

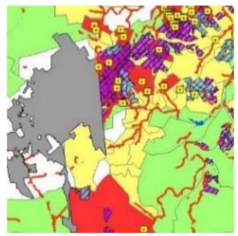



Considerations For Water Resource Recovery Facilities of the Future

Wendell O. Khunjar, PhD, PE

June 12, 2015

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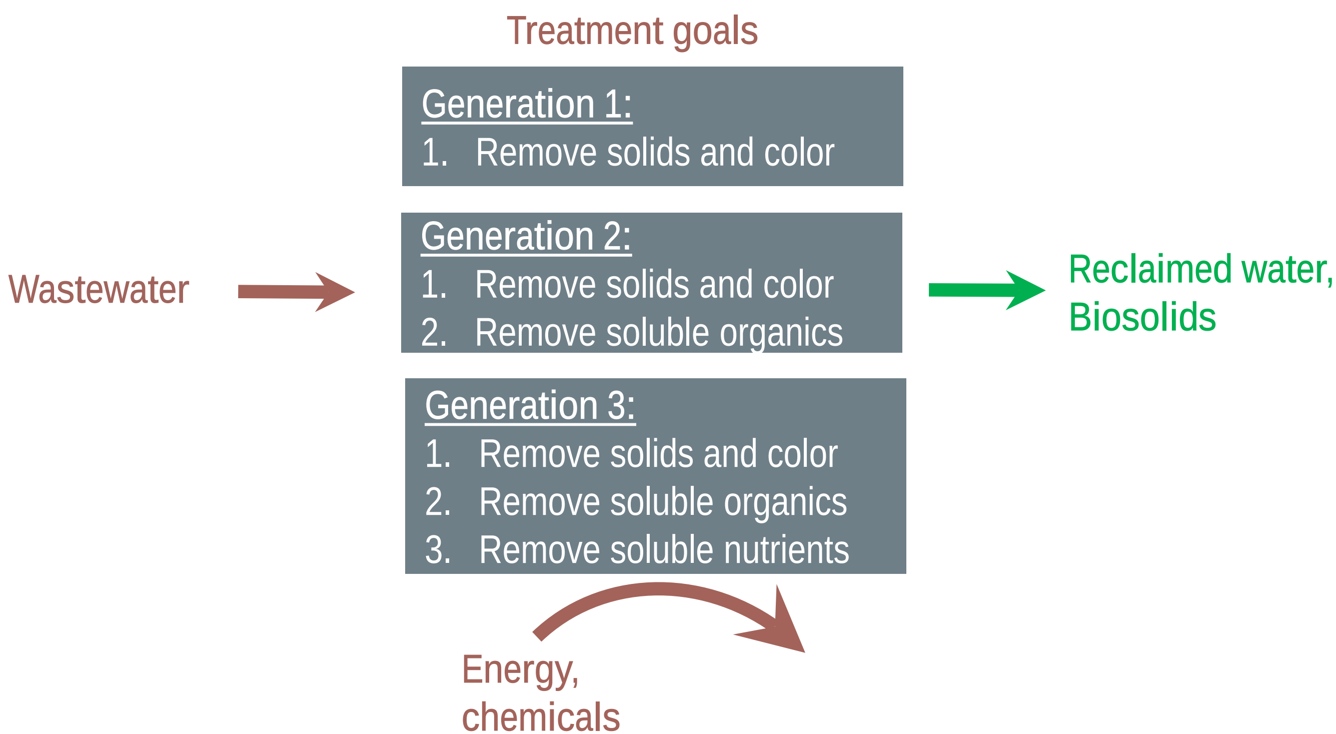
Wastewater treatment has traditionally focused on removing contaminants



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A new paradigm has emerged

Treatment goals

Wastewater →

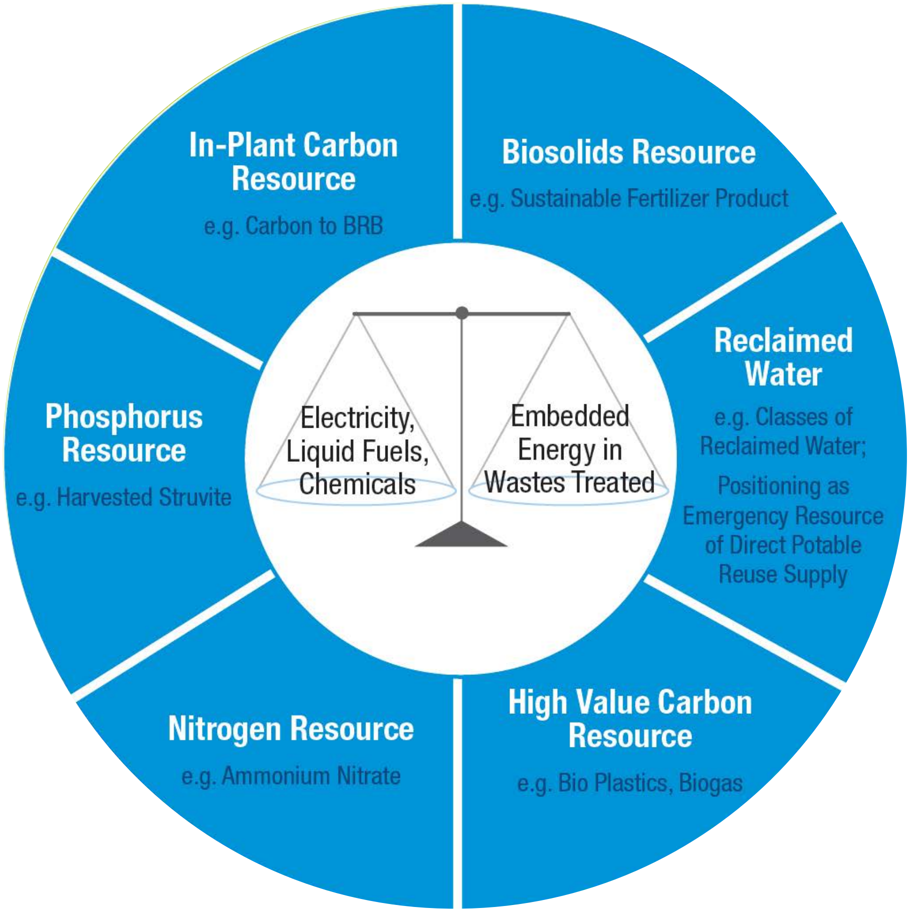
Generation 4:

1. Remove solids and color
2. Remove soluble organics
3. Remove soluble nutrients
4. *Minimize energy and chemical consumption*
5. *Maximize energy recovery*
6. *Maximize resource recovery*

→ Reclaimed water, Biosolids

→ Energy, Chemicals

How do we make this transition?



- Nutrients
- Energy
- Water
- Other Resources

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Nutrients and Energy

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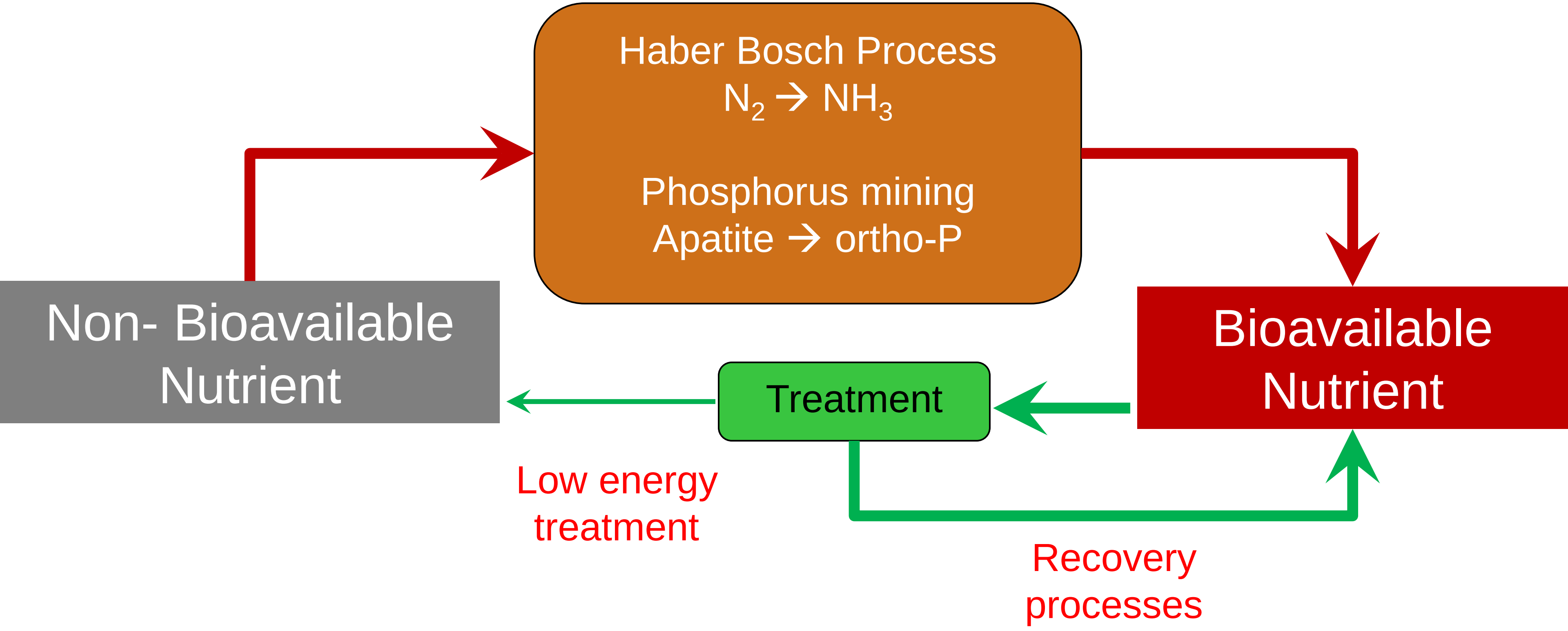
Nutrient recovery should be considered as part of a holistic nutrient management plan



- Combination of removal and recovery is necessary

From a technological perspective, a three step framework is 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

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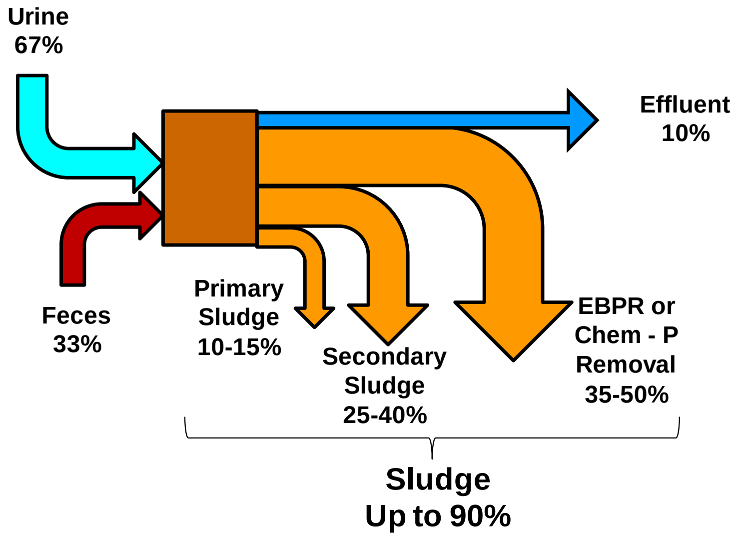
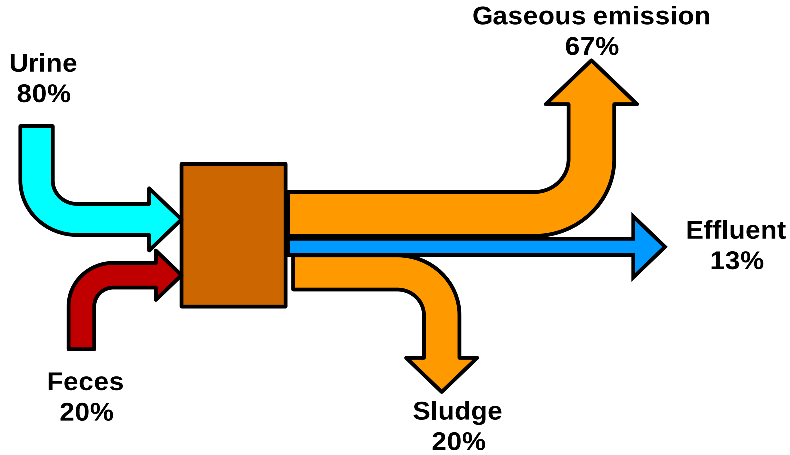
WRRFs already accumulate nutrients within the solids process

Adapted from Cornel et al., 2009



Up to 90% of the influent P can be present in the solids stream

Adapted from Phillips et al., 2011



Up to 20% of the influent N can be present in the solids stream

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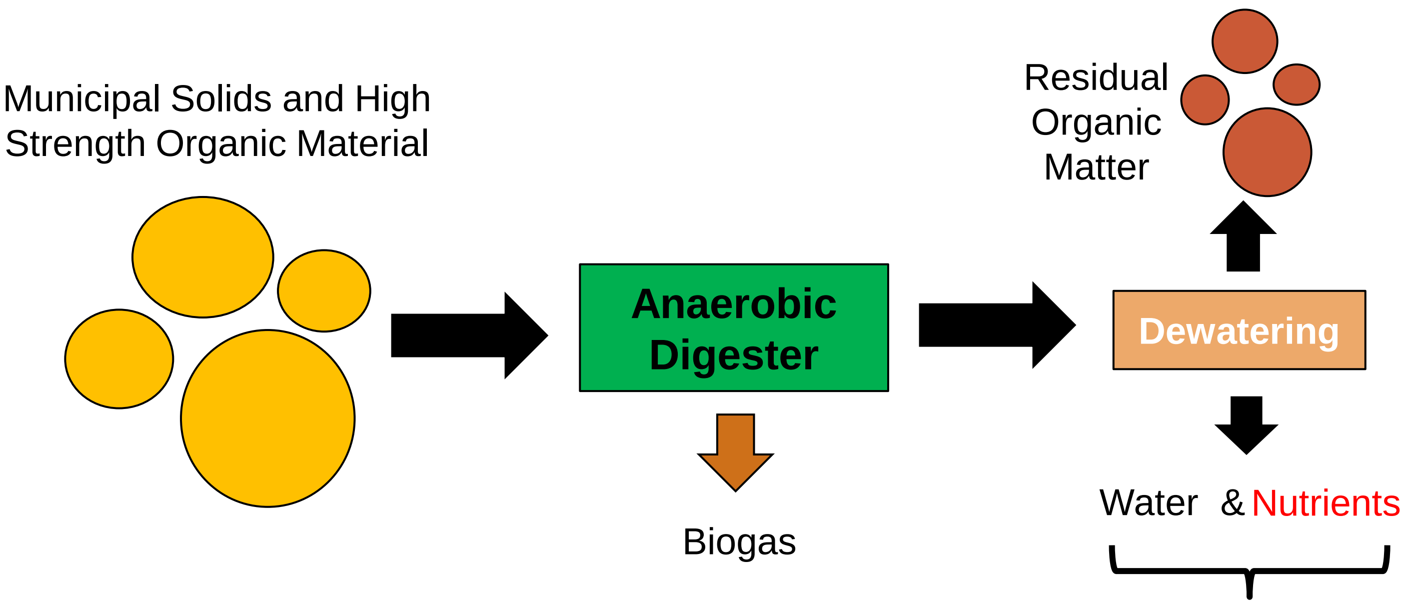
Nutrients are released using solids stabilization technology



Following ANA Digestion, digester sludge and dewatering supernatant can contain:

- **20-40% of P load to main plant**
- **10-20% of N load to main plant**

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High nutrient loads in digester sludge and dewatering can result in nuisance struvite formation

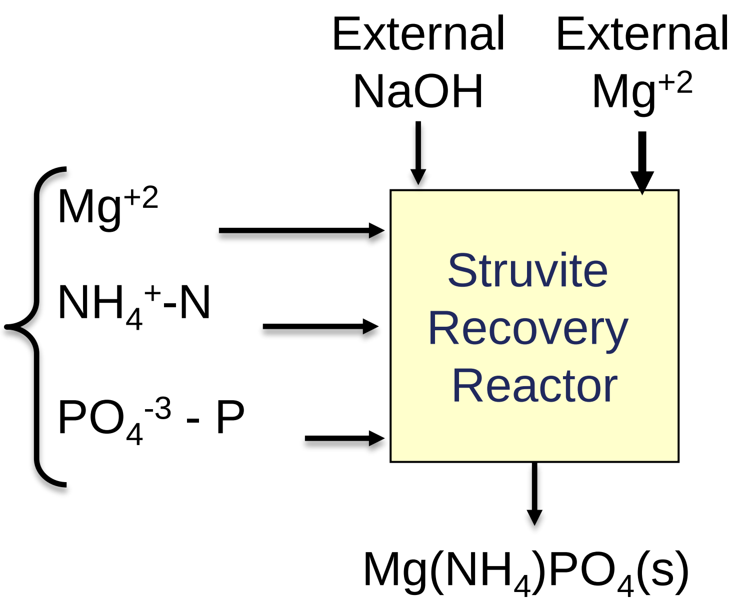
- Struvite = Mg + NH_4 + PO_4
  - NH_4 & PO_4 released in digestion
  - Typically Mg limited
  - Mg addition (i.e. $Mg(OH)_2$) can promote struvite formation

NYC Newtown Creek WPCP

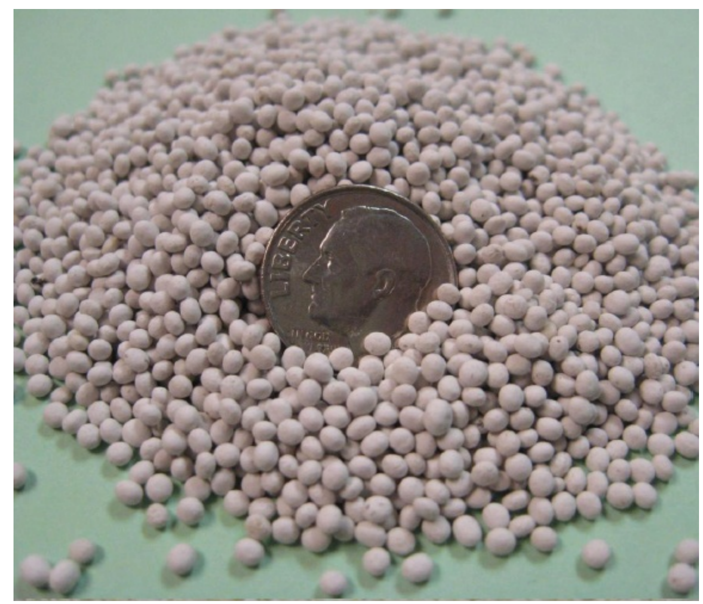
Miami Dade SDWRF

Intentional struvite recovery helps minimize nuisance struvite formation

- Struvite precipitation
  - N:P ratio in struvite = 0.45 lbs N required per lb P removed
  - N:P ratio in filtrate ~ 2.4-2.6, ammonia in excess



$Mg(NH_4)PO_4(s)$ = struvite



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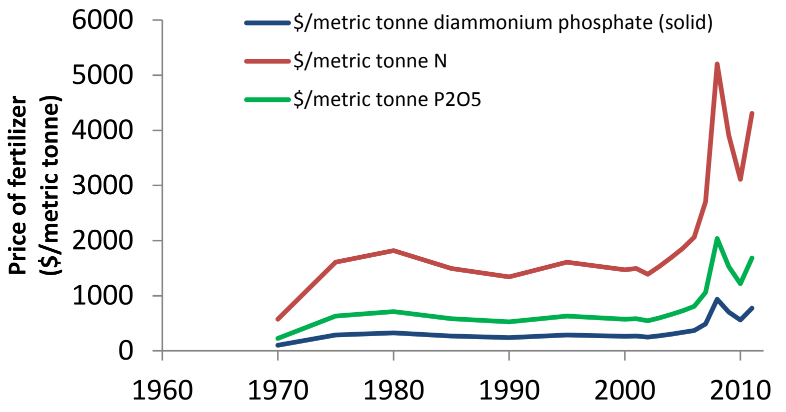
Magnesium struvite is a valuable slow release fertilizer



- 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

Benefits of recovery extend beyond nuisance struvite prevention

- Minimize nuisance struvite formation, reduce O&M costs and regain capacity

- Provide factor of safety associated with Bio-P
- Reduce energy and chemical consumption

- Reduce or increase the P content of biosolids
- Improve sludge dewaterability

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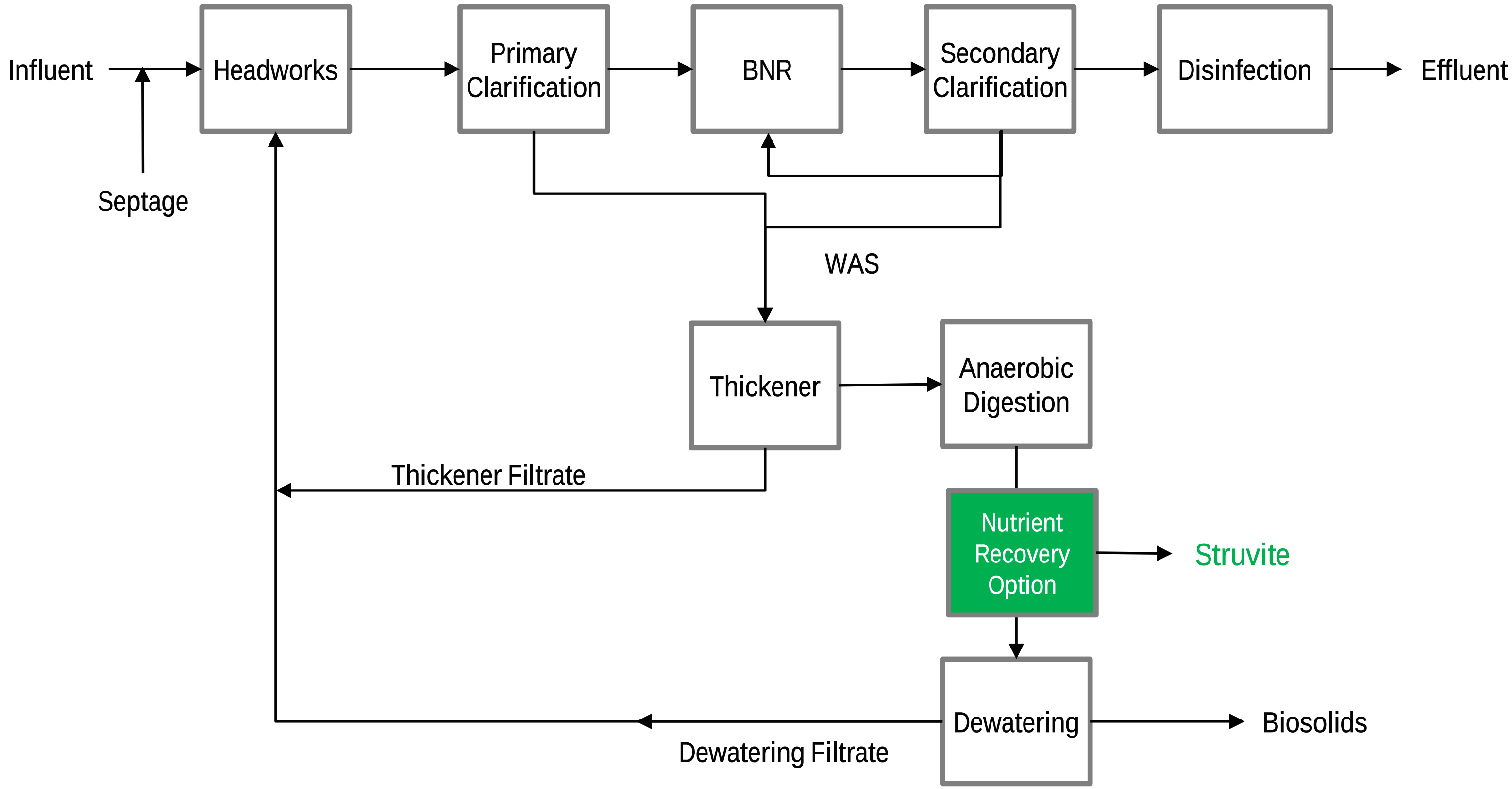
There are several commercial options for struvite recovery

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 (as of 2012)	8	2	7	6	4	3

How can struvite recovery be applied?



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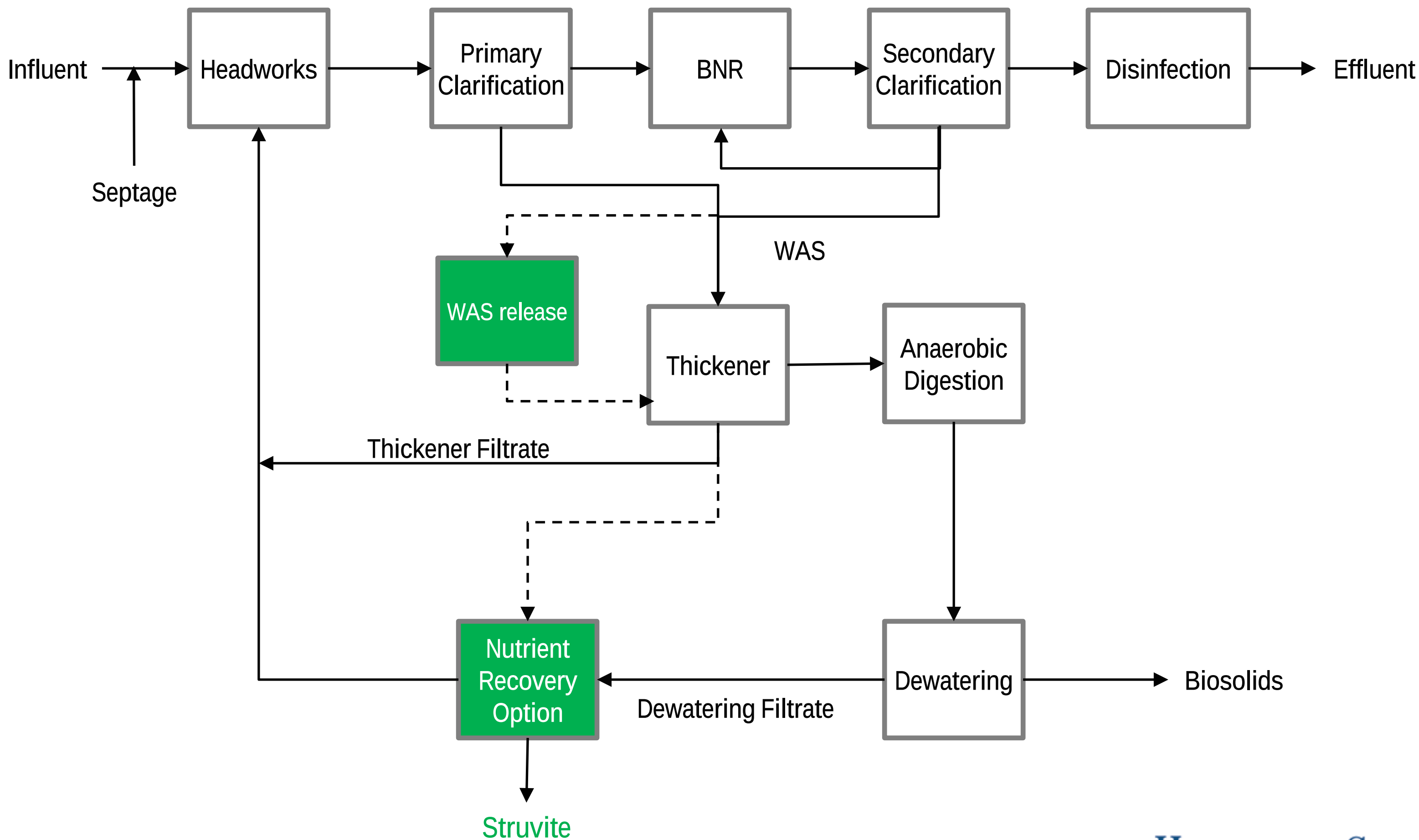
How can struvite recovery be applied?



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Tool for Evaluating Resource RecoverY developed to facilitate preliminary evaluation

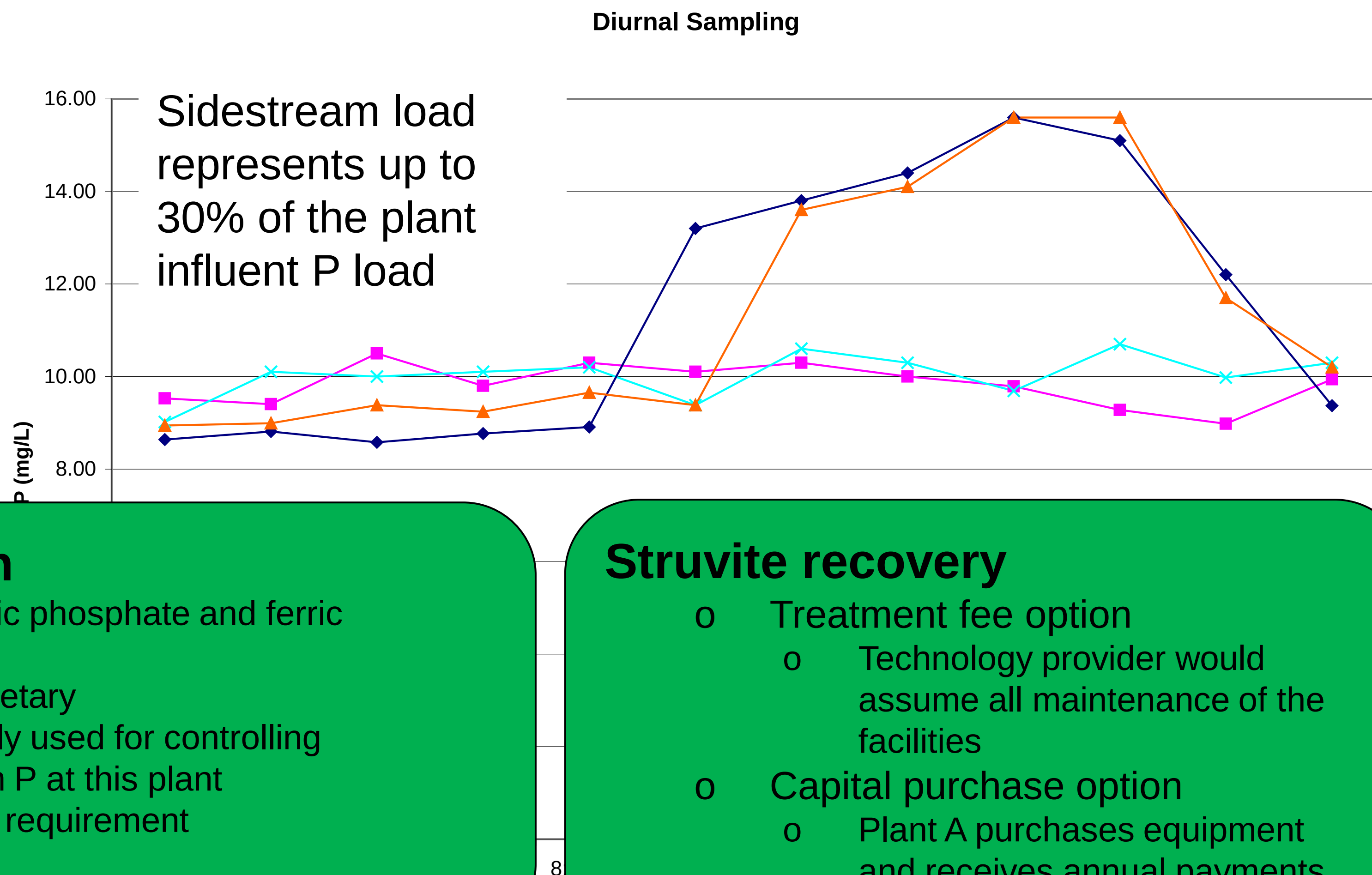
- High level economic evaluation of struvite recovery versus other technology
- www.werf.org
  - Go to nutrient recovery challenge homepage

WERF

							Business Case Model Criteria		Business Case Model Benefits Selection	
README	Start Page	Summarized Results	Plant Mass Balance	Capital and O&M Estimate Results	Business Case Evaluation Results	Do Nothing Financial Model Input	Struvite High Estimate Financial Model Input	Struvite Low Estimate Financial Model Input	Ferric Financial Model Input	Alum Financial Model Input

Title:	Tool for Evaluating Resource Recovery Beta Version 6
Contents:	Fact sheet describing struvite crystallization technology
	Ostara Pearl | Multiform Harvest | Procorp/Royal HaskoningDHV Crystalactor | Nuresys | Paques Phospaq
	Module for estimating capital and O&M costs associated with implementing sidestream P control using struvite recovery
	Module for performing cost benefit analyses of alternatives
Quick reference instructions:	Click on Start Tab
	Enter facility specific data into relevant sections in the each worksheet.
	The user will be guided to enter data in subsequent worksheets using the color code provided in the key below.
	The user can navigate between worksheets using hyperlinks embedded in each worksheet.
	Data Entry Instructions
	Green cell requires data entry by user
	Blue cell indicates calculated value that should not be changed
Detailed Instructions:	Click here for tutorial for using TERRY (not available in this version)
Cite as:	Latimer, R.; Rohrbacher, J.; Nguyen, V.; Khunjar, W. O.; Jeyanayagam, S. Towards a Renewable Future: Assessing Resource Recovery as a Viable Treatment Alternative (NTRY1R12) - Tool for Evaluating Resource Recovery Beta Version 1; Water Environment Research Foundation: 2013.

Nansemond Treatment Plant is a 30 MGD ENR Facility



Sidestream load represents up to 30% of the plant influent P load

Ferric addition

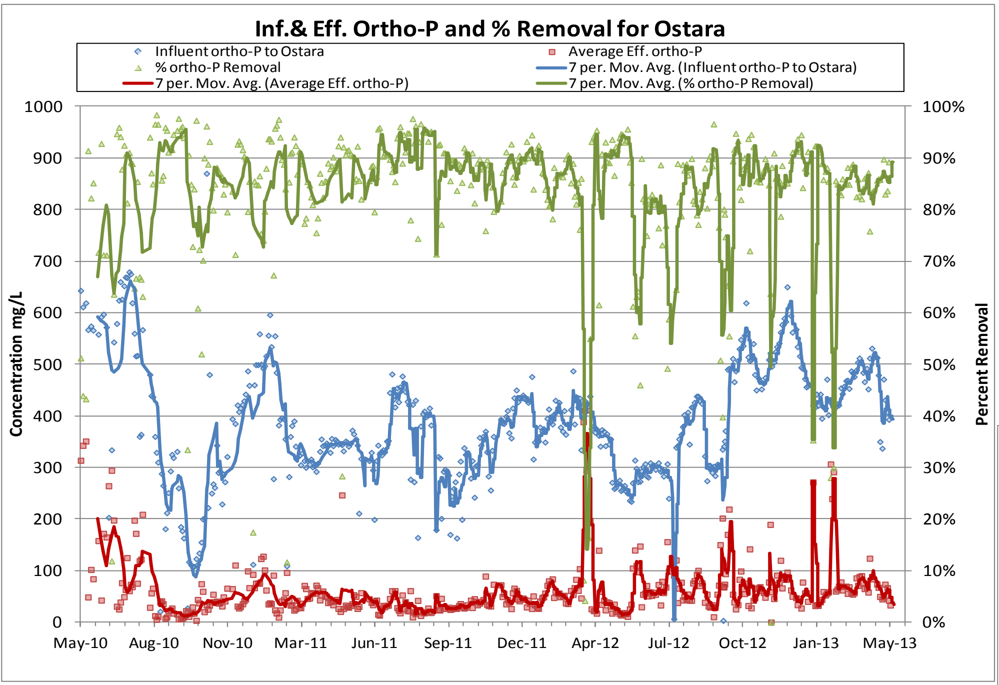
- Forms ferric phosphate and ferric hydroxide
- Non-proprietary
- Traditionally used for controlling sidestream P at this plant
- High O&M requirement

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

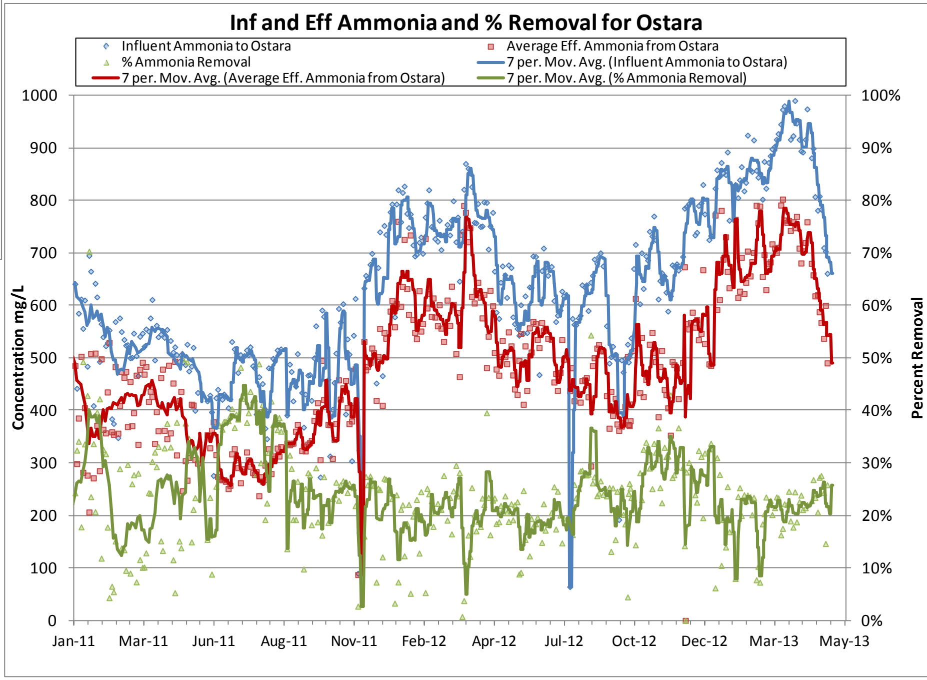
Extractive nutrient recovery option was more cost effective than ferric addition option

Orthophosphate and ammonia removal have been consistent throughout operation

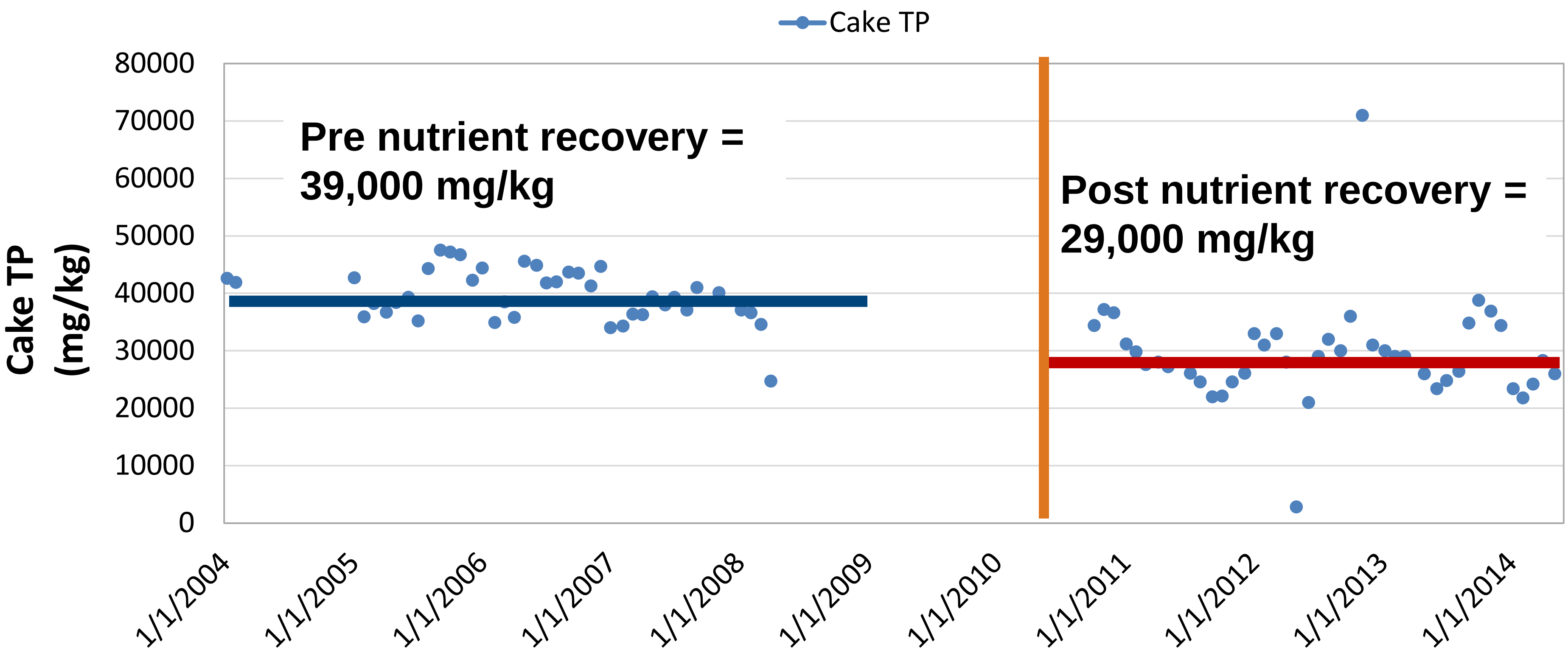


- Ortho-P removal approaches 85%

- Ammonia removal approaches 25-30%



Struvite recovery has reduced the phosphorus content of the biosolids



29% reduction in cake TP content

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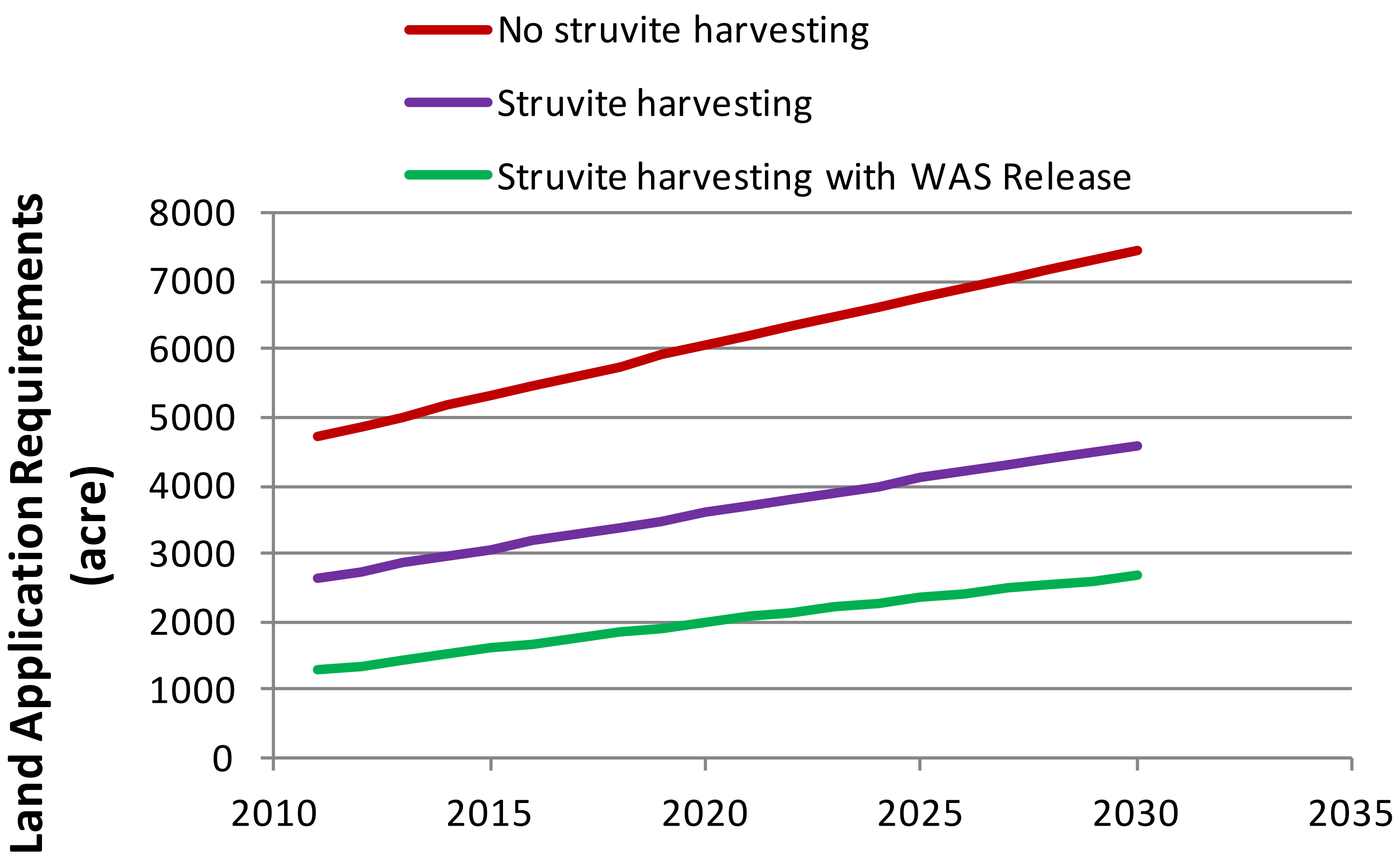
Manipulating the P content of the biosolids can reduce land application requirements

Projected land application requirements at WRRF in North Carolina



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

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

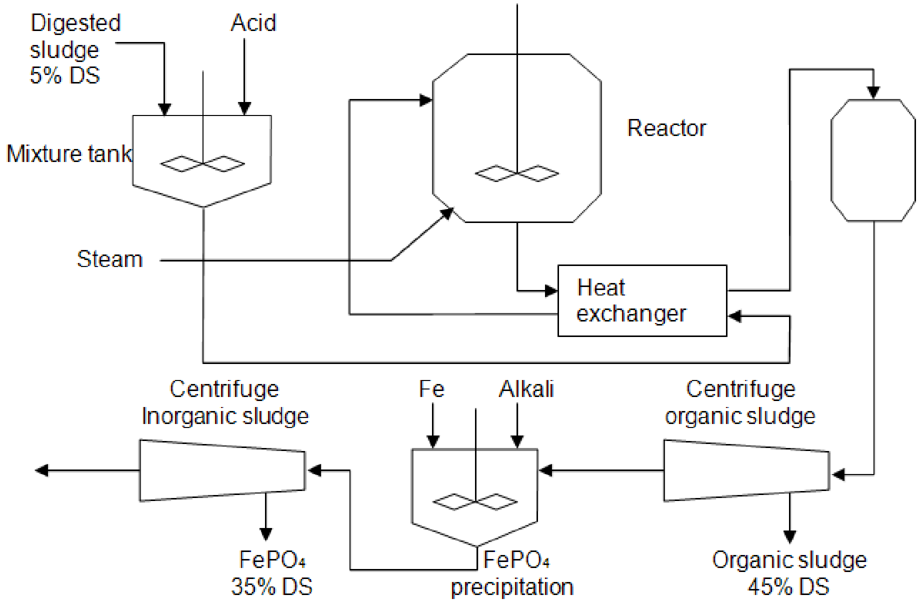


Figure 1. The KREPRO system [11].

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

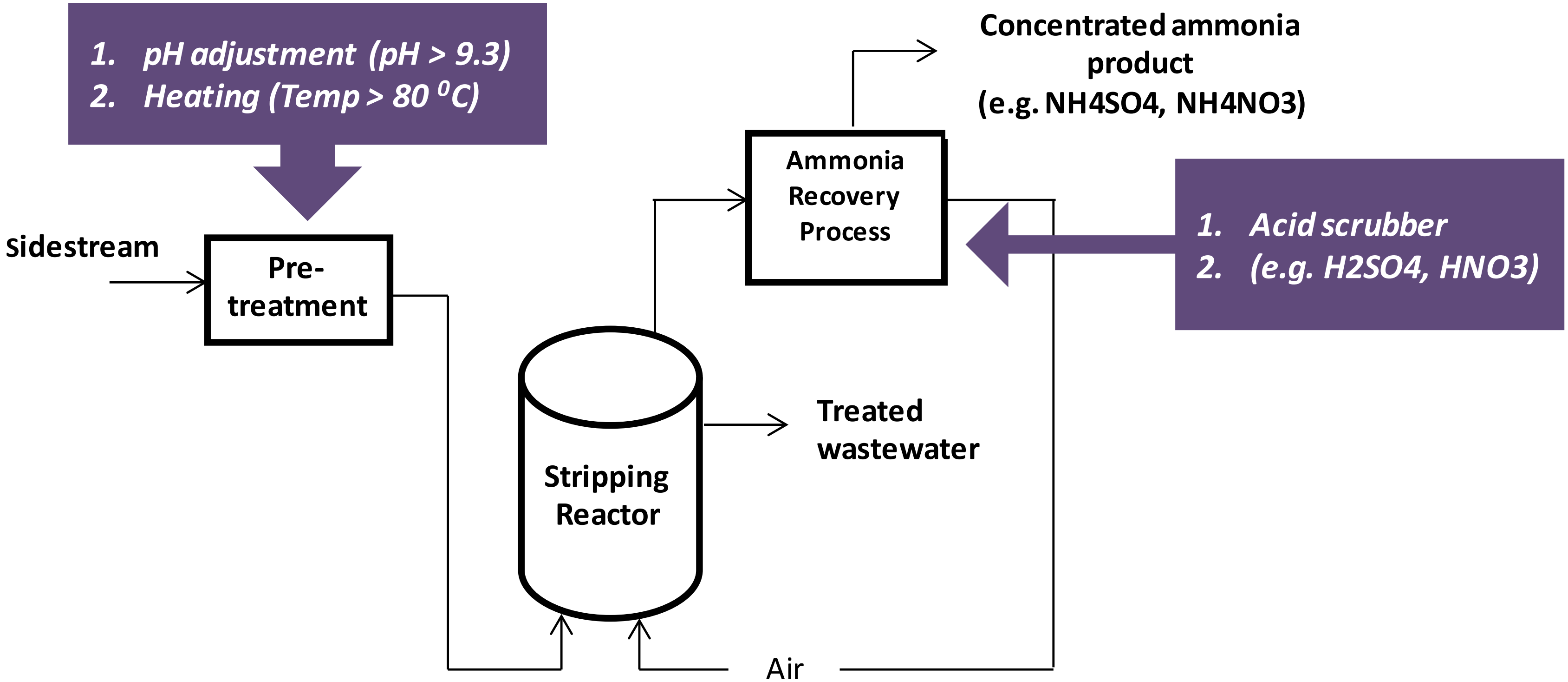
There are options to allow us to recover nutrients from ash/sludge

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

What about nitrogen only recovery?

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



Nitrogen only recovery is more economical at high nutrient concentrations

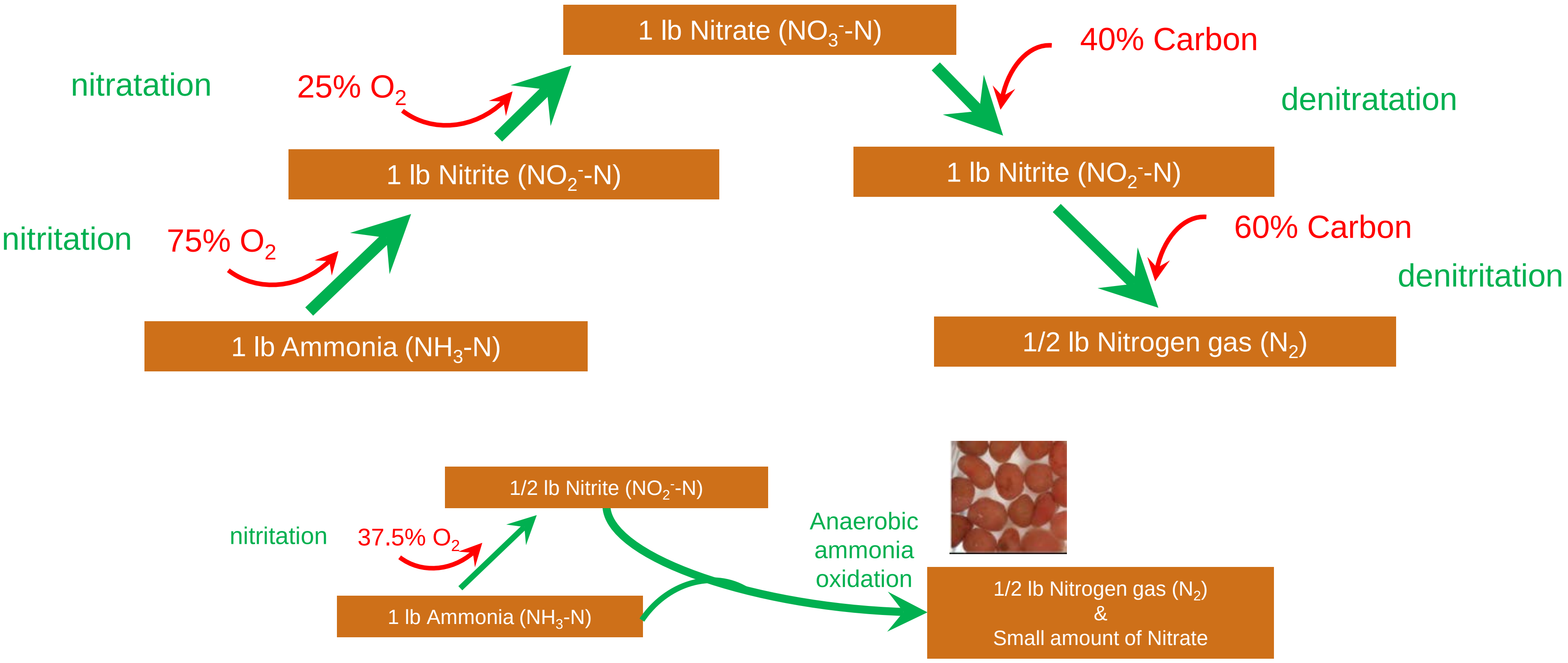
From Fassbender 2001

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
- N recovery as part of combined N and P product has higher revenue potential
- Nitrogen only recovery also limited by low cost alternatives for N treatment
  - E.g., Deammonification

What is deammonification?



Deammonification

- Save ~63% on theoretical O_2 requirements
- Save ~100% of theoretical supplemental donor requirements
- Uses Anammox bacteria

Consider two 20 MGD facilities employing 5-stage BNR for N and P removal

- City of Durham, North Carolina operates two 20 MGD WRFs
  - North Durham WRF (Plant A)
  - South Durham WRF (Plant B)

- Similar operations
  - 5-stage BNR
  - 23-hour HRT
  - Historically similar influent characteristics

Sidestream loads at N/SDWRF are significant

Plant	Percent of Total Influent Nitrogen Load
NDWRF	19%
SDWRF	21%

Equalization\reduction of these loads is fundamental to all long-term planning scenarios

Deammonification is the most cost effective option

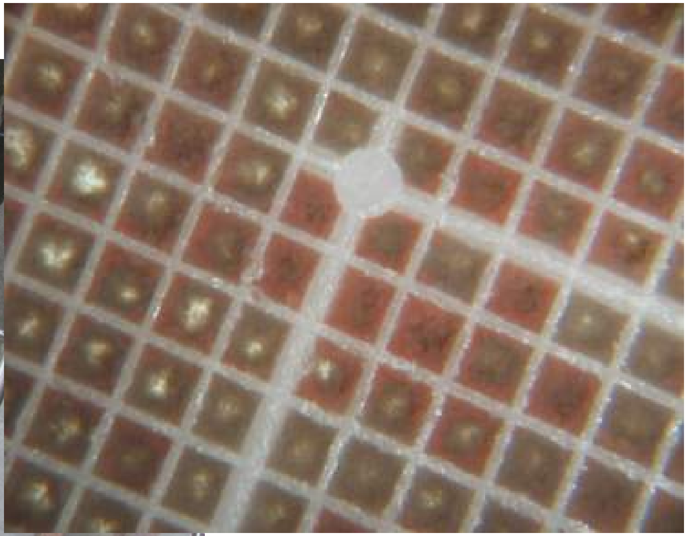
South Durham

Category/Parameter	Units	Deammonification	Nitrification and Denitrification
Cost per pound TN removed (capital)	$/lb	$0.74	$0.82
Cost per pound TN removed (O&M)	$/lb	$0.39	$1.32
Total	**$/lb**	**$1.13**	**$2.14**

North Durham

Category/Parameter	Units	Deammonification	Nitrification and Denitrification
Cost per pound TN removed (capital)	$/lb	$0.54	$0.29
Cost per pound TN removed (O&M)	$/lb	$0.39	$1.32
Total	**$/lb**	**$0.93**	**$1.61**

South Durham deammonification process is in startup



Utilizes Anitamox MBBR approach

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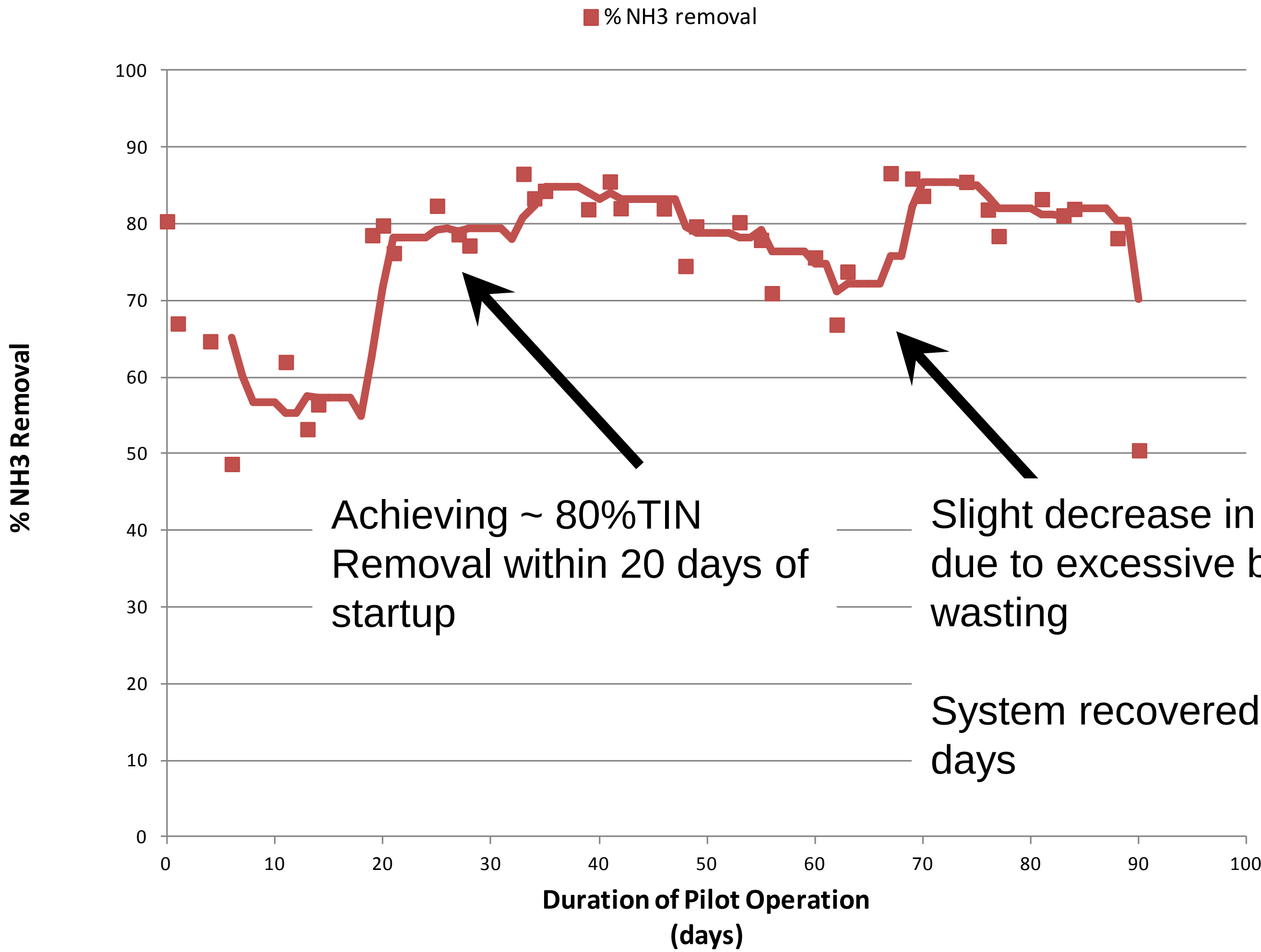
Deammonification sidestream processes stably remove nitrogen



Achieving ~ 80%TIN Removal within 20 days of startup

Slight decrease in TIN removal due to excessive biomass wasting

System recovered within 3-4 days

Perspectives on Sidestream Deammonification

- Savings from reduced aeration, supplemental carbon, lower sludge production
- Benefits to mainplant nitrification capacity
  - Seeding can also be utilized to help with nitrification performance
- Potential for seeding for mainplant deammonification
  - Sidestream biomass used to bioaugment
  - Sidestream system used to rejuvenated biomass

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Energy and Other Resources

The energy contained in wastewater is significant

Wastewater

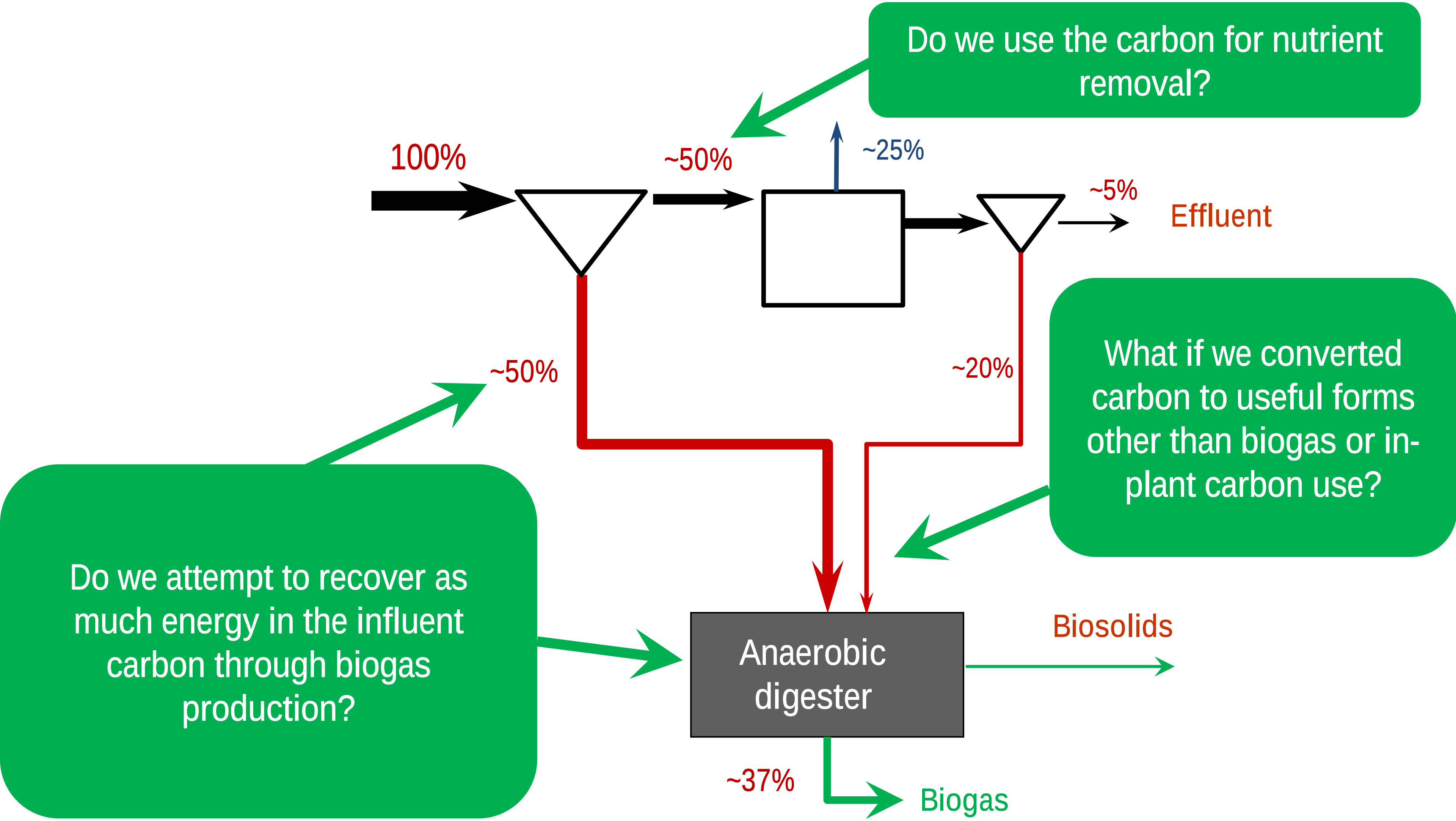
Thermal Energy
Heat

Hydraulic Energy
Moving Water

Chemical Energy
Soluble and insoluble contaminants

Images Courtesy Metro Wastewater Treatment Plant in MI and F. Wayne Hill Water Resources Center in GA

Managing chemical energy flow throughout the plant is a key element of plants of the future



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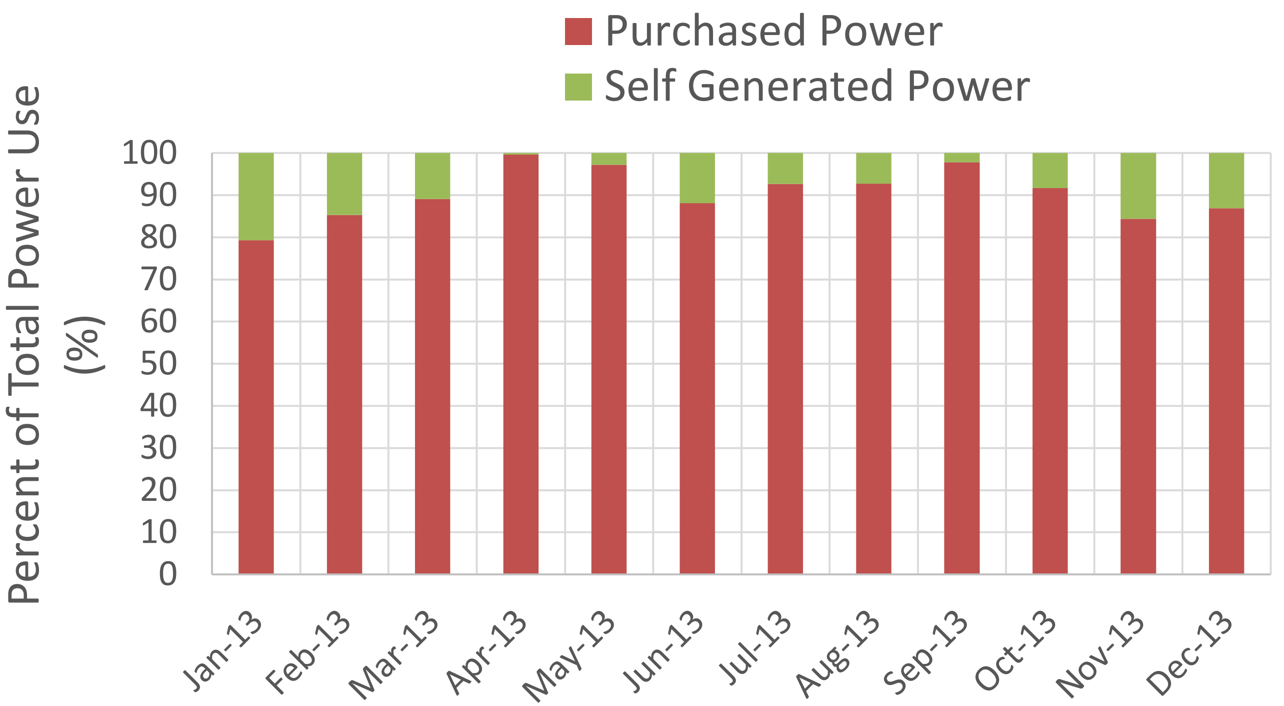
FOG and food waste co-digestion at the F. Wayne Hill WRC

- Have 2.1 MW CHP recovery system
- How to utilize capacity?
- Assessed co-digestion to enhance energy recovery
  - Poultry DAF Skimmings
  - FOG Source A
  - Grocery DAF Skimmings
  - FOG Source B
  - Dewatered FOG Source B
  - Chewing Gum Waste (CGW)

Full-scale implementation of co-digestion has led to savings of up to $2 million per year



- **Not just magnitude of production**
- **Store gas and utilize during peak hours to reduce electrical cost**
- **Energy procurement contracting cannot be ignored**

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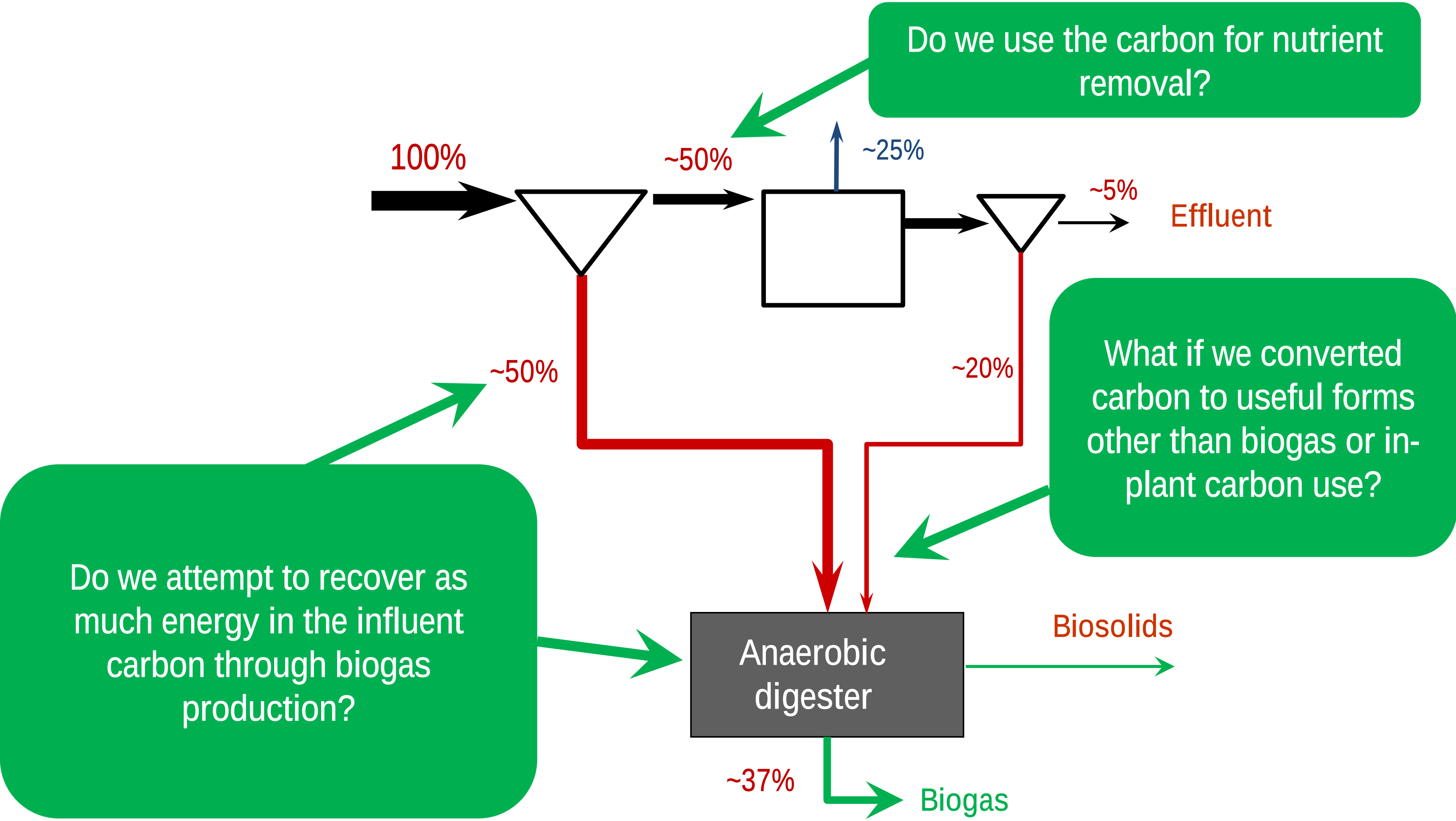
Managing chemical energy flow throughout the plant is a key element of plants of the future



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Nansemond Treatment Plant

- 30 mgd design flow
  - TN < 8 mg/L
  - TP < 1 mg/L

- Low C:N and C:P influent characteristics
- >10,000 lbs / day purchased supplemental carbon (as COD)

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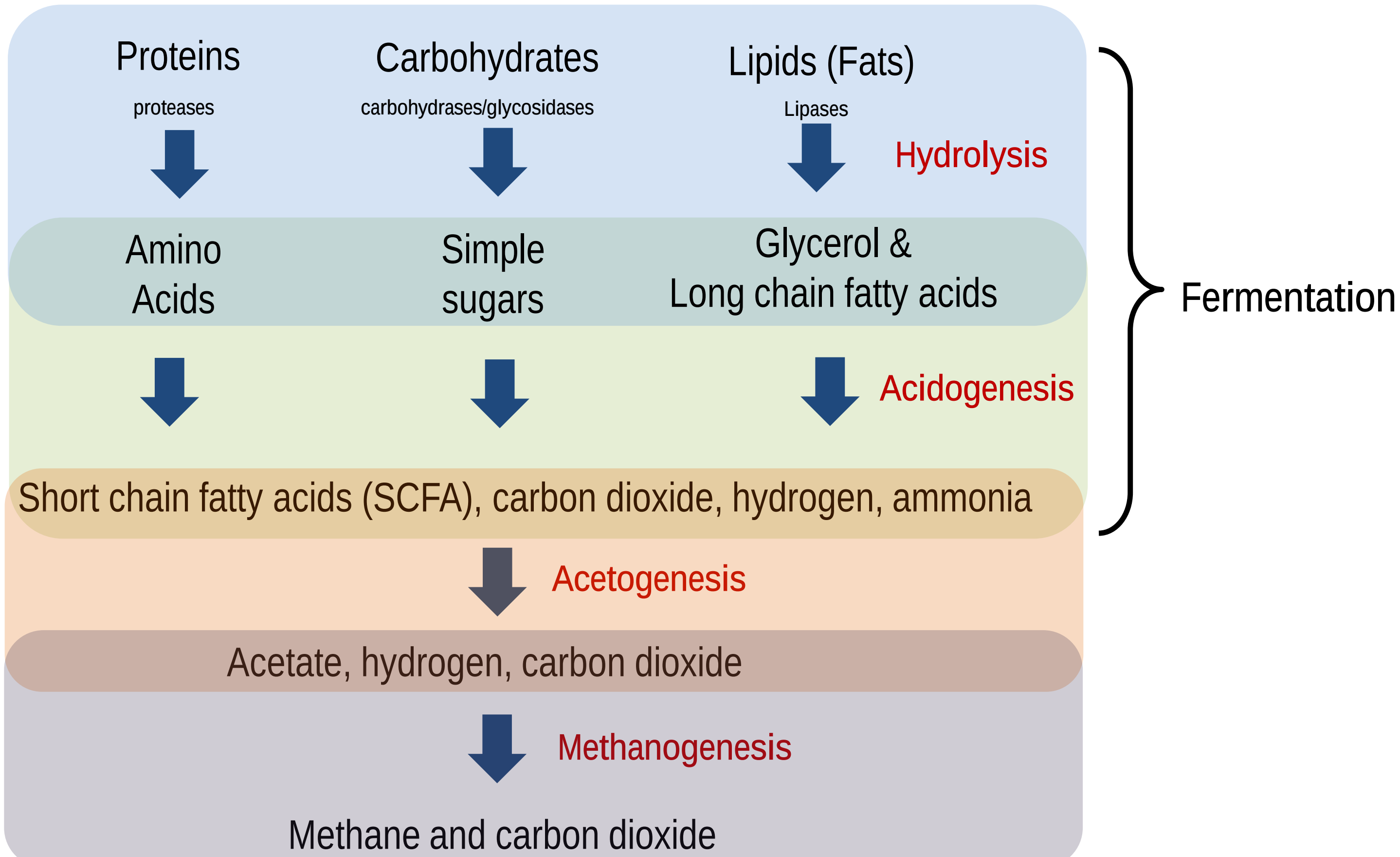
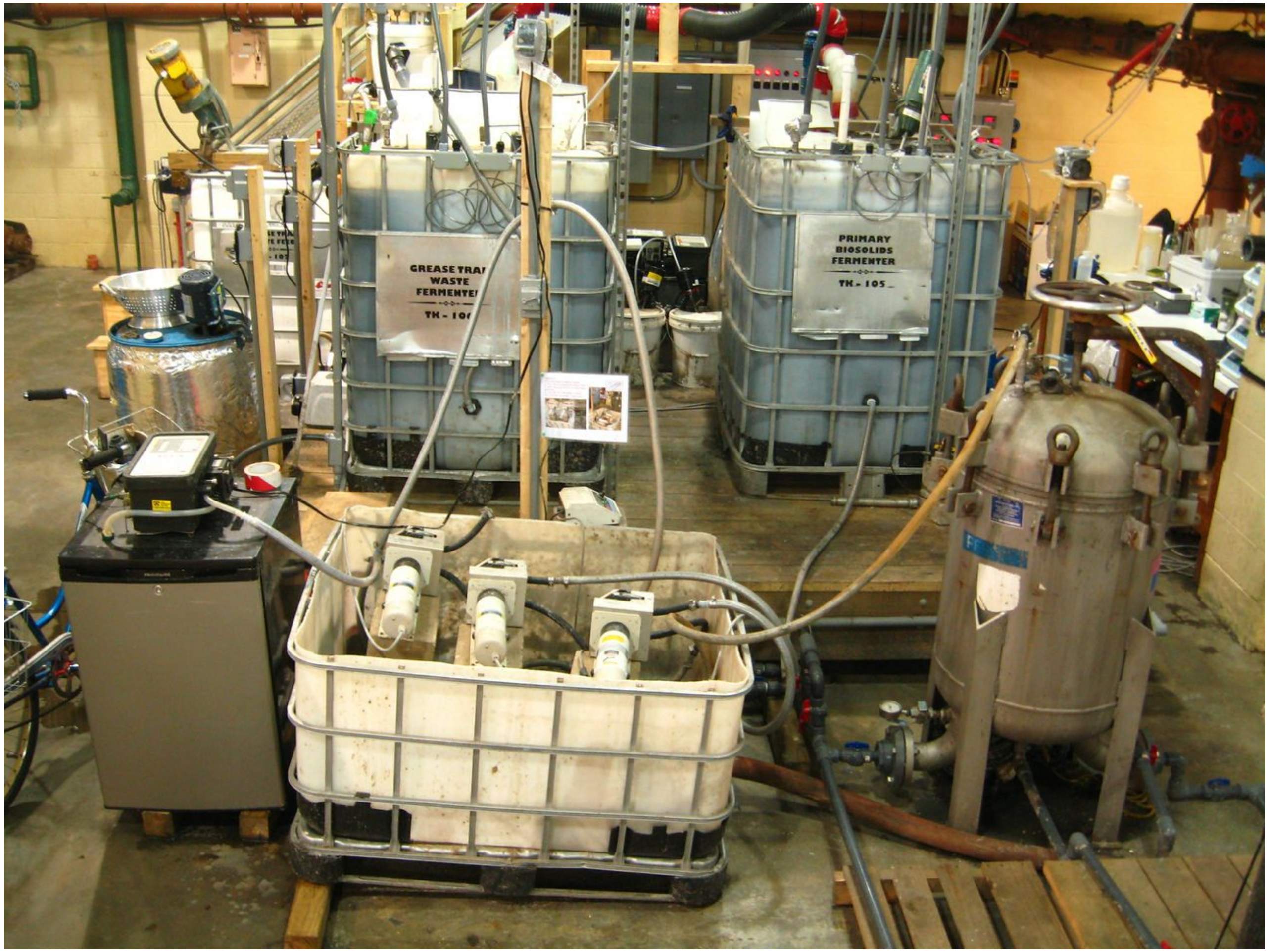
Recovering carbon can offset operational costs



- Preferentially produce volatile fatty acids through fermentation of PS, FOG, High strength food wastes

Co-fermentation of FOG and PS was piloted at HRSD in VA



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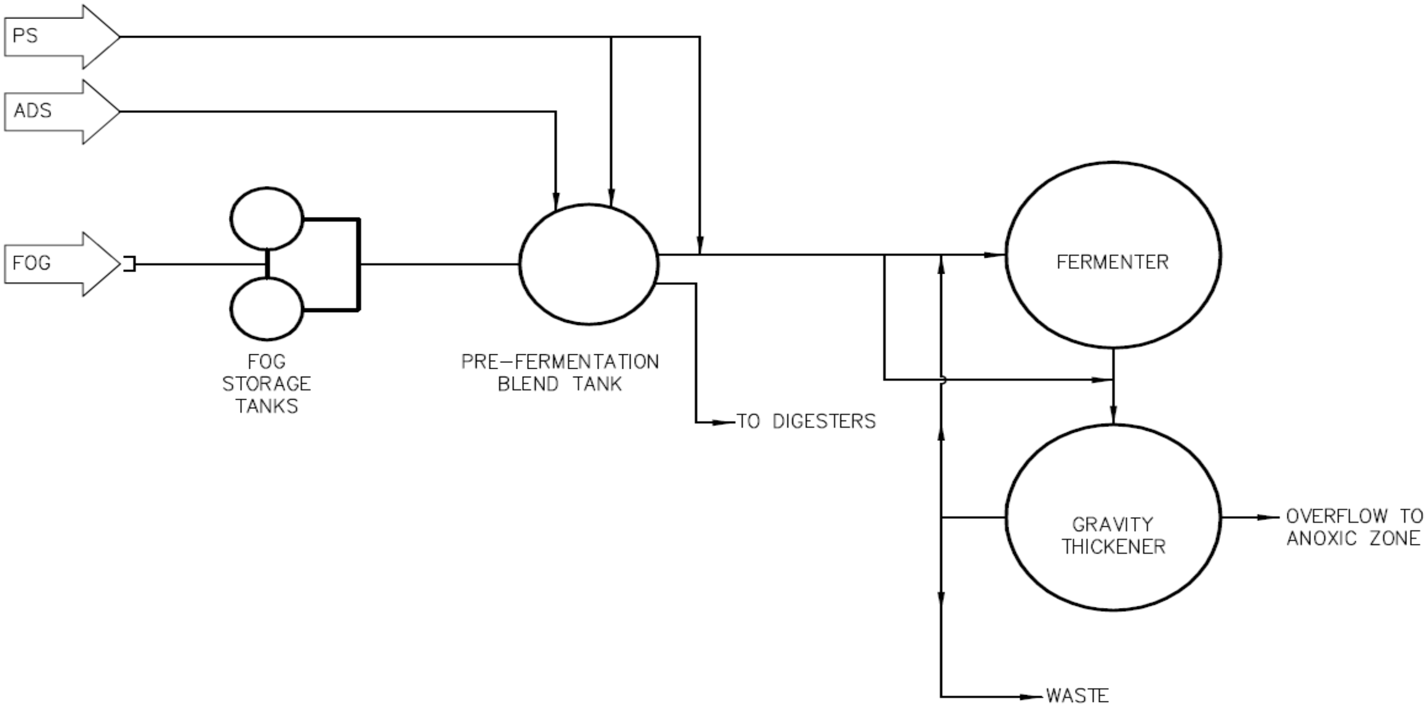
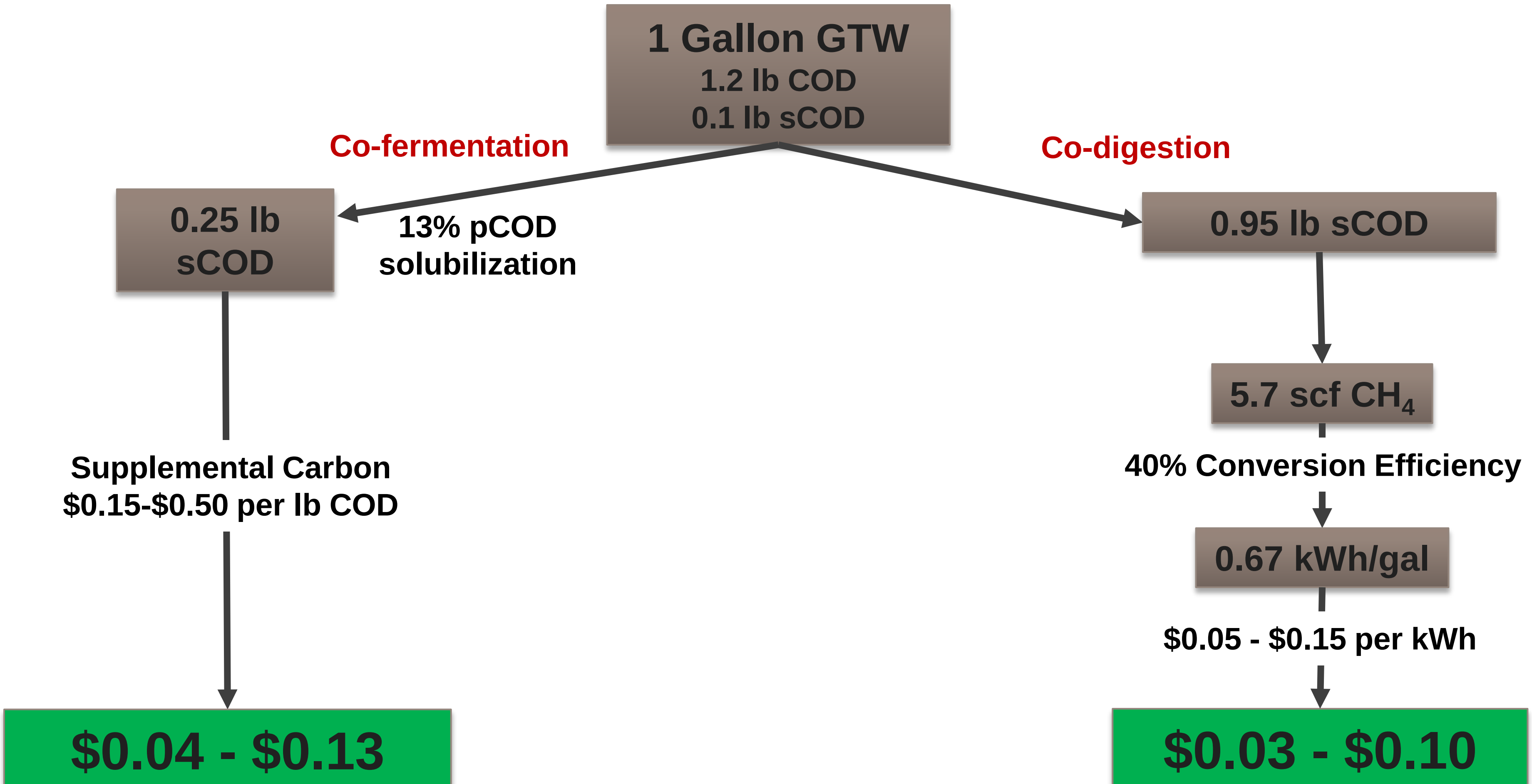
Data from the pilot was used to develop conceptual level designs for a full scale fermentation facility



Value of Carbon

Co-Fermentation and Co-Digestion



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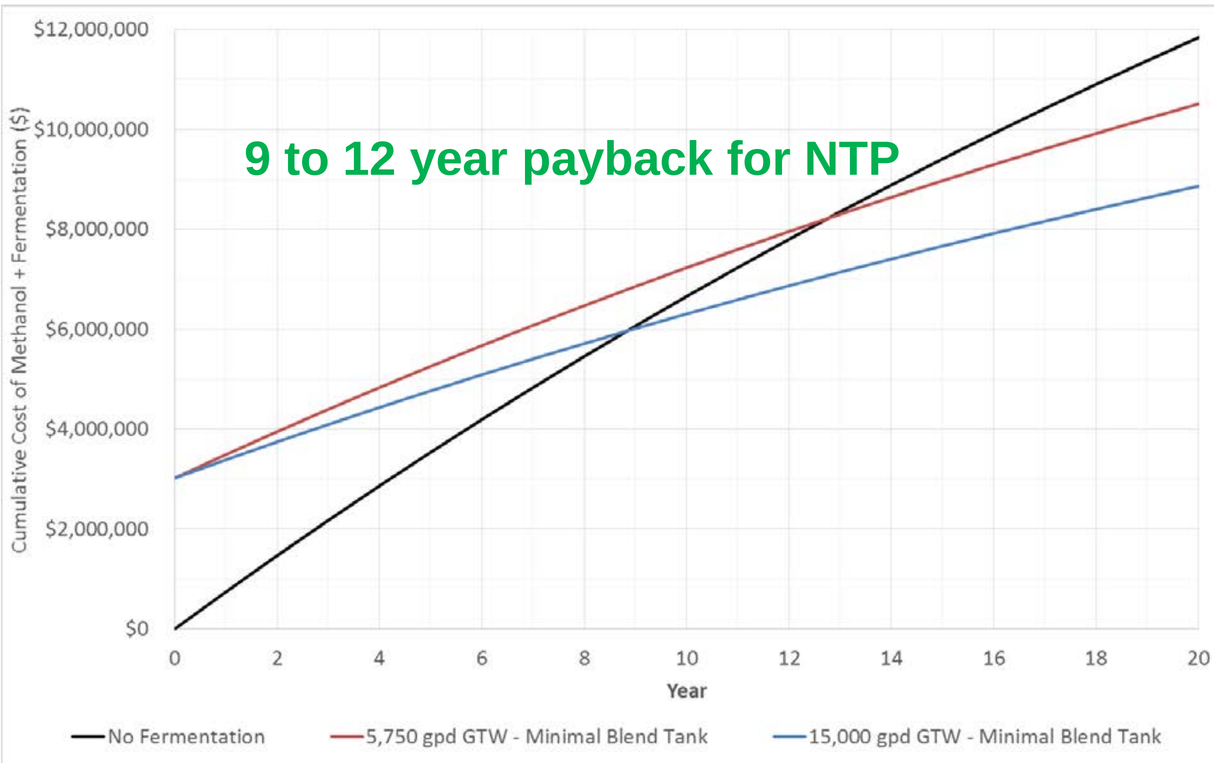
Implementing co-fermentation would result in savings over the 20 year lifetime



- **Co-Fermentation vs. Co-Digestion**
  - Not always an either/or decision
  - Depends on supplemental carbon cost and electricity/natural gas cost
  - Site specific evaluation is necessary

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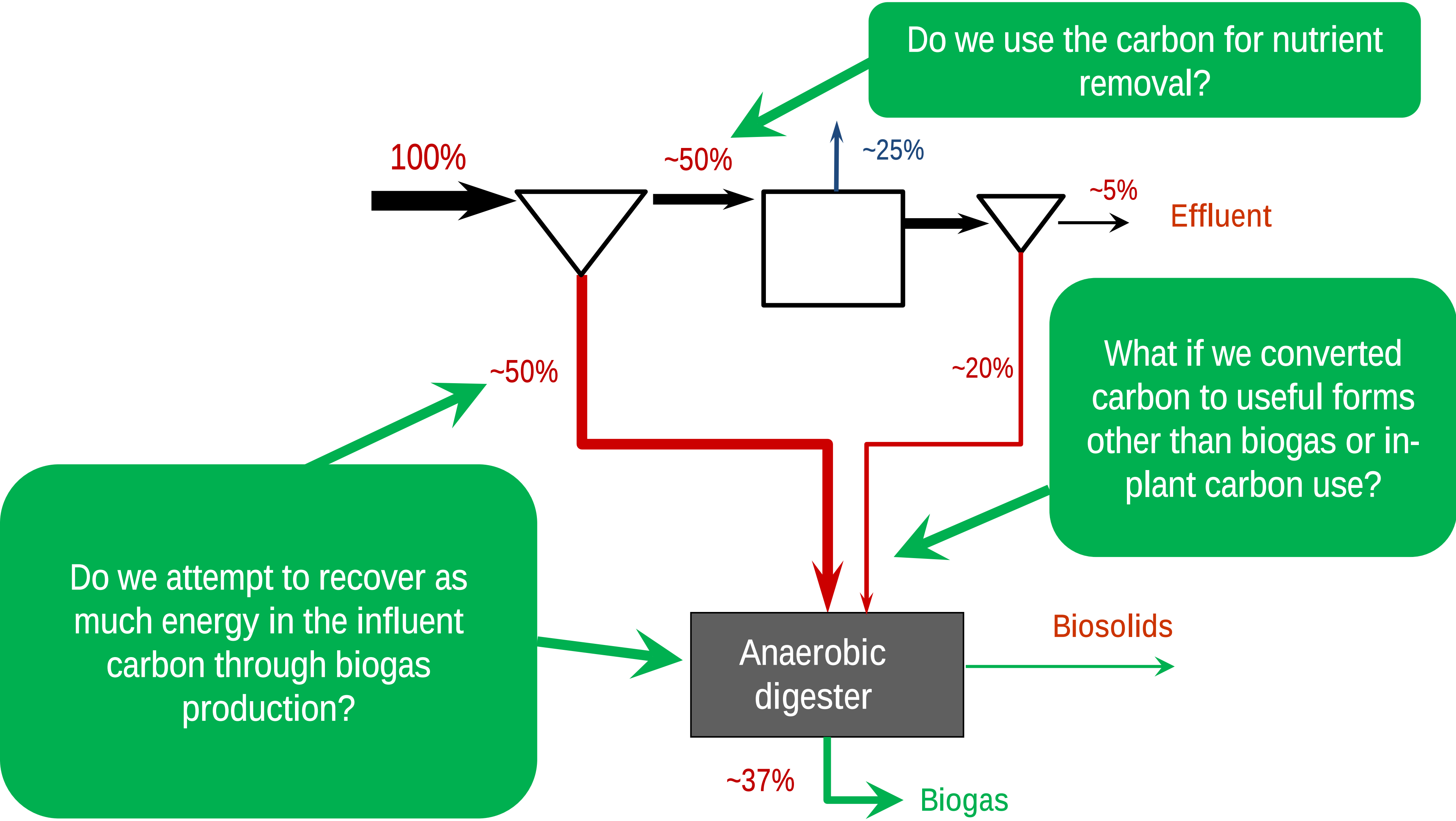
Managing chemical energy flow throughout the plant is a key element of plants of the future



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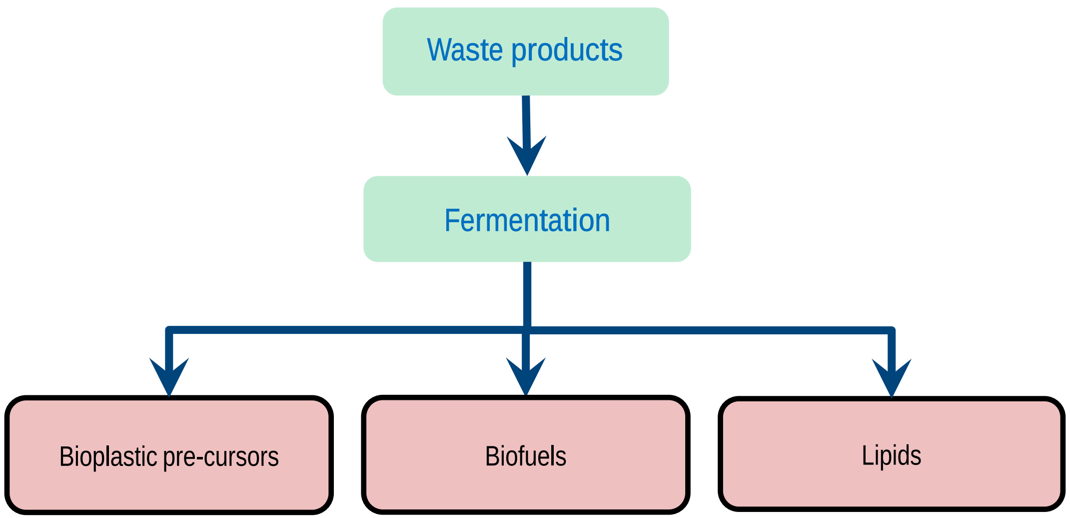
Fermentation products can also be used for to produce other valuable resources



WERF NTRY3R13-
Beyond Nutrients: Recovering Carbon and Other Commodity Products from Wastewater

WERF NTRY4R13-
Multi-Platform Approach to Recovering High Value Carbon Products From Wastestreams

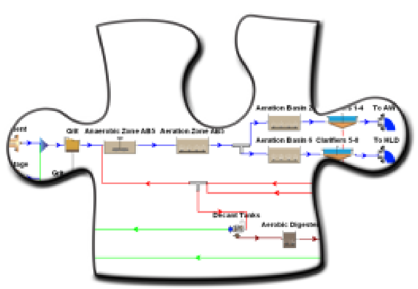
Today we sit at a crossroad of opportunity…

Business as usual

Utility of the Future

Liquid Treatment

Sidestream Treatment



Solids and Residuals Treatment

Reuse

Stormwater

Wendell Khunjar, PhD, PE

4035 Ridge Top Road, Suite 400, Fairfax VA 22030

1 South St #1150, Baltimore, MD 21202

703 267-2759 (direct)

wkhunjar@hazenandsawyer.com

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