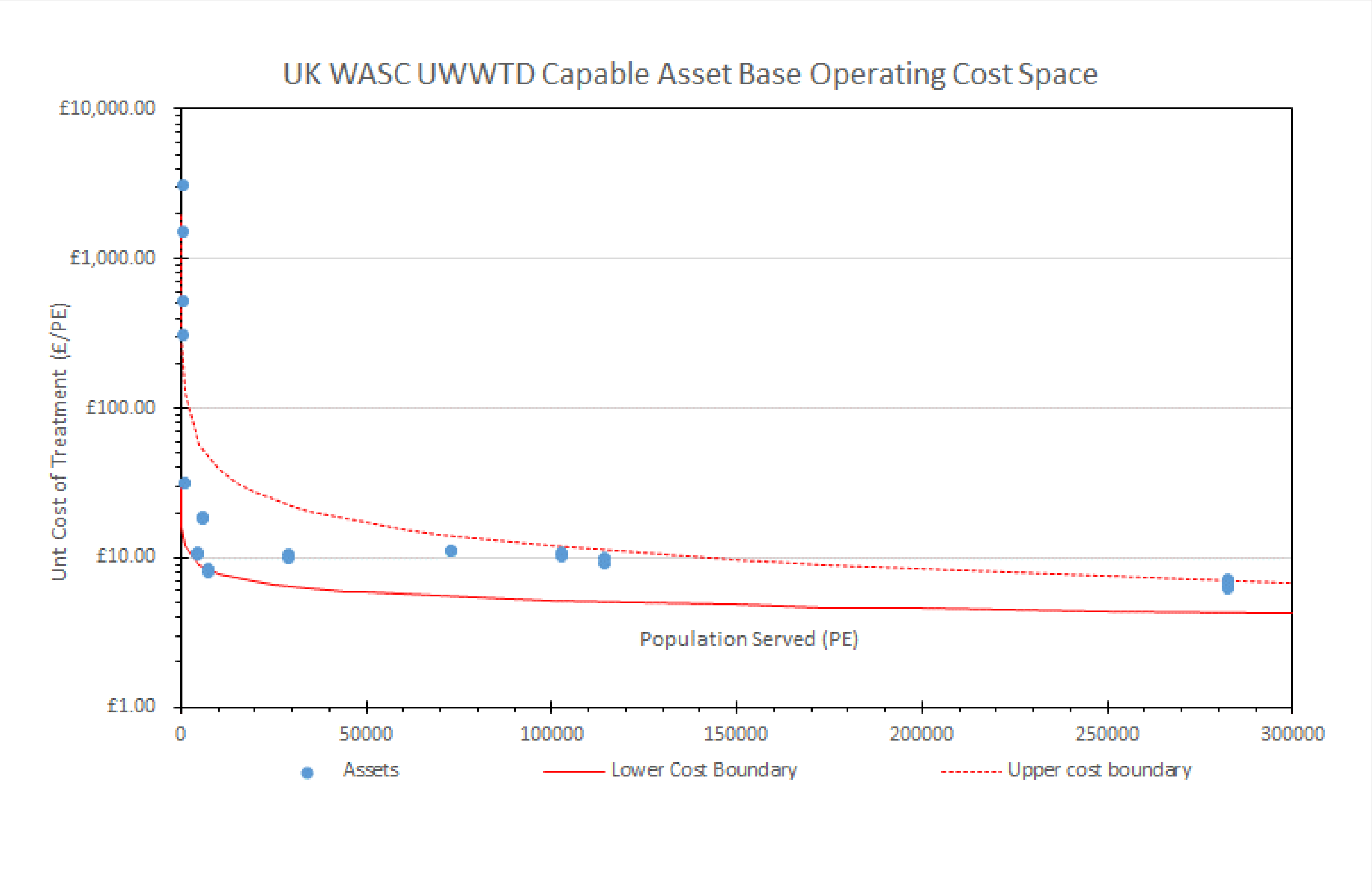


CECs

- ❑ How do they partition between waste streams?
- ❑ Why do they partition between waste streams?

- ❑ **Pollutant load profile** is mass-flow based: Emerging CEC pollutant risk follows the same trend- loading and risks will be highest at the larger urban STCs due to mass flow and most CEC sources being associated with urban areas

Affordability and OPEX: understanding the operational economic behaviour of the asset base

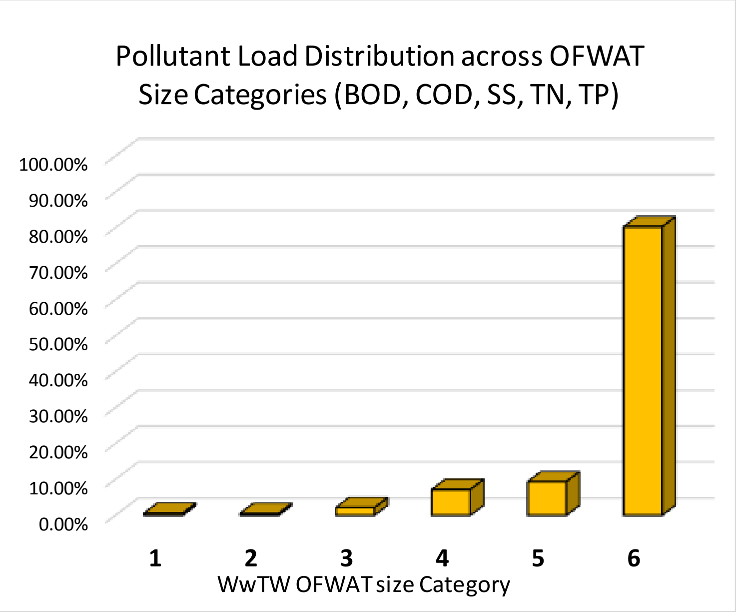


- The relationship between OPEX, CAPEX (and TOTEX) across a typical UK WASC asset base has the same general mathematical power law form:

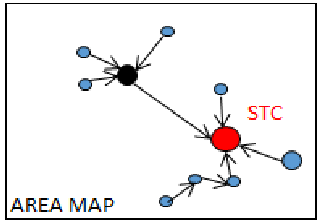
$$£/PE = K.(PE^{-k})$$

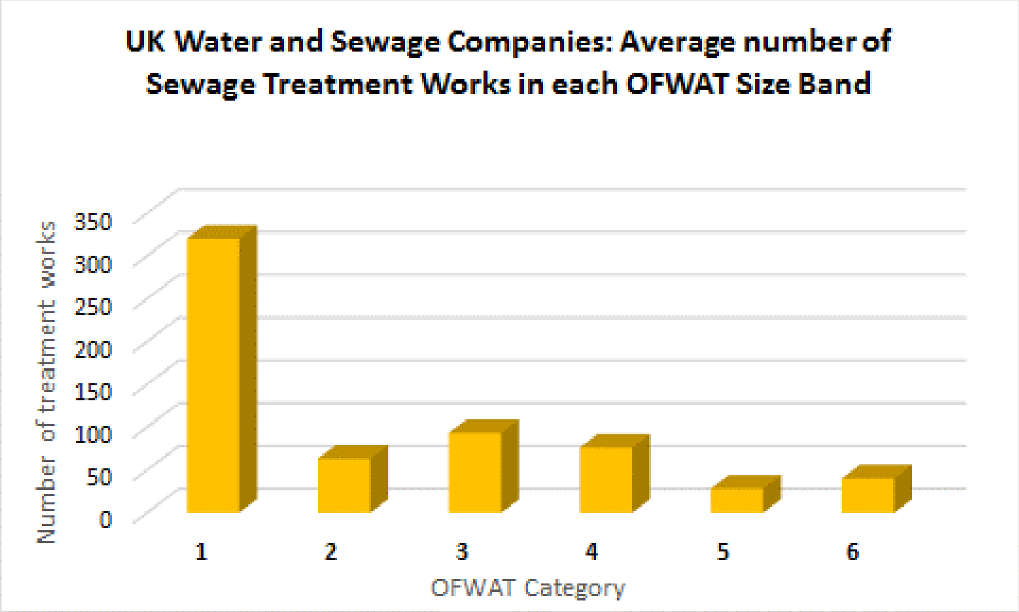
- This reflects physical economies of scale with an upper and lower power law cost boundary containing all plants across an asset base
- Part of work done is mass transport of water to and from treatment; mass load of pollutants is tiny in comparison – consequently source control and source minimization of pollutants offers good value for money
- Technologies doing physical work to meet regulatory needs deliver best capital outcomes *per capita* at large scale works due to economies of scale

WASC Wastewater Asset Base Profile: Targeted treatment



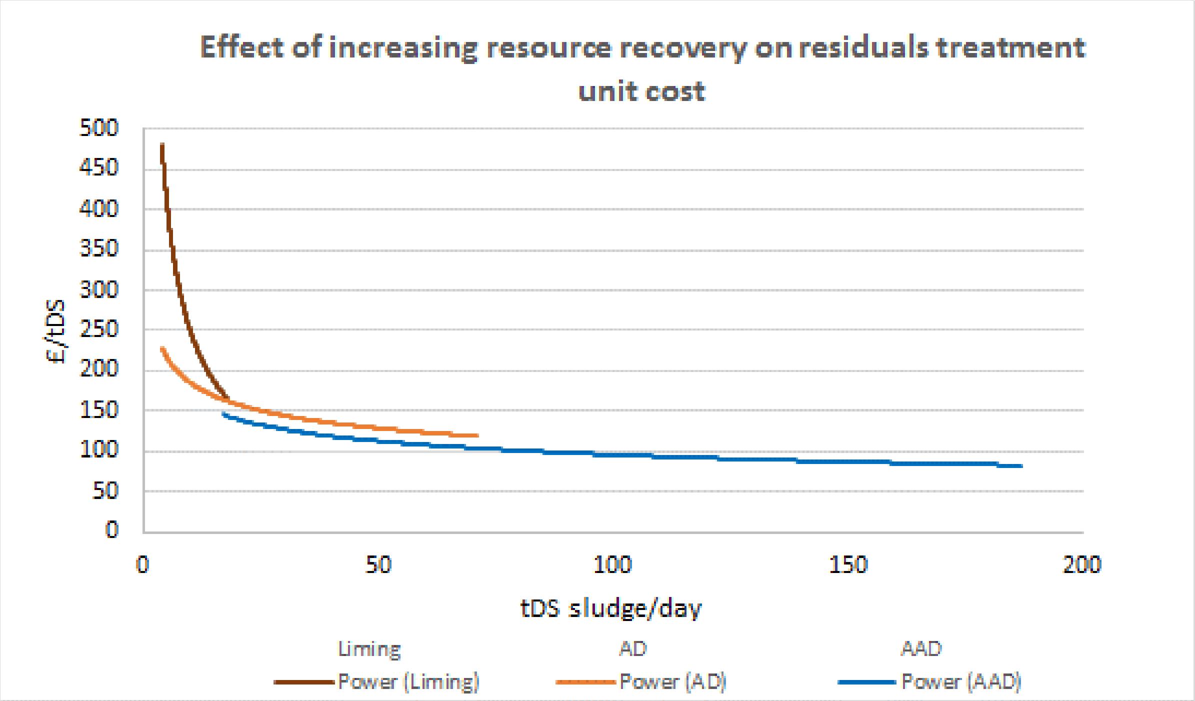
OFWAT WwTW Size Bandings	Population Equivalent
1	0 – 250
2	250 – 500
3	500 – 2,000
4	2,000 – 10,000
5	10,000 – 25,000
6	> 25,000

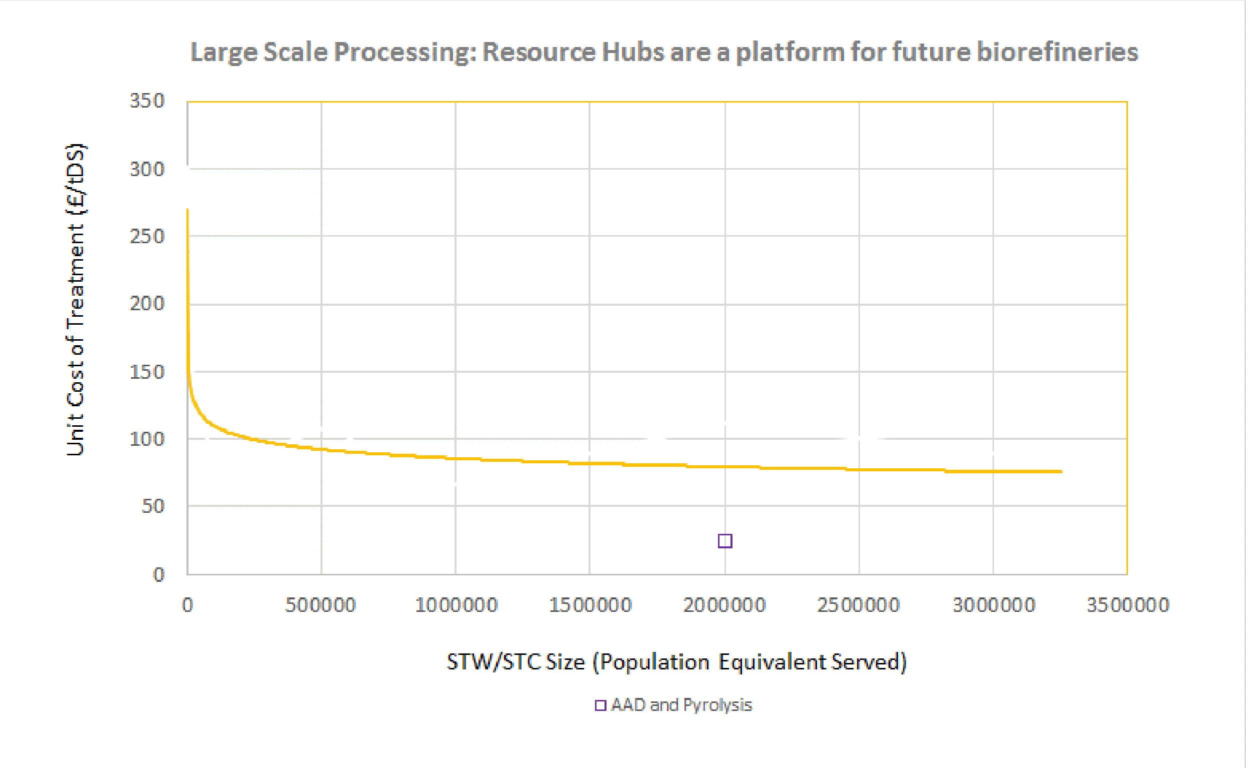




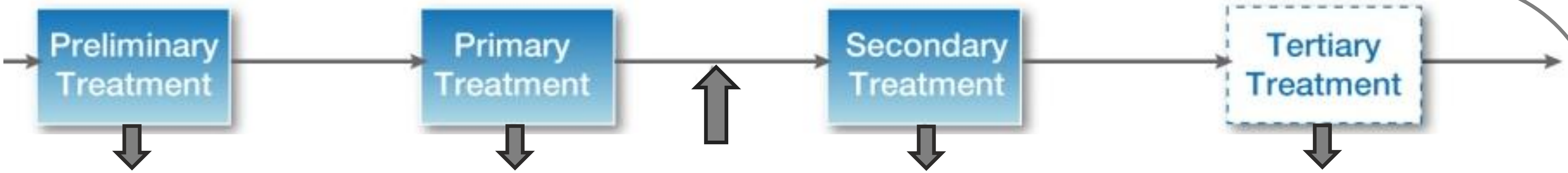
- ❑ For removable pollutants, the bulk of removal work is done in the largest plants
- ❑ For example, more than 80% of wastewater treatment and up to 100% of SLUDGE residuals treatment takes place in OFWAT Category 6 WwTW
- ❑ Specific industry discharges are risk hot-spots for CECs
- ❑ Source control for industrial sources is very cost effective (e.g. previous example in metals industry)

Affordability : Effect of increased economic efficiency through increased resource recovery from bioresources





Systems Engineering: High Intensity, Low Landtake, Increased Capability Solution Components



Preliminary and PRIMARY TREATMENT

- ❑ Microbubble DAF
- ❑ Actiflo
- ❑ Salsnes Filters
- ❑ Screenings composting or Pyrolysis or
- ❑ Grit washing and reuse

BIOLOGICAL TREATMENT

- ❑ Conventional AS(-BNR) or biofilm
- ❑ Psychrophilic (Granular) UASB
- ❑ Autonomous ASP
  - ▪ Engineered Niche Biotech (*e.g* Microvi or similar)
  - ▪ Granular Biomass
- ❑ Autonomous Biofilm System
  - ▪ Engineered Niche Biotech (*e.g* Microvi or similar)

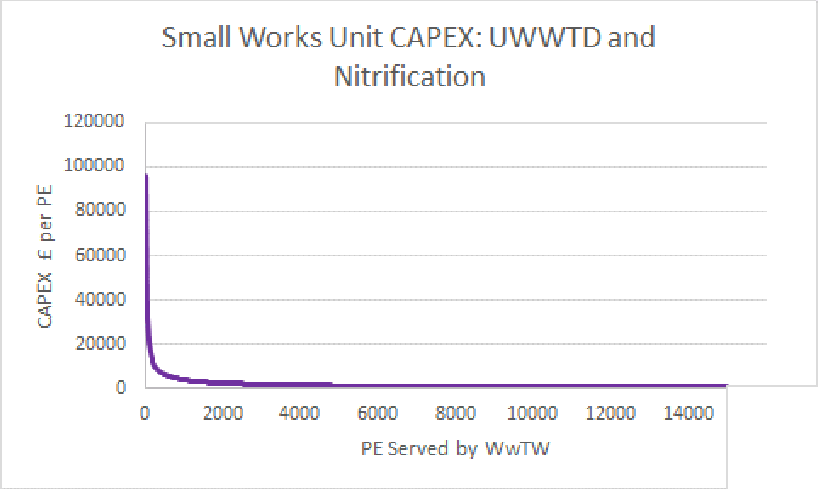
TERTIARY TREATMENT

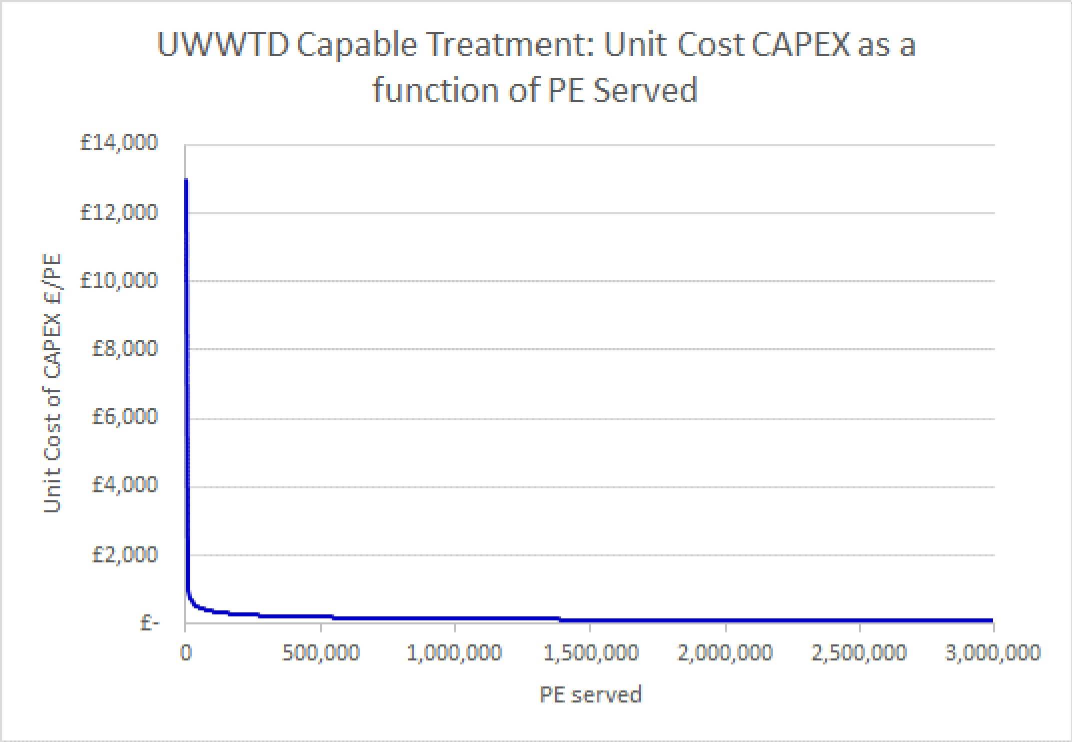
- ❑ Coagulant/polyelectrolyte dosed Filtration (CpF); CpF in –series
  - ▪ Actiflo
- ❑ Advanced Oxidation Process(es)
- ❑ Specific Adsorption Media
- ❑ Reactive media
- ❑ Adsorbtion and electrochemical treatment (*e.g.* Ariva or similar)

Feasible Integrated Resource Recovery

- ❑ Ion Exchange (Ammonia and P recovery)
- ❑ Ammonia stripping and ammonia recovery
- ❑ Algal scavenging (P removal and algal biomass to AD
- ❑ Activated Sludge, Granular Media or Biofilm WAS: Enzyme recovery and/or PHA recovery (Bioplastics)
- ❑ Serial Digestion and Digestate harvesting (VFAs to support temperate climate BNR); (VFAs for downstream Bioprocessing)
- ❑ P recovery integrated with AD (Struvite recovery: >250,000PE plant with MAD, P consent and chemical P removal)
- ❑ *In situ* Downstream processing: in situ polyelectrolyte production
- ❑ *In situ* energy recovery: renewable energy recovery and heat recovery from Wastewater
- ❑ Renewable energy recovery: advanced digestion and advanced conversion technologies (pyrolysis, gasification) replace incineration
- ❑ *In situ* Downstream processing: enzyme recovery from WAS
- ❑ *In situ* Downstream processing: PHA/PHB (bioplastics precursor) recovery from WAS
- ❑ *In situ* Downstream processing: Energy storage via biogas and methane fuel cell or hydrogen and hydrogen fuel cell; transport fuel
- ❑ Integrated advanced conversion: Pyrolysis/gasification char as carbon capture/or char to integrated small scale incineration for ash metals and P recovery

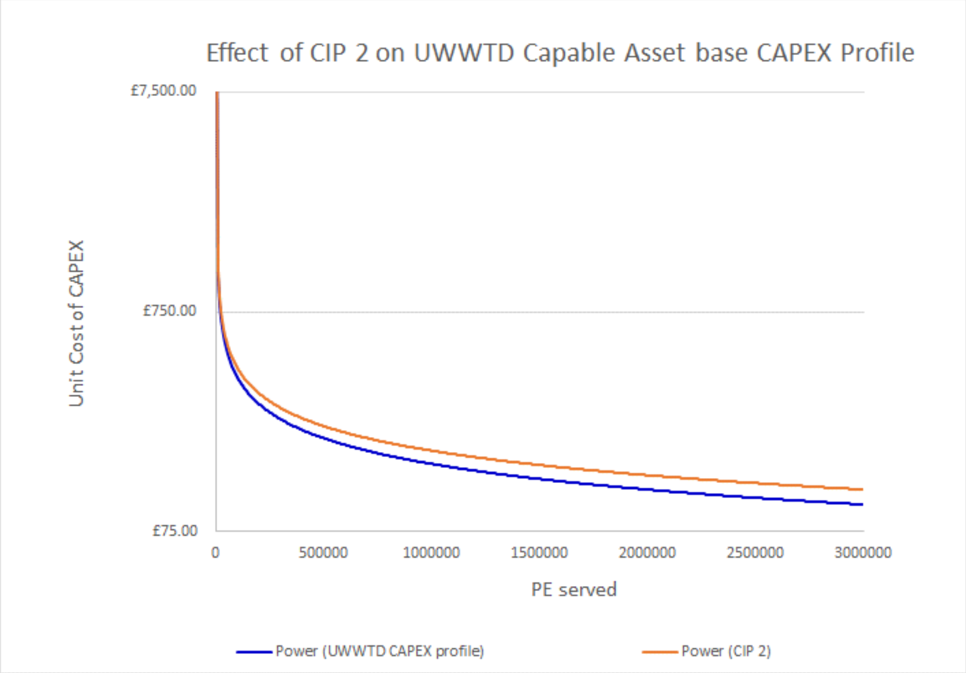
Affordability and CAPEX: the CAPEX profile of the utility asset base

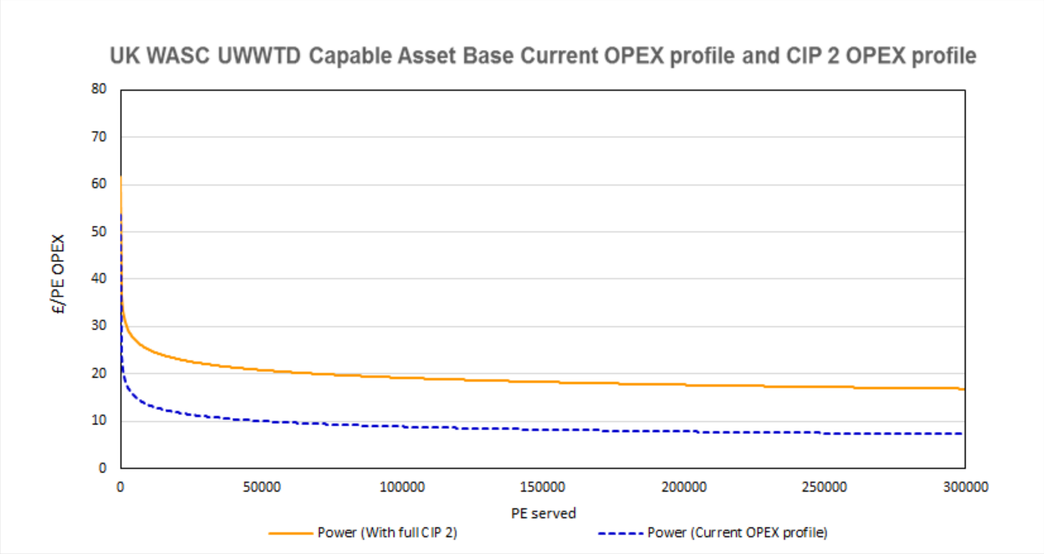




- ❑ Few very large water and sewage works (typical UK WASC 10% or less of total number)
- ❑ Many small water and sewage works (>90% of total number)
- ❑ Economies of scale are very significant in water treatment due to the sheer mass of material that is expected to be processed at low cost

Affordability : Effect of increased capability requirements for CEC removal





- CAPABILITY IMPROVEMENTS
  - **EQS Implications**
- U.K CIP in WFD: for SRP (ortho-P) at least 700WwTW require upgrading
- For existing UK CIP xenobiotic and metals EQS only:
  - £27-31 billion over 20 years
  - Monitoring costs add £27.3-45.3million over 20 years
  - Billing increases could average £100/recipient/year

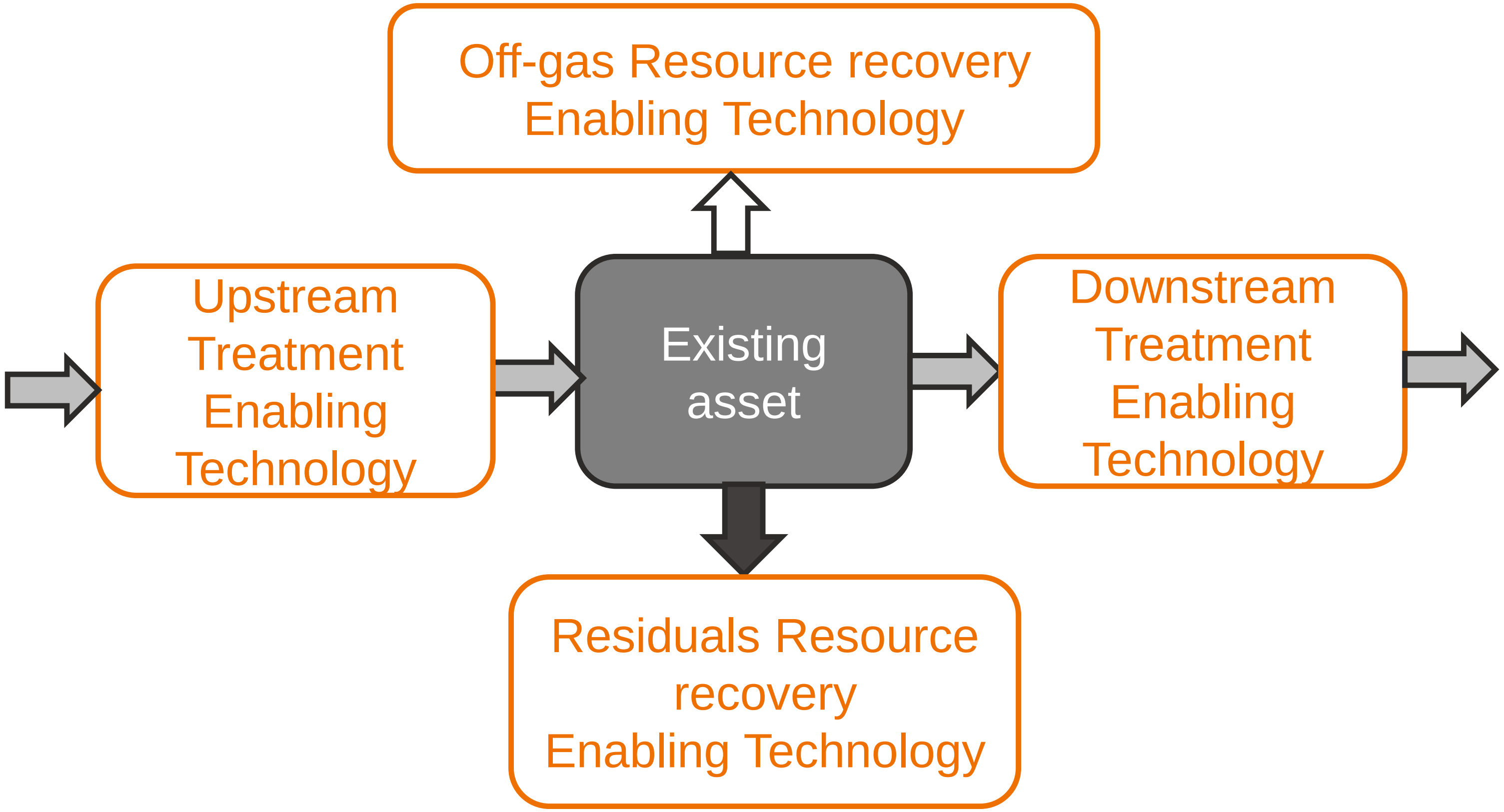
(Costs from HM Parliament Science and Technology Committee Report 2013)

see Craig, M. (2017) 'CIP 2'

Systems Engineering: Process Efficiency and Value for Money for Aging Assets

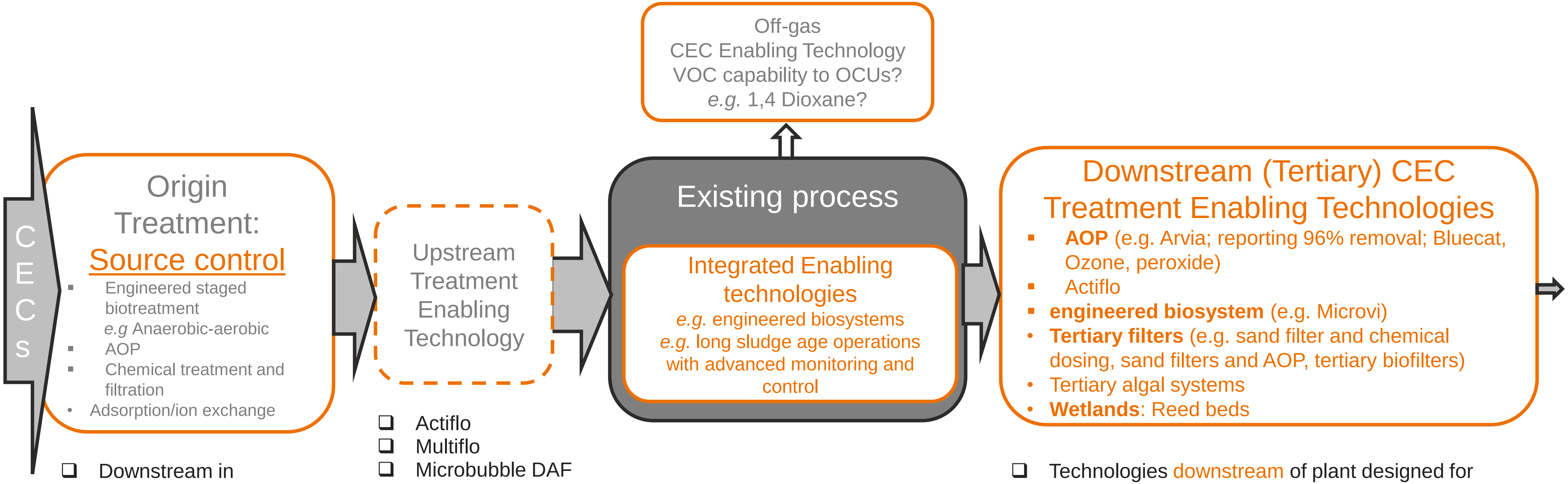
Deploy 'Enabling Technologies' to avoid asset stranding

- Minimize Asset write-off by deploying Enabling Technologies to extend life of existing assets
- Enabling technologies are those which can increase both CAPACITY and CAPABILITY of existing assets (e.g. THP for AD)



Systems Engineering for standard treatment systems biologically recalcitrant CECs

A generic approach to maximise treatment capability:



- ❑ Downstream in combined sewer pollutant load is only 0.2% w/w of wastewater mass. Some source control improves economic outcomes.

- ❑ Actiflo
- ❑ Multiflo
- ❑ Microbubble DAF

Load reduction on secondary treatment

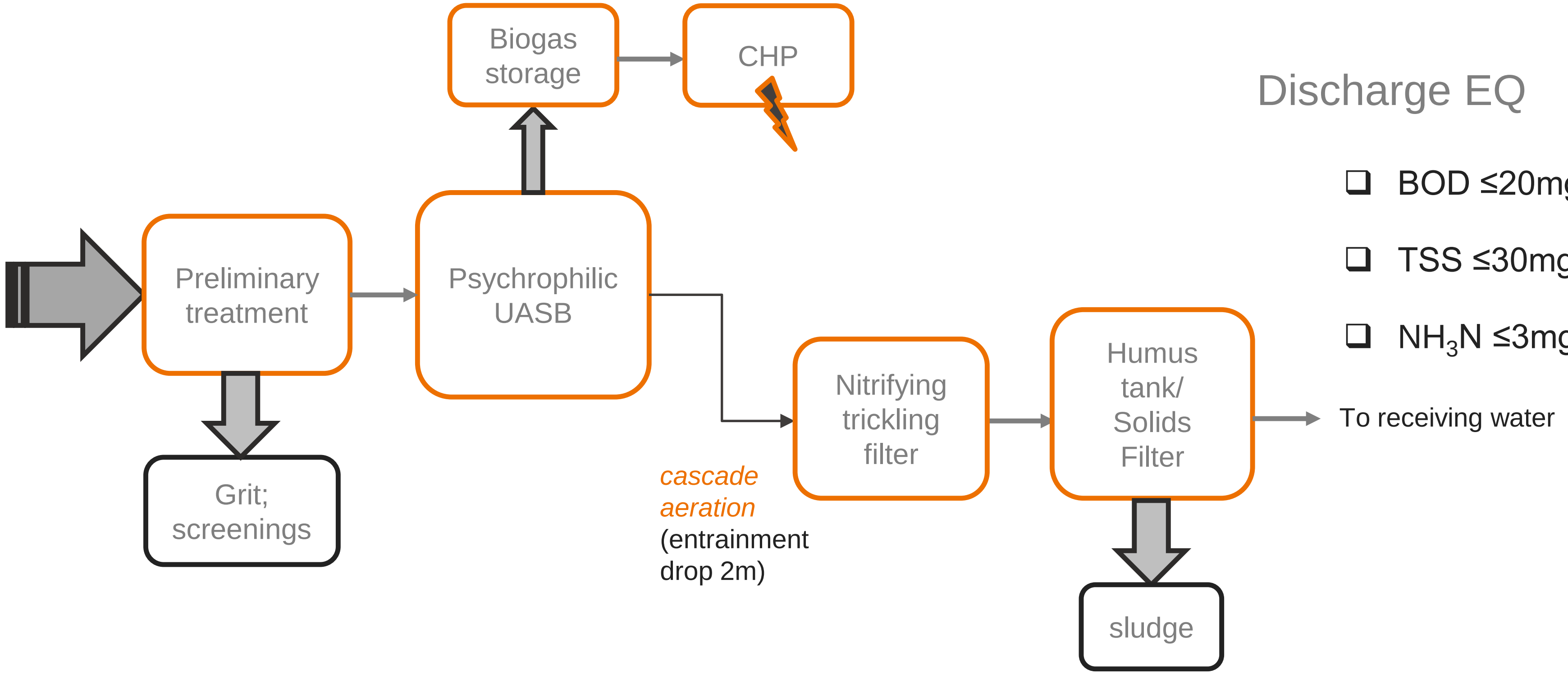
- ❑ Technologies downstream of plant designed for carbonaceous load and N and P load removal have to contend with a much lower load of general pollutants and other potential interferences

- ❑ Serial treatment, in which two lower efficiency tertiary CEC processes are run in series, can give more options for high overall rates of CEC removal

Systems Engineering:

Anaerobic Carbonaceous 2000PE to 50,000PE - Efficiency improvements

- ❑ Integrated Anaerobic Whole-stream and nutrient removal



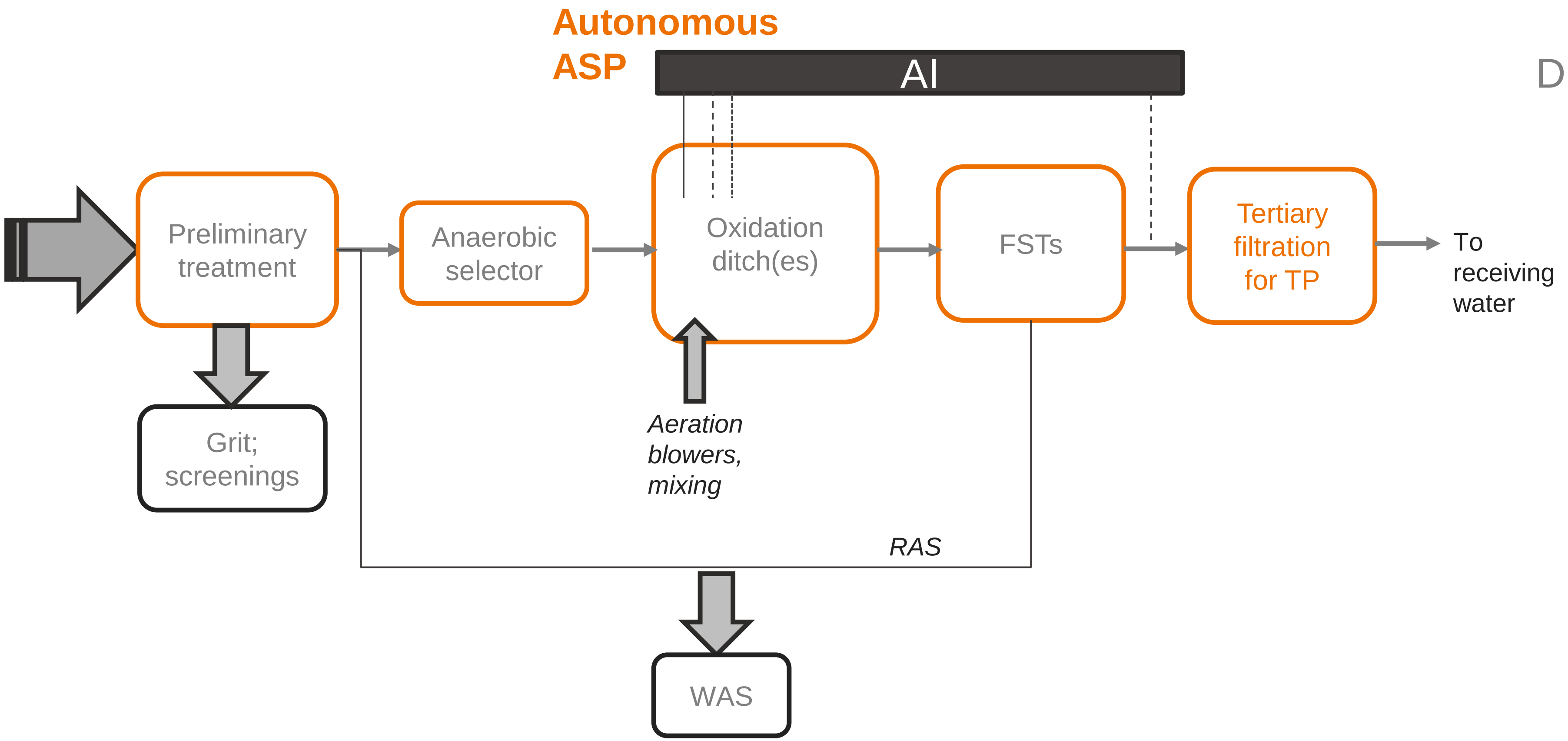
Discharge EQ

- ❑ BOD ≤20mg/l
- ❑ TSS ≤30mg/l
- ❑ NH_3N ≤3mg/l

Systems Engineering:

Aerobic Treatment 1000PE to 50,000PE: Efficiency improvements

- ❑ Autonomous plant = plant with real time control via a robust AI system which reduces amplitude of noise in performance – thus increasing process capability and reliability and maximising SRP removal

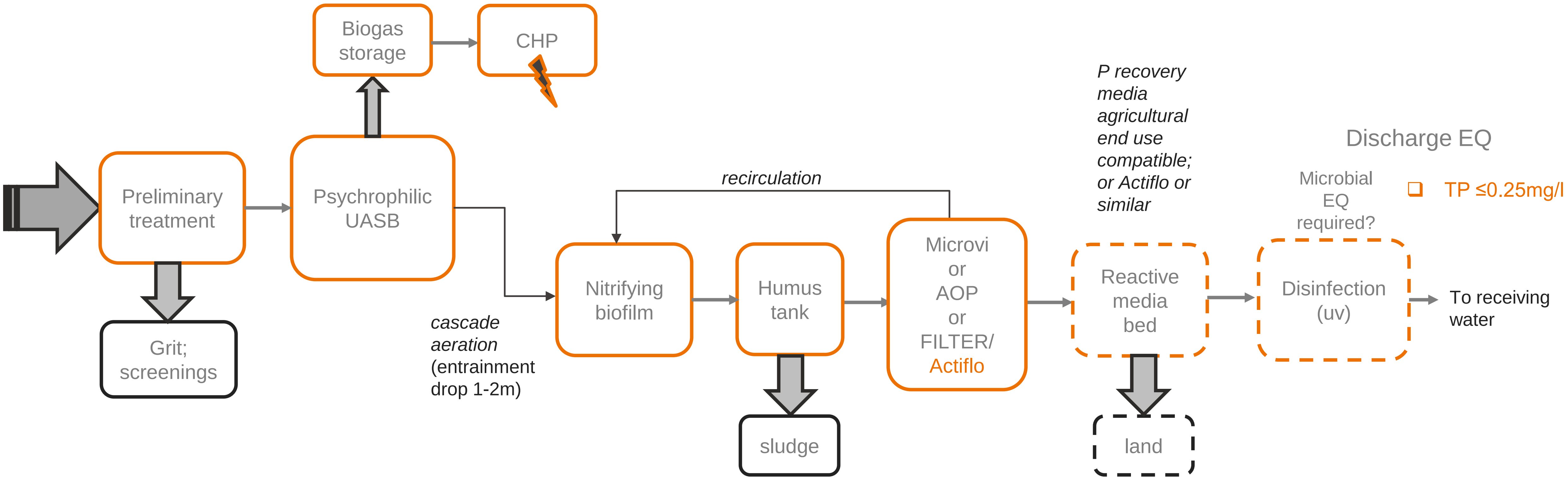


Discharge EQ

- ❑ BOD ≤10mg/l
- ❑ TSS ≤15mg/l
- ❑ NH_3N ≤3mg/l
- ❑ TP ≤0.3mg/l

Systems Engineering:
Anaerobic Carbonaceous &NR 2000PE to 50,000PE - Capability improvements

- Integrated Anaerobic Whole-stream and nutrient removal



Systems Engineering:
Aerobic Carbonaceous &BNR 1000PE to 50,000PE: Capability improvements

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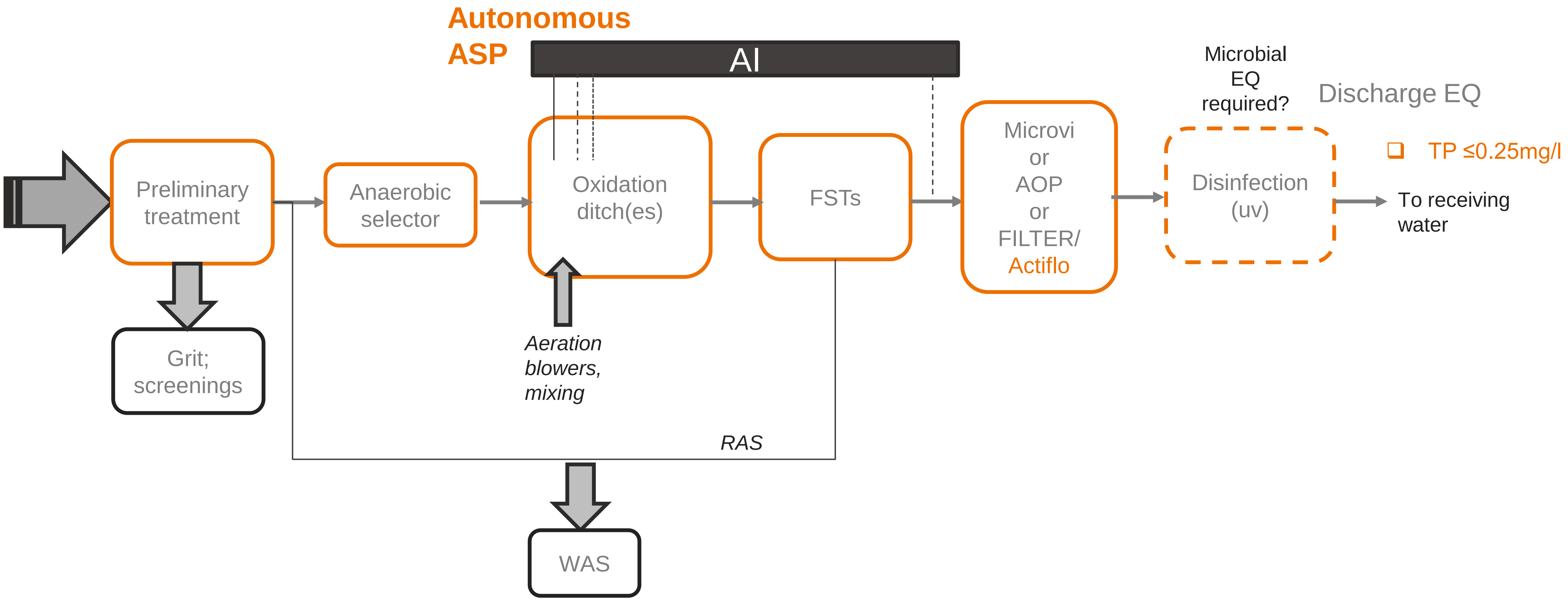
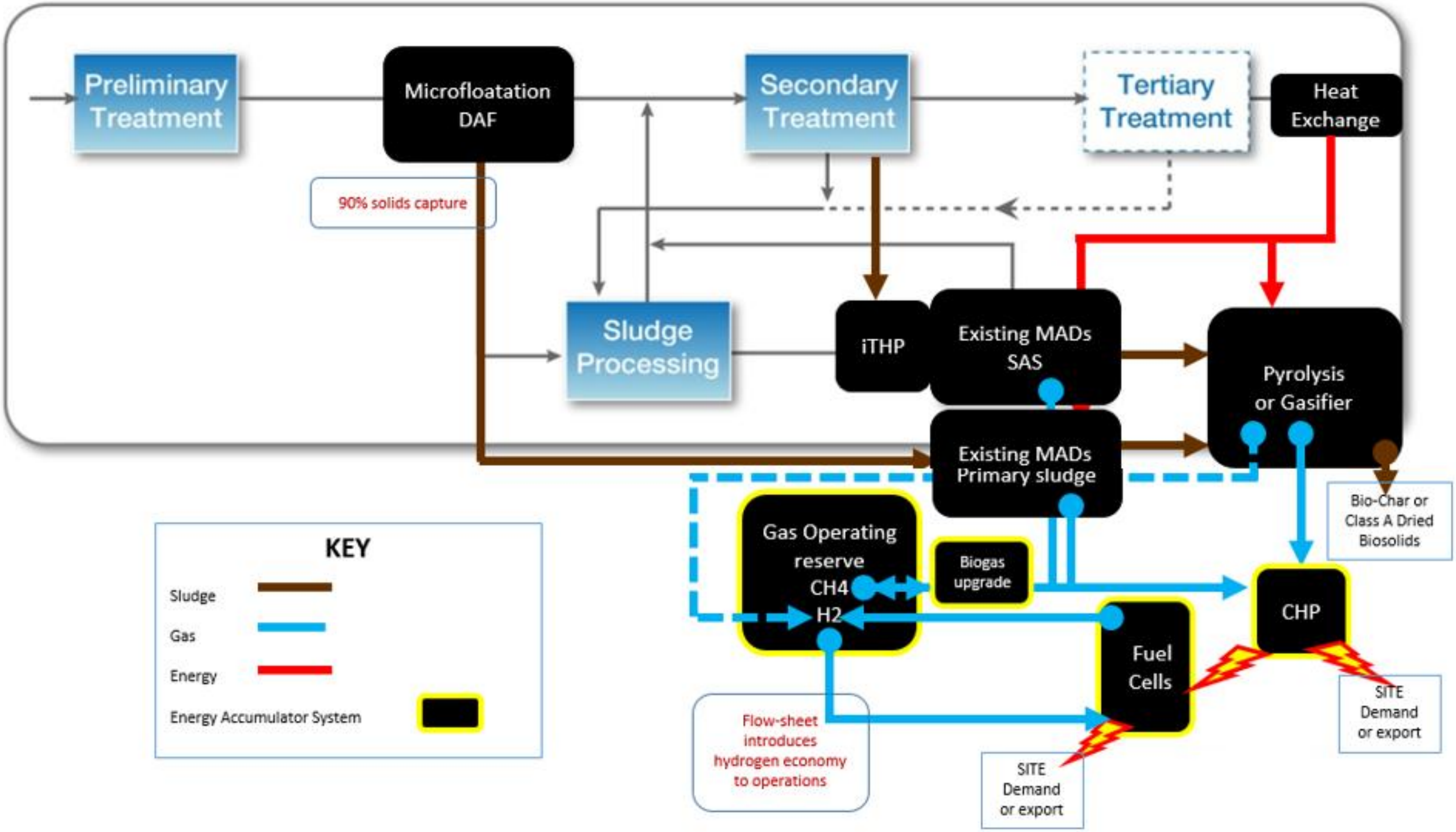
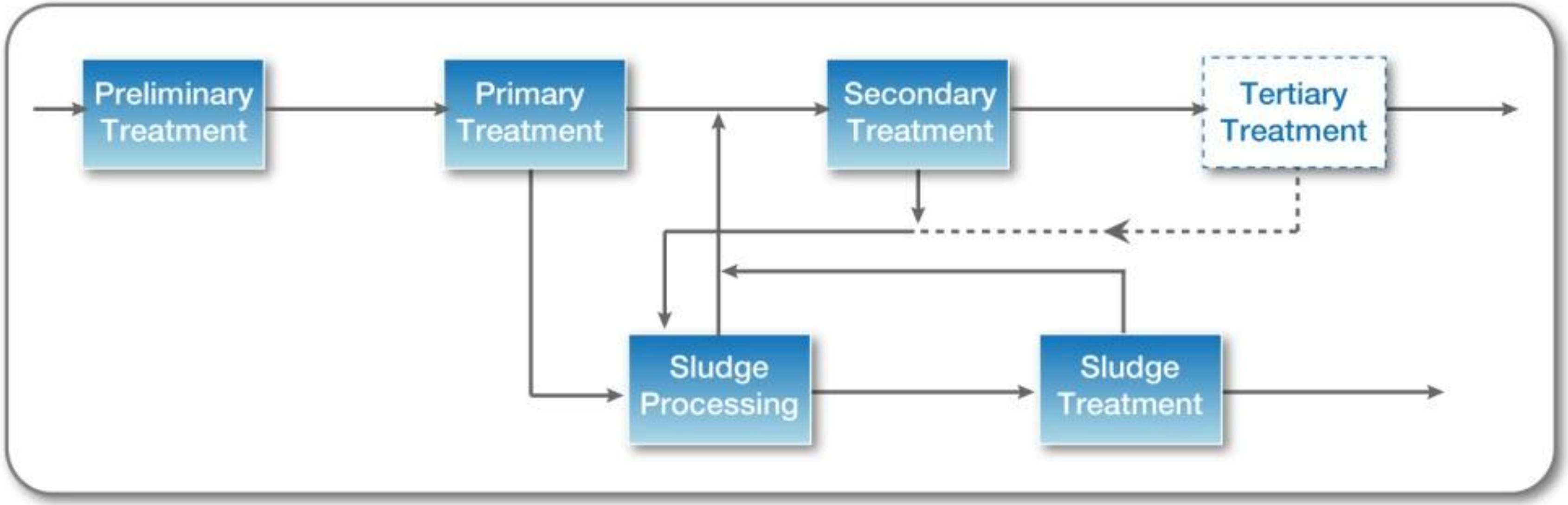


Systems engineering: Large STC Efficiency Improvements: hydrogen economy compatible energy storage

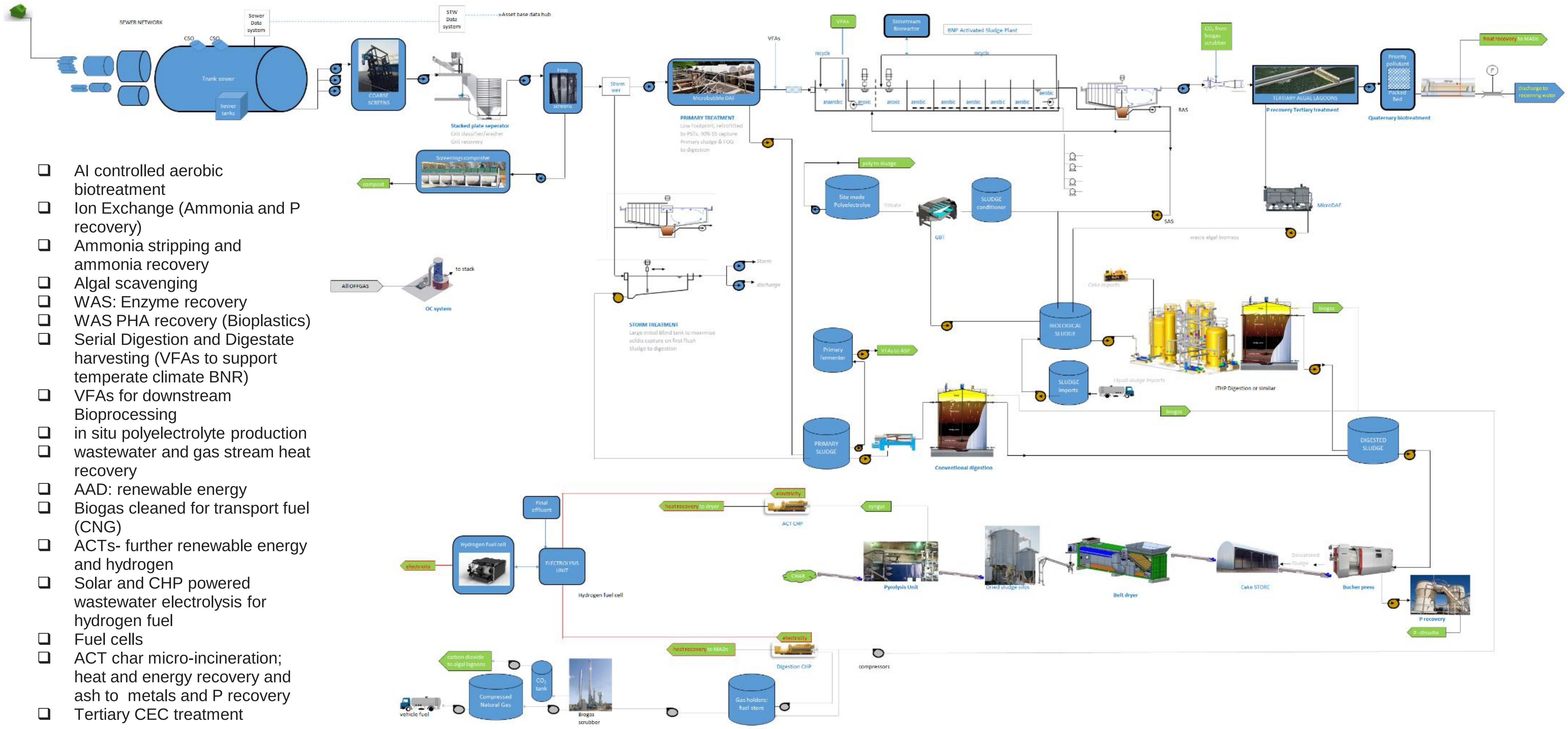


Systems engineering: Large WwTW Integrated Capability, Capacity, Landtake and Efficiency Improvements



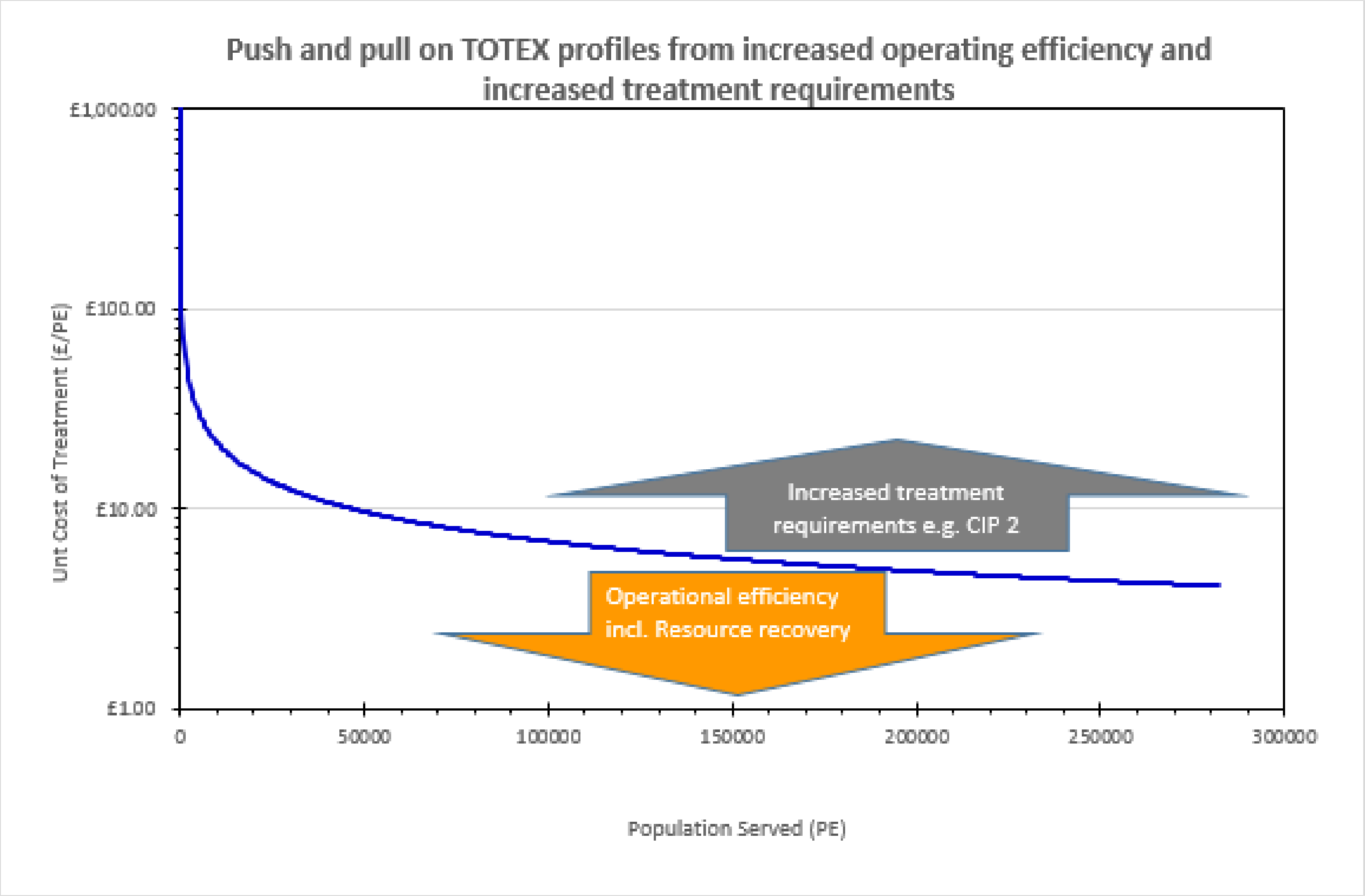
- ❖ Preliminary treatment: stacked plate grit systems
- ❖ Screenings to ACT (gasification or pyrolysis) or supercritical wet oxidation or RASCHA system)
- ❖ Primary Treatment: Actiflo or Mutiflo
- ❖ Primary treatment: microbubble DAF
- ❖ Primary treatment: SALSNES Filters
- ❖ No primary treatment: AI controlled stacked SBR or even lower footprint AI controlled deep shaft
- ❖ Algal scavenging in roof-mounted circulatory algal tube systems; algal biomass to AD
- ❖ High aspect ratio AD digesters
- ❖ Minimized site liquid storage integrated with AI full plant plan control ; high aspect storage
- ❖ Ion Exchange (Ammonia and P recovery)
- ❖ Ammonia stripping and ammonia recovery
- ❖ High aspect AAD: renewable energy
- ❖ High aspect Biogas storage for power and transport fuel, with integrated CO_2 scrubbing
- ❖ CO_2 recovery and CO_2 fed to algal scavenging, CH_4 compressed storage as CNG
- ❖ Solar and CHP powered final effluent electrolysis for hydrogen fuel
- ❖ Fuel cells
- ❖ ACT char micro-incineration; heat and energy recovery and ash to metals and P recovery
- ❖ Modular Tertiary CEC treatment

Systems Engineering: Biorefineries (1,000,000 PE and above (in residuals mass))



- AI controlled aerobic biotreatment
- Ion Exchange (Ammonia and P recovery)
- Ammonia stripping and ammonia recovery
- Algal scavenging
- WAS: Enzyme recovery
- WAS PHA recovery (Bioplastics)
- Serial Digestion and Digestate harvesting (VFAs to support temperate climate BNR)
- VFAs for downstream Bioprocessing
- in situ polyelectrolyte production
- wastewater and gas stream heat recovery
- AAD: renewable energy
- Biogas cleaned for transport fuel (CNG)
- ACTs- further renewable energy and hydrogen
- Solar and CHP powered wastewater electrolysis for hydrogen fuel
- Fuel cells
- ACT char micro-incineration; heat and energy recovery and ash to metals and P recovery
- Tertiary CEC treatment

Asset Base Operating Cost Space (Affordability) shifts from Efficiency and Capability Improvements: the ongoing development conflict



- ❑ Cost Efficiency includes circular economy cost benefits: resource recovery
- ❑ Resource recovery benefits shift cost curve to the left on the X axis and down the Y axis- *i.e.* operating costs and TOTEX reduce compare to current costs
- ❑ Capability improvements for EQS, from SRP to emerging EQS/CEC xenobiotics will shift the operating cost/TOTEX curve to the right on the X axis and up the Y axis- overall cost will increase
- ❑ Any additional provisions for microplastics, nanoparticles, metals etc will shift the cost curve further up towards increased costs

Thank You