Critical comparison of nutrient (N,P,K) recovery techniques from sludge, biosolids and manure

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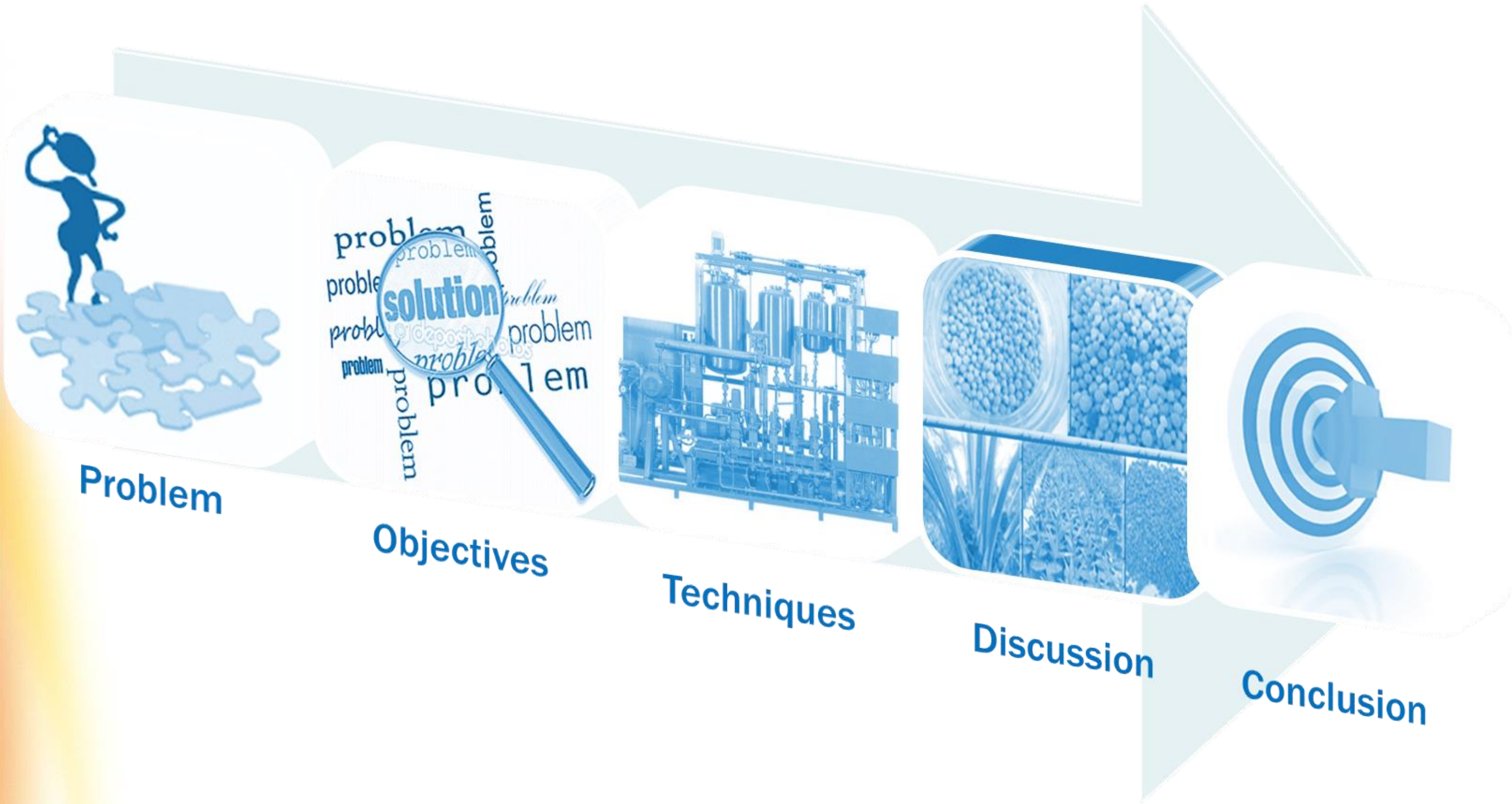
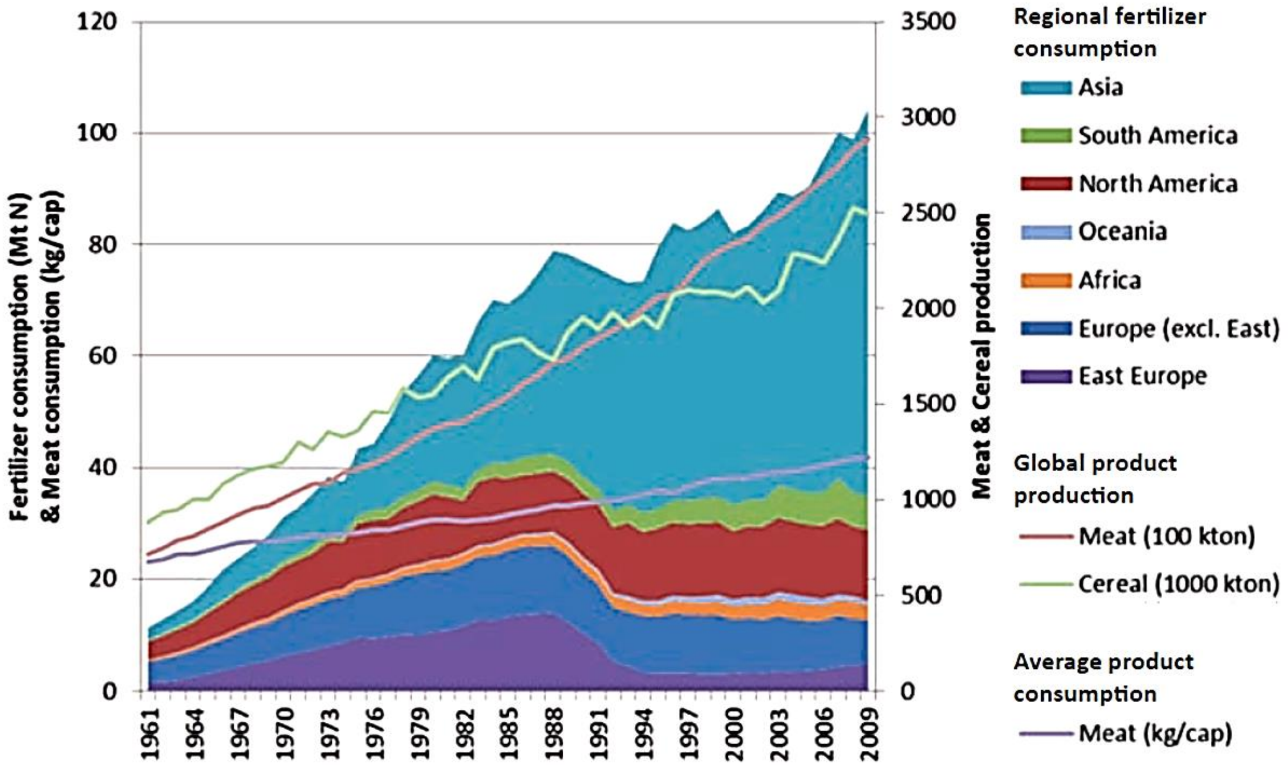
Presentation outline



PROBLEM STATEMENT

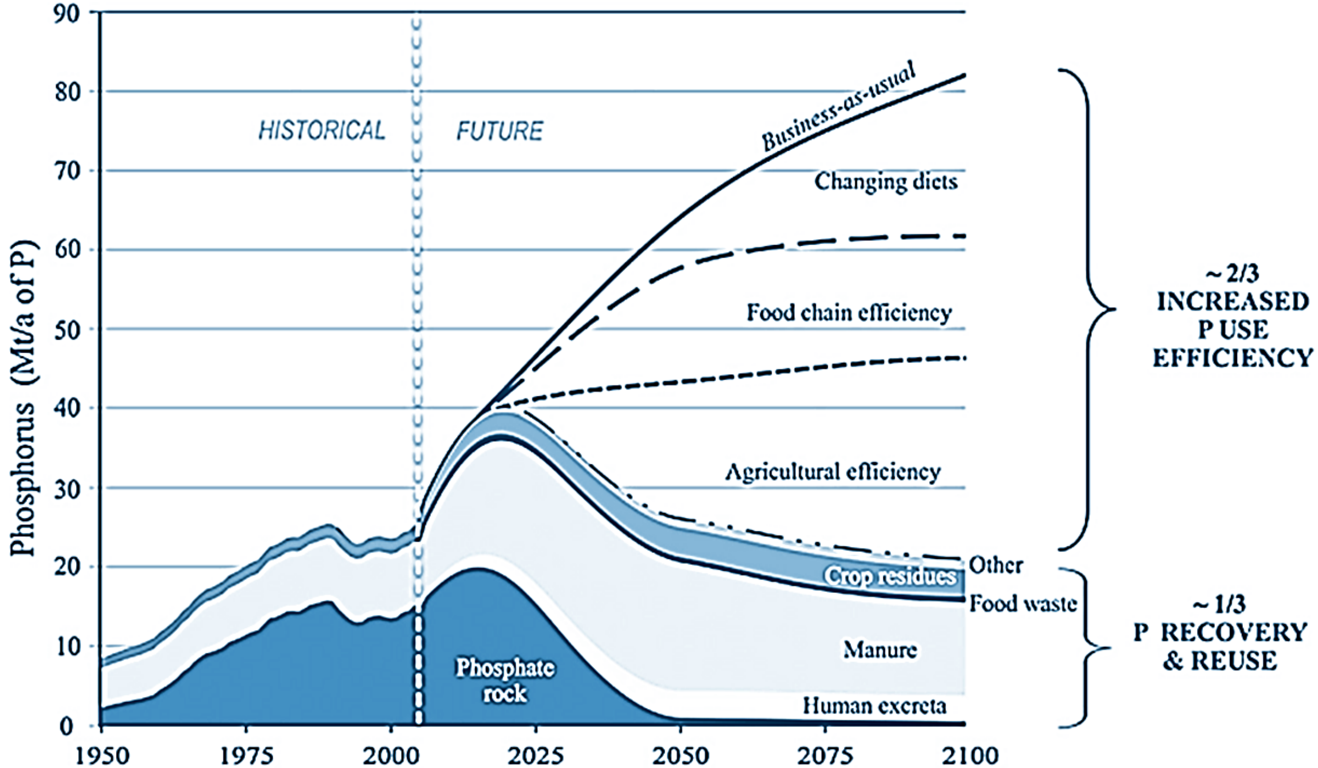
Global use of synthetic fertilizers



Demand ↑ ⟹ Energy use ↑ ⟹ Costs ↑

Sutton et al. (2013)

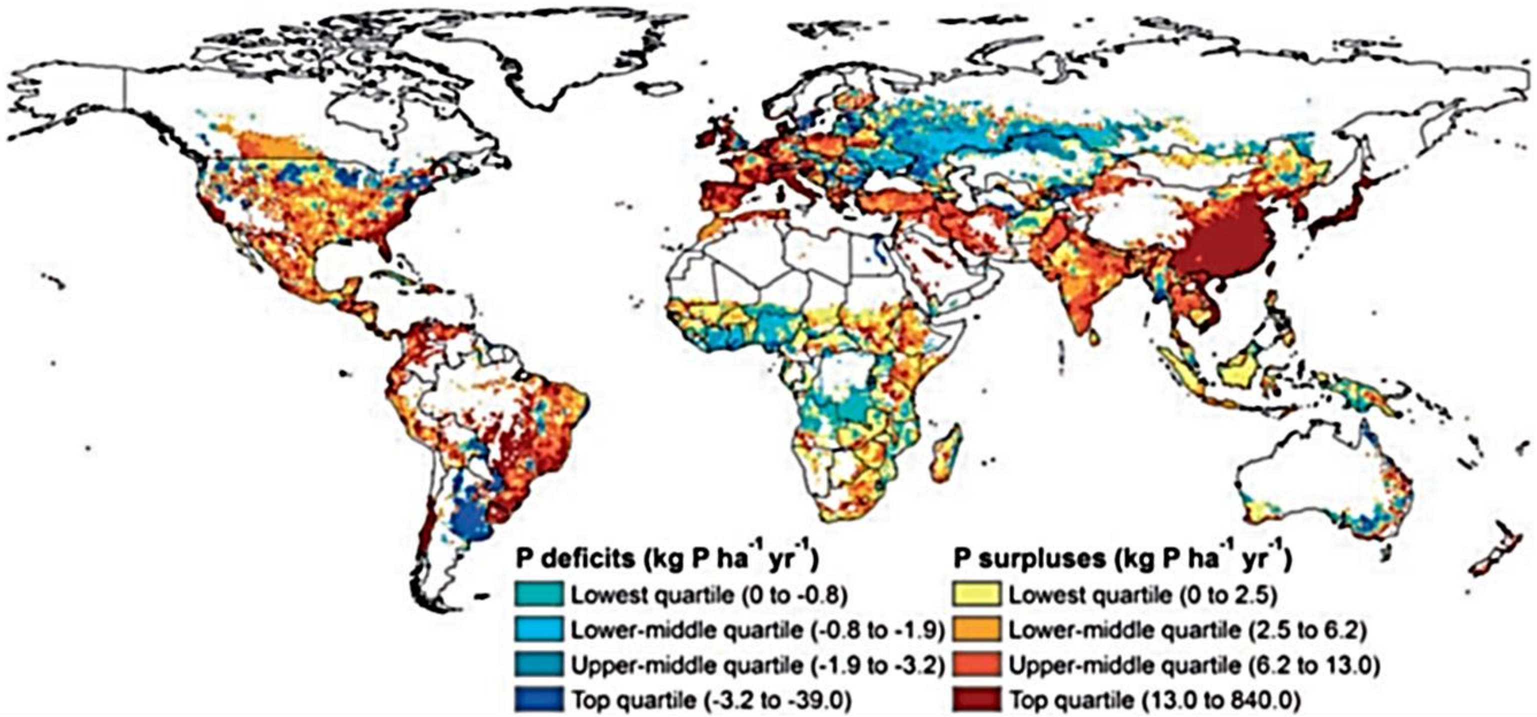
Increasing demand vs. anticipated depletion



Natural resources ↓ ⟹ Quality ↓

Cordell et al. (2011)

On the other hand: nutrient excesses in the environment



Sutton et al. (2013)

Environmental concerns

Need for sustainable resource management !

OBJECTIVES

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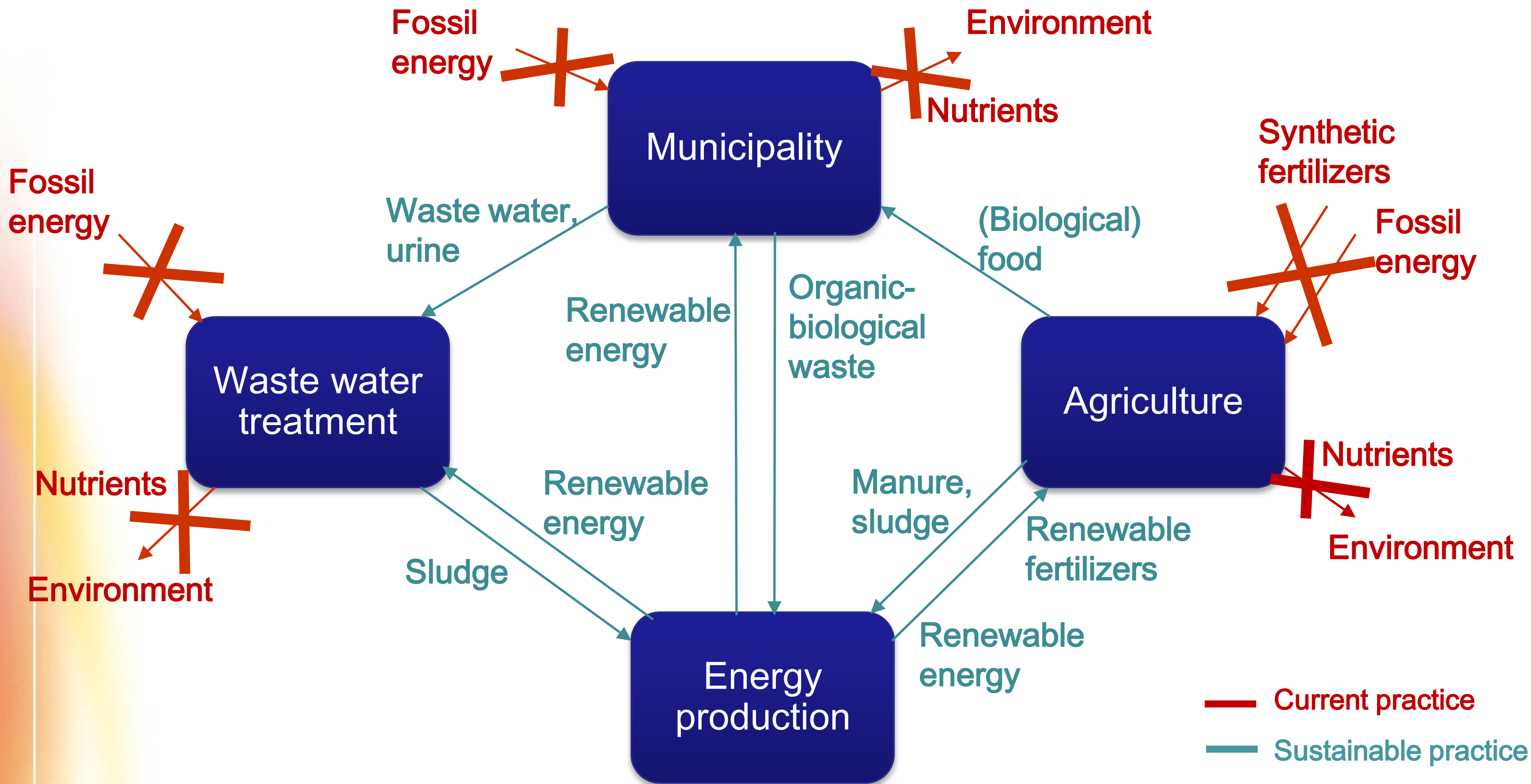
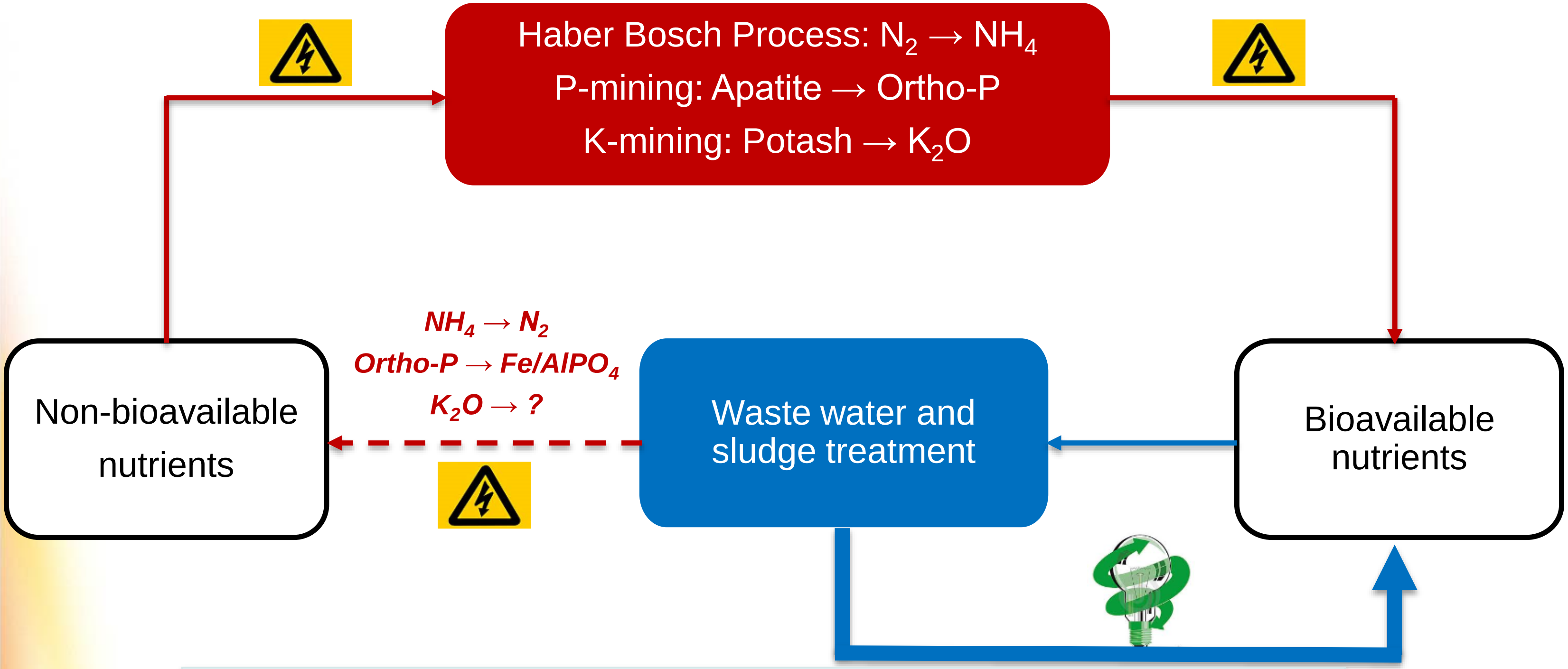
Global objectives



Specific objectives



Waste Water Treatment Plant (WWTP)
→ Water Resource Recovery Facility (WRRF)

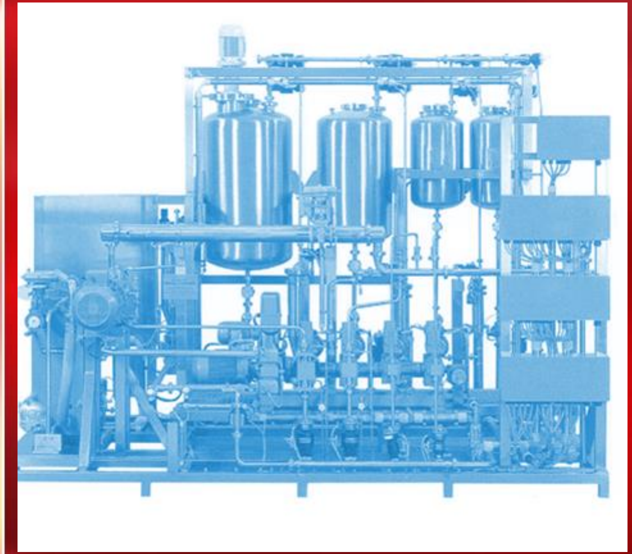
Points of attention

- The nutrient recovery process must have equivalent treatment efficiency as conventional treatment
- The process must be cost-effective
- The process must be simple to operate and maintain
- <u>There must be a market for the recovered nutrient products</u>

Status in Québec

- ± one million tonnes of fertilizer residuals are used annually on agricultural soils
- 'Plan agro-environnemental de valorisation' (PAEV)
  - MDDEP promotes the valorisation of reusable resources, such as nutrients, organic matter and energy from municipal biosolids and sludges
  - Valorisation must rely on good management practices:
    - Strategies to reduce the risks for the environment and human health to a minimum
    - Strategies to reduce greenhouse gas emissions to a minimum
    - <u>Take in account the effectiviness and value of the resources (product efficiency)</u>

NUTRIENT RECOVERY TECHNIQUES (NRT)



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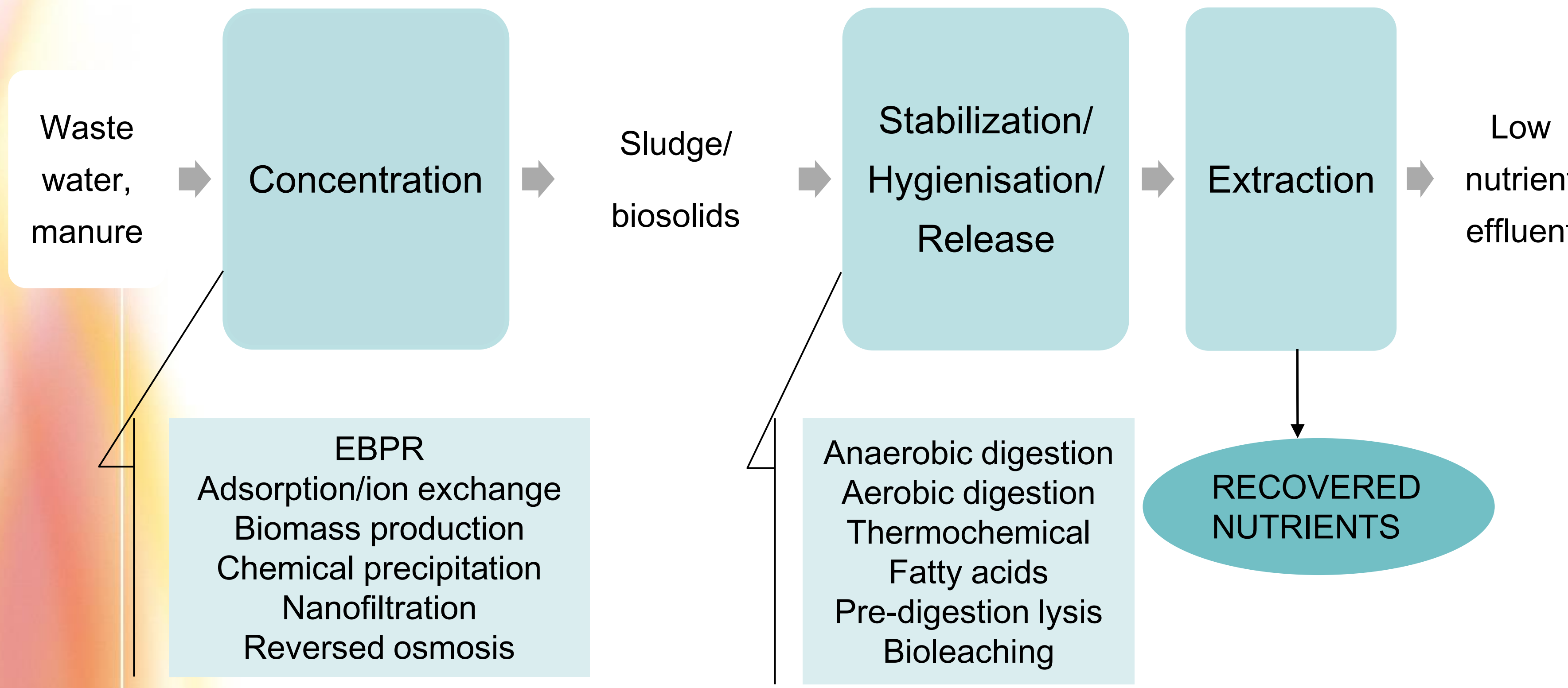
Three step framework

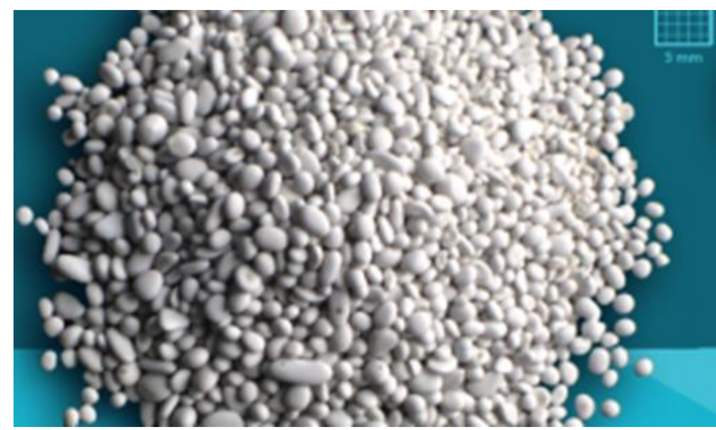


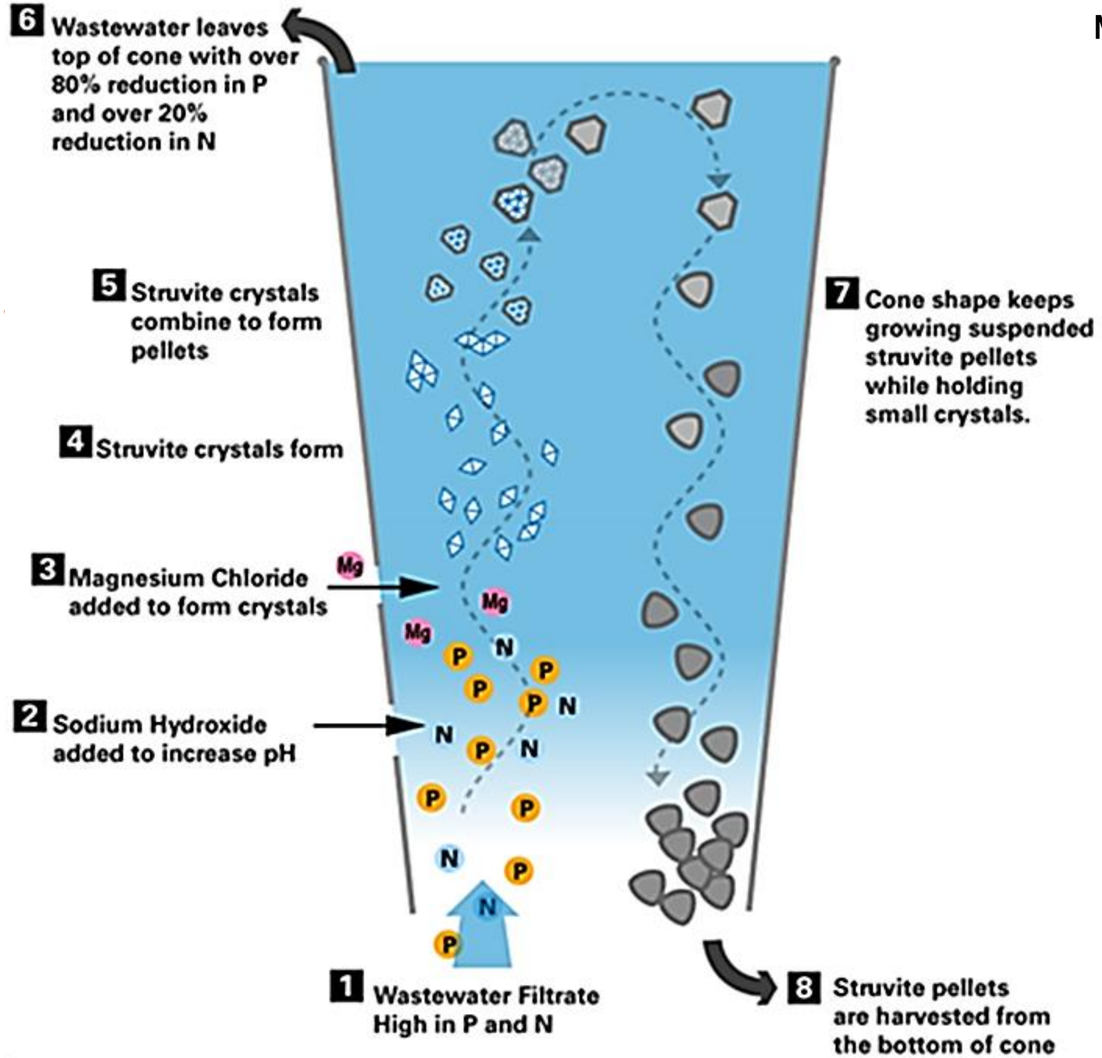
Extraction of nutrients after anaerobic digestion

Digestate
Evaporation
Thermal drying
Mechanical separation (with or without polymer addition)
Solid fraction
Liquid fraction
Composting
Thermal drying
NRT 3 : Acid air scrubber
NRT 1: P crystallization
NRT 2: NH_3 stripping
Air
Air + NH_3
NRT 4: Membrane filtration
Forward osmosis
Elektrodialysis
Transmembrane-chemosorption
NRT 5: Biomass production and harvest

NRT1: P crystallization

- Soluble P (ortho-phosphate) can be precipitated by:
  - Ca^{2+} → $Ca_3(PO_4)_2$
  - Mg^{2+} → $MgNH_4PO_4.6H_2O$ or $MgKPO_4.6H_2O$ (MAP of struvite)
  - K^+ → $K_2NH_4PO_4$ (potassium-struvite)
- Status: Full-scale for waste water, digested centrate and calf manure; Pilot scale for raw digestate
- Valorisation end-product: Slow release fertilizer
- Economic viability
  - Slow release fertilizer
  - Elimination of Fe/Al





Design: Fluidized bed reactor or continuously stirred tank reactor

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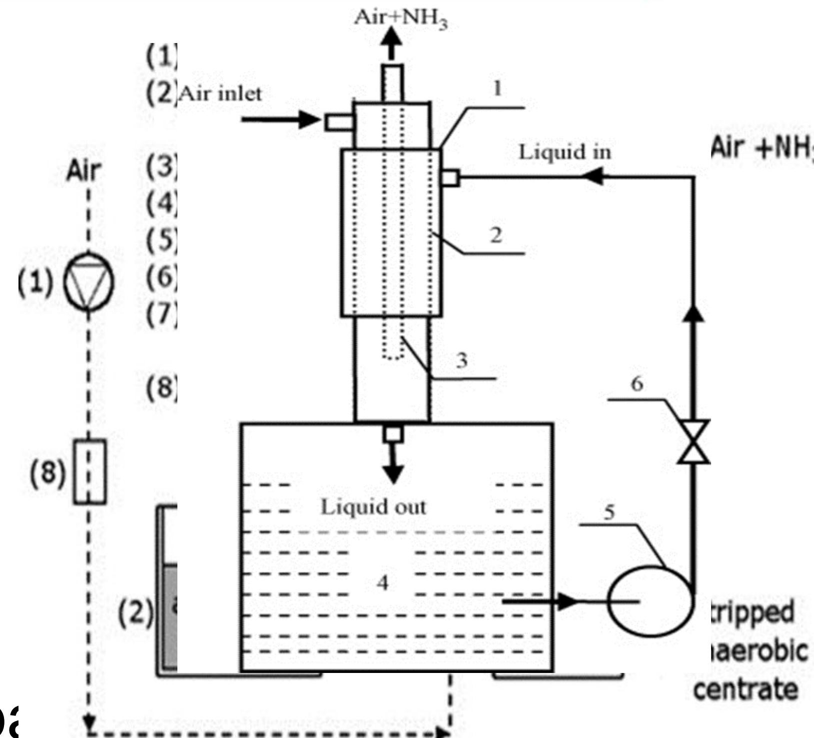
NRT2: NH_3-stripping and absorption

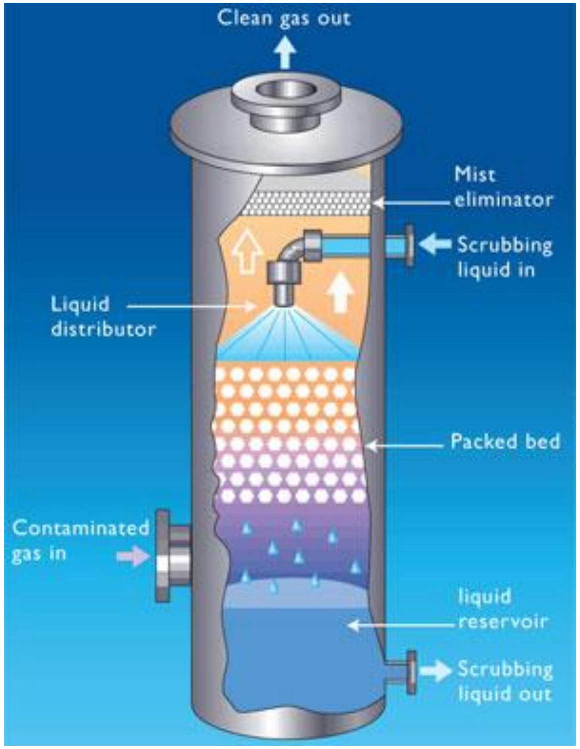
- Mass transfer of NH_3 from aqueous to gas phase
  - Elevated pH & T
  - Lime softening step
- Design: Packed column
  - Status: Full-scale
  - Bottlenecks: Fouling of the packing material
- Improved design: Water-spa
  - Status: Lab-scale (Quan et al. 2010)
  - Higher air stripping efficiency, better mass transfer



Gustin and Marinsek-Logar (2011)

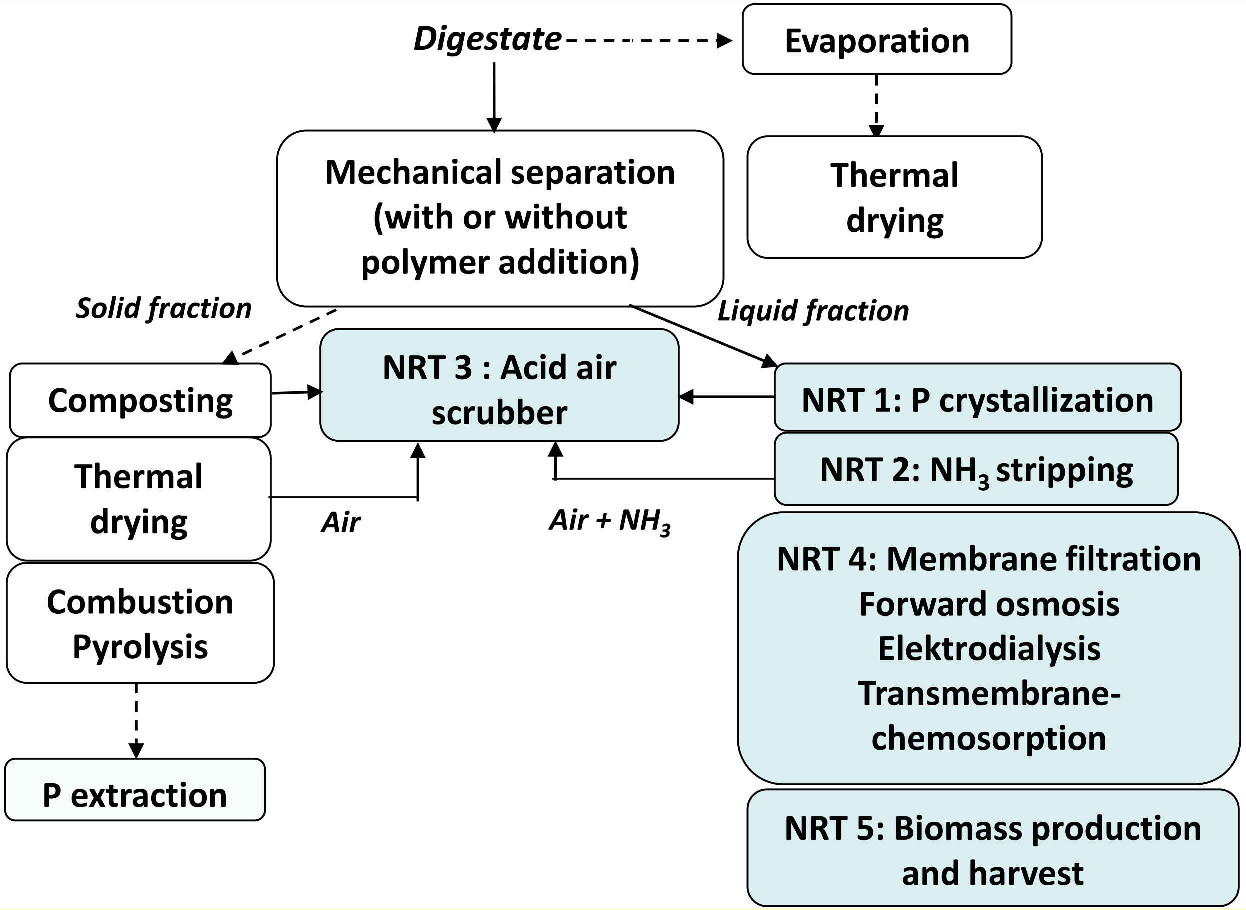
NRT3: Acidic air scrubber

- Capture of NH_3, dust particles, water vapour, odour compounds in acid, mostly H_2SO_4
  - $NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$
- Design: Packed bed reactor or venturi scrubber
  - Botlleneck: Corrosion problems
- Status: Full-scale
- Valorisation end-product
  - Sulphur content (30-40 kg m^{-3}) !
  - Variable N-content (30-70 kg m^{-3})
  - Low pH (3-7), high salt content



http://www.croll.com/wetscrubbers.html

Extraction of nutrients after anaerobic digestion

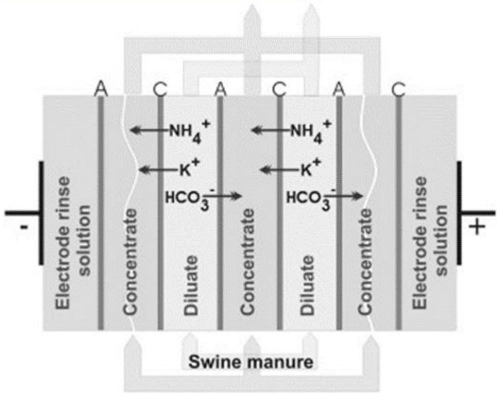


NRT4: Membrane filtration

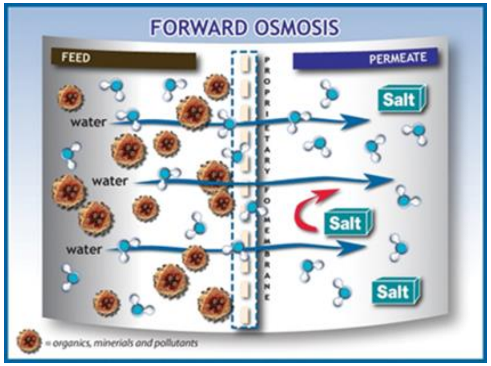
- Types: RO, UF, MF
- Valorisation end-product: N/K fertilizer (RO)
  - Variable N (2-10 g kg^{-1}) and K_2O (4-14 g kg^{-1}) content
  - High salt content
- Status: Full-scale for digestate and manure
- Bottleneck: Blocking of membranes (SS, salts, …)
- Economic viability
  - High chemical requirements
  - High energy use
  - High operational costs

Emerging membrane techniques

- Electrodialysis
  - Ion exchange membrane + electrical voltage
  - Transfer of NH_4^+, K^+ en HCO_3^-
  - Status: No full-scale for digestate, tests on lab-scale



- Transmembrane chemosorption
  - Diffusion of NH_3 through membrane & capture in H_2SO_4
  - Status: Pilot in NL (pig slurry)
- Forward osmosis
  - Use of draw solution instead of pressure (RO)
  - Status: Full-scale for sea water, food waste; no testing (?) with digestate



NRT5: Biomass production

- Removal of P&N by plant uptake (algae, duckweed)
- Status: Lab tests (algae) + pilots
- Bottlenecks
  - Suspended solids, humic acids,...
    → reduction of light penetration
  - Large surface required
  - High energy consumption and high costs
  - Harvest method
- Valorisation harvested biomass
  - Bio-based chemicals or fertilizer
  - Biofuels
  - Animal feed

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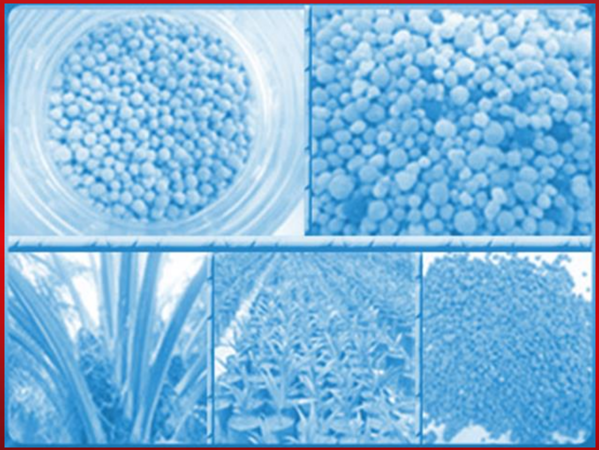
DISCUSSION



Comparison of techniques and end-products

Technique	P-crystallisation	NH_3- stripping & air scrubbing	Membrane filtration	Biomass production
% recovery	80-90% P 0-40% N	> 90 % N	Depends on pretreatment	80-90 % N and P
End-products	Struvite or Ca-P crystals = Slow-release fertilizer	$(NH_4)_2SO_4$ solution = N-S fertilizer	NK-fertilizer (RO)	Biomass: Duckweed (30% P on DW)
Main technical bottlenecks	➢ Precipitation in piping/equipment	➢ Fouling / corrosion	➢ Membrane blocking	➢ Harvest method ➢ Reduced light penetration
Ecological evaluation	➢ Chemical use ➢ Fe/Al ↓	➢ Odor ↓ ➢ Energy ↑ ➢ Acid ↑ ➢ Can replace N-D	➢ Chemicals ↑ ➢ Energy ↑	➢ Surface ↑ ➢ Energy ↑ ➢ Use of polymers
Economical evaluation	Can be profitable	➢ Can replace N-D ➢ Interest in S ↑	High capital and operational costs	High costs (algae)

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CONCLUSIONS AND PERSPECTIVES

Conclusions

- Best available techniques for nutrient recovery:
  - Struvite precipitation
  - NH_3-stripping and absorption in acidic air scrubber
- Further technical fine tuning
  - Fertilizer quality
  - Energy and chemical reduction
- Further developments will only take place if recovery is profitable

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Perspectives

- model*EAU* / Primodal
  Dynamic modeling of physico-chemical nutrient recovery systems for wastewater and sludge streams to sustainably produce marketable fertilizers with high nutrient use efficiency (BMP Innovation doctorat, NSERC/FRQNT)

THANK YOU FOR THE ATTENTION

QUESTIONS?

Further reading:
Inventory Techniques for nutrient recovery from digestate
http://arbornwe.eu/downloads