Extractive Nutrient Recovery as a Sustainable Nutrient Control Alternative

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Water Environment Research Foundation
Collaboration. Innovation. Results.

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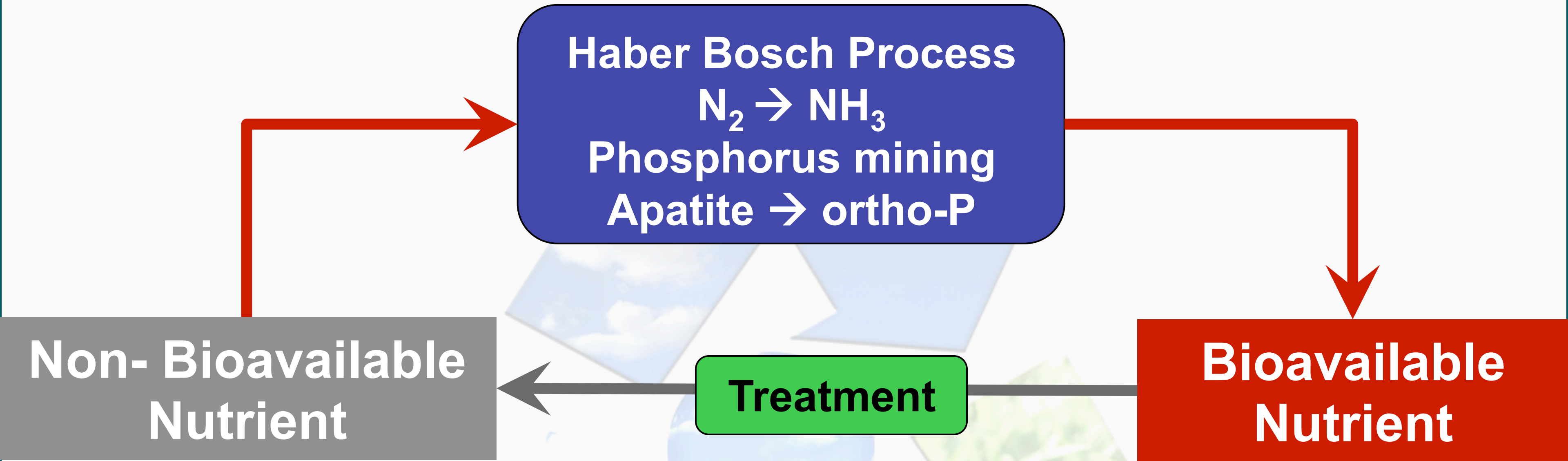
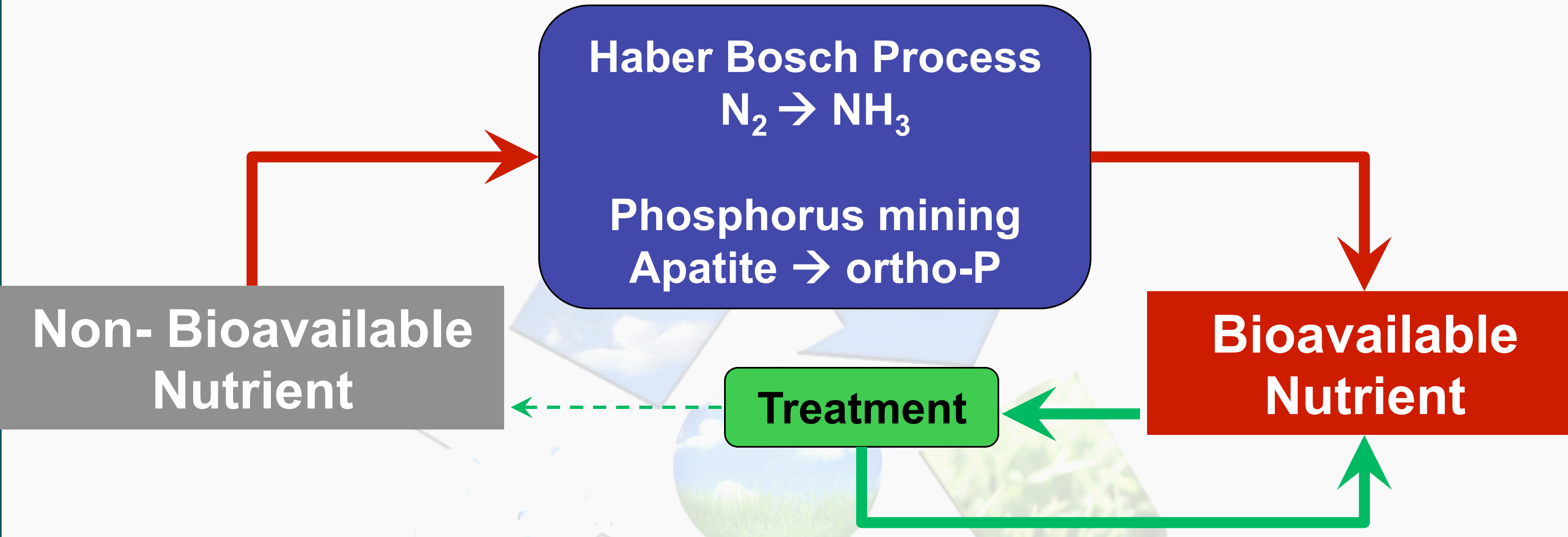
Nutrient usage cycle currently assumes an unlimited supply of resources and energy



- Nitrogen gas is a renewable resource but is not readily available for plant growth
  - Energy required for engineered N cycle 12.9 to 14.3 kWh/kg N
- Phosphorus is a NON-renewable resource
  - Phosphorus resources are declining both in quality and accessibility

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)**

Challenges revolve around technical, economic and regulatory limitations

Technical

- Technologies are unknown entities.
- Insufficient time and staff to review technologies
- Insufficient data to evaluate technology performance
- Insufficient experience in operating technology
- Unknown maintenance requirements and long-term operational viability

Economic

- Insufficient and/or competing needs for funds
- Unknowns regarding cost of implementation, operating costs, etc.
- Uncertainty with respect to future demand for fertilizer product.
- Competition for product if many utilities adopt the technology

Regulatory

- Lack of regulatory drivers i.e., no effluent nutrient limits.
- Lack of public acceptance

Addressing Technical Considerations

From a technological perspective, a three step framework may be appropriate

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

There are multiple options for each step of extractive recovery

Accumulation → **Release** → **Extraction**

Accumulation

- Enhanced biological phosphorus removal (EBPR)
- Algae
- Purple non-sulfur bacteria
- Adsorption/Ion exchange
- Chemical precipitation
- NF/RO

Release

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

Extraction

- Chemical crystallization
- Electrodialysis
- Gas permeable membrane and absorption
- Gas stripping
- Solvent extraction

- Not all systems require all three components
- Can optimize each option separately
- Can also stage implementation

Our technology matrix summarizes nutrient recovery state of science

Physical references

Ostara Installations

Site Name	Location	Status	Scale	Size of Plant (MGD)	Feed flow to Pearl® (MGD)	Characteristics of sidestream flow: $[PO_4\text{-}P]$ (mg/L)	Characteristics of sidestream flow: $[NH_3\text{-}N]$ (mg/L)	Removal Performance: % PO_4-P	Removal Performance: % NH_3-N	Product recovered (T/yr)	Contact
Durham AWWTP	Tigard, OR	5/1/2009	Full	25	0.125	400	1250	90	18	520	Nate Cullen 503-547-8176 cullenn@cleanwaterservices.org
Gold Bar/Clover Bar	Edmonton, AB	5/1/2007	Full	80	0.132	160	650	85	15	Demo plant	Vince Corkery 780-969-8429 vcorkery@epcor.ca
Nansemond WWTP	Suffolk, VA	5/1/2010	Full	20	0.104	450	650	90	30	602	Bill Balzer 757-638-7361 bbalzer@hrsd.com
York WWTP	York, PA	6/1/2010	Full	20	0.125	~300	700-800	90	~20	365	Steve Douglas 717-845-2794 sdouglas@yorkcity.org
Rock Creek AWWTP	Hillsboro, OR	1/1/2012	Full	35	0.701	132.5	268	83	19	930	Nate Cullen 503-547-8176 cullenn@cleanwaterservices.org
Nine Springs WWTP	Madison, WI	Spring 2013	Full	-----	-----	-----	-----	-----	-----	-----	Steve Reusser 608-222-1201 ext. 263 stever@madsewer.org
H.M. Weir WWTP	Saskatoon, SK	Fall 2012	Full	-----	-----	-----	-----	-----	-----	-----	Joe Zimmer 360-975-2330 Joe.zimmer@saskatoon.ca
Slough STW	United Kingdom	Fall 2012	Full	-----	-----	-----	-----	-----	-----	-----	Pete Pearce (01144) 774-764-0814 Pete.pearce@thameswater.co.uk
Southerly WWTP	Columbus, OH	Mar-12	Pilot	-----	-----	-----	-----	-----	-----	-----	Stacia Eckenwiler 614-645-0268 skeckenwiler@columbus.gov
Strasbourg	Strasbourg,	Sep-11	Pilot								Frederic Pierre +33-0-637-30-875

Technology Matrix | Struvite Crystallization | NH3-N stripping | Mag Sep | Electrodialysis | Adsorp-Ion Ex | Filt | Gas perm | Ana Dig | Tlysis | Duckweed | Algae | PAOs | Phospag

Consider a common scenario in which enhanced biological phosphorus removal is applied

		Nutrient recovery (% recovery efficiency)			Product (% wt nutrient)
		N	P	K	
Accumulation	EBPR	-	√ (15-50%)	-	Sludge (5- 7% P)
Release	Anaerobic digestion	√	√	√	Biosolids
Extraction	Crystallization	√	√ (> 90%)	√	Mg-Struvite (12% P, 5% N), K-struvite, Fe or Ca phosphate

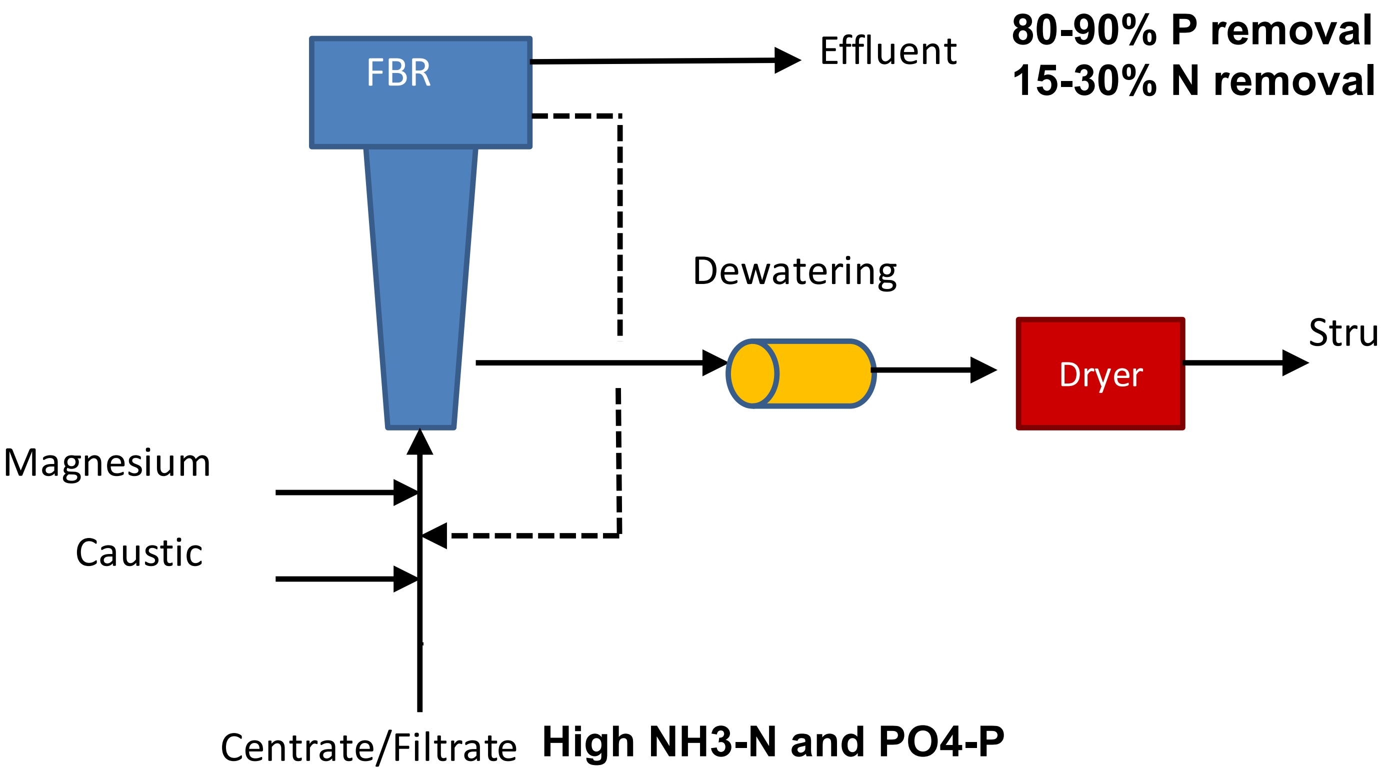
Nuisance struvite formation is commonly observed

- 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 helps minimize nuisance struvite formation and reduce P recycle

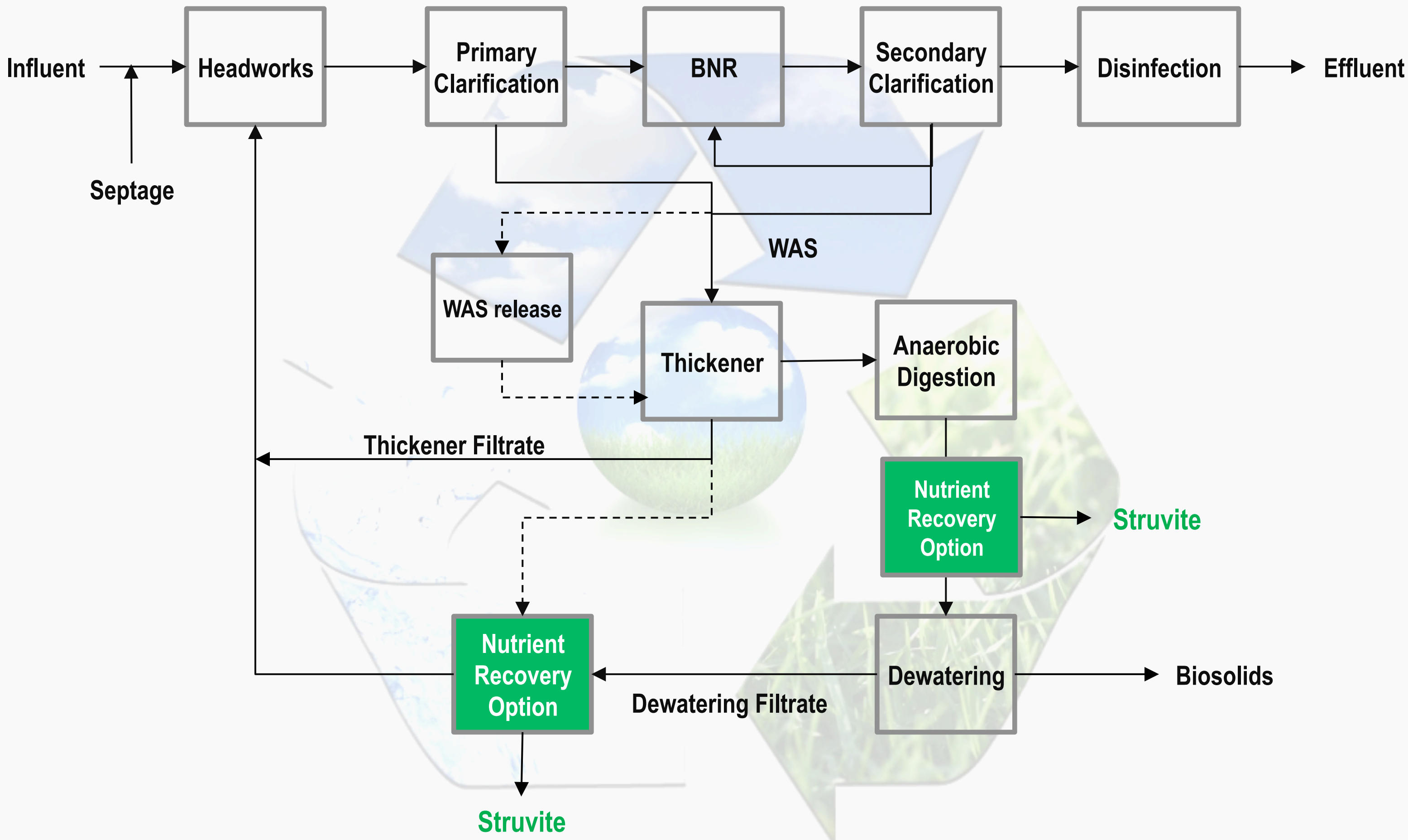


- Fluidized bed reactor or CSTR used for struvite recovery
- High quality, slow release fertilizer – revenue offsets costs
- Reduction in ferric/alum – payback on capital

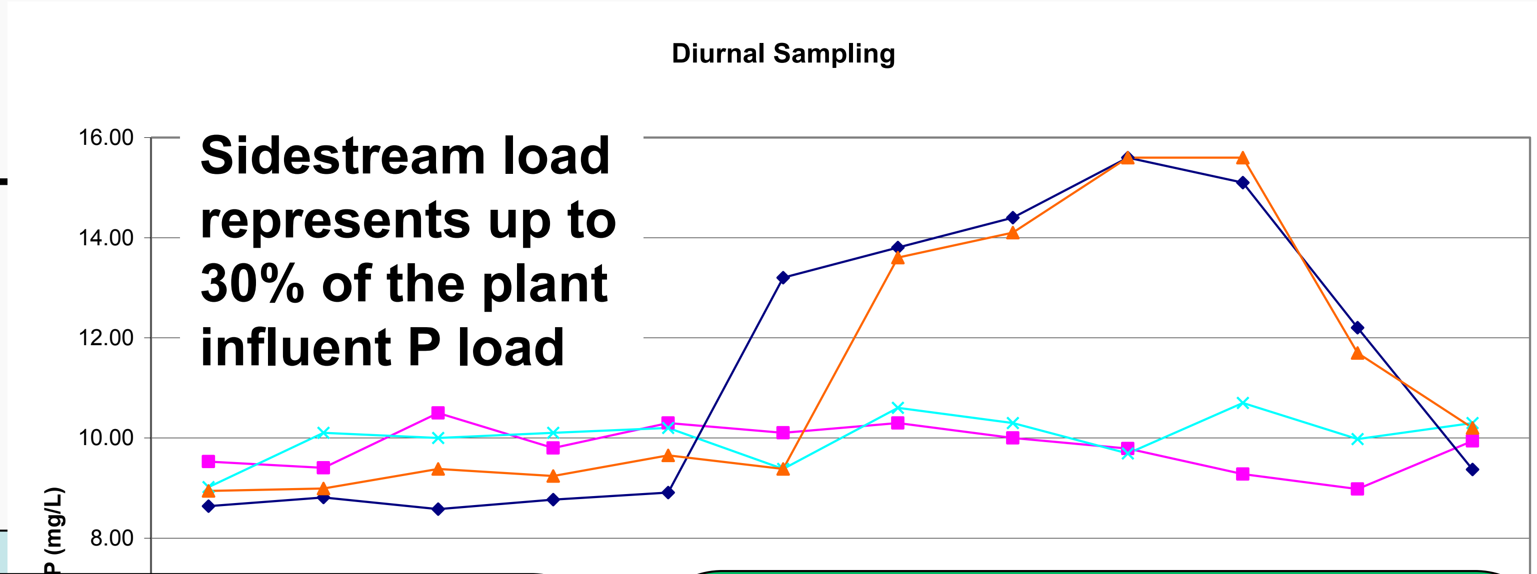
There are several commercial options for struvite recovery

Name of Technology	Pearl®	Multiform Harvest™	NuReSys™	Phospaq™	Crystalactor™	Airprex™
Type of reactor	upflow fluidized bed	upflow fluidized bed	CSTR	CSTR with diffused air	upflow fluidized bed	CSTR with diffused air
Name of product recovered	Crystal Green ®	struvite fertilizer	BioStru®	Struvite fertilizer	Struvite, Calcium-phosphate, Magnesium-phosphate	Struvite fertilizer
% Efficiency of recovery from sidestream	80-90% P 10-40% NH3-N	80-90% P 10-40% NH3-N	>85% P 5-20% N	80% P 10-40% NH3-N	85-95% P for struvite 10-40% NH3-N > 90% P for calcium phosphate	80-90% P 10-40% NH3-N
# of full-scale installations	8	2	7	3	4	3

Enhanced biological phosphorus removal, anaerobic digestion & nutrient recovery



Plant A is a 30 MGD facility that employs a 5-stage BNR configuration for N and P removal



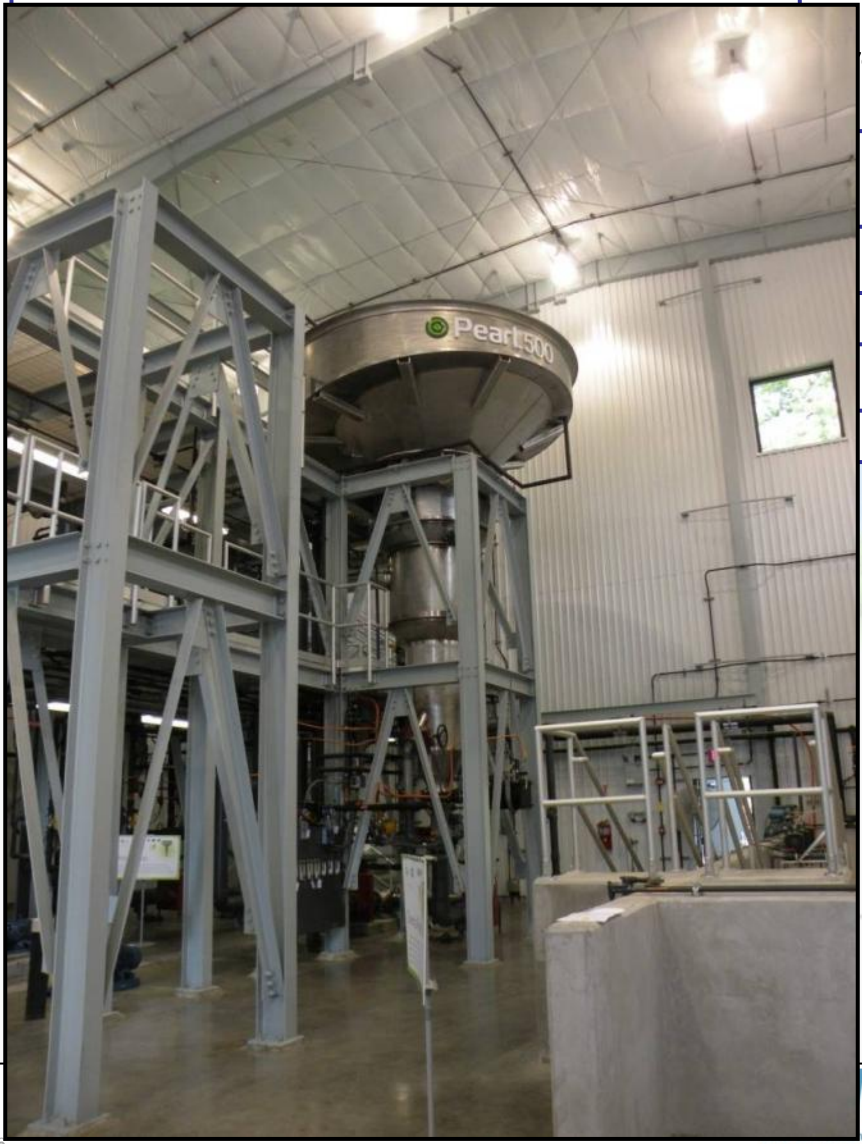
Ferric addition

- Forms ferric phosphate and ferric hydroxide
- Non-proprietary
- Traditionally used for controlling sidestream P at this plant
- High O&M requirement

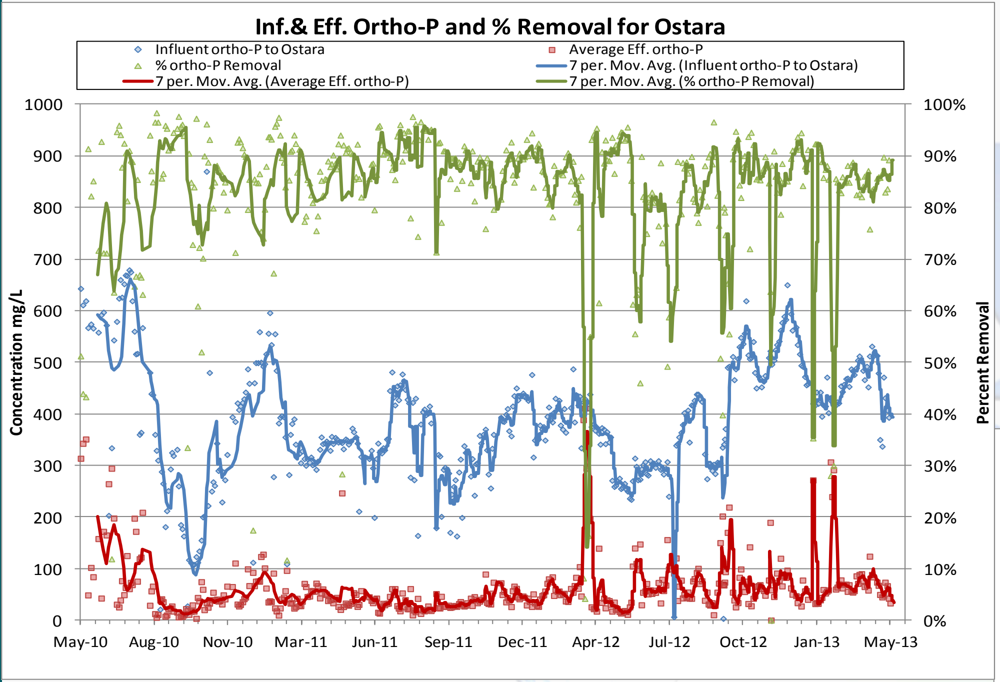
Struvite recovery

- Treatment fee option
  - Technology provider would assume all maintenance of the facilities
- Capital purchase option
  - Plant A purchases equipment and receives annual payments from Technology provider

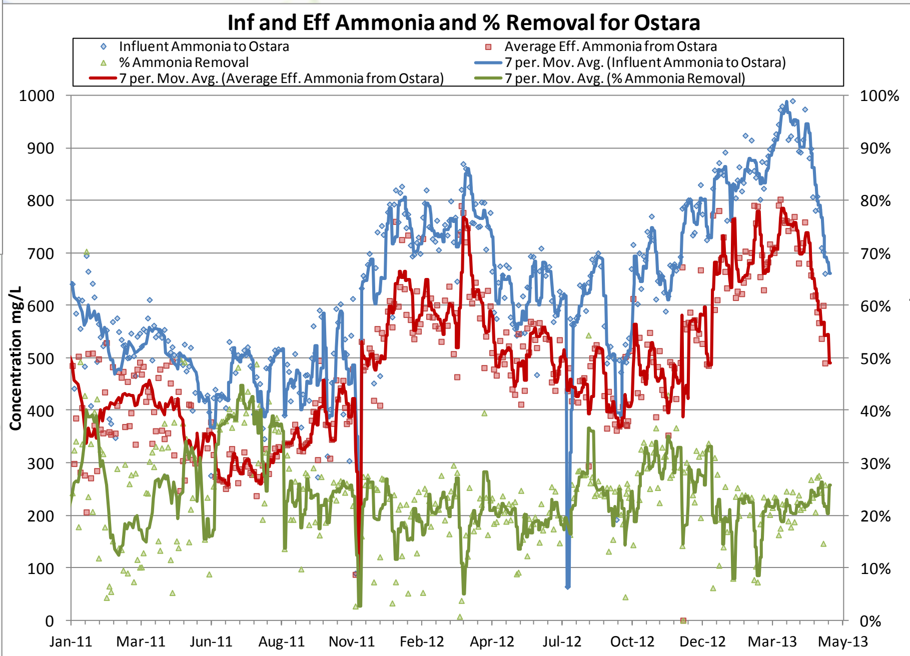
Extractive nutrient recovery option was more cost effective than ferric addition option



Orthophosphate and ammonia removal have been consistent throughout operation



- **Ortho-P removal approaches 85%**



- **Ammonia removal approaches 25-30%**

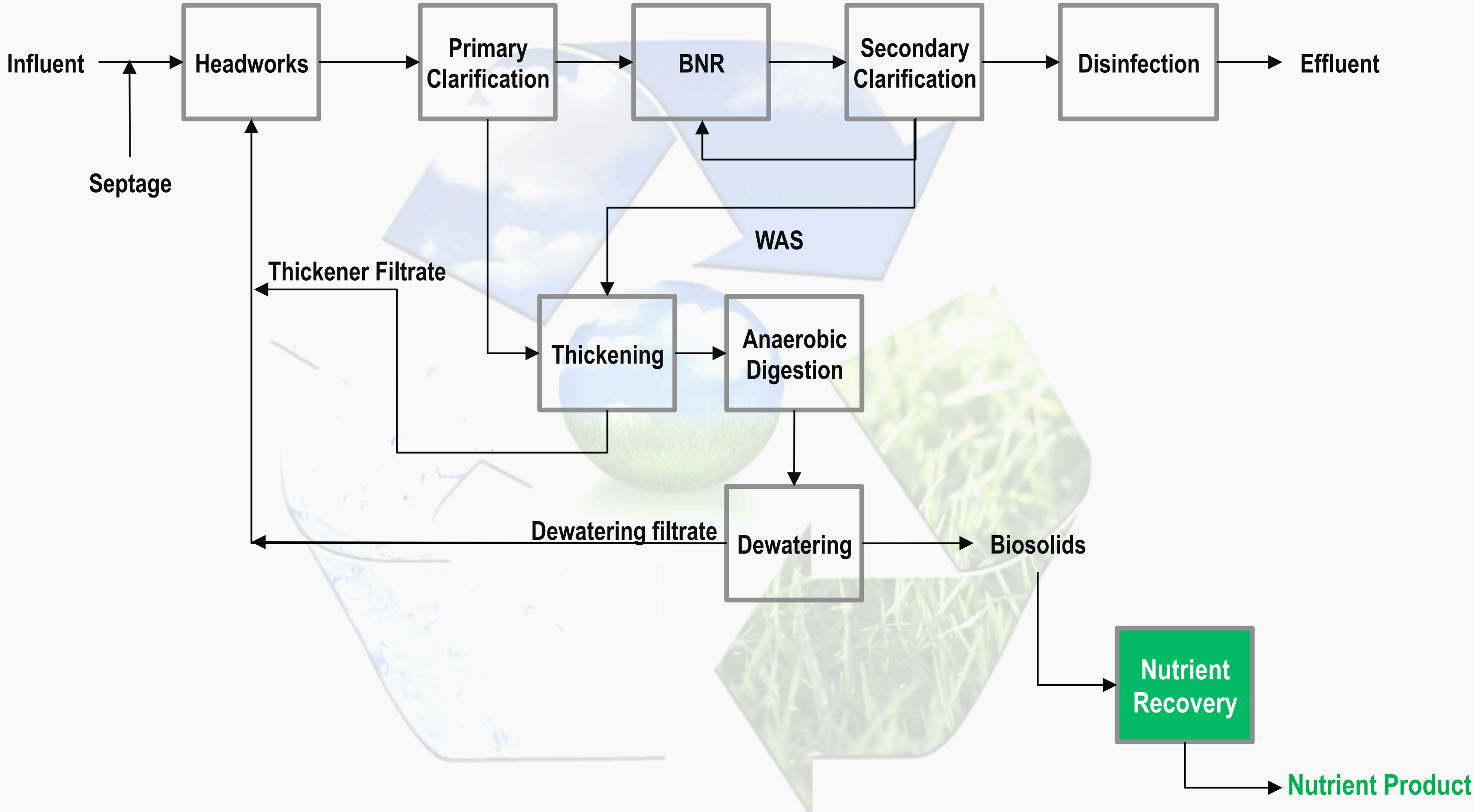
What about if we use chemical precipitation for mainstream P removal?

		Nutrient recovery (% recovery efficiency)			Product
		N	P	K	
Accumulation	Chemical (Precipitation)	√	√ (> 90 %)	-	Sludge
Release	Anaerobic digestion	√	-	√	Biosolids

- **Release via Anaerobic digestion solubilizes limited amount of P**

Extraction	Acidification or bioleaching followed by crystallization, liquid extraction , ion exchange	√	√	√	Struvite; diammonium sulfate (DAS), iron phosphate, phosphoric acid, calcium phosphate, biosolids

Chemical precipitation, anaerobic digestion and nutrient recovery



There are options to allow us to recover nutrients from sludge

Name of Process	Seaborne	Krepro	PHOXNAN
Product recovered	struvite; diammonium sulfate (DAS)	iron phosphate as a fertilizer	phosphoric acid
Process feedstock	sludge	sludge	sludge

- **One full-scale installation of Krepro in Sweden**
- **Regulatory mandate for recycling P is needed to drive implementation of these technologies**

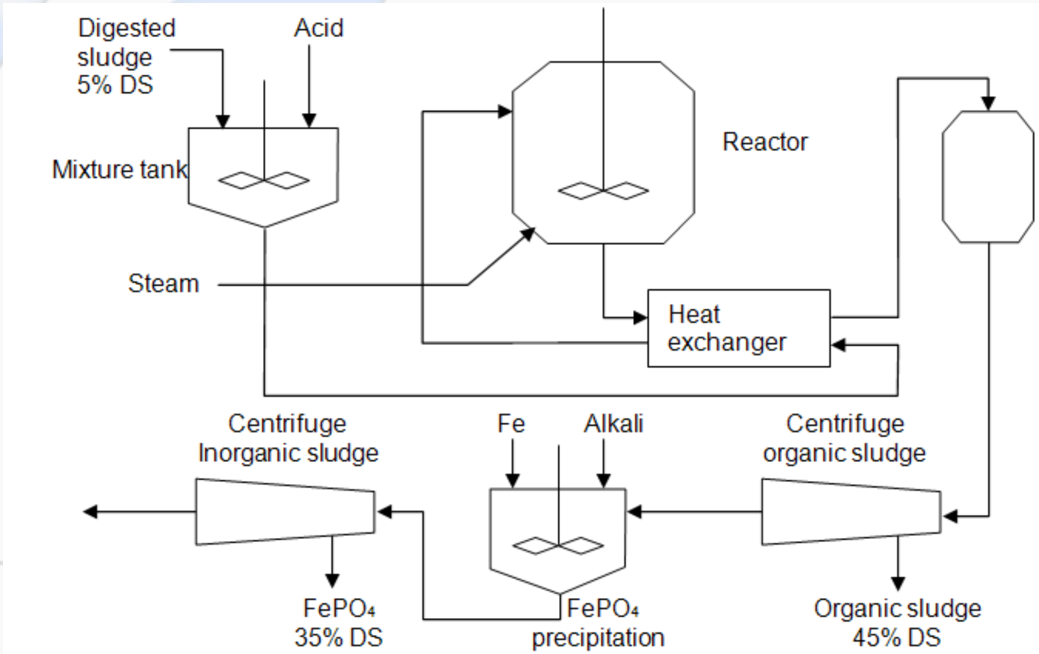


Figure 1. The KREPRO system [11].

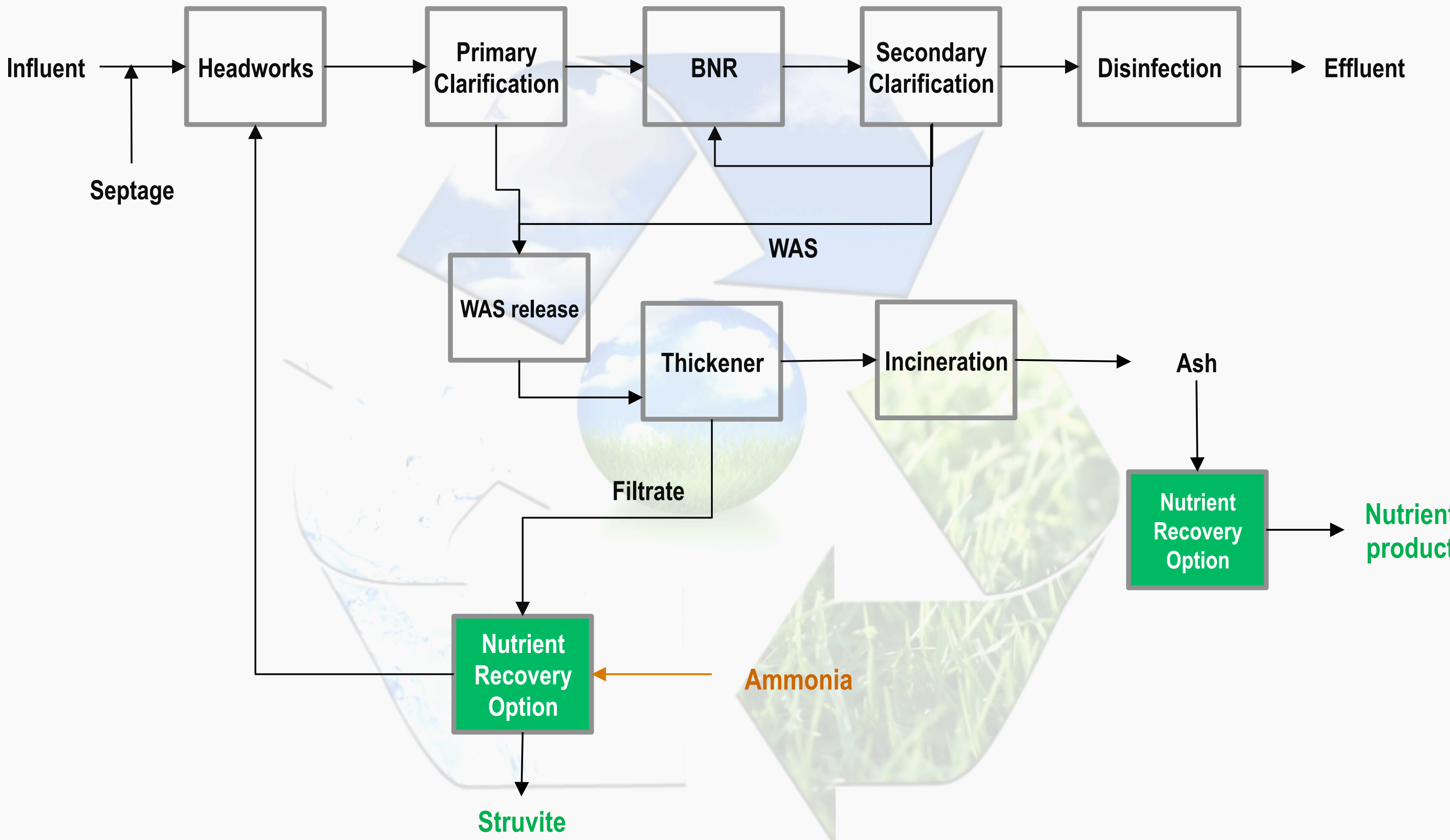
What about if we use have thermochemical stabilization (i.e., incineration)?

		Nutrient recovery (% recovery efficiency)			Product
		N	P	K	
Accumulation	Biological or Chemical	√	√ (> 90 %)	-	Sludge

- **No release exists so P is bound into ash**

Option 1 - Release and Extraction	Enhanced WAS Lysis and crystallization	-	√ (20 to 50%)	√	Sludge
Option 2 - Release and Extraction	Acidification of ash followed by crystallization, liquid extraction , ion exchange	√	√	√	Struvite; diammonium sulfate (DAS), iron phosphate, phosphoric acid, calcium phosphate

Enhanced biological phosphorus removal, WAS release & nutrient recovery



There are options to allow us to recover nutrients from ash/sludge

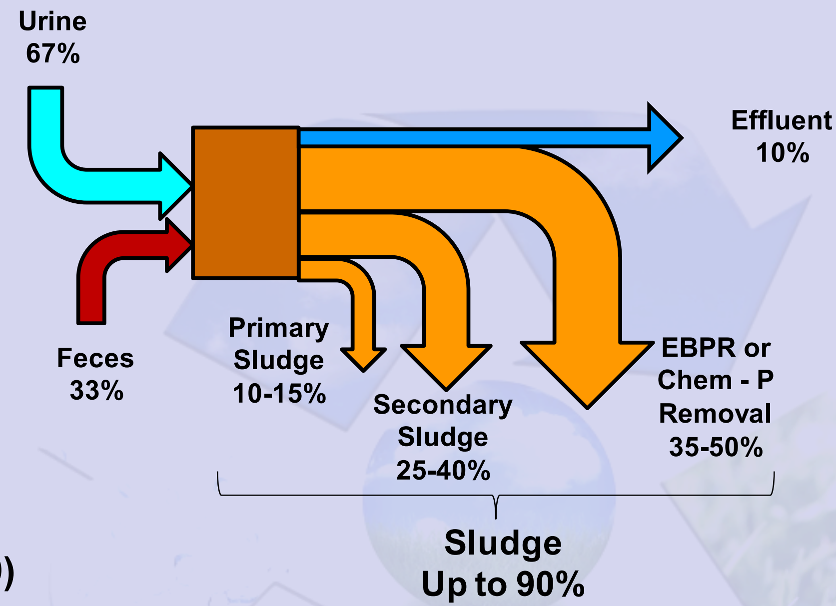
Name of Process	SEPHOS	BioCon®	PASH
Product recovered	aluminum phoshate or calcium phosphate (advanced SEPHOS)	phosphoric acid	struvite or calcium phosphate
Process feedstock	sewage sludge ash	sewage sludge ash	sewage sludge ash

- **Post-processing to remove heavy metals may also be required**
- **Few full-scale installations are present**
- **Regulatory mandate for recycling P is needed to drive implementation of these technologies**
- **Ash can also be considered as direct fertilizer amendment**
  - **Consideration needs to be given to the heavy metal content**

Addressing Regulatory Considerations

Nutrient recovery is another strategy for removing P from WRRF

P mass balance in WRRF



From Cornel *et al.* (2009)

- Different scenarios
  - No nutrient limits
  - Nutrient limits on liquid effluent
  - Nutrient limits on liquid effluent and biosolids

Quantifying other benefits (cost and non-cost) can help make the case for nutrient recovery

- **Struvite recovery can:**
  - **Provide factor of safety associated with Bio-P**
    - **Minimizes impact of sidestream return**
  - **Reduce energy and chemical consumption**
    - **Offsets due to reduction in aeration and supplemental carbon**
    - **Reduction in sludge quantity and hauling costs**
  - **Minimize nuisance struvite formation and reduce O&M costs**
  - **Reduce or increase the P content of biosolids**
    - **If land application P index limited, removing P in the form of struvite will shift N:P ratio**
    - **If more P is appreciated, selectively precipitating P into biosolids will increase biosolids P content**
  - **Improve sludge dewaterability**
    - **Result in higher sludge cake %TS**
    - **Reduce polymer demand**

Addressing Economic Considerations

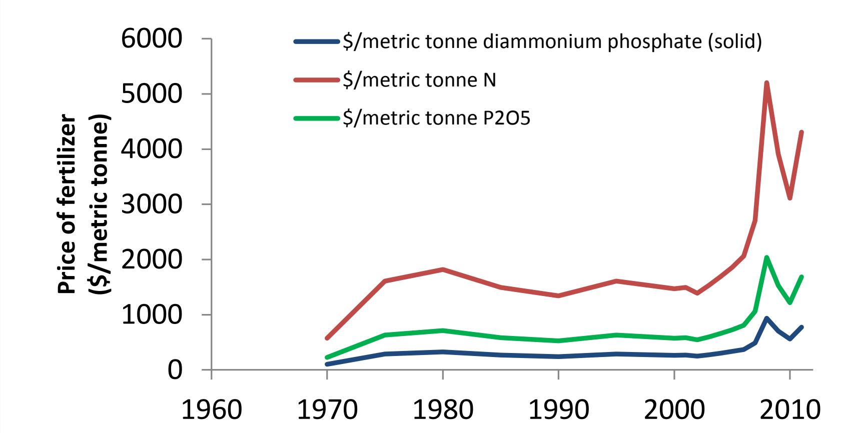
Recovery of a high demand chemical nutrient product is the goal

- **Approximately 85% of all nutrient products used in developed countries is related to agriculture**

- **Focus on producing products for the agricultural sector**
  - **Niche within specialty agriculture and ornamental markets**

Common Name	Chemical Formula	Product Form
Magnesium Struvite	**$NH_4MgPO_4 \cdot 6H_2O$**	**Solid**
Hydroxyapatite	$(Ca_5(PO_4)_3(OH))$	Solid
Vivianite	$Fe_3(PO_4)_2 \cdot 8H_2O$	Solid
Phosphoric acid	H_3PO_4	Liquid
Ammonium nitrate	NH_4NO_3	Liquid or Solid
Ammonium sulfate	$(NH_4)_2SO_4$	Liquid or Solid

Magnesium struvite is the most commonly encountered product

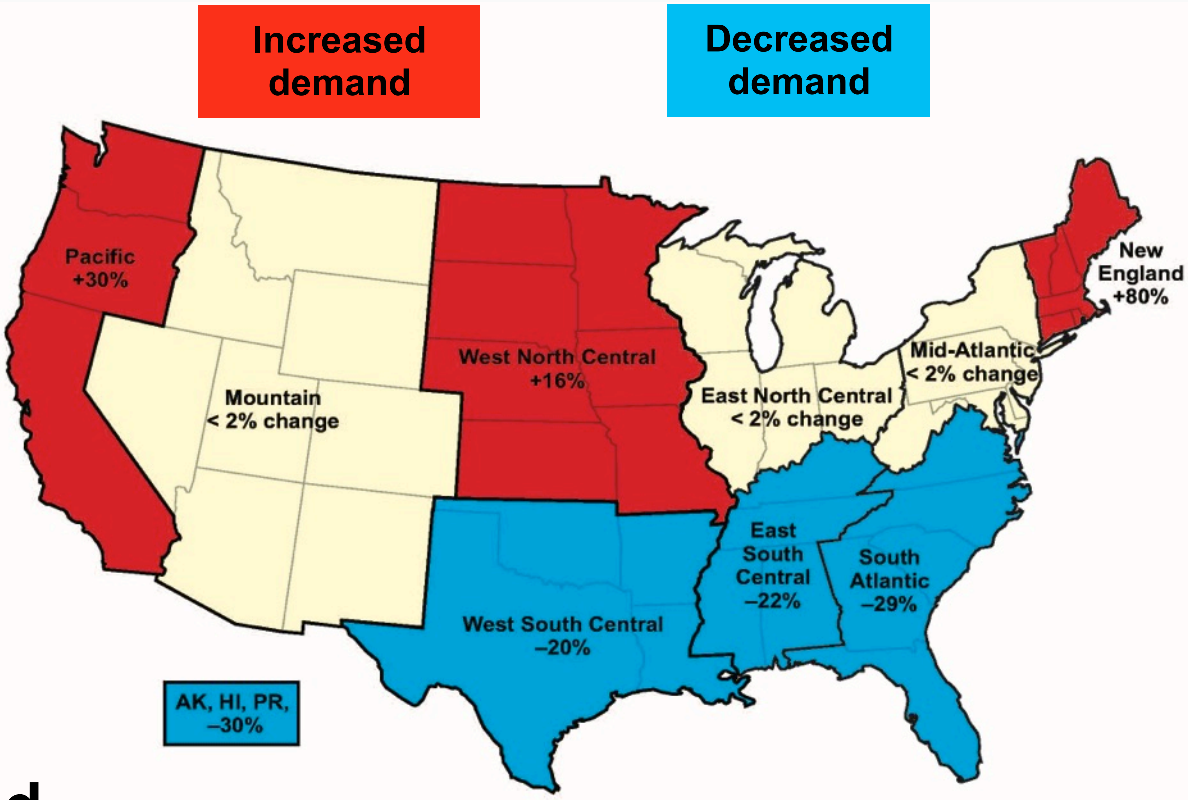


- **Closest analogues are mono and diammonium phosphate**
- **Based on historical pricing, can expect Mg-struvite value to range from $200 to $600/metric tonne**

Characteristic	Magnesium struvite	Monoammonium phosphate	Diammonium phosphate
Chemical formula	$MgNH_4PO_4$-$6H_2O$	$NH_4H_2PO_4$	$(NH_4)_2HPO_4$
Average price/metric tonne	$200 - $600	$570 - $615	$420 - $680
Grade (N-P-K)	5-29-0	11-52-0	18-46-0
Water solubility at 20 °C	Insoluble - 0.2 g/L	328 - 370 g/L	588 g/L
Application description	Spread on soil	Normally spread of mixed in soil	Normally spread of mixed in soil
Typical application rates*	255 lb/A	142 lb/A	160 lb/A

Region specific needs also play a role in the overall demand for recovered nutrient products

- **Overall national fertilizer demand has been relatively steady over the past 10 yrs**
- **If we look a little deeper….**
- **Demand in specific regions has fluctuated**
  - **see WERF report for more details on region specific demand data**

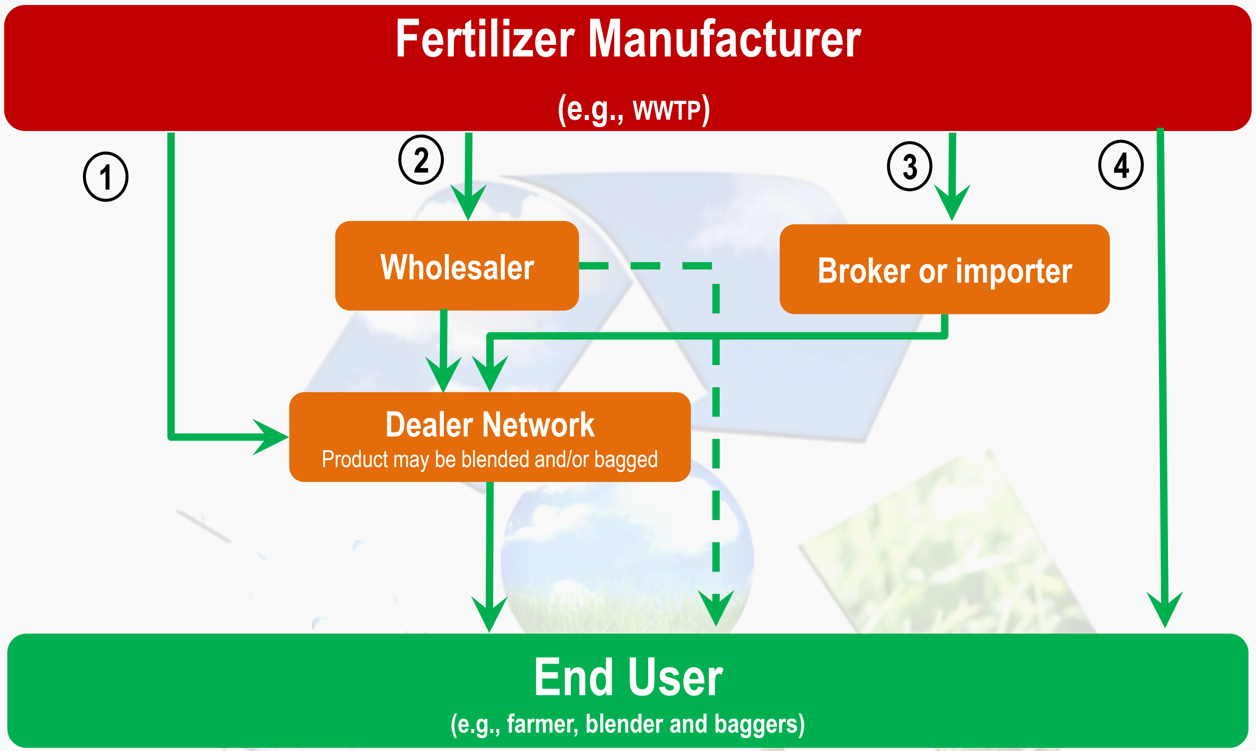


The specialty agriculture and ornamental markets are receptive to WRRF products

- **Specialty agriculture and ornamental markets**
  - **325,000 metric tonne P_2O_5/ year,**
  - **110,000 metric tonne TN/year**
  - **Represents 1 to 5% of total agricultural demand**

- **WWT industry can potentially meet these demands (optimistic projections)**
  - **Between 30 and 100% of the specialty and ornamental P_2O_5 fertilizer demand (as struvite)**
  - **Between 30 and 194% of the specialty and ornamental N fertilizer demand (as ammonium sulfate solution)**

There are multiple entry points for the nutrient fertilizer market



- Multiple points of entry into the secondary market
  - Most technology providers for struvite production facilitate interaction with the market
  - Facility has the choice of entering the market directly

What are the economics associated with implementing struvite recovery at WRRFs?

Objective 2 – Provide guidance on the implementation of resource recovery technologies at WWTP

Case studies of full-scale facilities also developed

- **Developed case studies in 3 categories**
  - **Category 1 – Currently operating or constructing struvite harvesting**
  - **Category 2 – Performed desktop analyses and/or pilot**
  - **Category 3 – No evaluation but may have piloted**
- **Each case study describes:**
  - **Nutrient limits,**
  - **Plant configuration,**
  - **Challenges faced,**
  - **Drivers for nutrient recovery,**
  - **Economics associated with struvite harvesting,**
  - **Lessons learned where applicable**

Plant Designation	Plant 1
Location	Virginia, USA
Current Nutrient limits (mg/L)	TN - 8.0 mg/L AA TP - 2.0 mg/L AA These are treatment goals, the utility has a permit for combined effluent from 7 plants discharging in the James River basin.
Emerging Nutrient limits (mg/L)	Expected 2017 TN reduction to 5.0 mg/L and TP reduction to 1.0 mg/L. Plan to treat with additional supplemental carbon and ferric chloride if needed.
BNR configuration	5-stage BNR
Solids management configuration	Primary sludge + GBT co-thickened. Thickened sludge to anaerobic digesters then centrifuged. Cake is hauled and incinerated.
Biosolids disposal method	Biosolids transported to another plant within utility for incineration
Mainstream Design flow (MGD)	30
Mainstream current operation flow (MGD)	18
Minimum operating temperature (ºC)	12
Effluent nutrient concentrations (June 2011 to February 2013)	TP - 1.5 mg/L TN – 6.5 mg/L (includes periods with 3 and 5 stage BNR)
Sidestream flow (MGD)	0.1
Sidestream nitrogen concentration (mg/L N)	Before implementation of nutrient recovery: 576 After implementation of nutrient recovery: 448
Sidestream ortho-phosphorus concentration (mg/L P)	Before implementation of nutrient recovery: 351 After implementation of nutrient recovery: 54

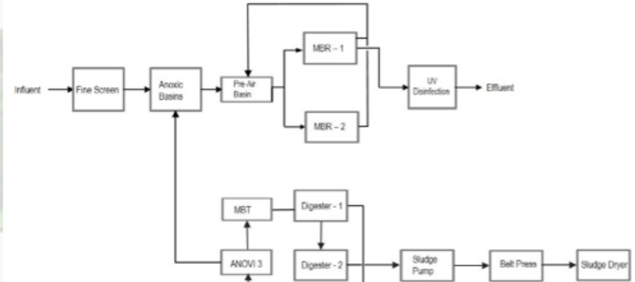
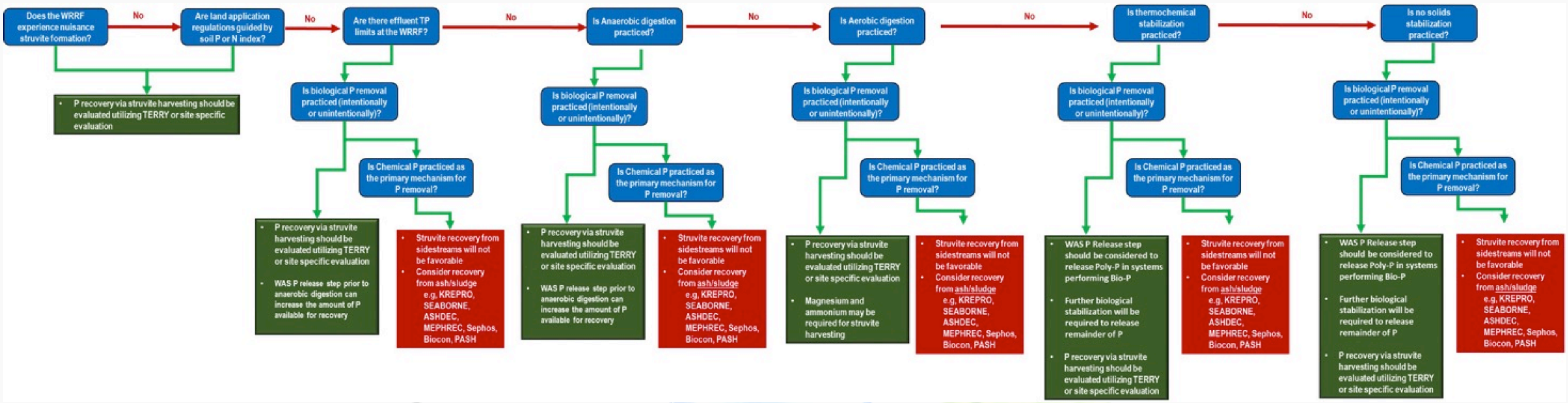


Figure 2-2. Process Flow Diagram

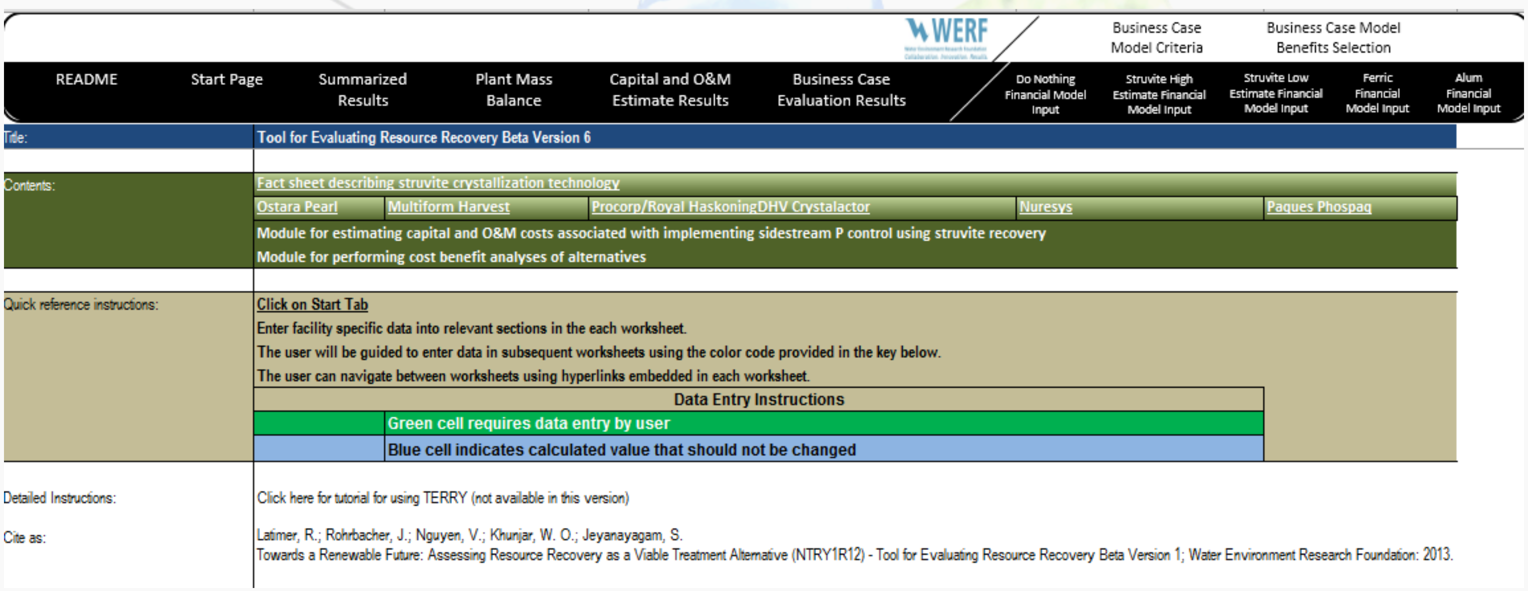
Flowsheet has been developed to aid decision making process



- **Preliminary multi-criteria analyses can be performed using the Tool for Evaluating Resource RecoverY**

Tool for Evaluating Resource RecoverY developed to facilitate preliminary evaluation

- **Compare struvite crystallization with precipitation with coagulant (i.e., alum or ferric)**
- **Different scenarios evaluated in current version**
  - **Known sidestream characteristics**
  - **Unknown sidestream characteristics; Anaerobic digestion**
  - **Unknown sidestream characteristics; Anaerobic digestion & imported sludge**
  - **Unknown sidestream characteristics; Aerobic digestion**
  - **Unknown sidestream characteristics; Aerobic digestion & imported sludge**
  - **Unknown sidestream characteristics; No stabilization**

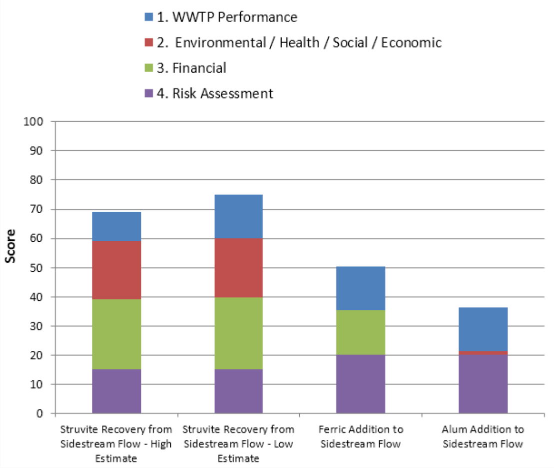


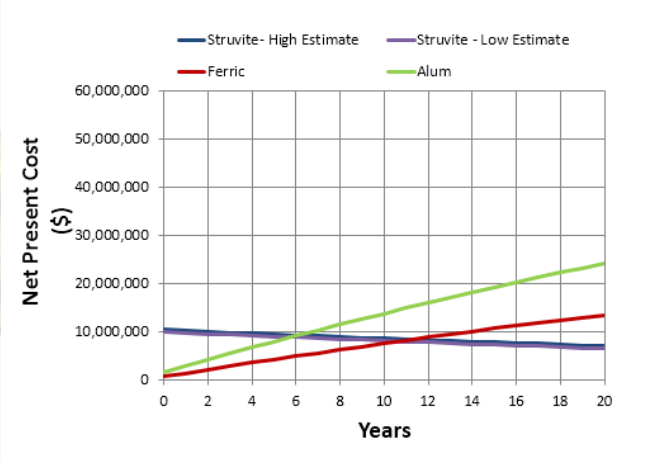
Cost benefit analyses model takes into account non-financial criteria

Criterion No.	Criterion	Description of Criterion	Criterion Weight (%) (Sum for all criteria must equal 100%)
1. WWTP Performance			Enter data in green cells only
1a.	Reduce nuisance precipitate formation	The alternative will/will not reduce the formation of struvite in the sludge cake	5.00%
1b.	Remove phosphorus in the sidestream versus in the mainstream	The average pounds of Phosphorus removed per day in the sidestream	5.00%
1c.	Improve reliability for meeting effluent total phosphorus limits by reducing EBPR upsets from sidestream load	Will biological phosphorus removal upset frequency be reduced?	5.00%
2. Environmental / Health / Social / Economic			
2a.	Perform nutrient recycling	Average pounds of struvite recovered per day	5.00%
2b.	Reduce amount of chemical sludge produced and disposed	Pounds of sludge produced and disposed per day on average	5.00%
2c.	Reduce supplemental carbon demand	Quantity of supplemental carbon use avoided (lb/day)	5.00%
2d.	Alternative is more acceptable to the public than the baseline	If the Alternative recovers and reuses nutrients, then the project is more acceptable to the public that is the baseline	5.00%
3. Financial			
3a.	Net Present Value of Alternative	Change in Present value of revenues minus present value of costs due to Alternative	35.0%
3b.	Payback Period	Number of Years until the Capital or Initial Cost of the Alternative is Paid Off with Revenue from the Alternative	10.00%
4. Risk Assessment			
4a.	Technological Track Record	Reflects the degree to which the Alternative's technology has a successful track record or the technology does not require specialized training to operate.	5.00%
4b.	Sufficient Information for Proper Assessment	Reflects the quality of the information used to evaluate this alternative.	5.00%
4c.	Additional Building Footprint Required	Will new building space need to be constructed?	5.00%
4d.	Manpower Hours and Skill Required	Reflects the degree to which the Alternative requires significant manpower hours and skill.	5.00%

TERRY output allows you to estimate capital, O&M and rank alternatives based on non-cost critieria

Option	BCE Score	Capital Cost ($)	Net Present Cost (20 year) ($)	Struvite Recovered (lb/day)	Value of Struvite Recovered ($/year)
Struvite Recovery from Sidestream Flow - High Estimate	69.1	$ 10,630,000	$ (7,240,000)	6536	$ 358,000
Struvite Recovery from Sidestream Flow - Low Estimate	74.9	$ 10,200,000	$ (6,720,000)	6536	$ 358,000
Ferric Addition to Sidestream Flow	50.4	$ -	$ (13,000,000)		
Alum Addition to Sidestream Flow	36.3	$ 400,000	$ (23,270,000)		





TERRY status and implications

- User manual and tutorial under development
- Beta-testing with numerous facilities
- Who do we envision using this tool?
  - Utility managers, research and development personnel
  - Consultants
  - Regulators
- Future applications
  - Incorporate regulatory, economic and technical constraints
  - Estimate the value of benefits that can not be quantified currently. E.g. Environmental benefits

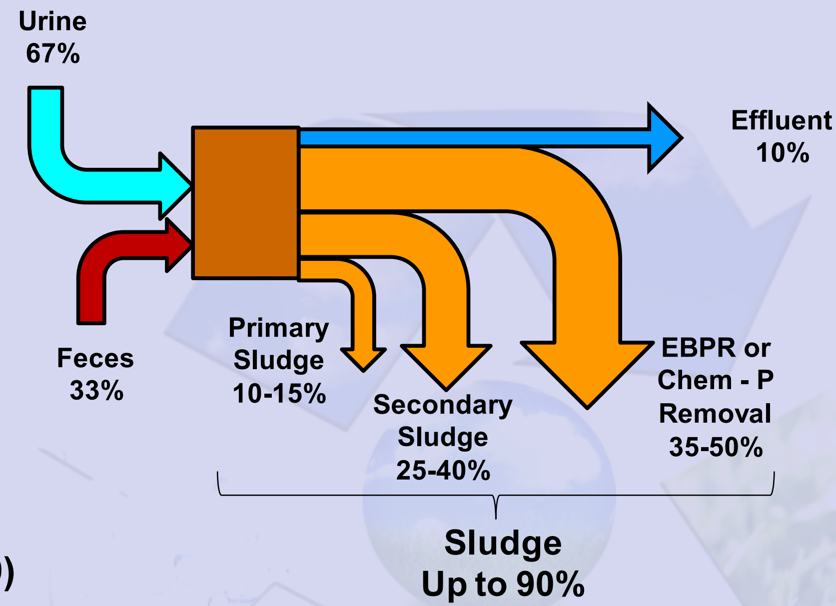
Objective 3 - Experimentally evaluate nutrient (focus on P) recovery technologies

Two projects underway

- **Project 1 - Optimize phosphorus release and availability during and after anaerobic digestion**
  - **Goal is to increase productivity of struvite recovery systems**
- **Project 2 – Examine the benefits of P, N and K recovery via electrodialysis and its influence on sludge dewatering**
  - **Goal is to achieve simultaneous recovery of P, N, K and improve sludge dewaterability in Bio-P applications**

Enhancing recovery potential with existing technology

P mass balance in WWTP



From Cornel *et al.* (2009)

	% P from influent
Accumulation via EBPR	Up to 90
Release via Anaerobic Digestion	Up to 60
Recovery via crystallization	**Up to 50**

Conclusions

Quantifying other benefits (cost and non-cost) can help make the case for nutrient recovery

- **Struvite recovery can:**
  - Provide factor of safety associated with Bio-P
    - Minimizes impact of sidestream return
  - Reduce energy and chemical consumption
    - Offsets due to reduction in aeration and supplemental carbon
    - Reduction in sludge quantity and hauling costs
  - Minimize nuisance struvite formation, reduce O&M costs and regain capacity
  - Reduce or increase the P content of biosolids
    - If land application P index limited, removing P in the form of struvite will shift N:P ratio
    - If more P is appreciated, selectively precipitating P into biosolids will increase biosolids P content
  - Improve sludge dewaterability
    - Result in higher sludge cake %TS
    - Reduce polymer demand

Questions and Contact Information

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