Nutrient Recovery as a Sustainable Biosolids Management Strategy

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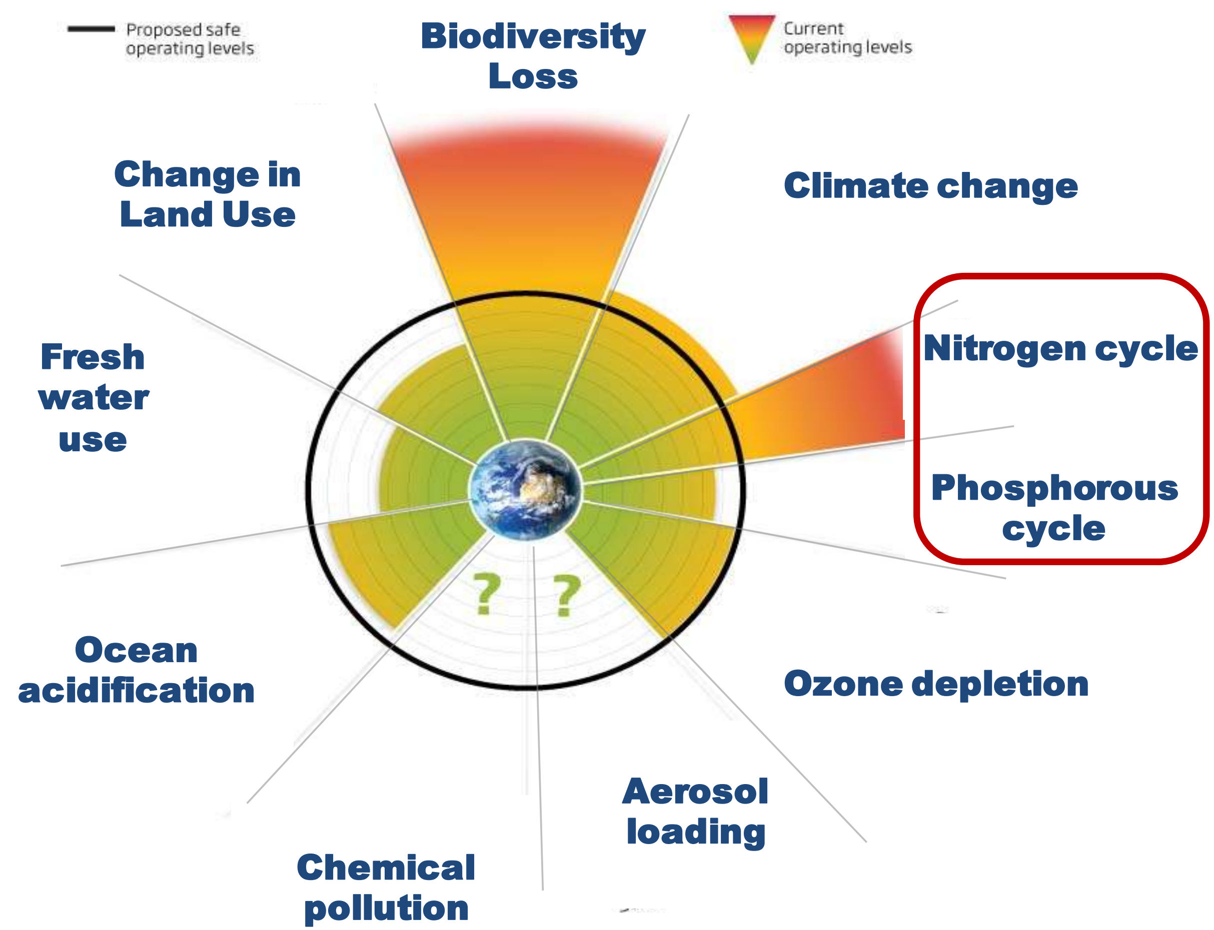
Presentation Outline

- Nutrients and the Environment
- Resource Recovery for Management of Nutrients in WWTPs
  - Recovery from sidestreams
  - Recovery from biosolids/ash
- Future Directions

Nutrient planetary boundaries are being exceeded due to increased anthropogenic inputs

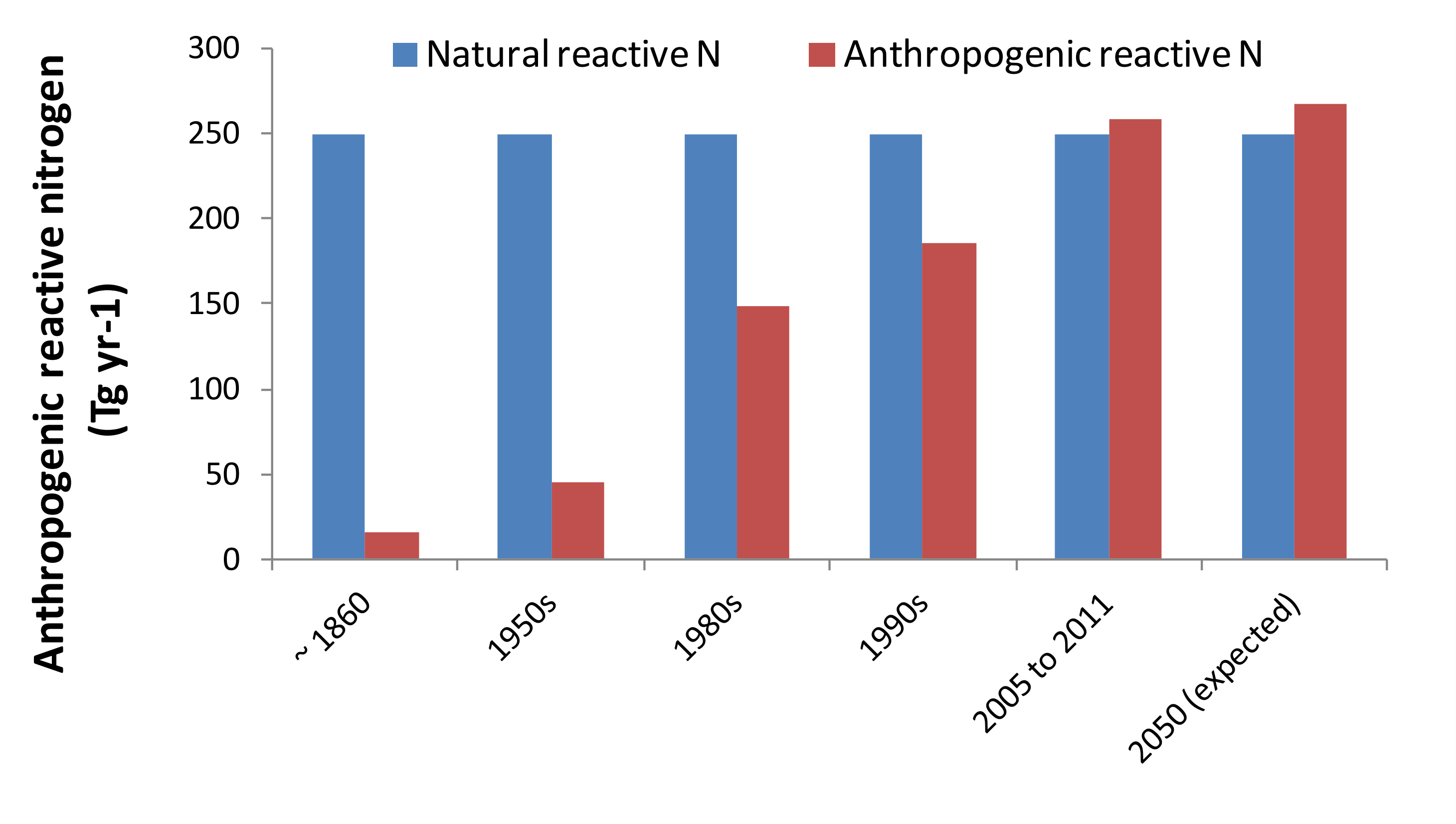
Adapted from Rockstrom, J., et al. (2009), Nature 461 (7263), 472-5
Adapted from Penuelas, J., et al. (2012), Global Change Biology 18, 3-6



Human activities have doubled the amount of N in the environment

Adapted from Rockstrom, J., et al. (2009), Nature 461 (7263), 472-5
Adapted from Penuelas, J., et al. (2012), Global Change Biology 18, 3-6

Tg = 10^{12} grams



~50% of anthropogenic N due to high rate farming applications

Human activities are responsible for a 10-fold increase in P input to the environment

Adapted from Rockstrom, J., et al. (2009), Nature 461 (7263), 472-5
Adapted from Penuelas, J., et al. (2012), Global Change Biology 18, 3-6

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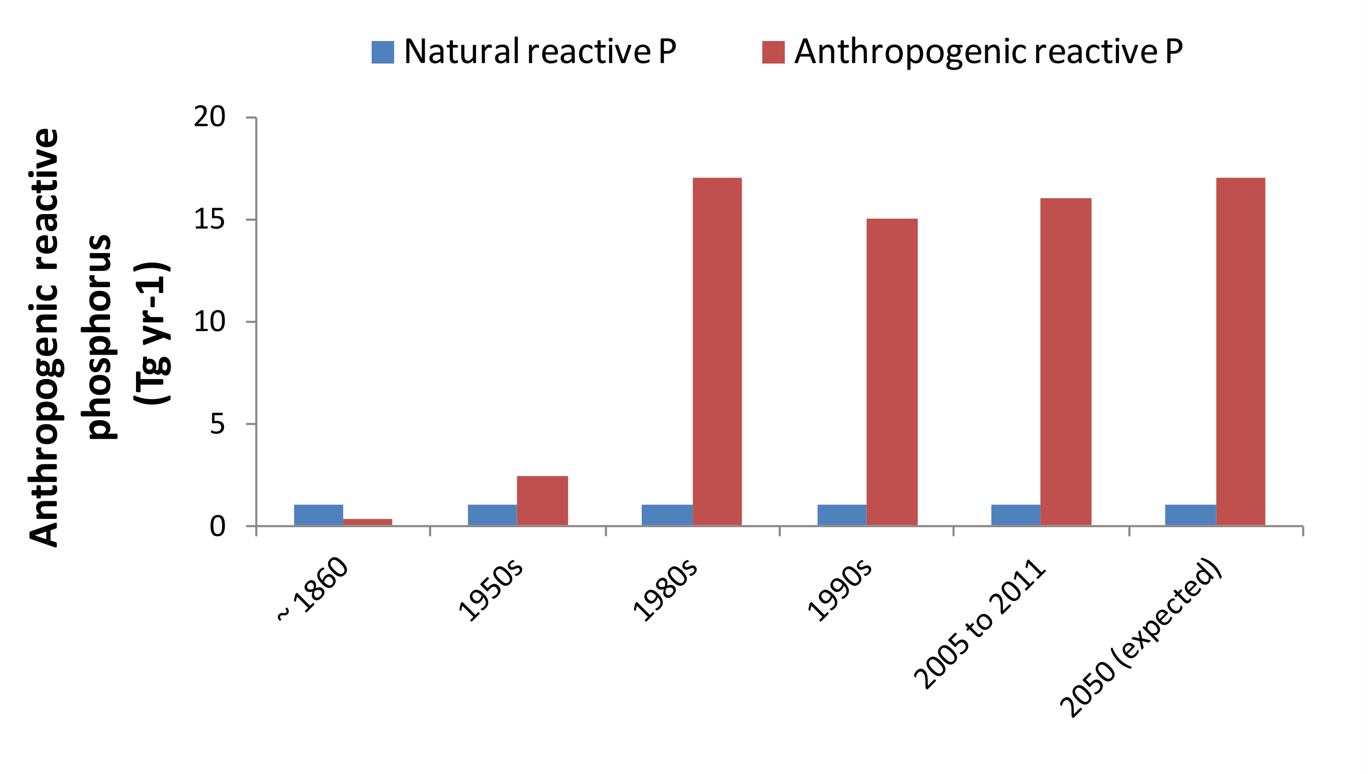
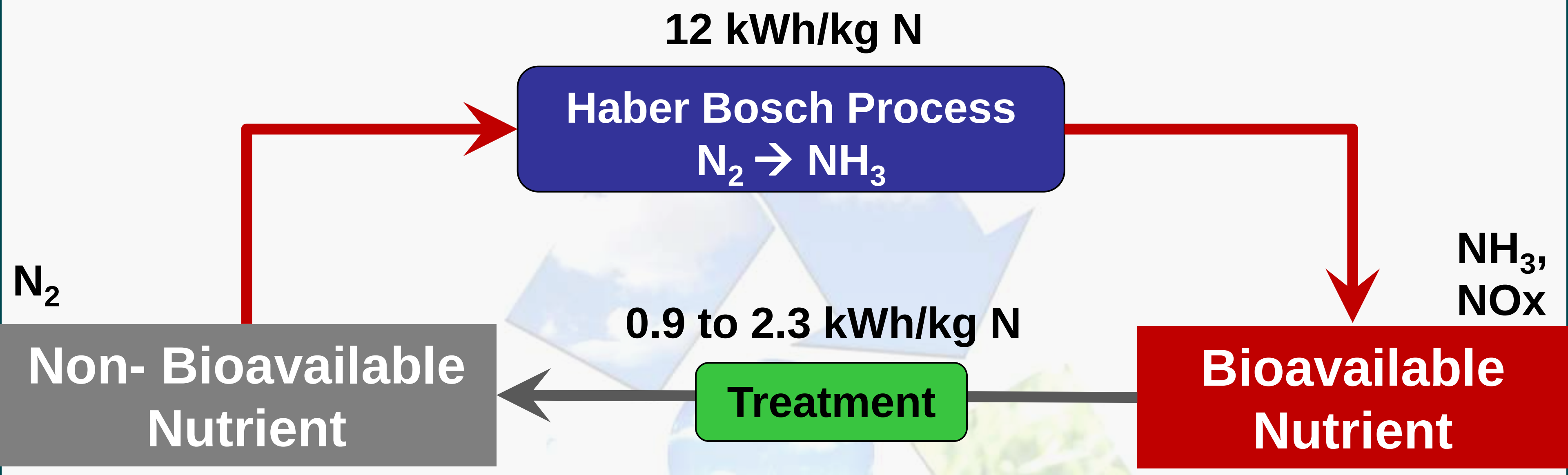


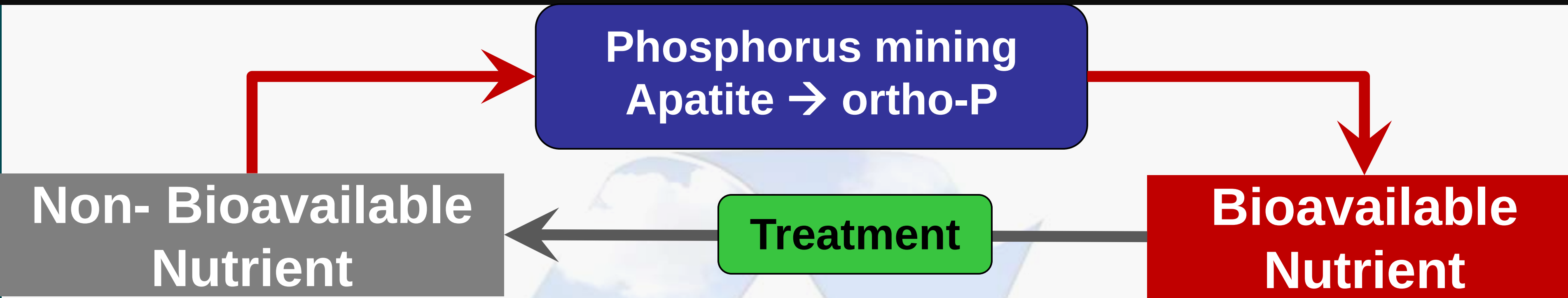
~50% of the anthropogenic P is lost to the environment

Nutrient usage cycle currently assumes an unlimited supply of resources and energy

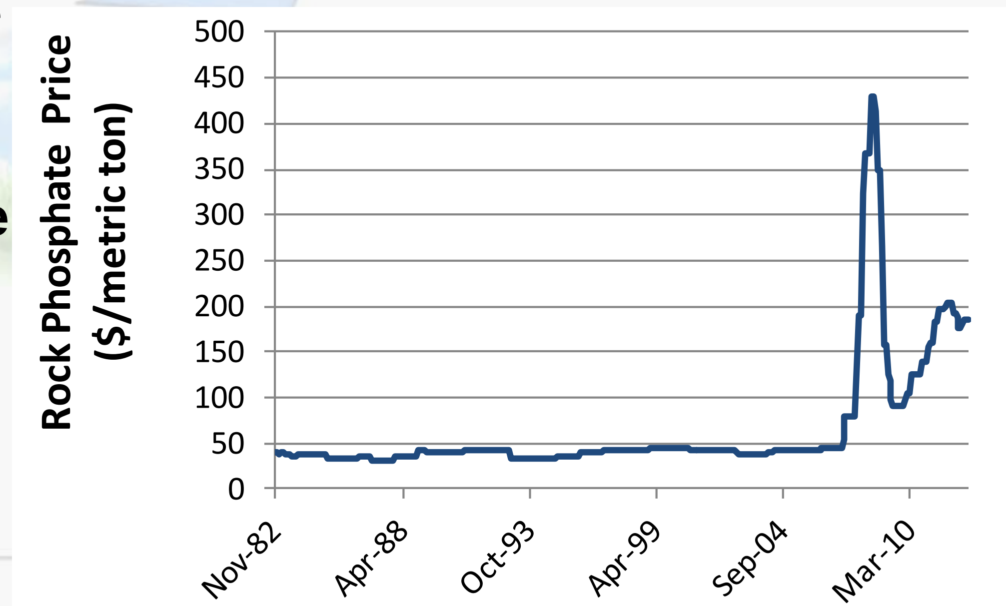


- Nitrogen gas is a renewable resource but is not readily available for plant growth
- Energy required to convert from non-reactive to reactive
- Energy also required to convert from reactive to non-reactive
- Energy required for engineered N cycle 12.9 to 14.3 kWh/kg N

Nutrient usage cycle currently assumes an unlimited supply of resources and energy



- **Phosphorus is a NON-renewable resource**
- **90% of easily minable rock phosphate reserves found in five countries**
  - **Morocco, Iraq, China, Algeria and Syria**



- **Phosphorus resources are declining both in quality and accessibility**

Nutrient treatment /removal focuses on removing nutrients from liquid streams

Traditional paradigm of wastewater treatment

Energy, chemicals

Wastewater → **Recovered Water**

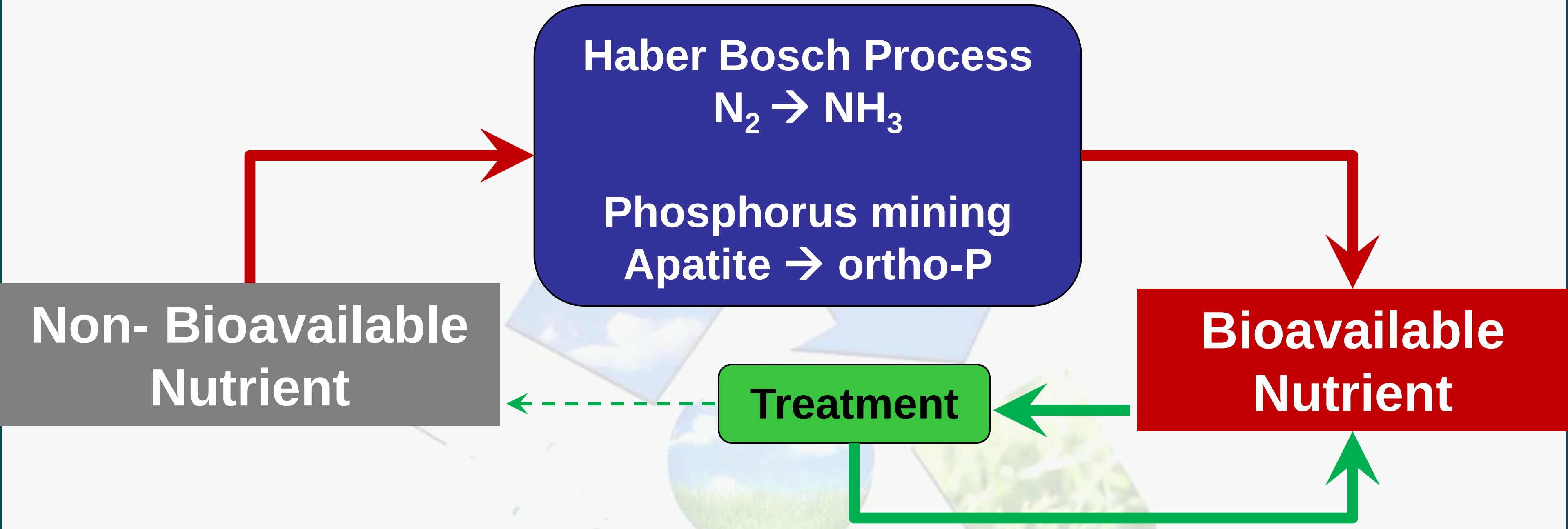
A new paradigm of recovery has emerged

Recovery of energy and value added products from wastewater

Energy, nutrients, organics, metals

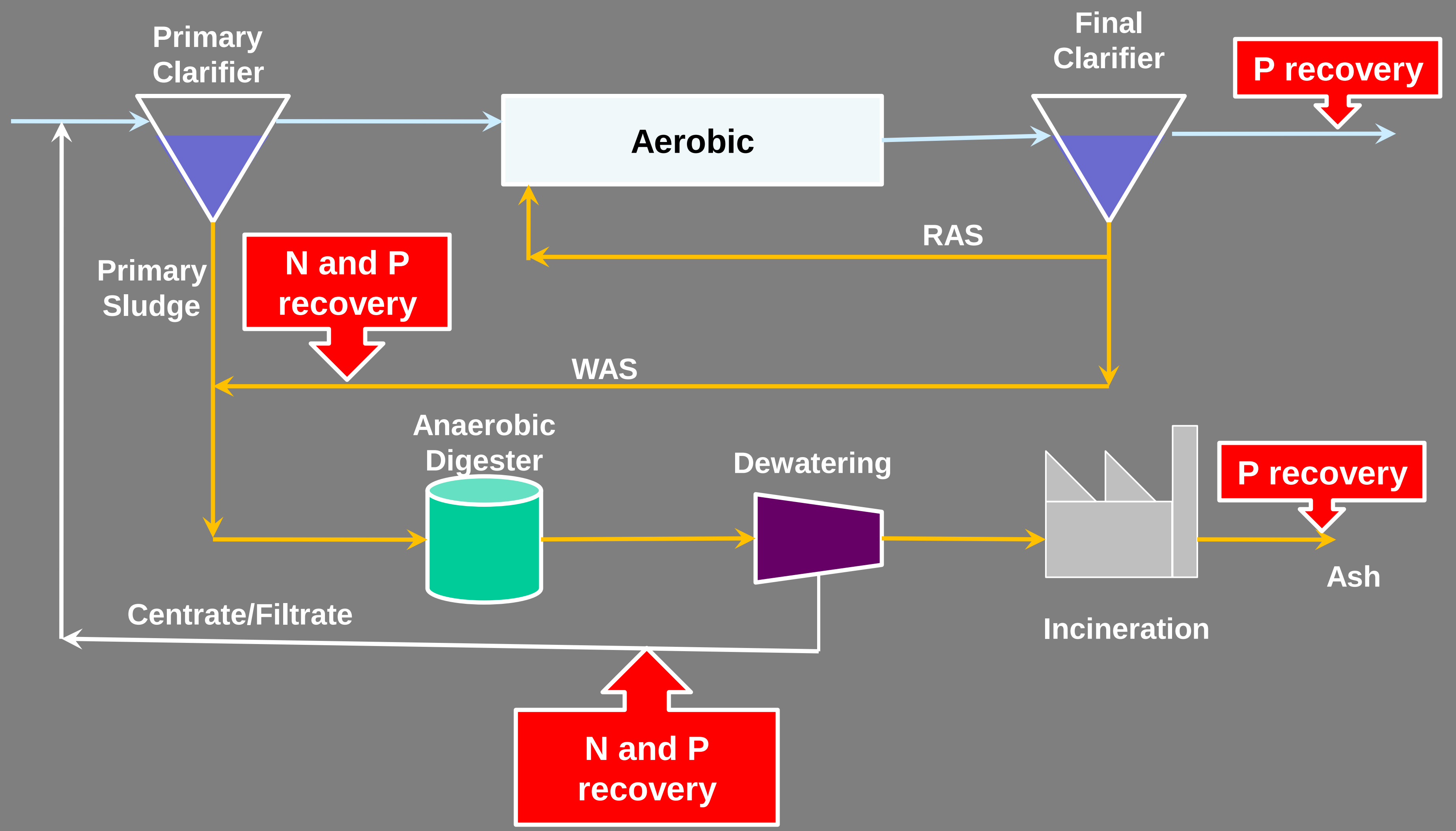
Wastewater → **Recovered Water**

Nutrient recovery facilitates the recycling of reactive nutrients



- **For nutrient recovery to be a viable option,**
  - **The process must have equivalent treatment efficiency as conventional treatment**
  - **The process must be cost-effective**
  - **The process must be simple to operate and maintain**
  - **There must be a market for the recovered nutrient product(s)**

How do we enable nutrient recovery in WWTPs?



Effective nutrient recovery requires a three component approach

- Accumulation step to increase N content > 1000 mg N/L and P content > 100 mg P/L
- Release step to generate low flow and high nutrient stream
- Recovery step produces high nutrient content product

Effective nutrient recovery from municipal wastes requires a three component approach

Accumulation → **Release** → **Recovery**

Accumulation
- Enhanced biological phosphorus removal (EBPR)
- Algae
- Purple non-sulfur bacteria
- Membrane filtration
- Adsorption/Ion exchange
- Solvent extraction

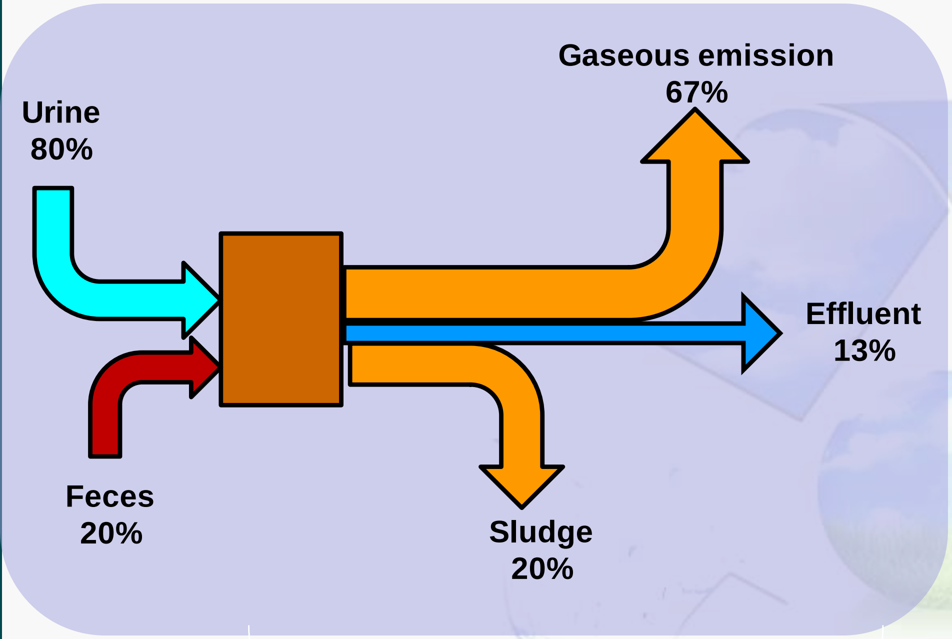
Release
- Anaerobic digestion
- Thermolysis
- WAS release
- Sonication
- Microwave
- Chemical extraction

Recovery
- Chemical precipitation
- Electrodialysis
- Gas permeable membrane and absorption
- Gas stripping
- Solvent extraction

- Numerous options to chose from
- Not all systems require all three components

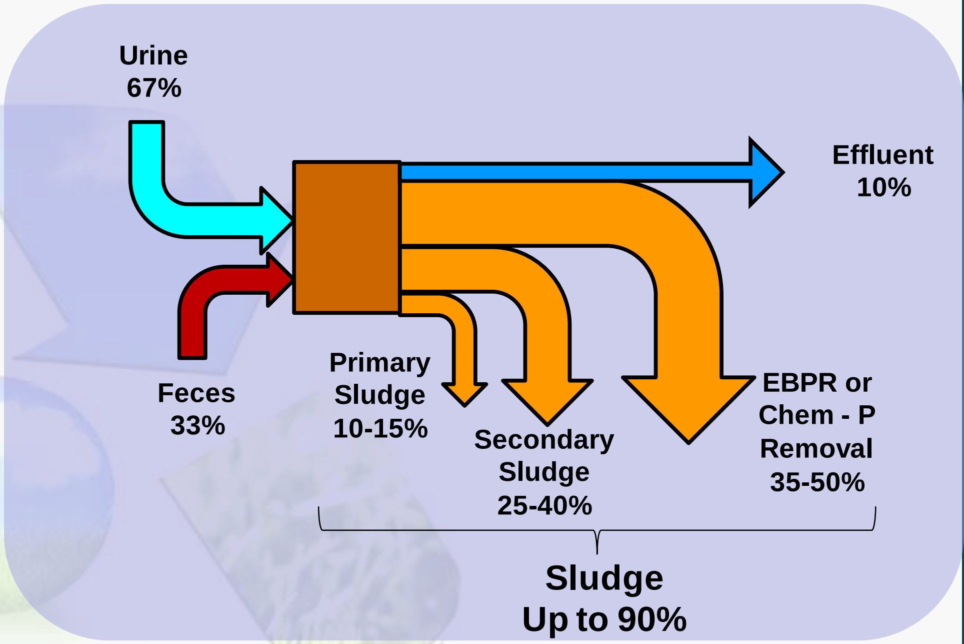
WWT Ps accumulate nutrients into the solids treatment process

N mass balance in WWTP



From Phillips *et al.*, (2011) and Jonsson et al., (2006)

P mass balance in WWTP



From Cornel *et al.* (2009)

- **The solids treatment process dictates the nutrient content of the biosolids produced**

Solids treatment via digestion can act as the release mechanism

1^0 Treatment

2^0 Treatment

Description	Percent of Total Influent Nitrogen Load	Percent of Total Influent Phosphorus Load
Nansemond, Suffolk, VA Centrate	13%	29%
Bowery Bay, NYC Centrate	17%	*
Henrico County, VA Centrate	15%	*
High Point Eastside, NC Fermenter	*	50%
Wards Island, NYC Centrate	30-40%	*
North Durham, NC Centrate	19%	30%
South Durham, NC Centrate	21%	25%

Nutrient recovery step produces a high nutrient content product

Accumulation → **Release** → **Recovery**

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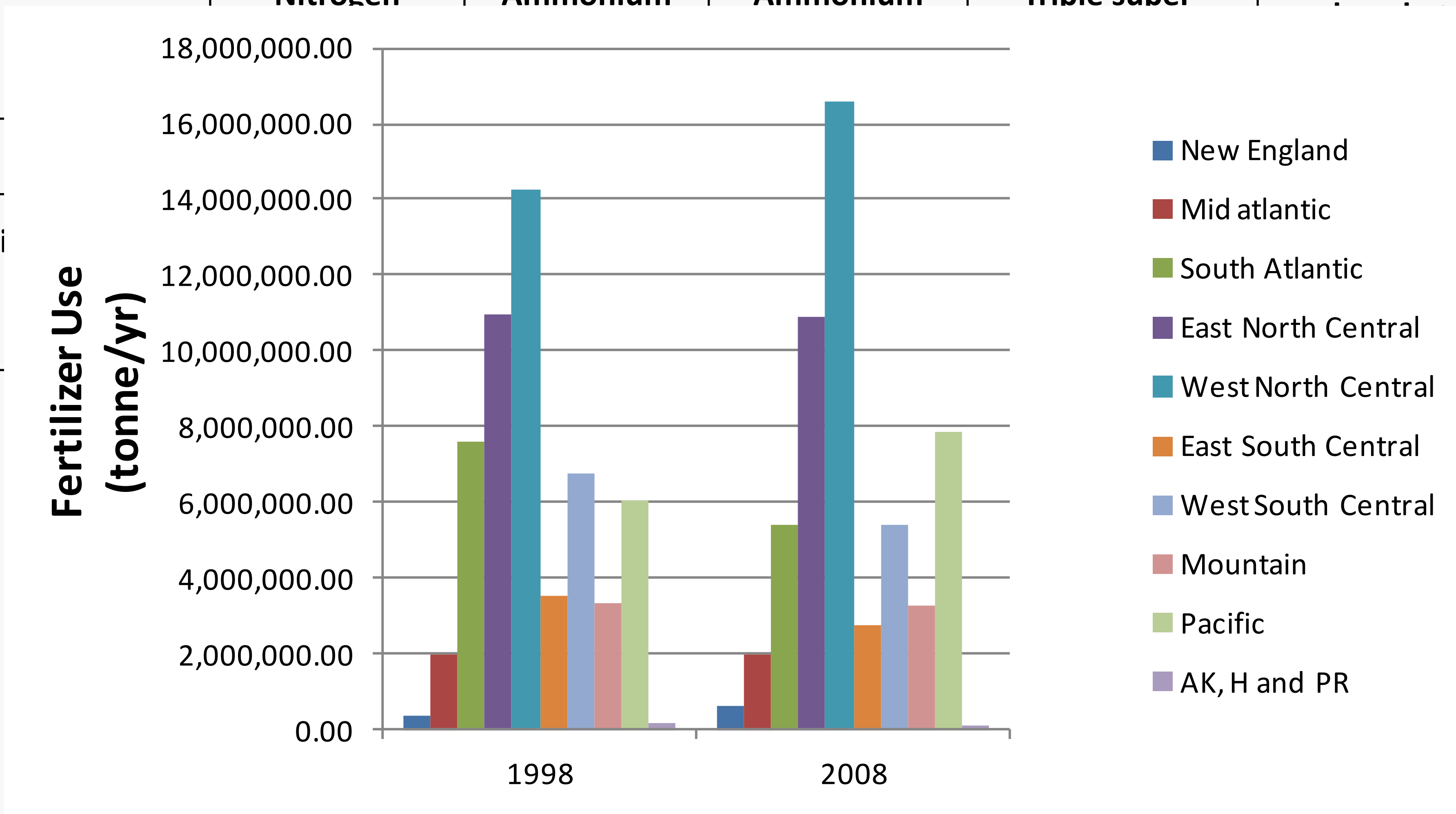
Recovered product must:

1. Have consistent nutrient composition and uniform distribution
2. Have no/minimal odors
3. Have no/minimal pathogen content
4. Have appreciable market value
5. Have desirable physical characteristics

Market analyses has indicated that P products have a higher value than N products

	Nitrogen	Ammonium	Ammonium	Triple super-	Diammonium
					%
Pri					



The nutrient recovery step is based on chemical precipitation/concentration steps

Accumulation → **Release** → **Recovery**

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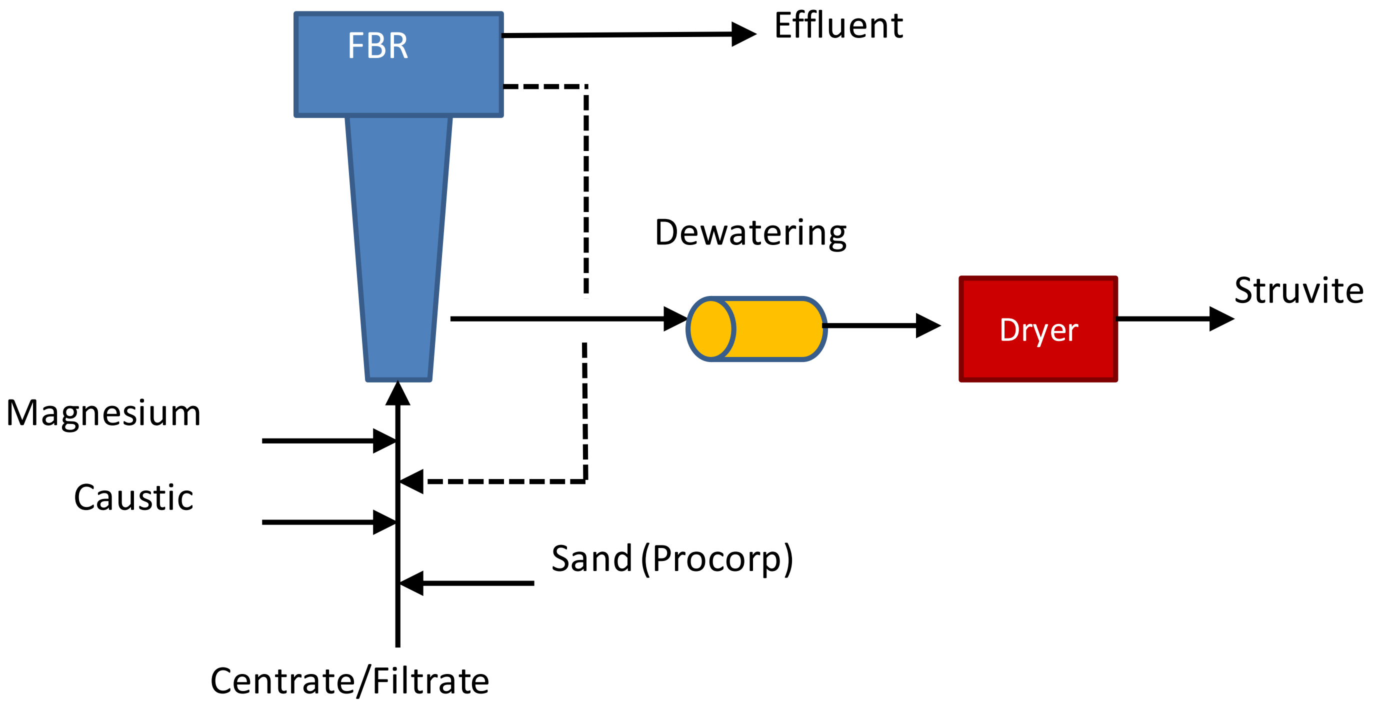
Struvite is often the recovery product of necessity

- Struvite = Mg + NH_4 + PO_4
  - NH_4 & PO_4 released in digestion
  - Typically Mg limited
  - Mg addition for odor control (i.e. $Mg(OH)_2$) can promote struvite formation

NYC Newtown Creek WPCP

Miami Dade SDWRF

Intentional struvite recovery exploits pH dependent chemical precipitation phenomena



N:P ratio in filtrate ~ 2.4-2.6, ammonia in excess

N:P ratio in struvite = 0.45 lbs N required per lb P removed

- **Fluidized bed reactor or CSTR used for struvite recovery**

There are several commercial options for struvite recovery

Name of Technology	Ostara Pearl®	Multiform Harvest struvite technology	NuReSys	Phospaq	Crystalactor®
Type of reactor	upflow fluidized bed	upflow fluidized bed	CSTR	CSTR with diffused air	upflow fluidized bed

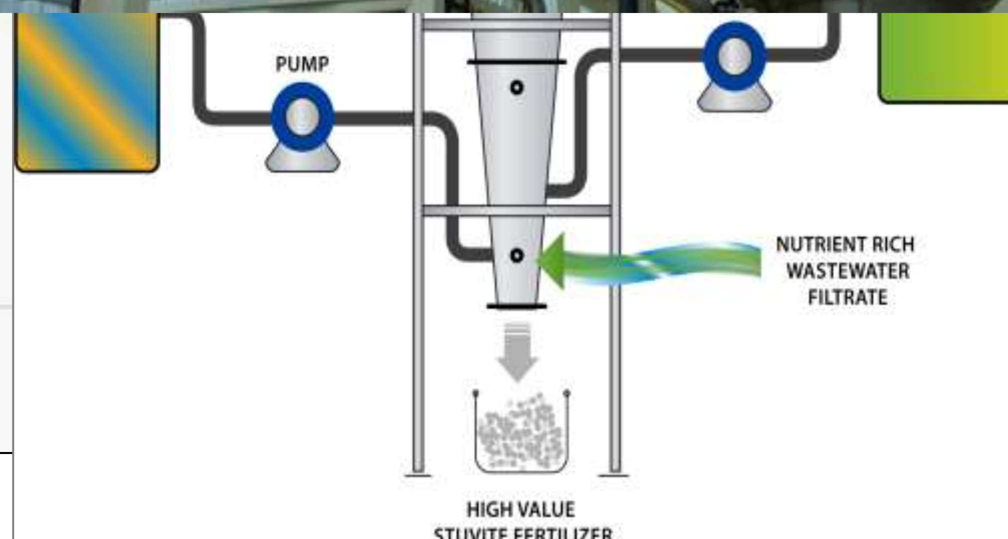
Ostara Pearl™ process markets and sells finished product as Crystal Green fertilizer

- 8 full-scale facilities in operation
  - Durham AWTP OR,
  - Gold Bar WWTP Canada,
  - Nansemond WWTP VA,
  - York WWTP PA,
  - Rock Creek WWTP OR,
  - Nine Springs WWTP WI,
  - HM Weir WWTP Canada,
  - Slough STW, United Kingdom
- 27 pilot facilities
  - US, Europe, Mid-East, China, UK
- Resale of products facilitated by Ostara

Multiform Harvest also recovers struvite from sidestreams

- Lower Capital Cost
  - Smaller footprint, smaller reactors
- Less refined product
  - Blended and refined in secondary markets
- 2 full scale municipal installations
  - Yakima WWTF
  - West Boise WWTF
  - 2 pilots facilities (US)
- Resale of products facilitated by MFH

Images courtesy MFH



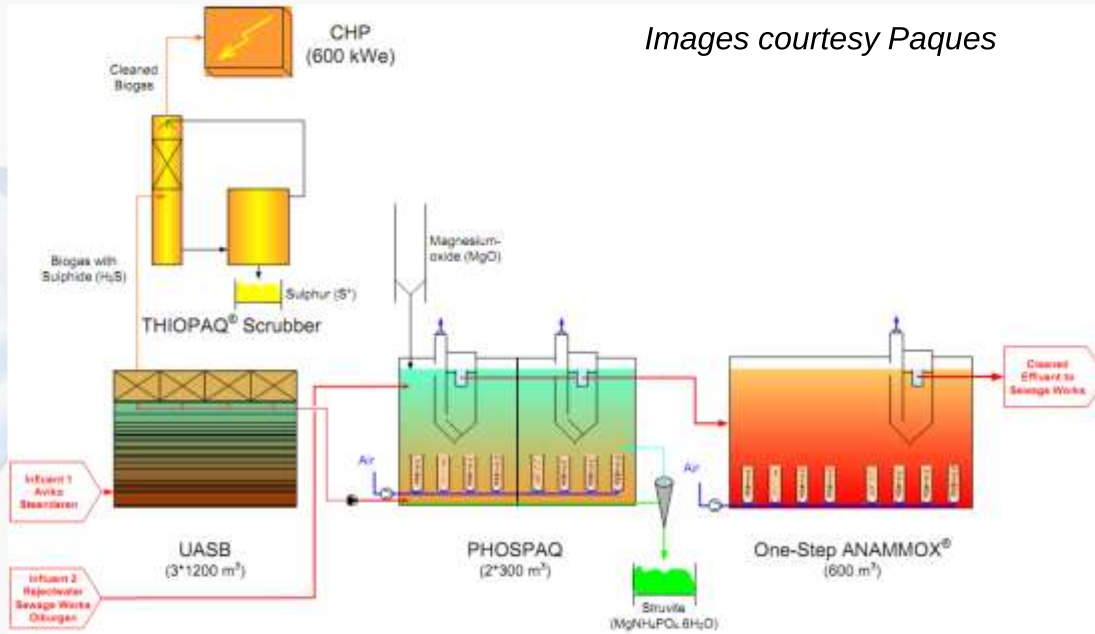
DHV Crystalator® technology is licensed for use in the US by Procorp

- **DHV Crystalator®**
  - **Also used for water softening, metal recovery**
  - **30 facilities worldwide**
- **4 full-scale in the US at industrial plants**
  - **Alto Dairy WI,**
  - **Meat processing WWTP OH,**
  - **Dairy WWTP OH,**
  - **Solid waste digester FL**
  - **4 pilot installations (US, China)**
  - **Resale of products facilitated by 3rd party through Procorp**

Images courtesy Procorp/DHV

Paques Phosphaq™ uses CSTR configuration for struvite recovery

- **3 installations in the Netherlands**
  - **Olburgen STW**
  - **AVIKO Lomm* (Potato processing)**
  - **AVIKO Steenderen (Potato processing)**
- **Can be used in combination with ANAMMOX™ option**
- **Resale of products facilitated by third party through Paques**



Images courtesy Paques

NuReSys also uses CSTR configuration for struvite recovery

- 7 full-scale installations focused on industrial applications
  - 4 potato processing plants (Belgium)
  - 1 Dairy processing plant (Germany)
  - 1 Pharmaceutical industry (Belgium)
  - 1 Municipal plant (Belgium)
  - 2 pilot installations (Belgium
- Uses completely stirred reactor (CSTR) configuration

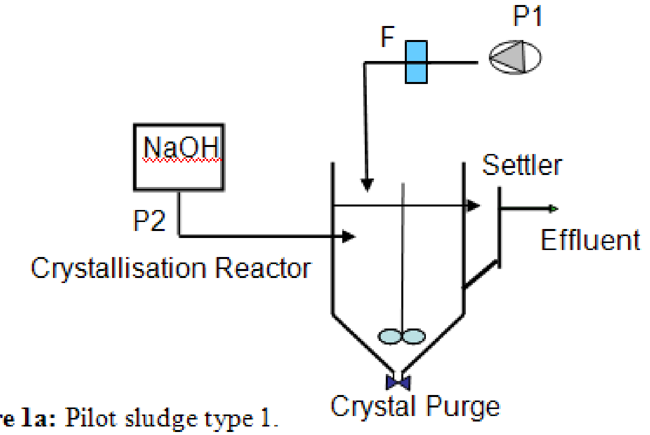


Figure 1a: Pilot sludge type 1.

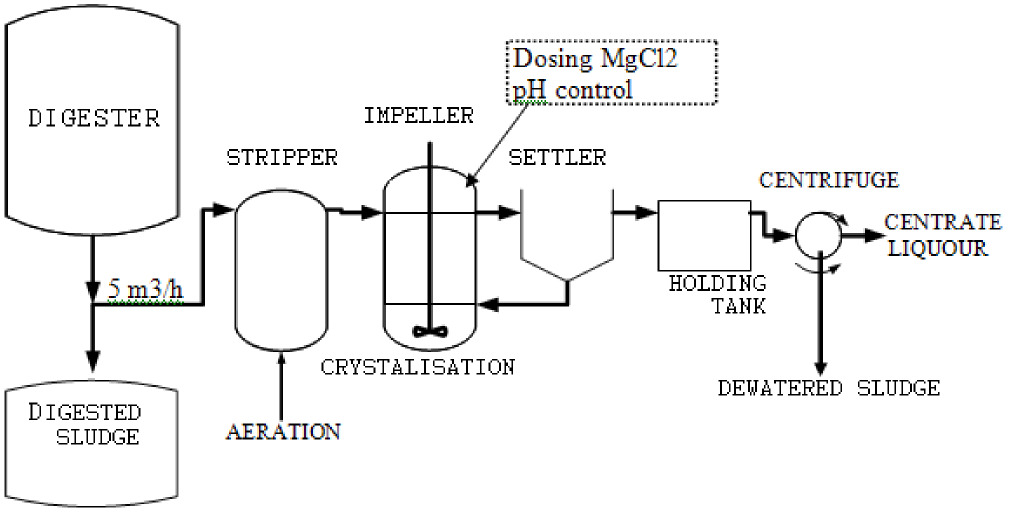


Figure 1b: Pilot sludge type 2

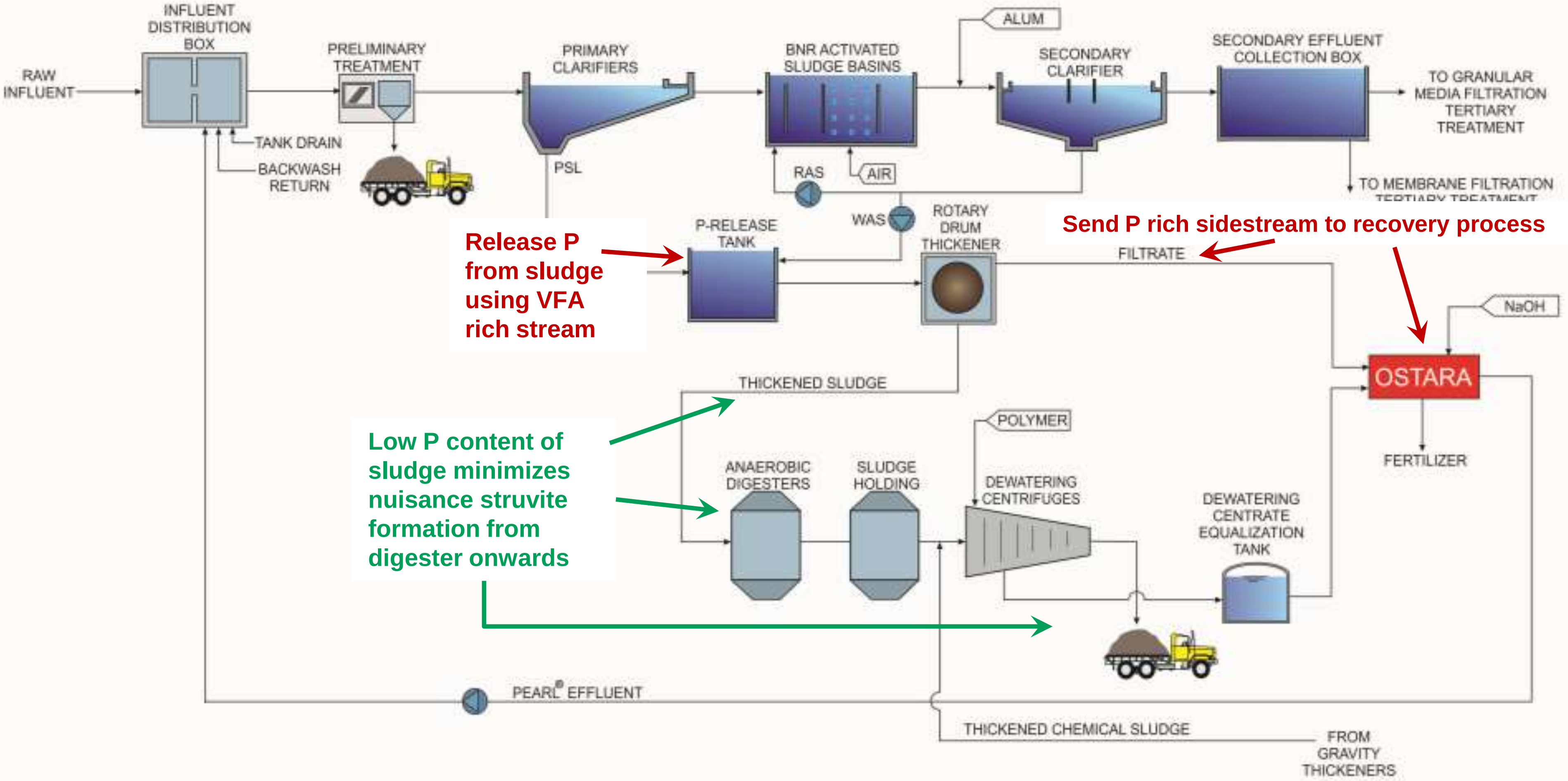
Images courtesy NuReSys bvba

There are several commercial options for struvite recovery

Name of Technology	Ostara Pearl®	Multiform Harvest struvite technology	NuReSys	Phospaq	Crystalactor®
Type of reactor	upflow fluidized bed	upflow fluidized bed	CSTR	CSTR with diffused air	upflow fluidized bed
Name of product recovered	Crystal Green ®	struvite fertilizer	BioStru®	struvite fertilizer	Struvite, Calcium-phosphate, Magnesium-phosphate
% Efficiency of recovery/ treatment (range)	80-90% P 10-50% N	80-90% P	45% P	80% P	85-95% P for struvite > 90% P for calcium phosphate
Product marketing/resale	Ostara	Multiform Harvest	N/A	N/A	Third party facilitated by Procorp

P release prior to anaerobic digestion can further minimize nuisance struvite formation





Nutrient recovery via struvite is a mature technology

- **Struvite recovery can:**
  - **Reduce energy and chemical consumption**
  - **Minimize nuisance struvite formation and reduce O&M costs**
  - **Control the nutrient content of the biosolids**
- **Struvite recovery can be economical when sidestreams contribute:**
  - **≥15% of the influent TN load**
  - **≥20% P load**
- **Several commercial technology providers with proven track record**
  - **Recovered struvite is marketed as a slow release fertilizer**
  - **Technology providers have different business models for this purpose**

The nutrient recovery step is based on chemical precipitation/concentration steps

Accumulation → **Release** → **Recovery**

Accumulation
- EBPR
- Algae
- Purple non-sulfur bacteria
- Membrane filtration
- Adsorption/Ion exchange
- Solvent extraction

Release
- Anaerobic digestion
- Thermolysis
- WAS release
- Sonication
- Microwave
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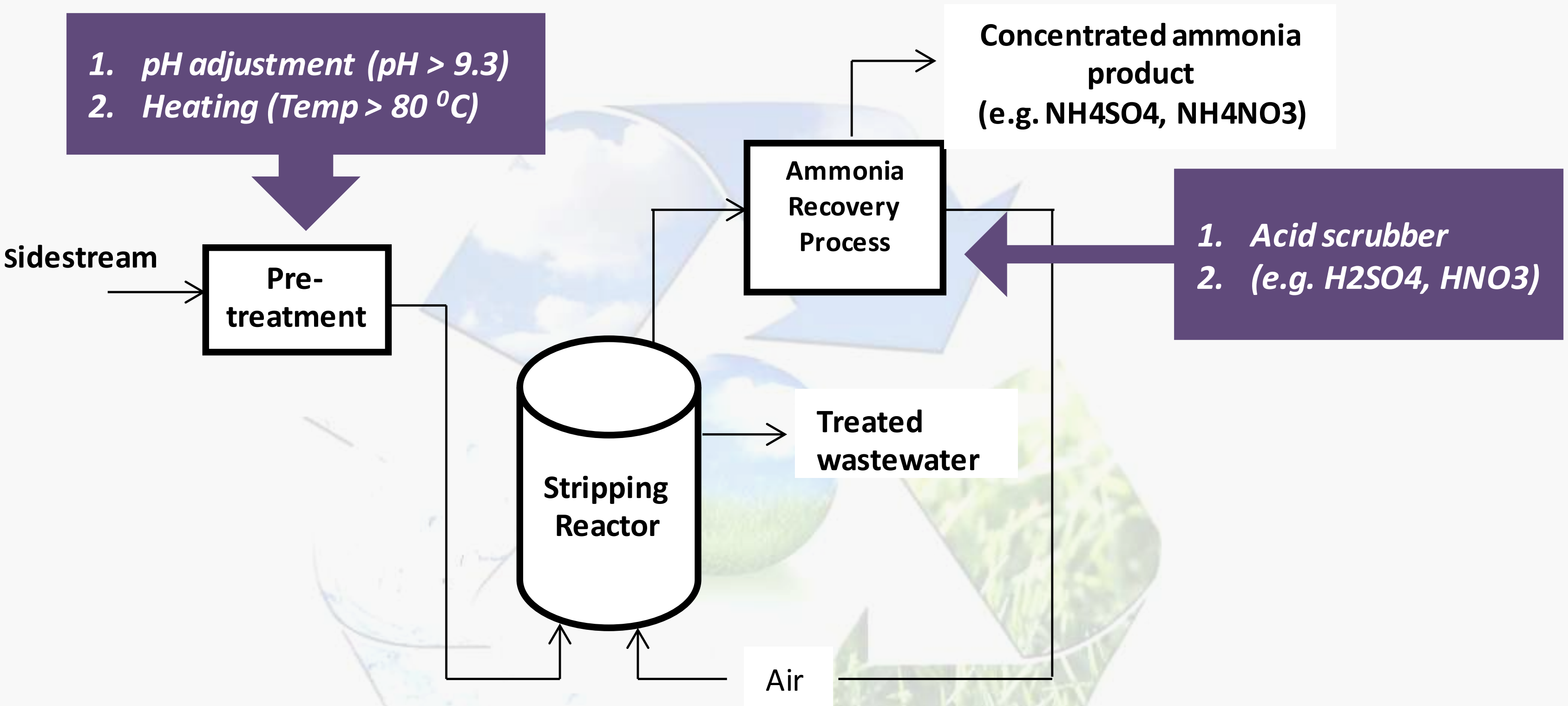
Recovery
- Chemical precipitation
- Electrodialysis
- Gas permeable membrane and absorption
- Gas stripping

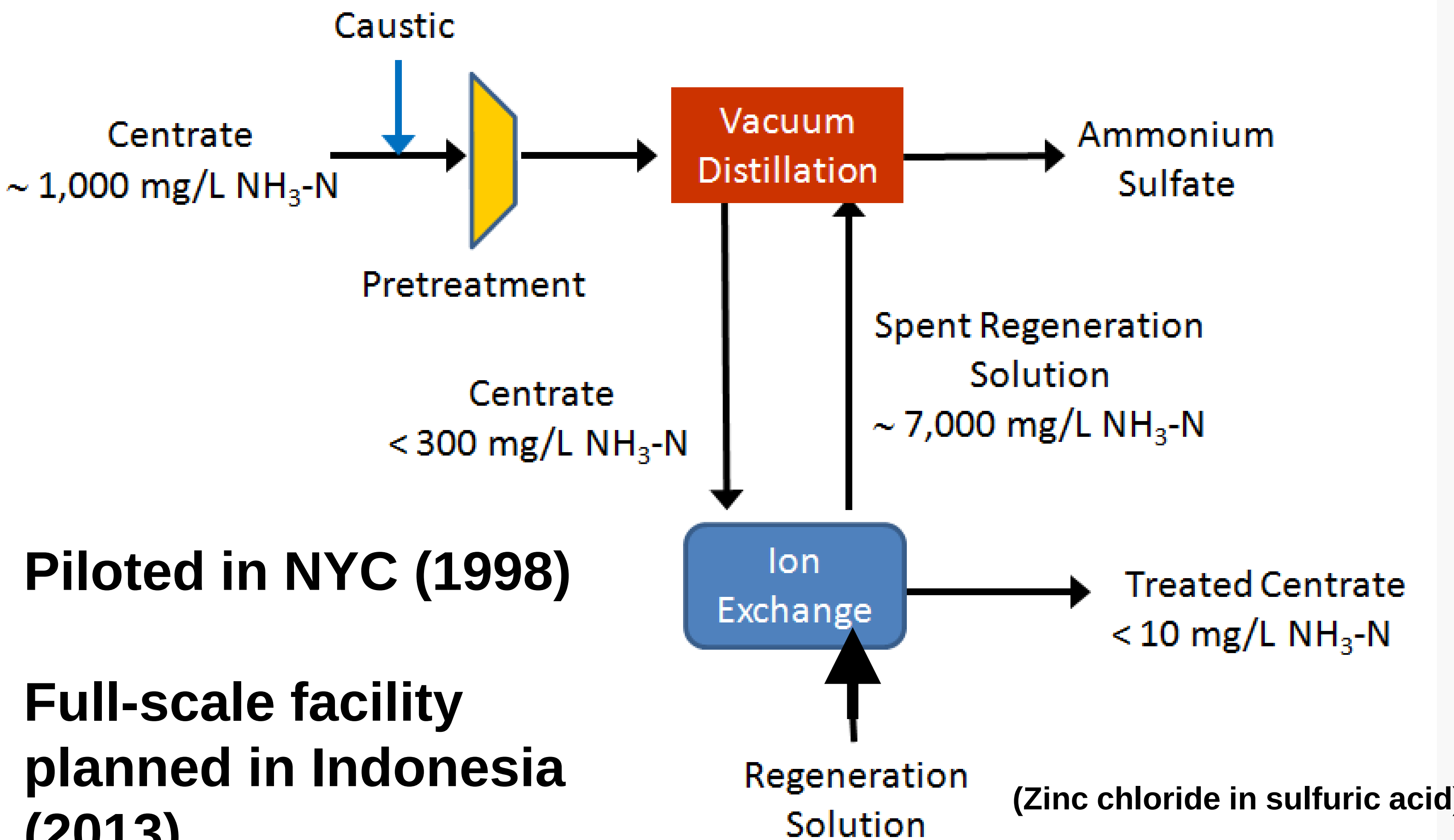
- Gas stripping is appropriate for NH_3 recovery

Nitrogen can also be recovered from sidestreams via gas stripping and ion exchange



- Large capital investment
- Effective for concentrations > 1000 mg N/L
  - Industrial
  - Agricultural

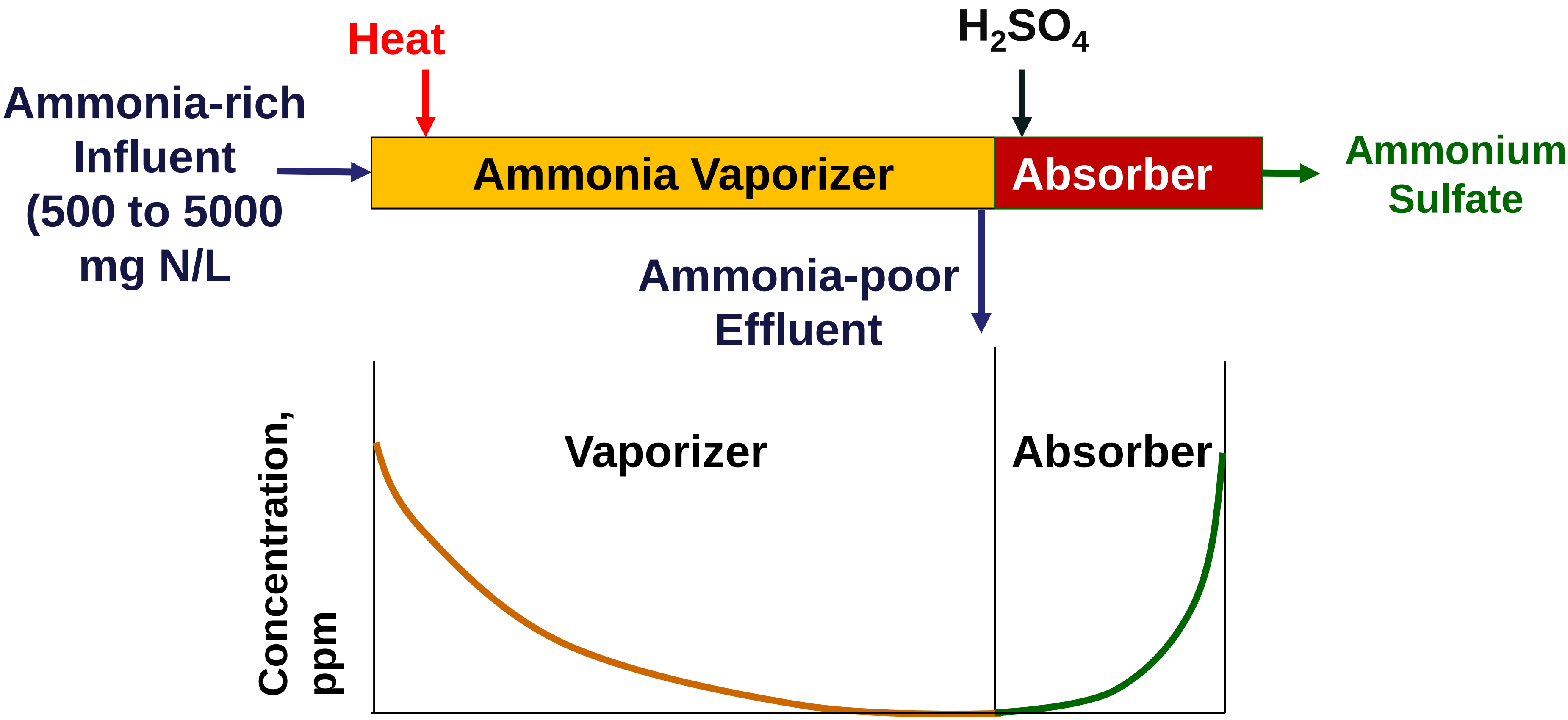
Ammonia recovery process from ThermoEnergy is one commercial process for N recovery



Piloted in NYC (1998)

Full-scale facility planned in Indonesia (2013)

AmRHEX™ ammonia recovery system from 3XR is also used for N recovery



No full-scale applications to date

Nitrogen recovery is more economical at high nutrient concentrations

From Fassbender 2001

TABLE 1
Centralized Ammonia Recovery Plant Budgetary Estimates

GPM	[NH_3] ppm	No. Resin Beds	Size Resin Beds	Cap. Cost, $MM	O&M, cents/gal
250	1000	3	8′	5.6 – 10.6	2.6
550	1000	3	12′	9.3 – 17.0	1.5
1000	1000	3	16′	15.2 – 24.3	1.2
2100	650	7	16′	35.8 – 44.0	1.0

- **Low resale value of N only products makes N recovery challenging**
- **N recovery as part of combined N and P product is more economical at present**
  - **Will need to be revisited as natural gas price/demand varies**

Recovery from biosolids and ash involves multiple steps

Accumulation → **Release** → **Recovery**

Accumulation

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Recovery

- Chemical precipitation
- Electrodialysis
- Gas permeable membrane and absorption
- Gas stripping

- Extraction/recovery can involve acidification, thermolysis, chemical extraction and chemical precipitation

These processes can be complex and are not yet mature

Seaborne process

- 1) acidification
- 2) solids separation
- 3) solids incinerated
- 3) heavy metals precipitation
- 4) de-sulfurized gas -> cogen. plant
- 5) struvite precipitation
- 6) ammonia stripping

Krepo process

- 1) sludge thickening (5% DS)
- 2) acidification (pH 1-3)
- 3) thermal hydrolysis (140 C, 30-40-min)
- 5) organic sludge separation (50% DS)
- 6) phosphate precipitation
- 7) recycling of precipitant

Seaborne piloted at Gifhorn WWTP in Germany (2006)

KREPO Full-scale facilities at Helsingborg and Malmo WWTFs(Sweden)

Nutrient recovery from solids and ash produces familiar products

Name of Process	Seaborne	Krepro	SEPHOS	BioCon®	PASH	PHOXNAN
Product recovered	struvite; diammonium sulfate (DAS)	iron phosphate as a fertilizer	aluminum phoshate or calcium phosphate (advanced SEPHOS)	phosphoric acid	struvite or calcium phosphate	phosphoric acid
Process feedstock	sludge	sludge	sewage sludge ash	sewage sludge ash	sewage sludge ash	sludge

- **Few full-scale applications currently exist**
- **Work is on-going in Europe to make these economical options**

We have multiple options for nutrient recovery for municipal applications

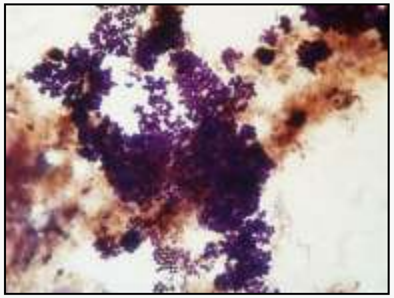
Accumulation → Release → Recovery

- **Nutrient recovery is an integral component of the WWTP of the future.**

- **Nutrient recovery can be economical when sidestreams contribute:**
  - ≥15% of the influent TN load
  - ≥20% P load

- **Four main drivers**
  1. Reduce energy and chemical consumption
  2. Minimize nuisance struvite formation and reduce O&M costs
  3. Control the nutrient content of the biosolids
  4. Provide plant with alternative revenue stream

There are challenges preventing the adoption of nutrient recovery is challenged by barriers



1. **What influences the adoption of resource recovery systems?**
   - Competing priorities
   - Lack of regulatory driver
   - Relatively long payback period
   - Lack of knowledge
   - Vague timeline

2. **How should WWTPs implement resource recovery?**

3. **What nutrient recovery technologies are effective?**

Questions and Contact Information

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