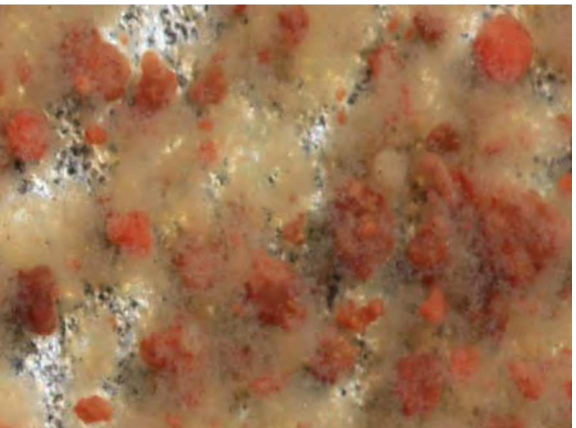
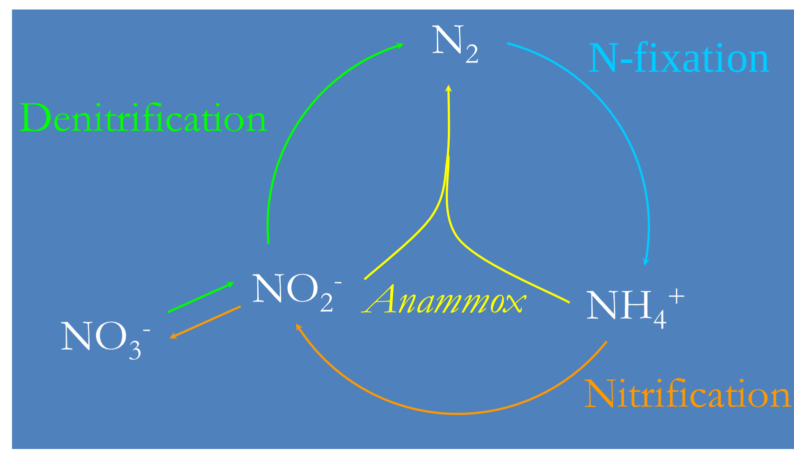
Advances in Point Source Nutrient Removal Technologies: Doing more with less…



Charles B. Bott, PhD, PE, BCEE

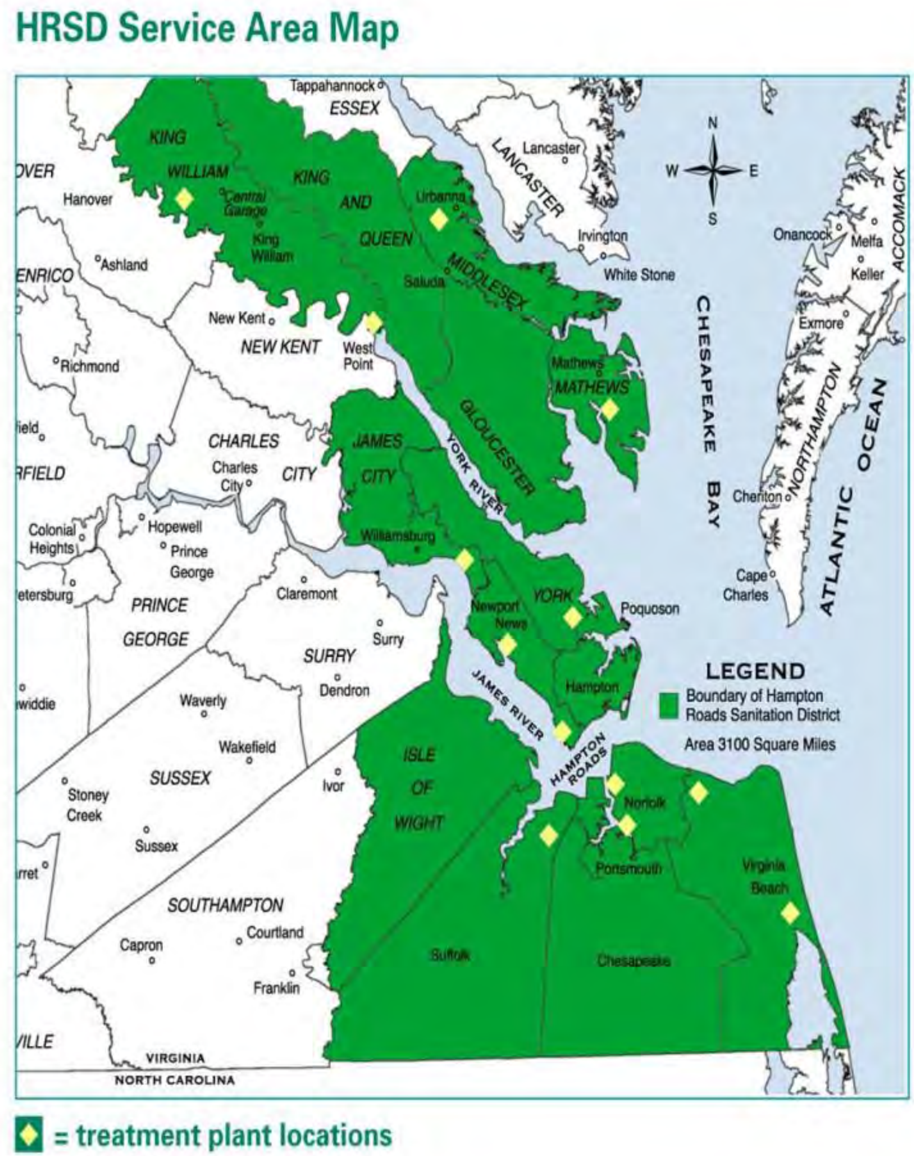
Chief of Research and Development

Hampton Roads Sanitation District

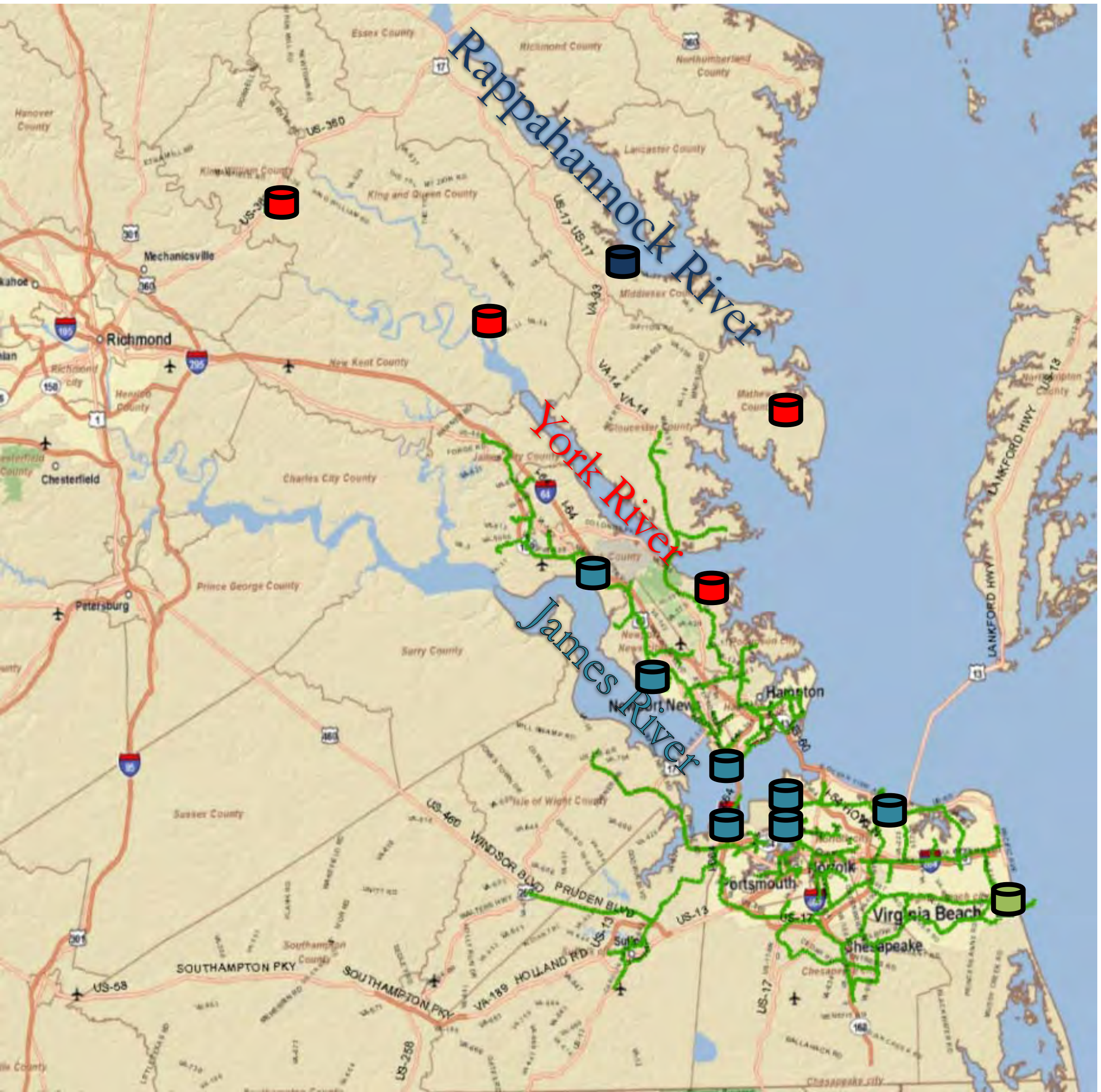


Hampton Roads Sanitation District

- Created in 1940
- Serves 1.7 million people
- Includes 17 jurisdictions – 3,100 square miles
- 9 major plants, 4 small plants
- Capacity of 249 MGD



HRSD's Bubble Permit - 2011



- James River
  - 6,000,000 lbs/yr TN
  - 573,247 lbs/yr TP
- York River
  - 288,315 lbs/yr TN
  - 33,660 lbs/yr TP
- Rappahannock River (one plant)
  - 1,218 lbs TN
  - 91 lbs/yr TP

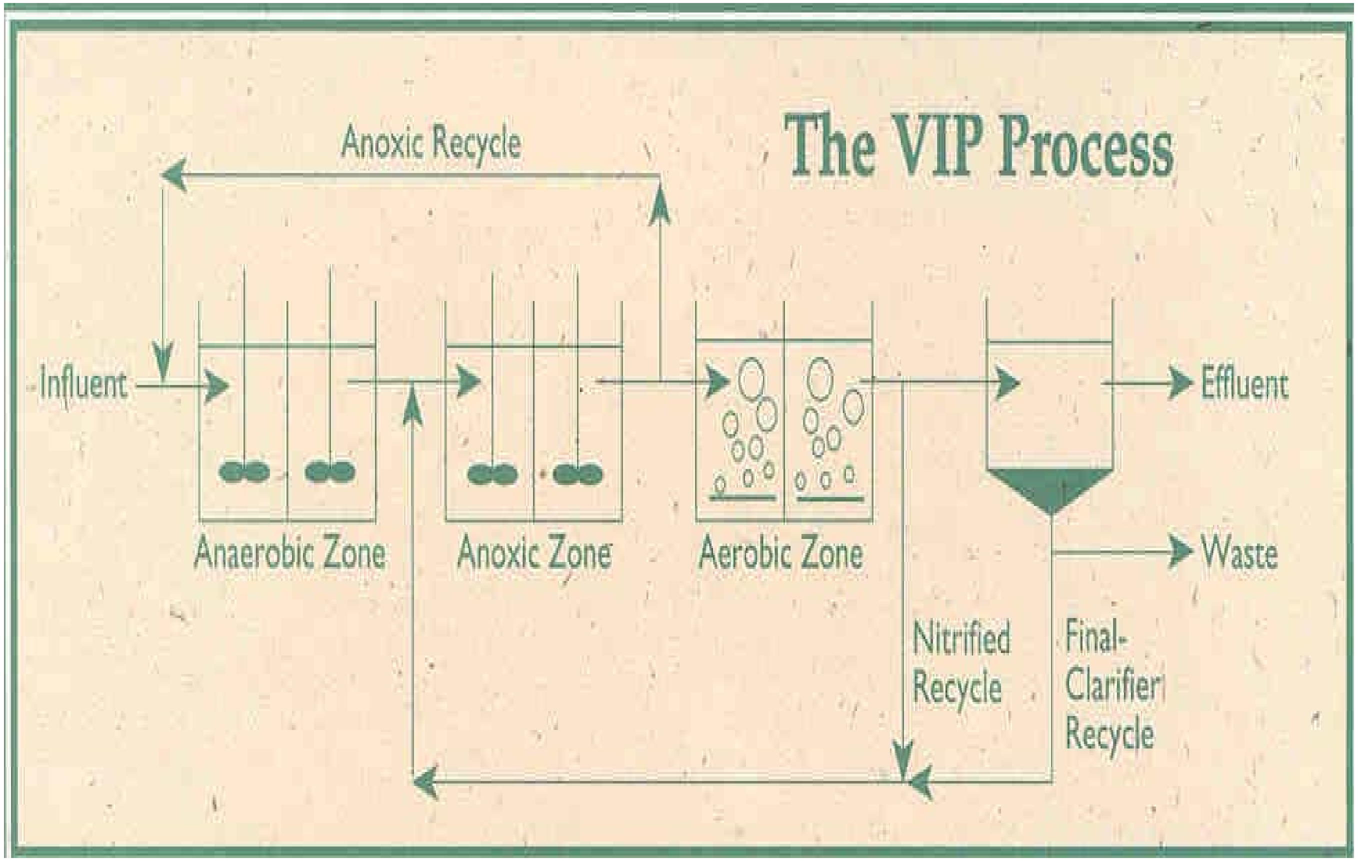
Chesapeake Bay TMDL & VA WIP

- Nitrogen – James River
  - 2011 – 6.0 million pounds/year
    - Major upgrades ongoing at Nansemond, James River, Williamsburg, Army Base
  - 2017 – 4.4 million pounds/year
    - VIP - biological process upgrade for improved denitrification
    - Small upgrade at Williamsburg possible
  - 2021 – 3.4 million pounds/year (possible?)
    - Upgrade or Close Chesapeake-Elizabeth?
- Nitrogen – York River
  - Rapid upgrade to add denite filters for 2011 compliance
  - Additional upgrade needed for cost-effective BNR and reliability

HRSD R&D Program Focus

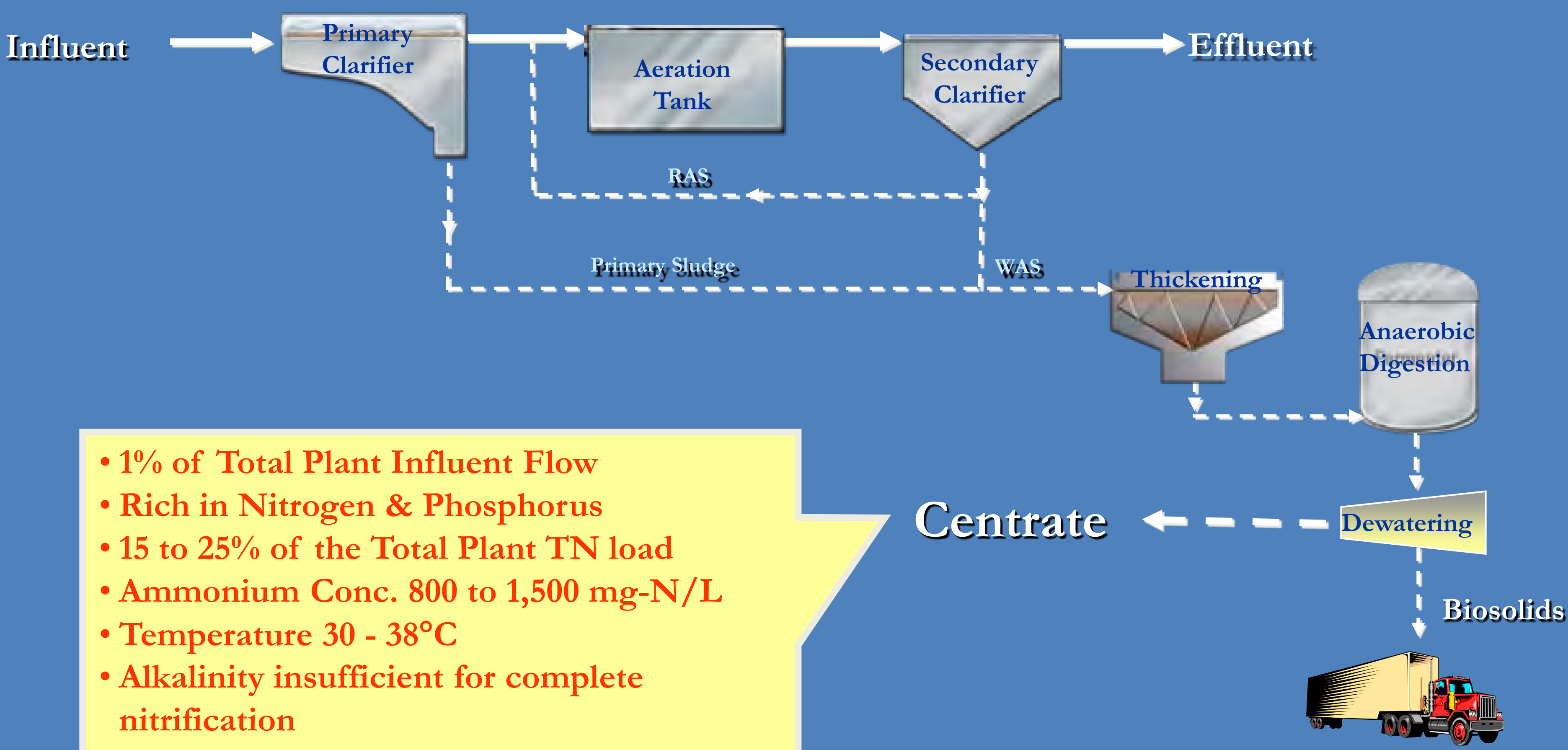
- Resource utilization:
  - Energy
  - Chemicals
  - Labor (operations, maintenance, instrumentation…)
  - Concrete, footprint, land area
- Resource recovery
  - Water
  - P
  - N (maybe)
  - CH_4 - biogas
  - Heat
  - Hydraulic energy
  - Chemicals of interest (maybe)
  - Biosolids (N, P, organics)
  - Etc, etc, etc

The VIP® Process



- It was developed and patented by HRSD, VT, and CH2M Hill
- Biological N and P removal
- Its free for any one to use…

Recycle Streams with High Ammonia - Sidestream



- 1% of Total Plant Influent Flow
- Rich in Nitrogen & Phosphorus
- 15 to 25% of the Total Plant TN load
- Ammonium Conc. 800 to 1,500 mg-N/L
- Temperature 30 - 38°C
- Alkalinity insufficient for complete nitrification
- Insufficient carbon for denitrification

- For a Bio-P plant with no iron addition:
    - Centrate TP = 200-800 mg/L

Sidestream Treatment Options

Biological - N

1.0 Nitrification / Denitrification & Bioaugmentation
- With RAS & SRT Control
- With RAS
- Without RAS

2.0 Nitritation / Denitritation
- Chemostat
- SBR
- Post Aerobic Digestion

3.0 Deammonification
- Suspended Growth SBR
- Attached Growth MBBR
- Upflow Granular Process

Physical-Chemical – N&P

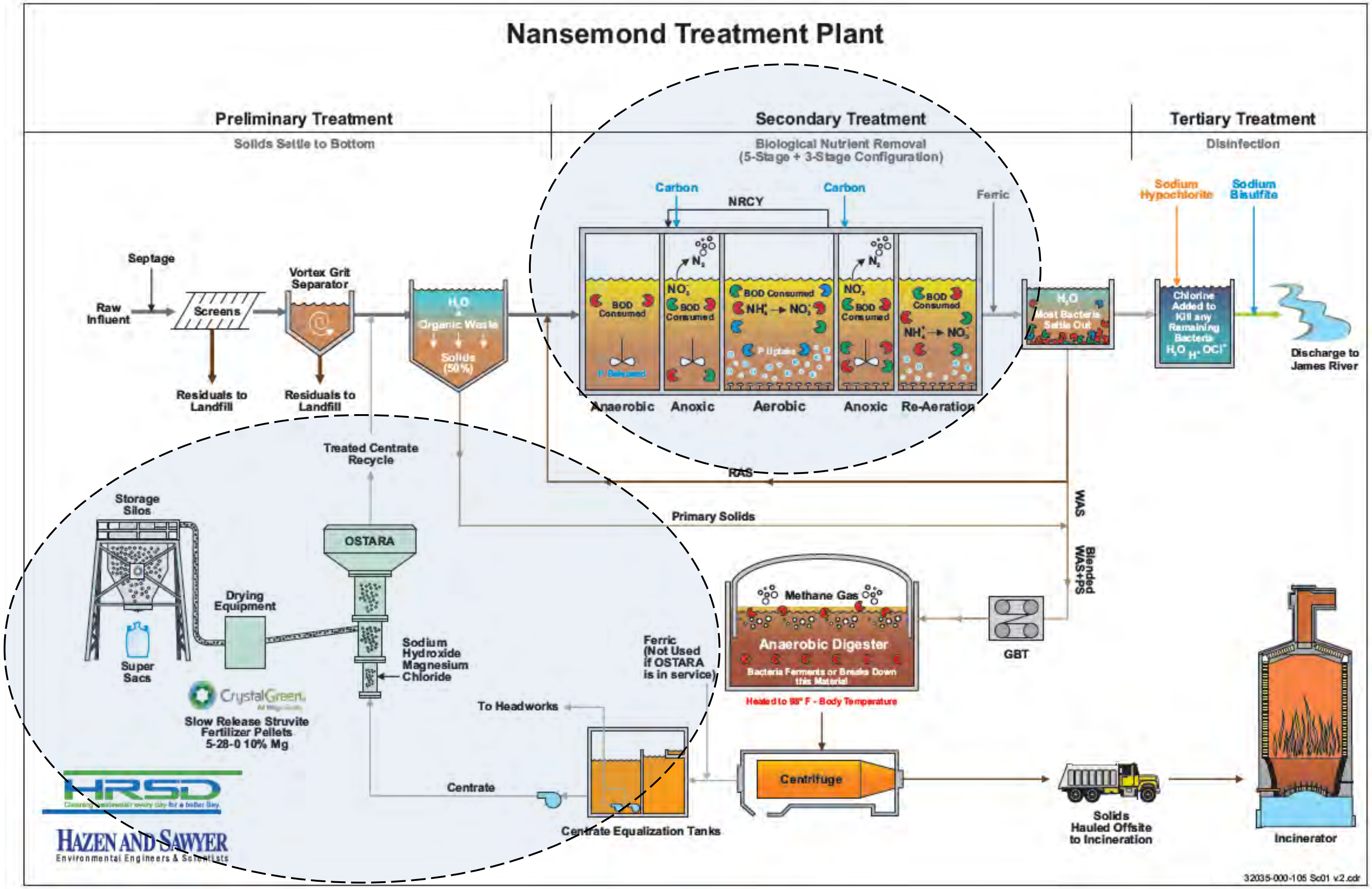
Ammonia Stripping
- Steam
- Hot Air
- Vacuum Distillation

Ion-Exchange
- ARP

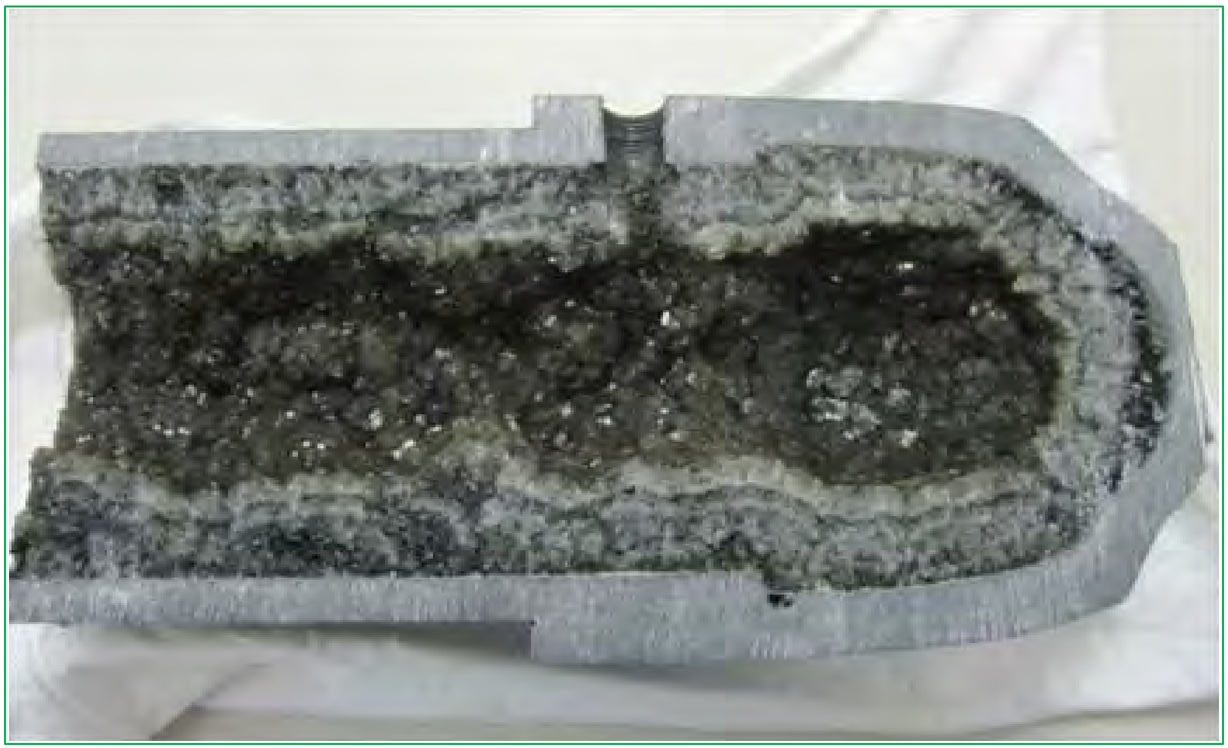
Struvite Precipitation
- Ostara Process
- PhosPaq Process
- Etc

HRSD Nansemond Treatment Plant Upgrade

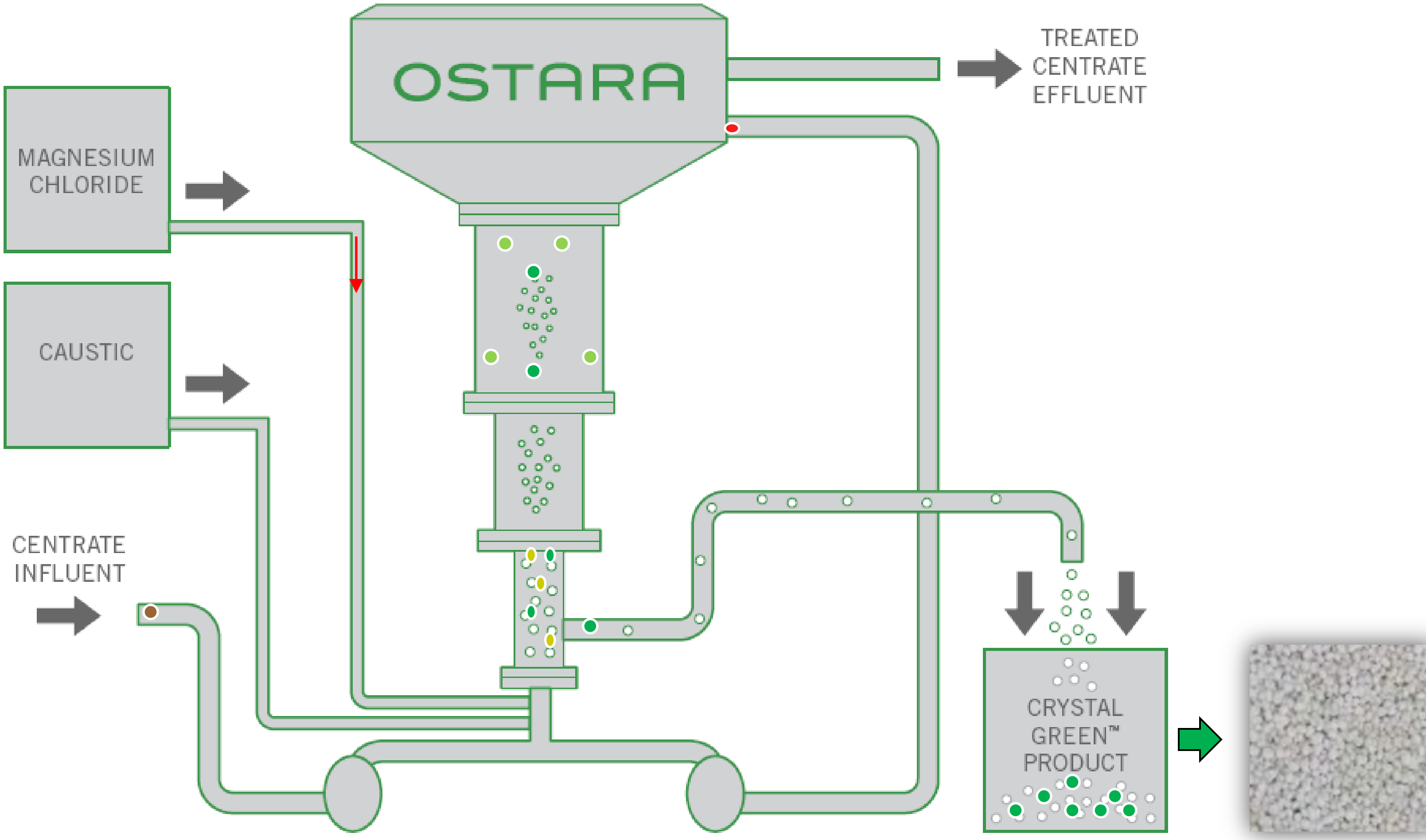
Nansemond Plant Process Flow Diagram



What is Struvite?



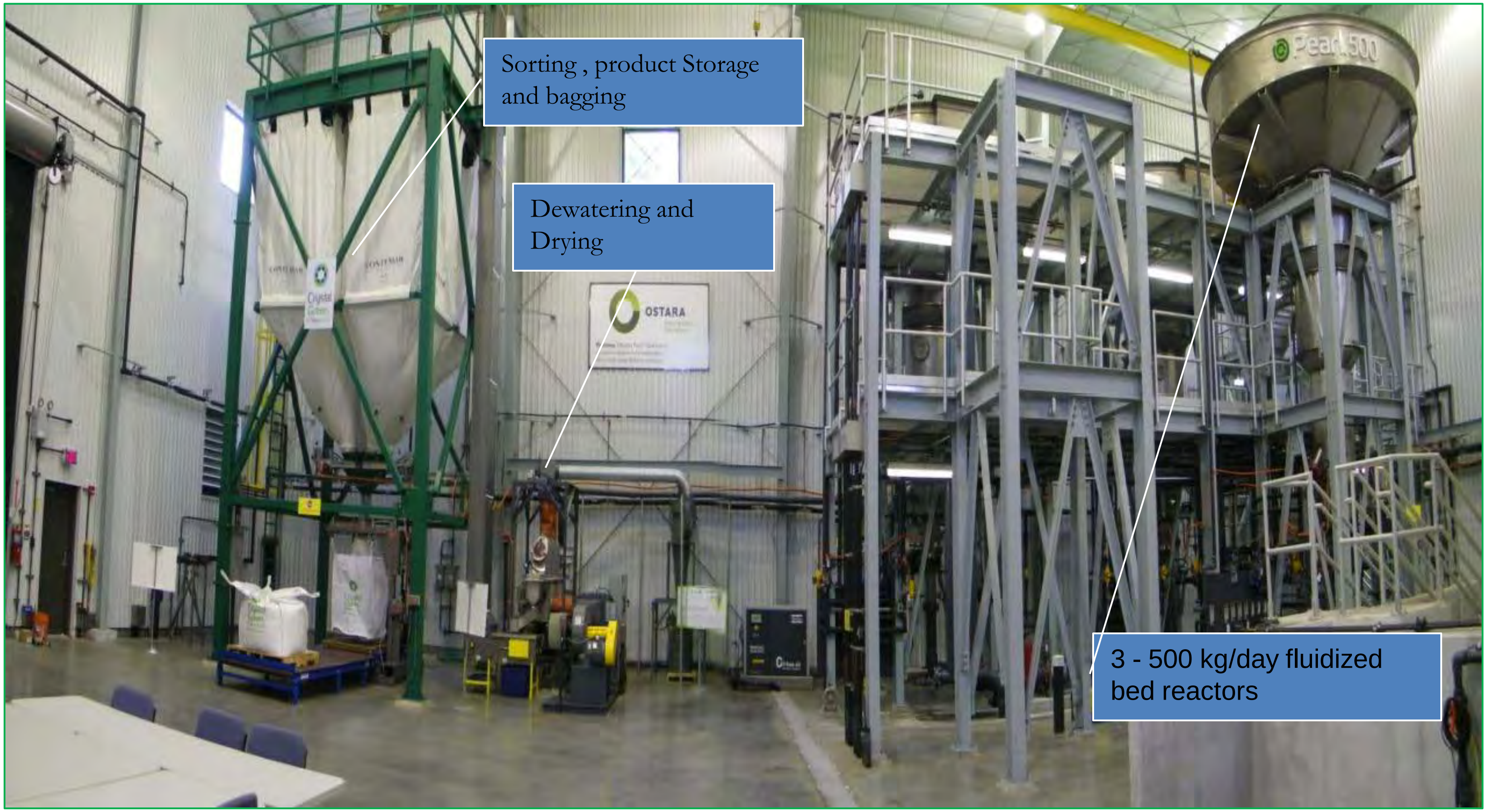
What is the Ostara® Process?



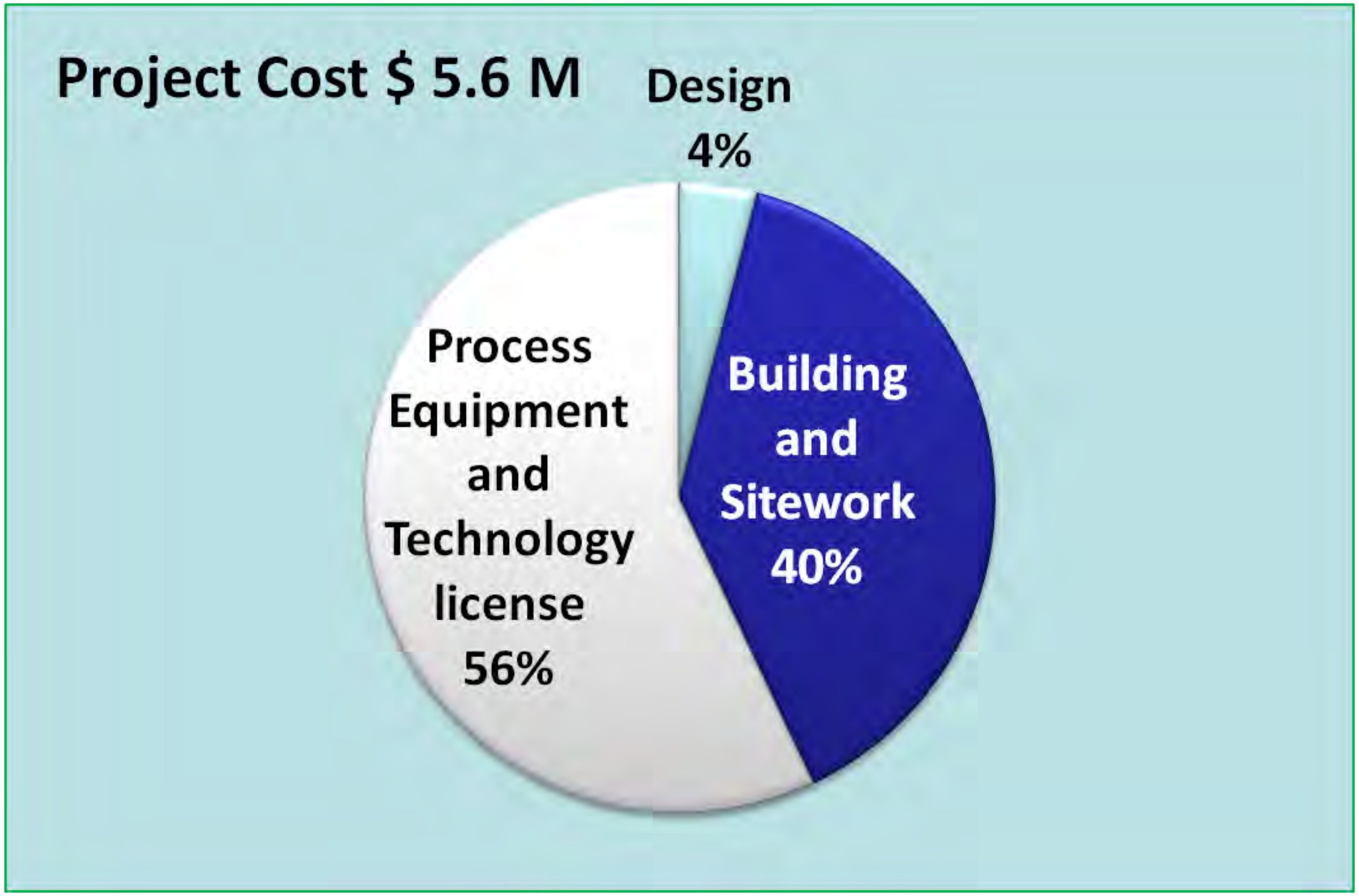
Struvite Facility Construction Schedule

- Proposal Submitted July 2009
- Commission Approval October 2009
- Contract Signed November 2009
- Operational May 2010
- Ribbon-cutting May 27, 2010

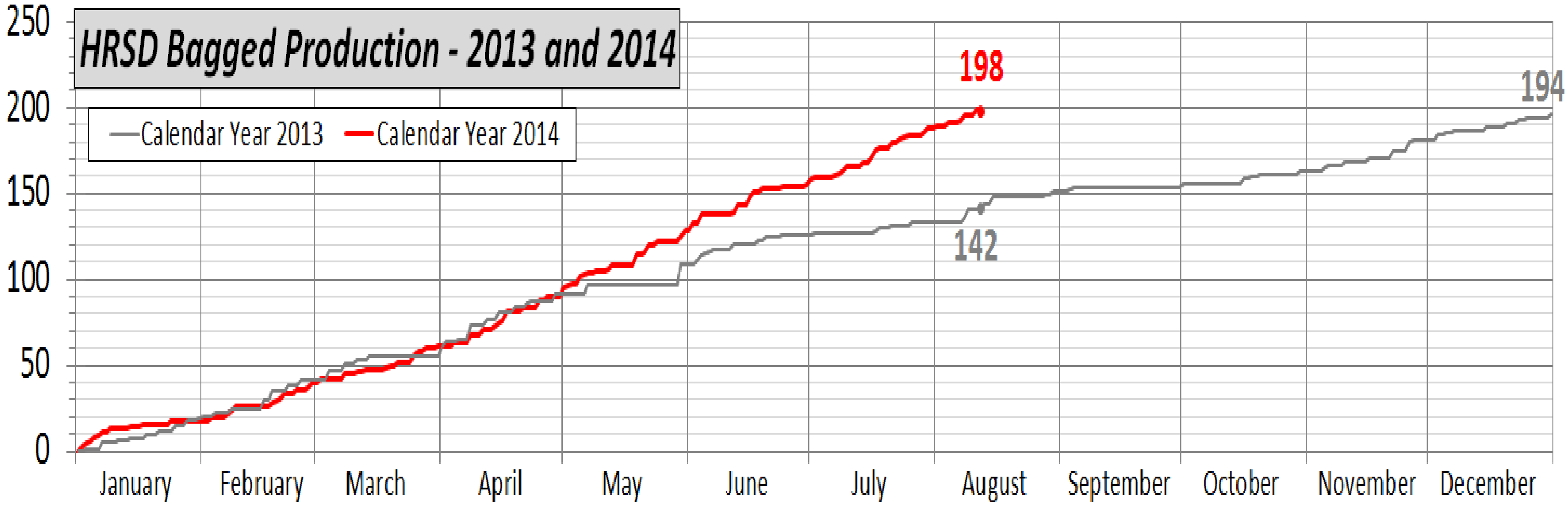
Struvite Recovery Facility



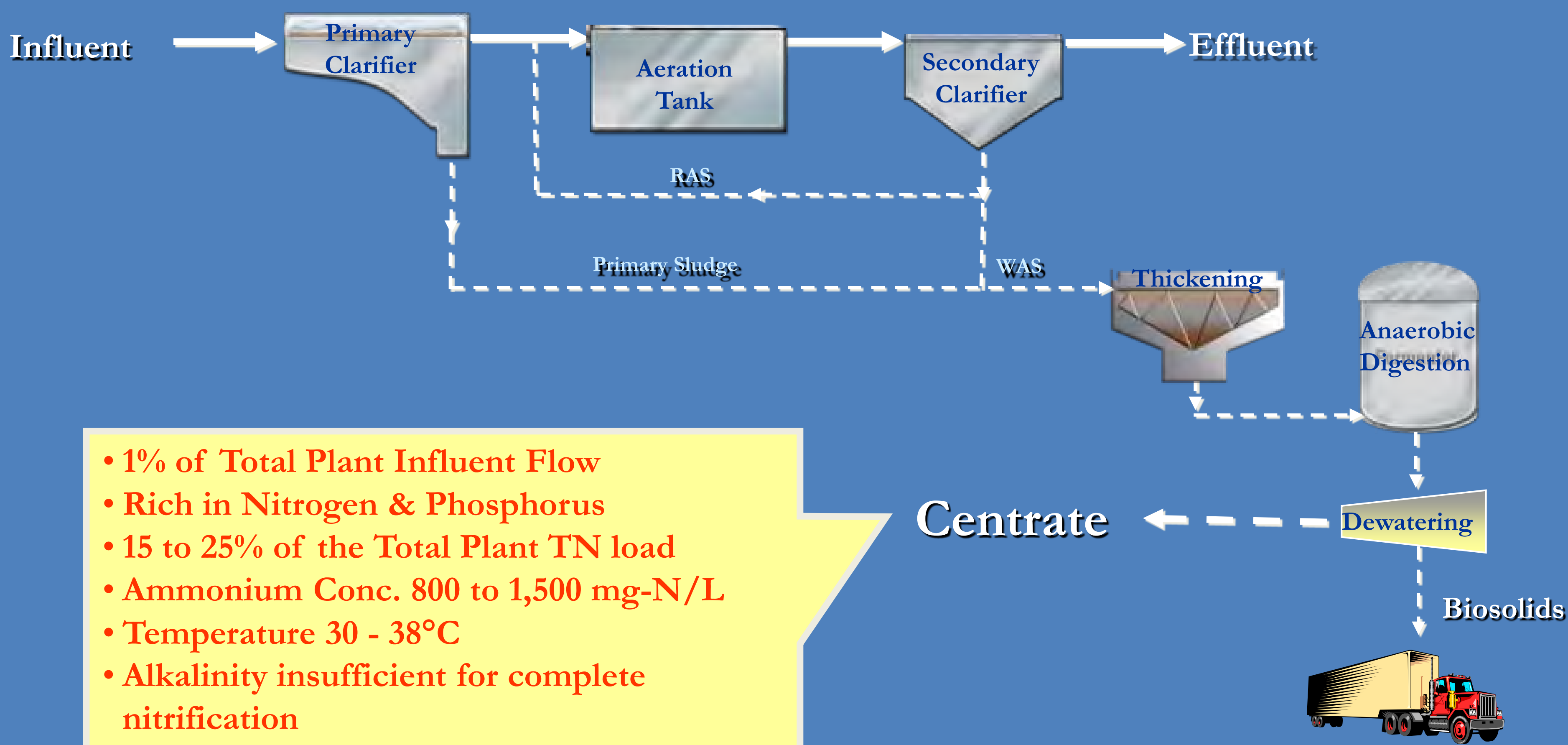
Struvite Facility Cost



Product Production/Sales



Recycle Streams with High Ammonia - Sidestream



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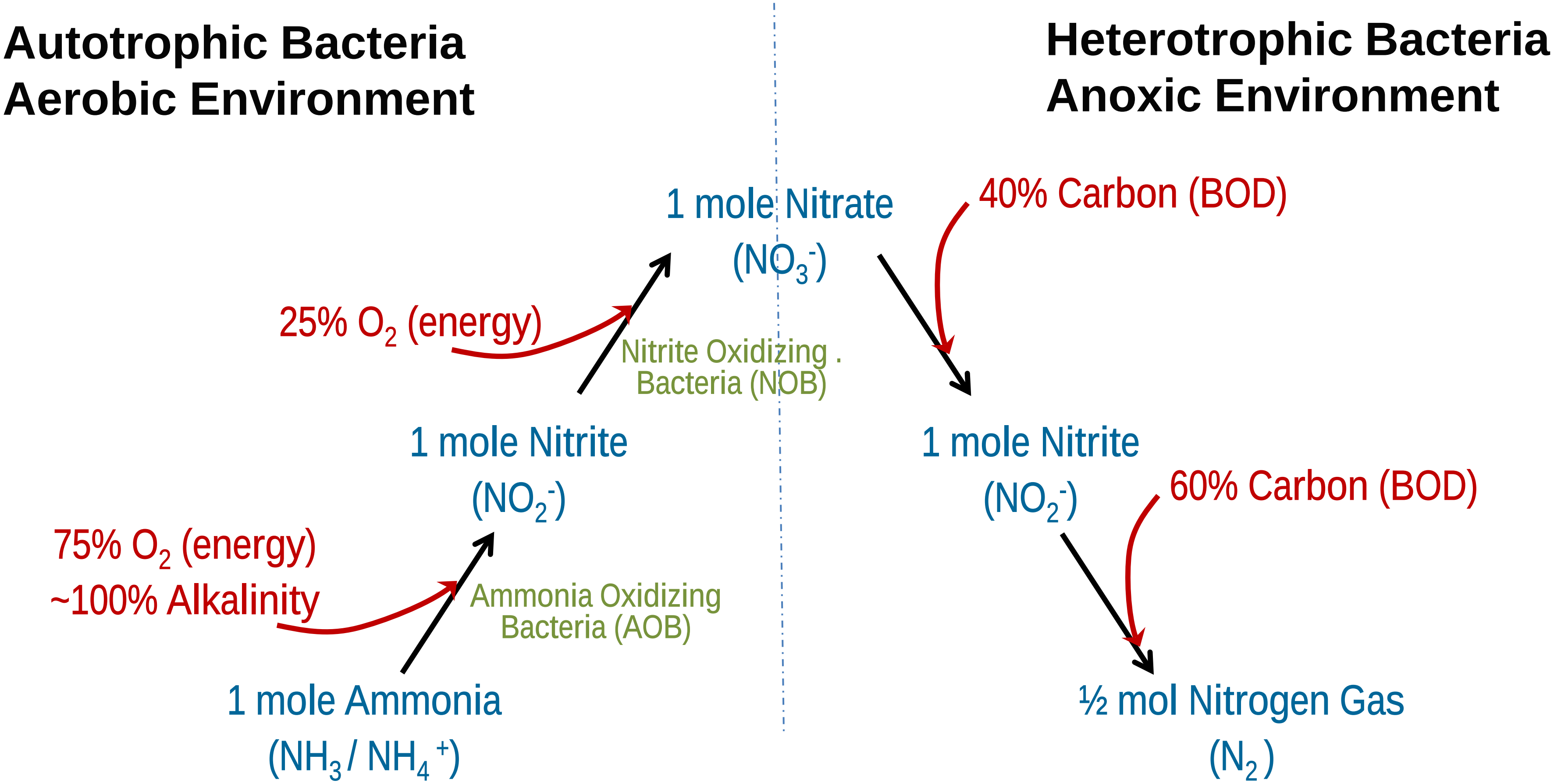
Conventional Nitrification-Denitrification



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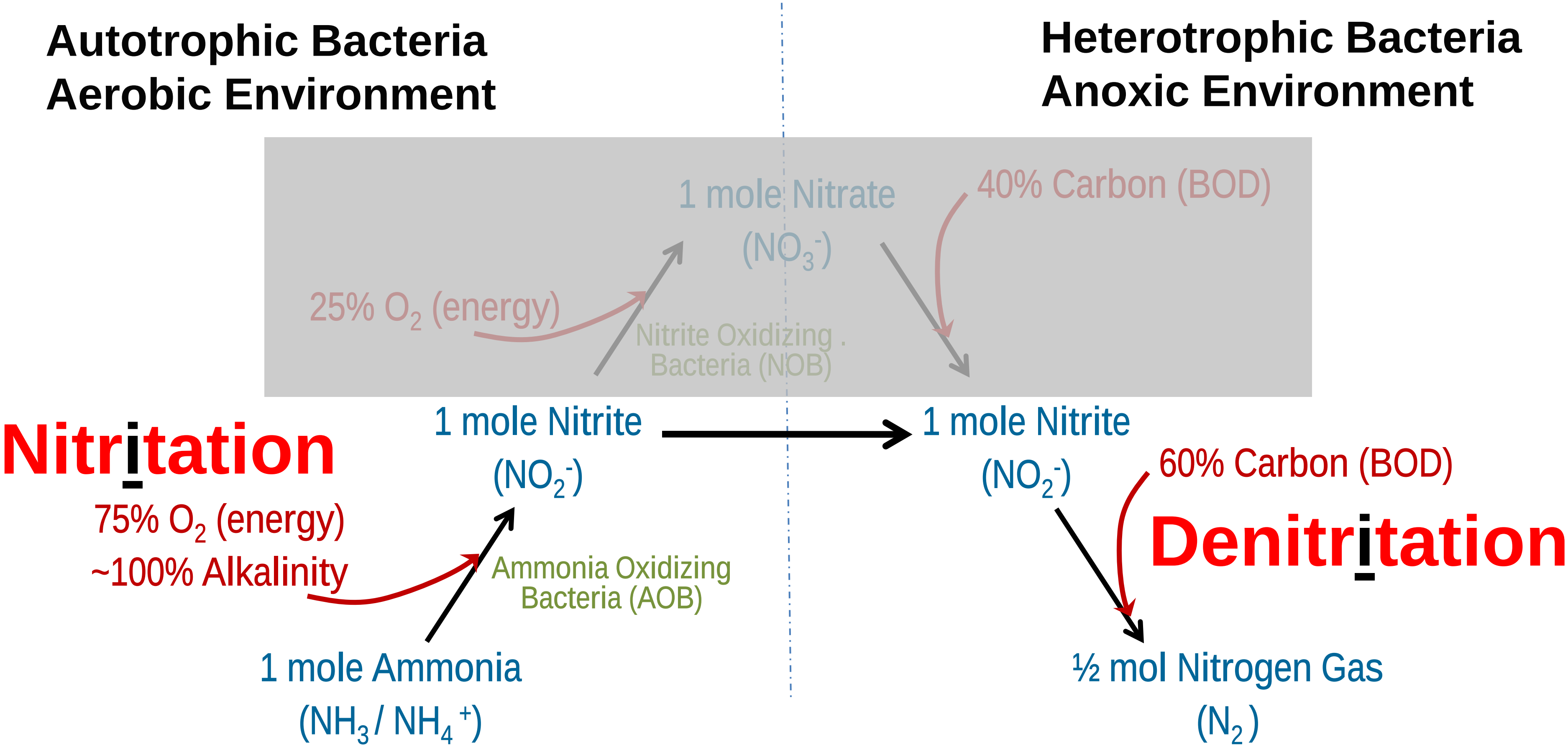
Nitritation-Denitritation = "Nitrite Shunt" (2.0)



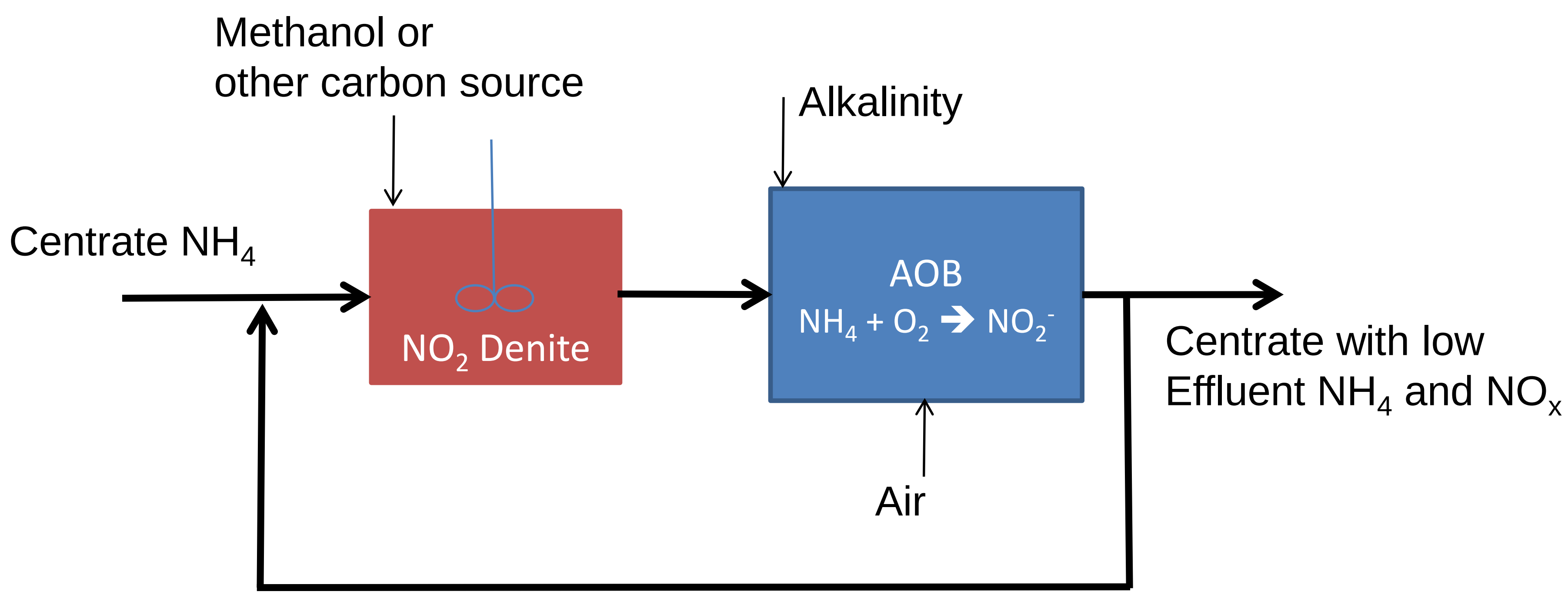
Advantages:

- 25% reduction in oxygen demand (energy)
- 40% reduction in carbon (e^- donor) demand
- 40% reduction in biomass production

Sidestream Nitritation – NOB Repression

- Control
  - Elevated temperature (30-35 deg C)
  - Low SRT (1-2 days)
  - Low DO (~0.5 mg/L)
- NOB Repression Mechanisms (all the possibilities)
  - AOB max growth rate > NOB max growth rate at high temp
  - Free NH3 inhibition of NOB > AOB
  - AOB DO affinity **>** NOB DO affinity *(*r-strategist *Nitrobacter…)*
    - For mainstream: AOB DO affinity **<** NOB DO affinity (K-strategist *Nitrospira*…)
  - Nitrous acid inhibition of NOB > AOB
- Processes:
  - SHARON – Continuous flow MLE with supplemental carbon
  - Strass - SBR

Nitritation – Denitritation - SHARON



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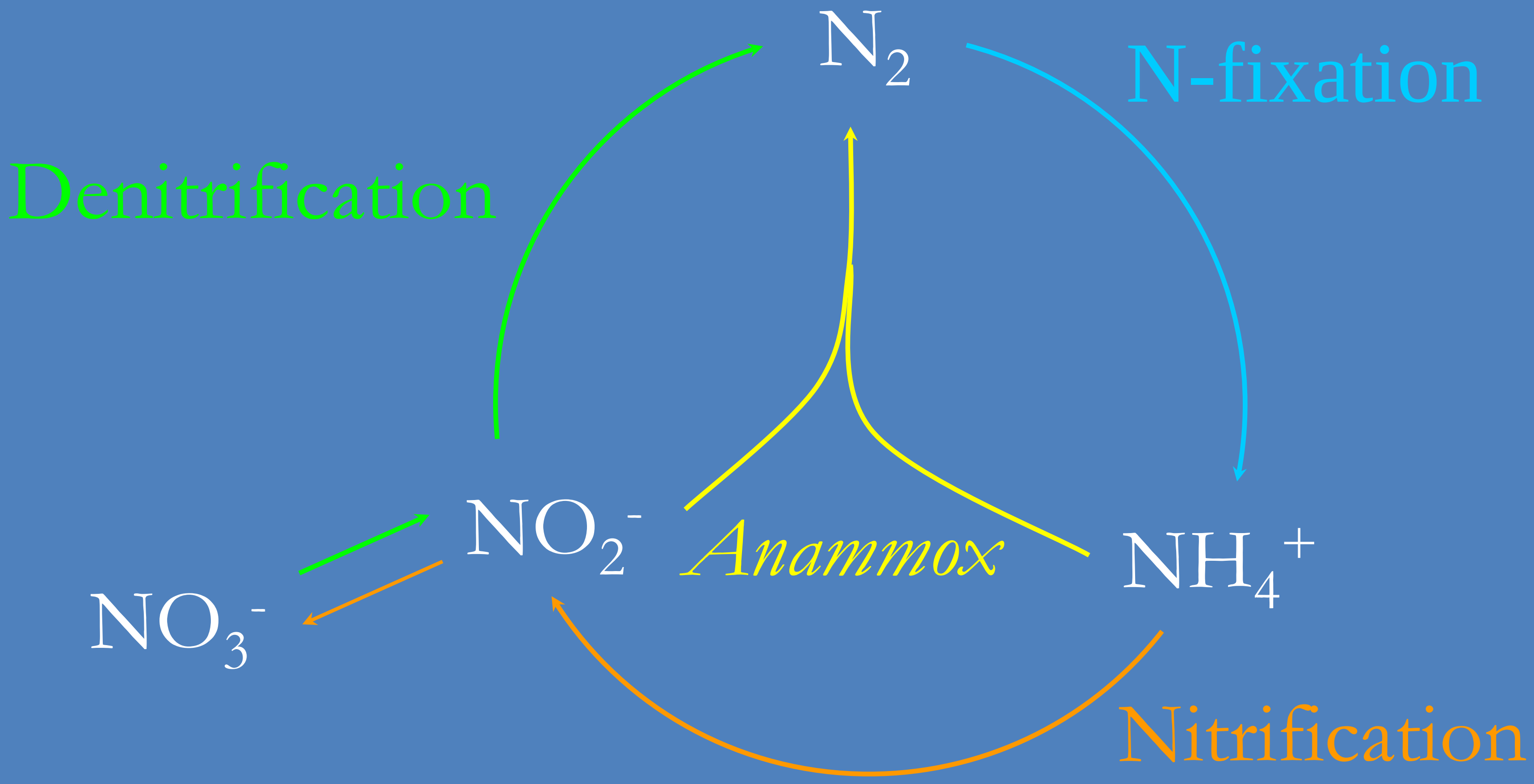
The N-Cycle



E. Broda (1977): „missing lithotroph“ … „might have existed or still exists“

free enthalpy -360 kJ/mol

Partial Nitritation-Anammox = "Deammonification" (3.0)

ANAMMOX

"Anaerobic" Ammonia Oxidation - (New Planctomycete - Strous et al, 1999)

$$NH_4^+ + 1.32\ NO_2^- + 0.066\ HCO_3^- + 0.13\ H^+ \rightarrow$$

$$0.26\ NO_3^- + 1.02 N_2 + 0.066\ CH_2O_{0.5}N_{0.15} + 2.03\ H_2O$$

Autotrophic Bacteria
Aerobic Environment

0.5 mole Nitrite (NO_2^-)

37% O_2 (energy)
~50% Alkalinity

Ammonia Oxidizing Bacteria (AOB)

1 mole Ammonia (NH_3 / NH_4^+)

Autotrophic Anoxic Environment

½ mol Nitrogen Gas (N_2) + a little bit of nitrate (NO_3^-)

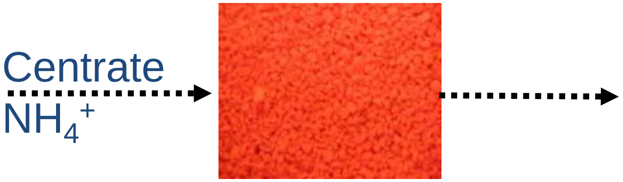
Advantages:

- 63% reduction in oxygen demand (energy)
- Nearly 100% reduction in carbon demand
- 80% reduction in biomass production
- No additional alkalinity required

One-Step Sidestream Deammonification

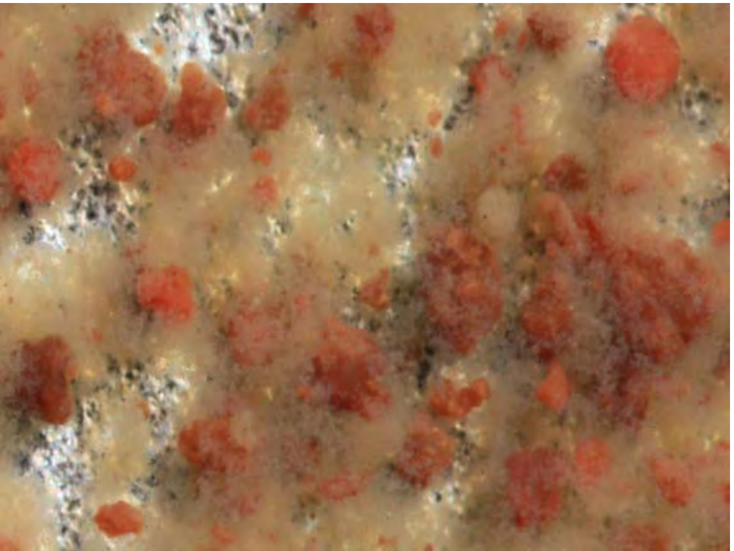
- **SBR + Hydrocyclone Granular Sludge (DEMON)**
  - Strass, Austria
  - Demon GmbH – World Water Works, Inc.

- **Upflow Granular Sludge (CANON/ANAMMOX)**
  - Olburgen, Netherlands
  - Paques (NL)



Partial Nitritation and Anammox
- combined in a single reactor

- **Biofilm process (MBBR-style)**
  - ANITA Mox
    - AnoxKaldnes – Kruger - Veolia
  - Deammon -- Hattingen, Germany & Stockholm
    - Purac

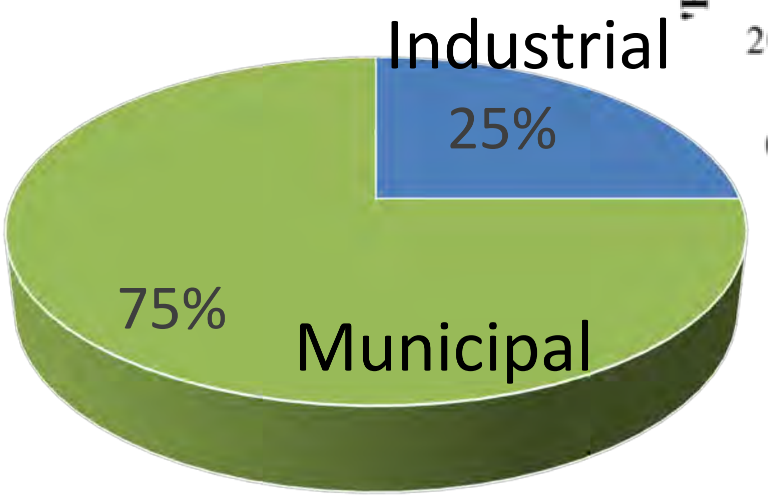


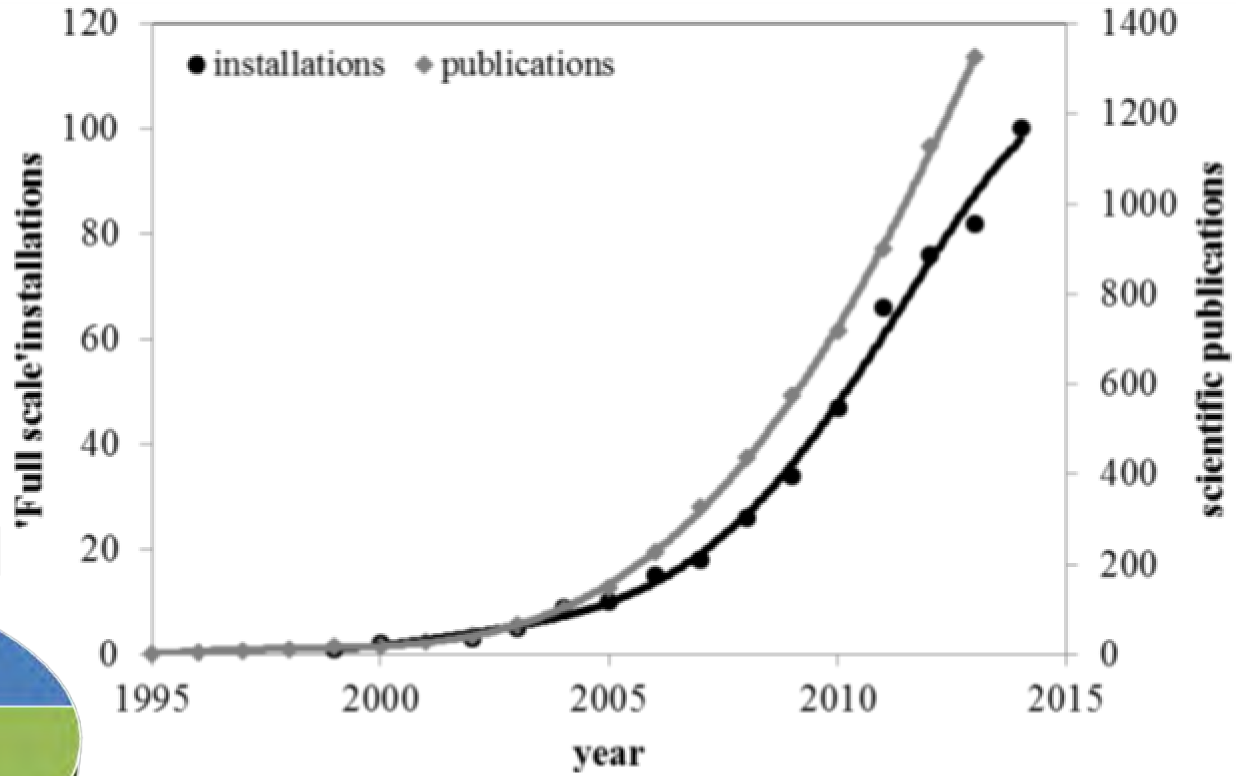
Sidestream Deammonification: What's the benefit?

- Remove ~20% of the N load to the plant by treating the centrate separately
- Do it with:
  - No chemicals (caustic & methanol)
  - < 40% of the energy cost
  - (as compared to traditional nitrification-denitrification)
- Business case is very good, particularly if existing tanks can be used
- Risks:
  - Requires robust process control, particularly during startup
  - *Process has been adequately demonstrated*
  - *Seeding required for fast startup*

S-curve for Sidestream Deammonification

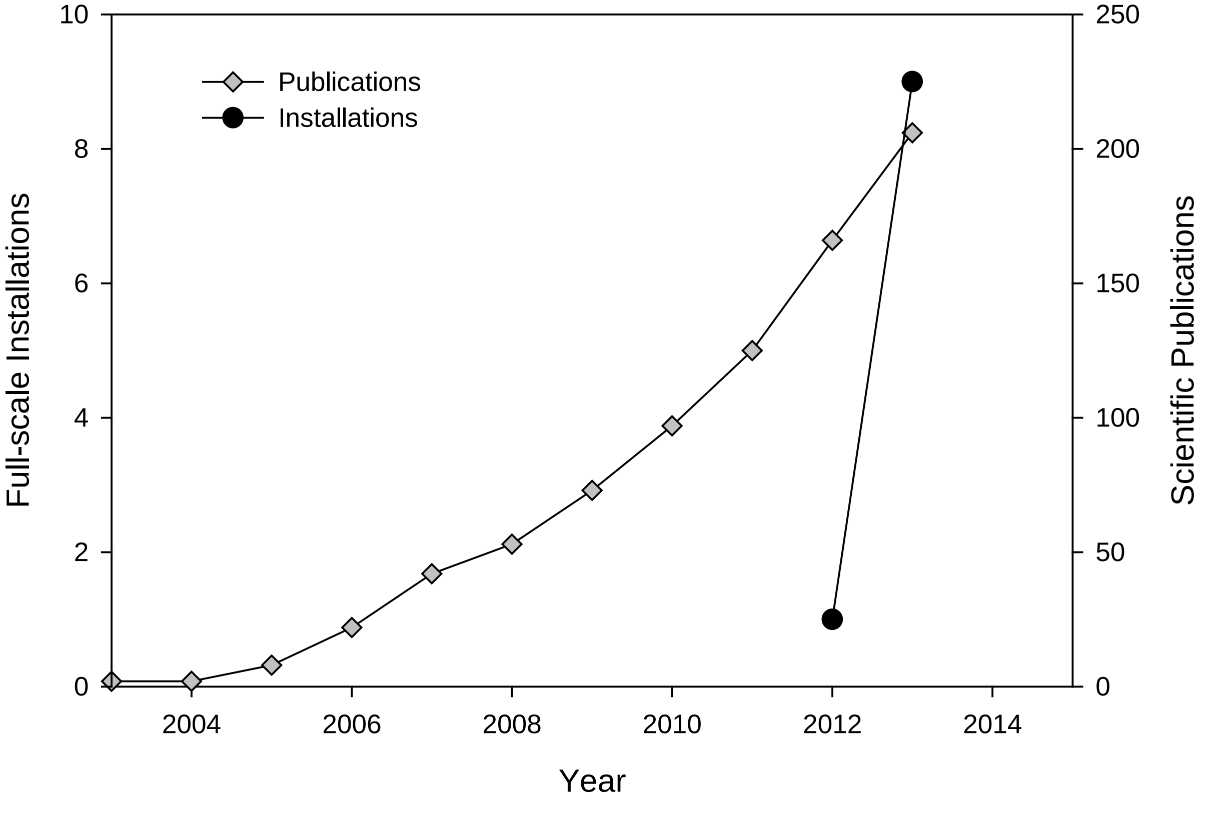
100 Full-scale Installations





Susanne Lackner, Eva M. Gilbert, Siegfried E. Vlaeminck, Adriano Joss, Harald Horn, Mark C.M. van Loosdrecht (2014), Full-scale Partial Nitritation/Anammox Experiences - an Application Survey, Water Research

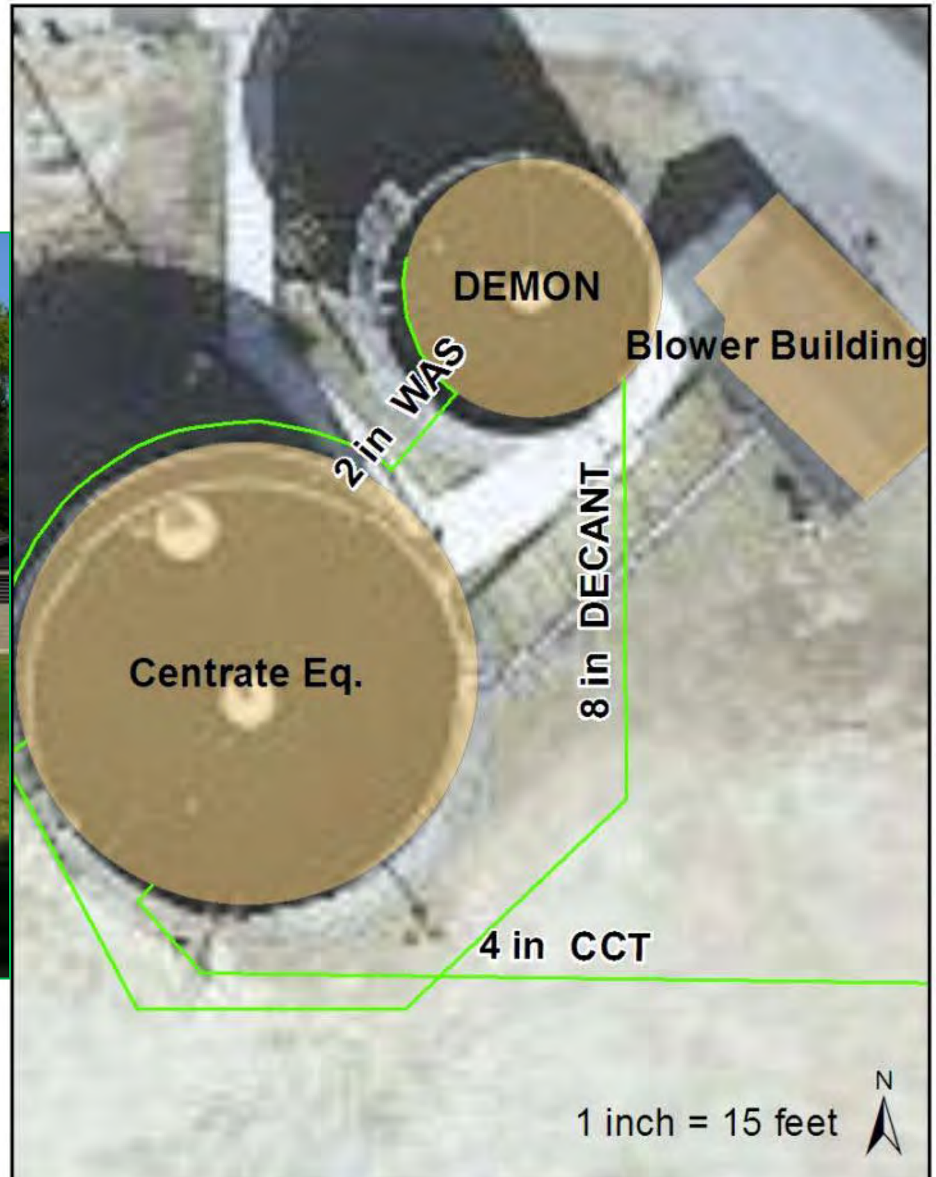
In the US



Publications
Installations
Full-scale Installations
Scientific Publications
Year
0
2
4
6
8
10
0
50
100
150
200
250
2004
2006
2008
2010
2012
2014

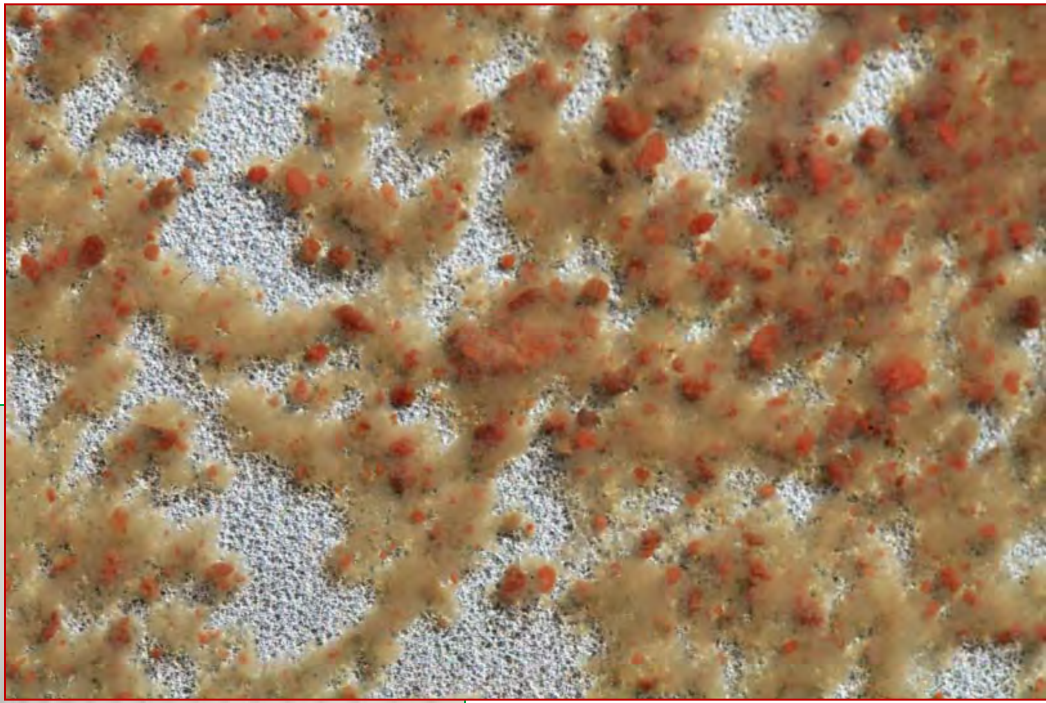
DEMON at HRSD York River (15 MGD)

Implementation of DEMON at York River



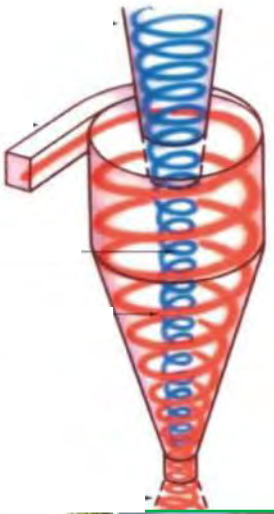

LIFERING

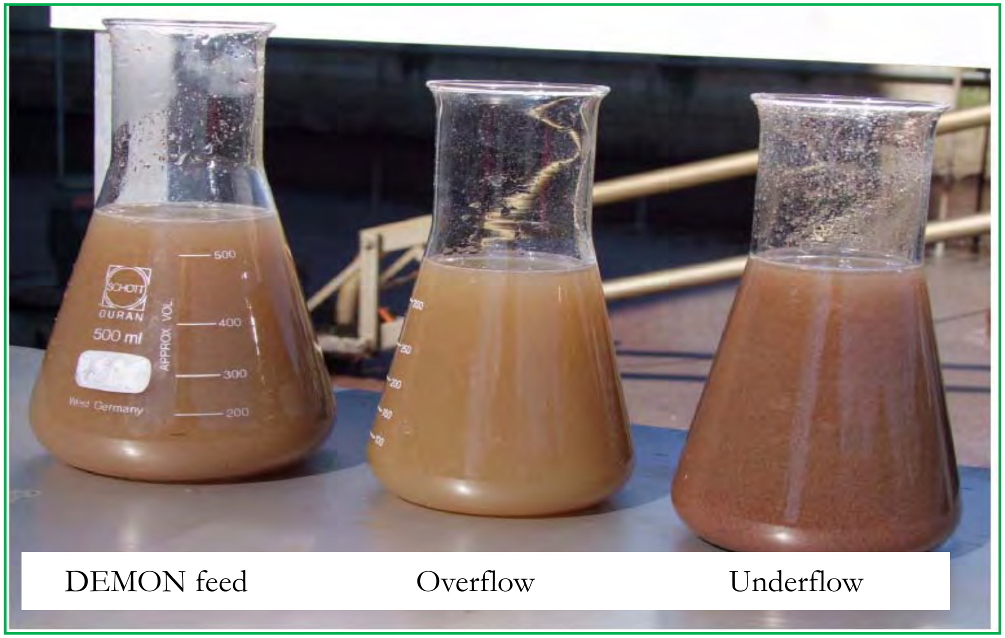

DEMON Seed Sludge



Hydrocyclone for Biomass Wasting

- Retain anammox in small dense granules
- SRT of anammox granules >> SRT of AOB, NOB, heterotrophs, debris
- Create "washout" conditions for NOB
- Control activity of AOB population

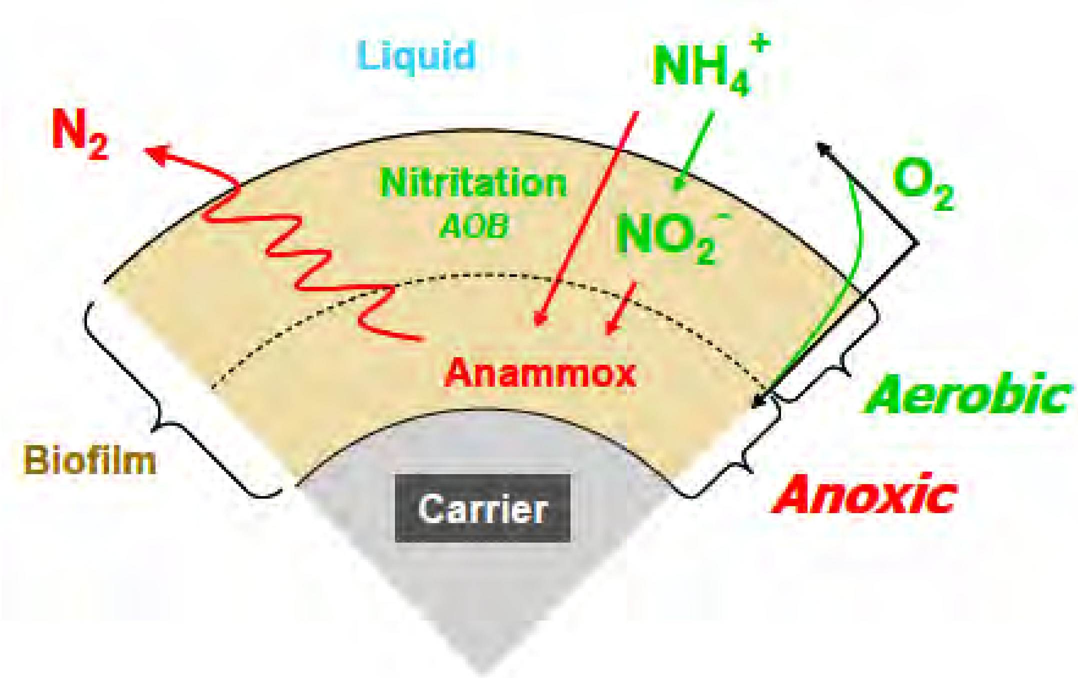




HRSD James River Treatment Plant

ANITA™Mox Sidestream Deammonification MBBR

- Seeding strategy to help speed up startup
  - 10% pre-colonized media
- 3 plants in Europe, this is the first in the US
- DO control based off of NH4 and NO3 sensors



Process Components

Aeration System

Instrumentation

Centrate Feed

Mixers and Heaters

K5 Media

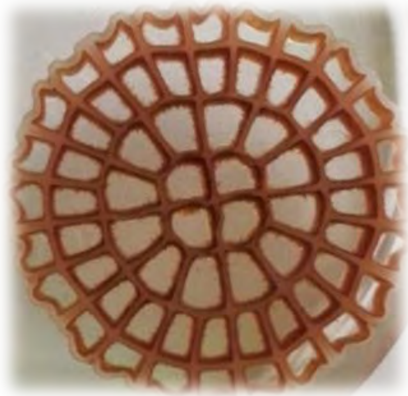
Media Retention

Seeding and Startup

Biofilm Growth

New media
12/12/13

New media
2/26/14



New media
4/10/14

New media
7/15/14

Seed media
12/12/13

Seed media
2/26/14

Seed media
4/10/14

Seed media
7/15/14

Short-Cut Nitrogen Removal Processes: Transitioning to Mainstream 2.0 & 3.0

Collaborators

HRSD
Cleaning wastewater every day for a better Bay.

AIZ

dc water

Brown AND Caldwell

HDR

Old Dominion University

Virginia Tech. VT

BV®

AECOM

Columbia University

Universiteit Gent

ARA consult GmbH

dynamita PROCESS MODELING

universität innsbruck

University of Central Florida

WERF
Water Environment Research Foundation
Collaboration. Innovation. Results.

United States Environmental Protection Agency

Mainstream Deammonification Project
3 different sites and scales

DC Water

WWTP Strass

HRSD

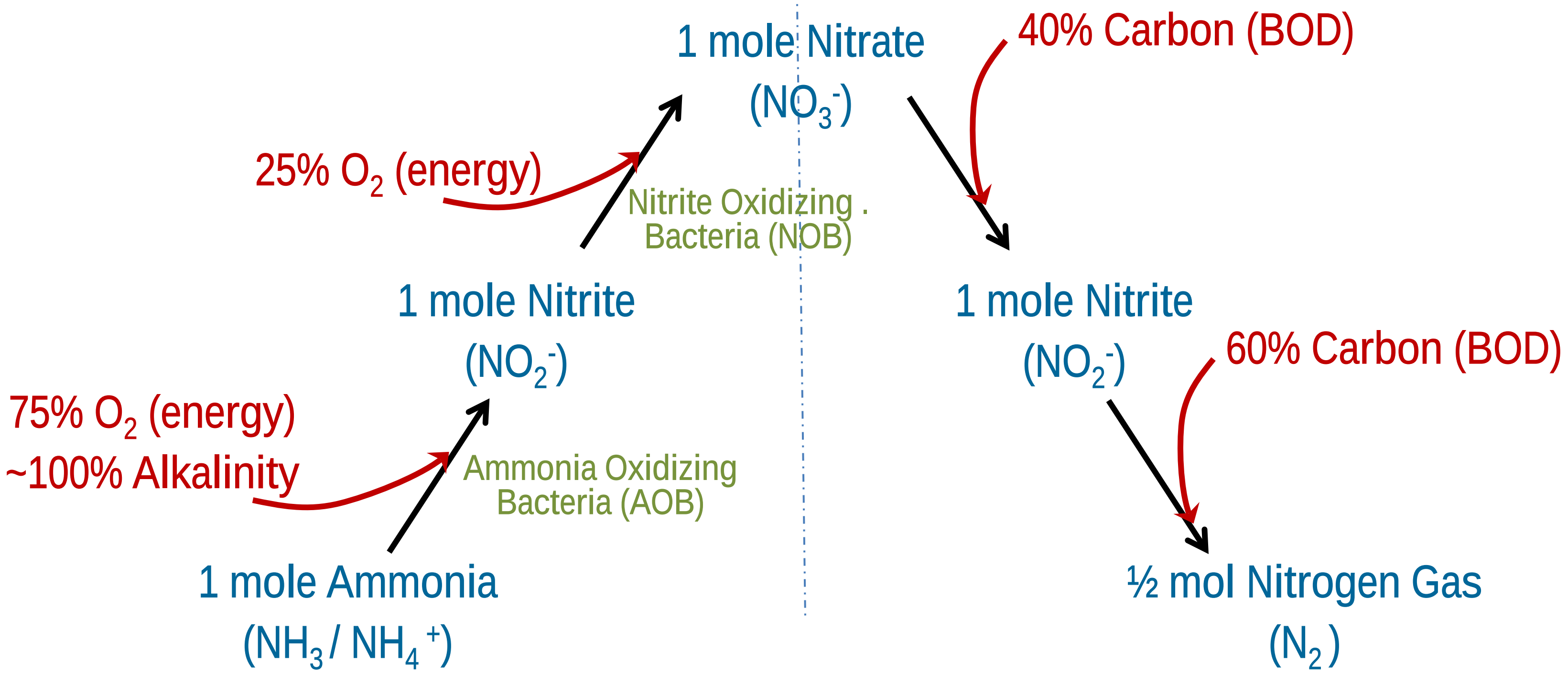
Challenges

1. Mainstream NOB suppression (out-selection)
2. Selective anammox retention
3. Wastewater carbon (COD) diversion & control

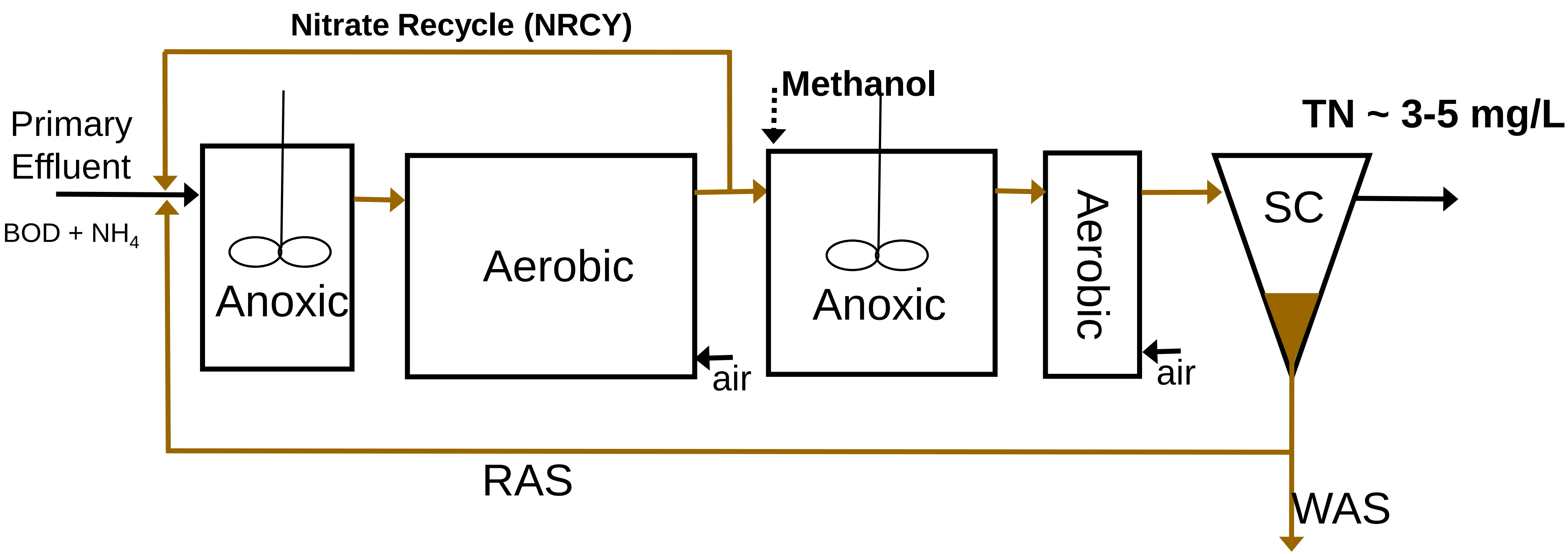
Conventional Nitrification-Denitrification **(1.0)**

Autotrophic Bacteria
Aerobic Environment

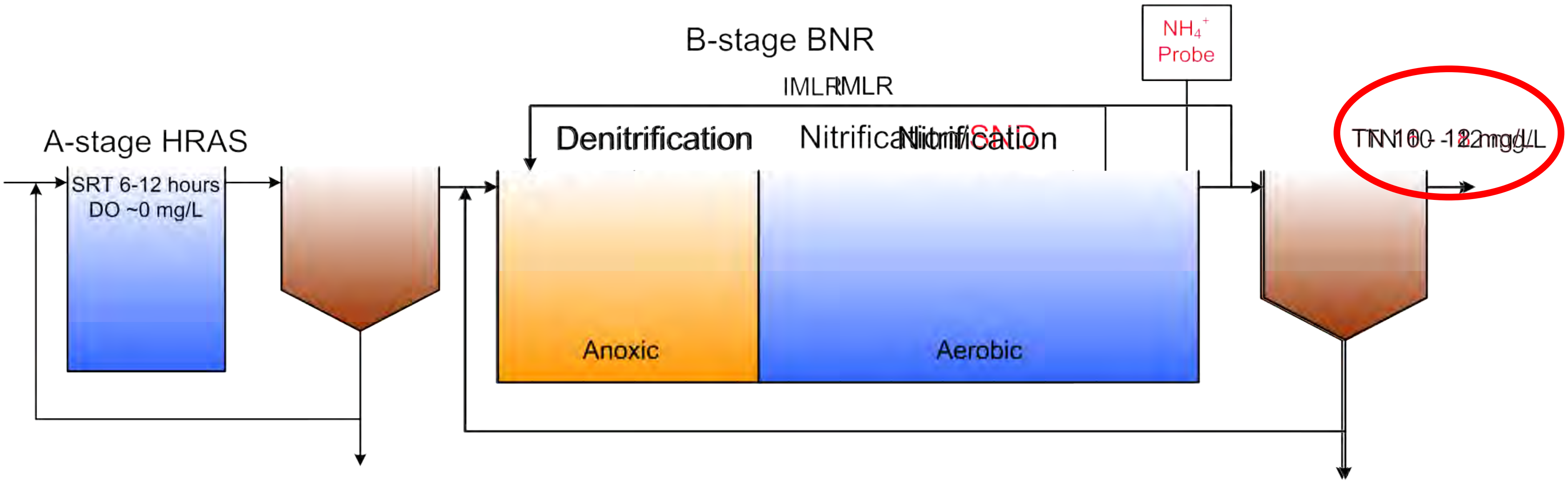
Heterotrophic Bacteria
Anoxic Environment



4-Stage Bardenpho (Better N Removal)

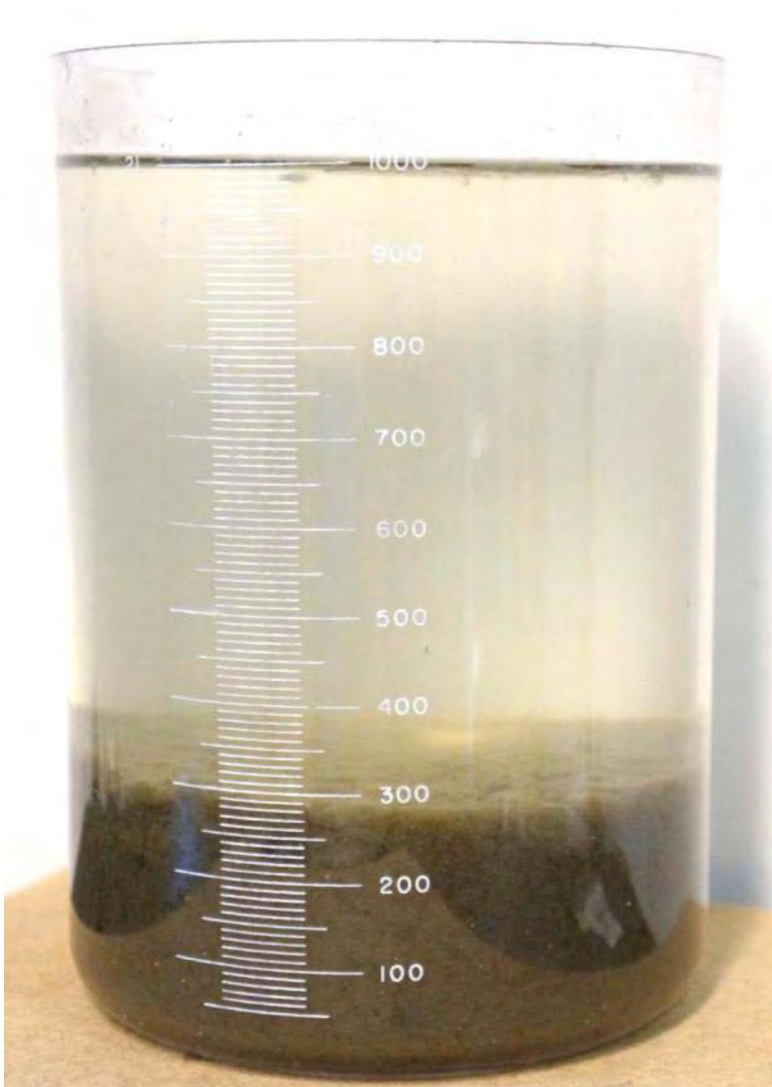


Adsorption/Bio-oxidation (A-B) Process



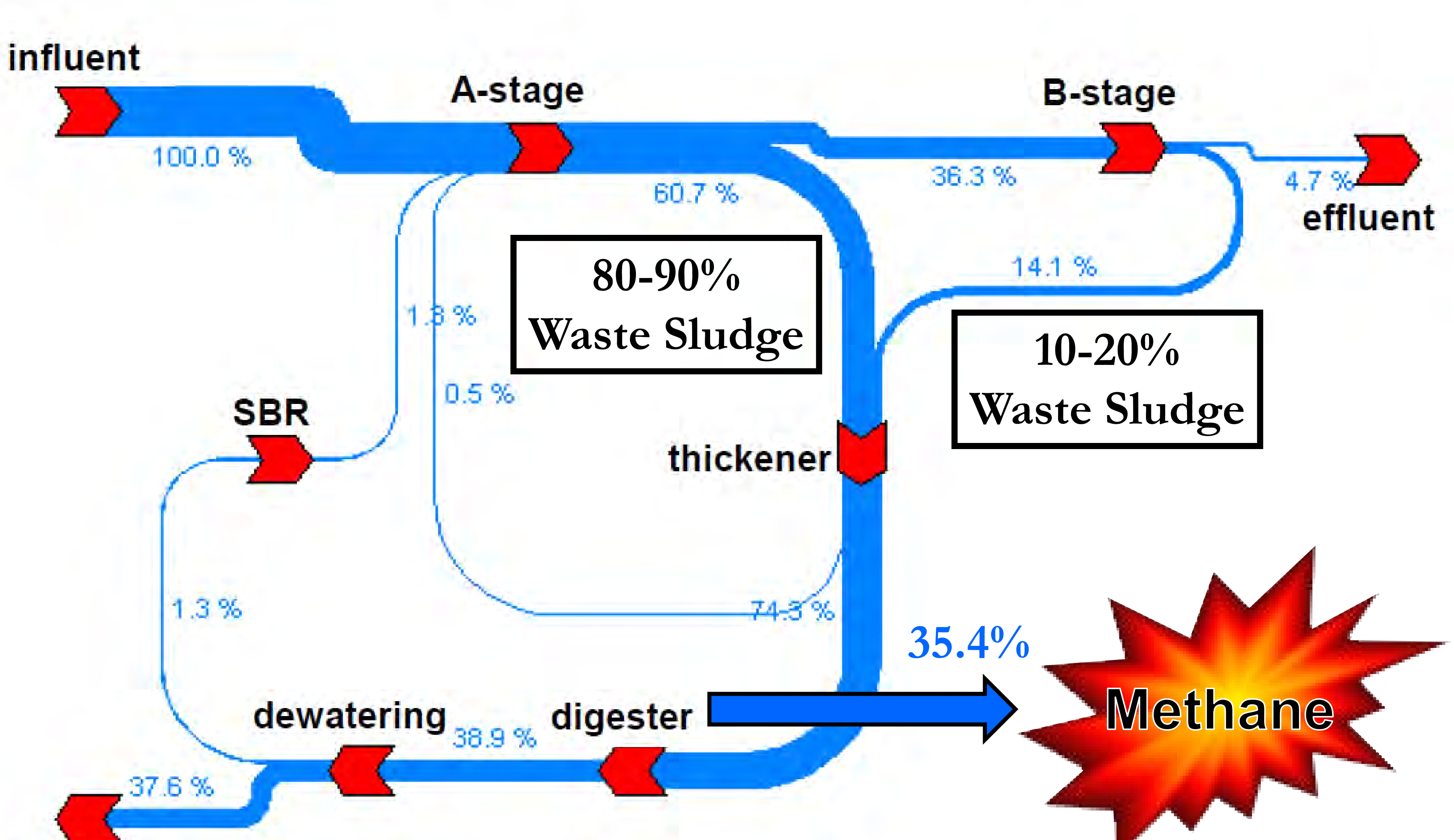
Advantages	Disadvantages
Low overall volume	Requires ammonia-based aeration control
Good nitrogen removal	Not operated to achieve complete nitrification
Redirect carbon to anaerobic digestion	
Low aeration energy requirement	

Conventional



A-Stage

Simulated COD Balance of the AIZ Strass WWTP



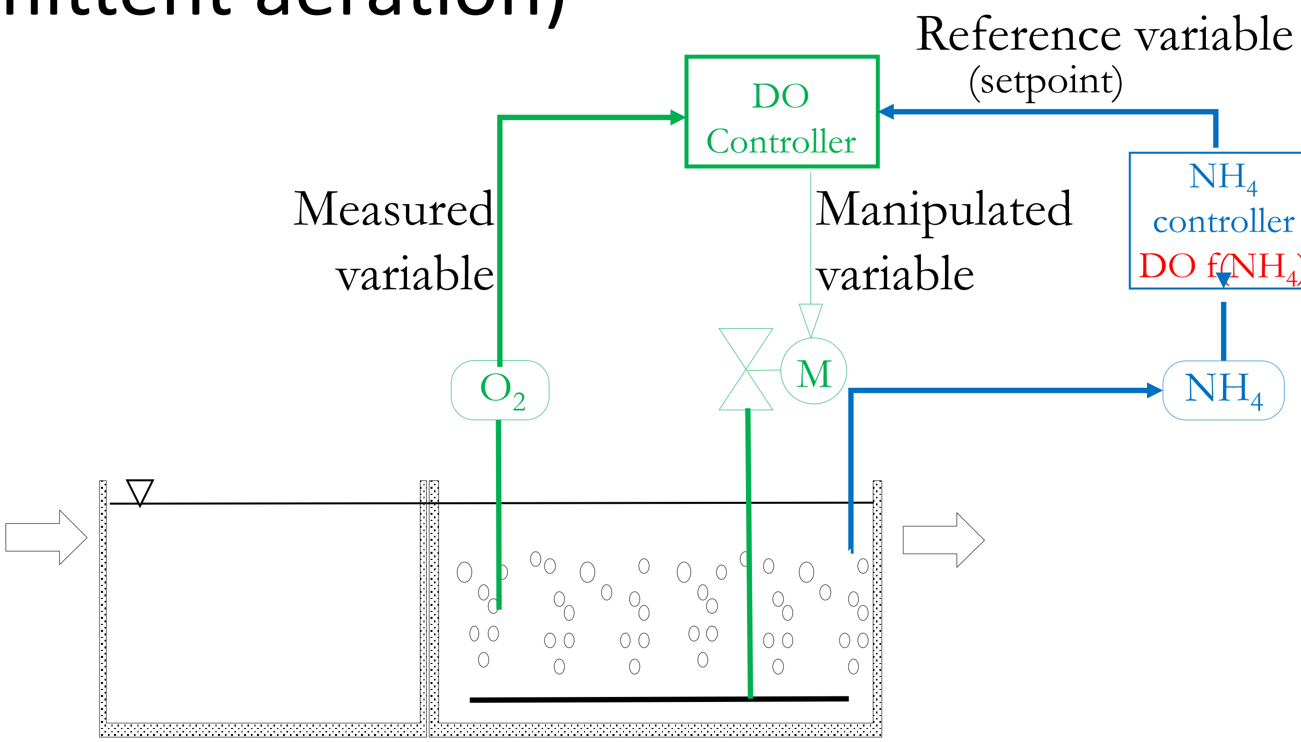
Wett, B.; Buchauer, K.; Fimml, C. (2007) Energy self-sufficiency as a feasible concept for wastewater treatment systems. *Proceeding of the IWA Leading Edge Technology Conference*, Singapore, Asian Water, 21-24.

Ammonia-Based Aeration Control

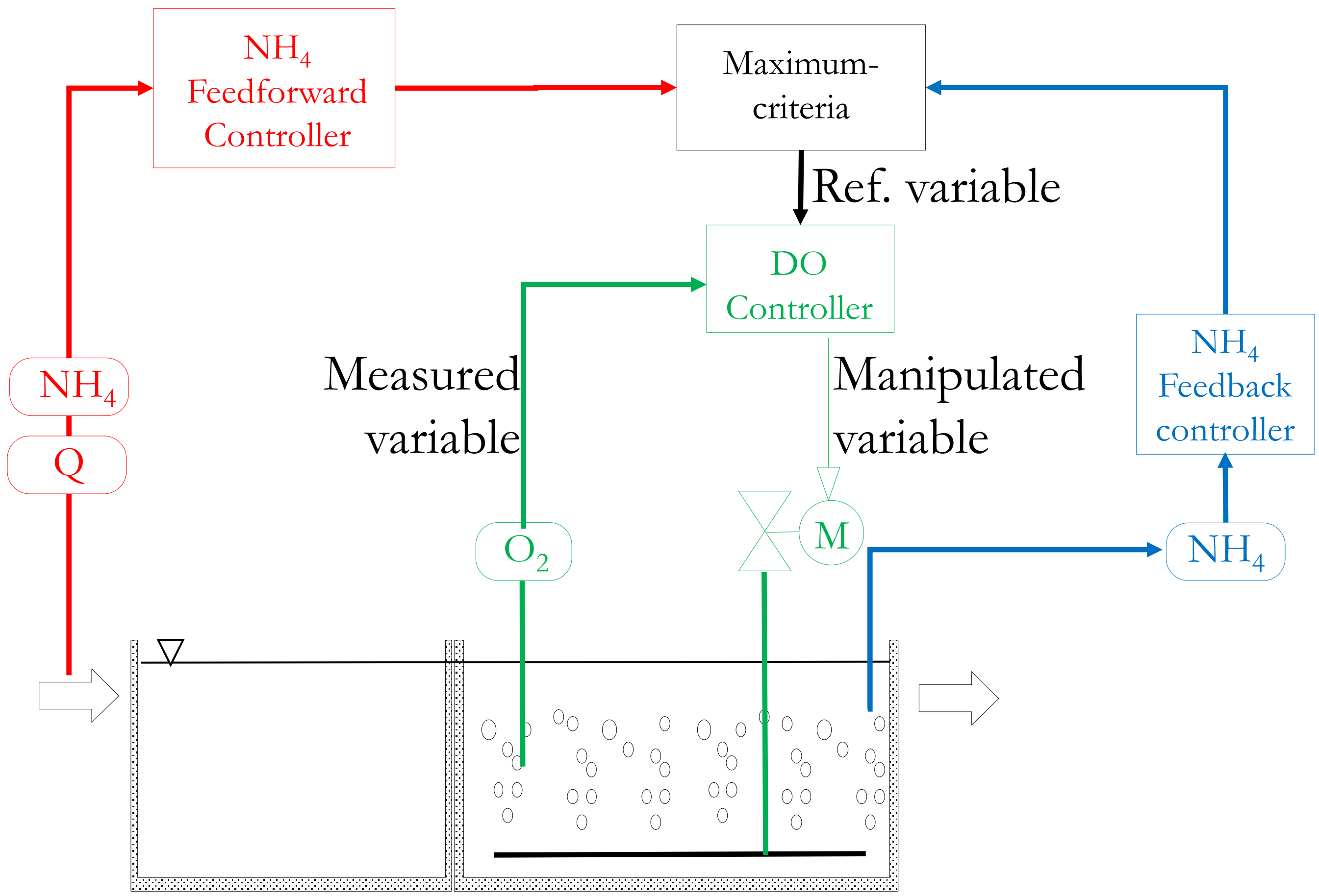
Feedback Control

Limiting aeration: *Cascaded NH_4/DO control*

Aeration intensity control
(or intermittent aeration)

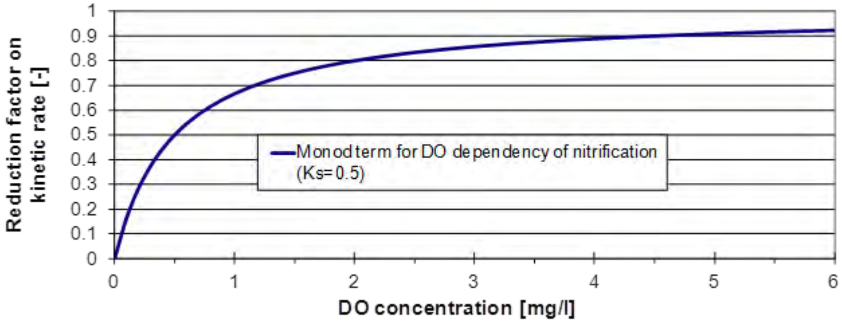


Feedback+Feedforward control

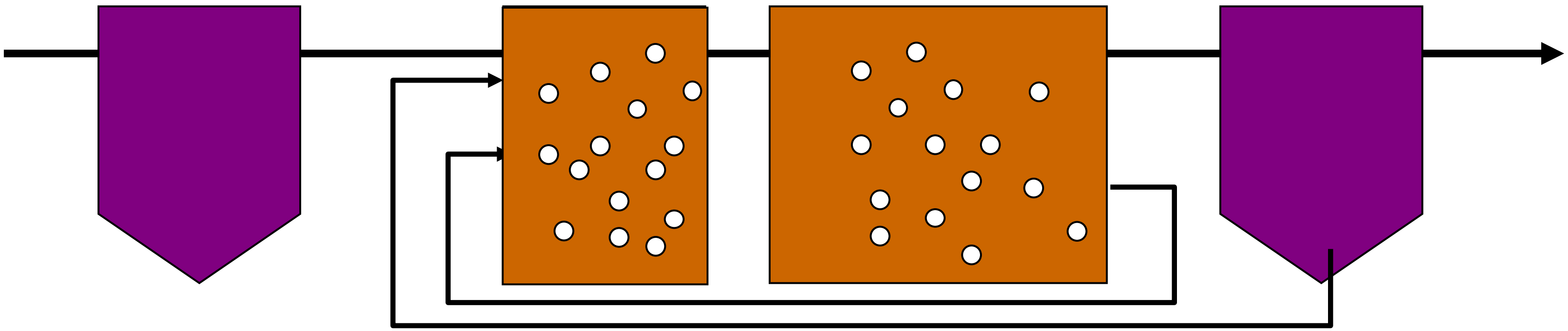


Reducing ammonia effluent peaks

- **Intensity control:** Manipulate aeration intensity early to create buffer for incoming peak



- **Volume control:** Change aerated volume by switching on/off swing zones

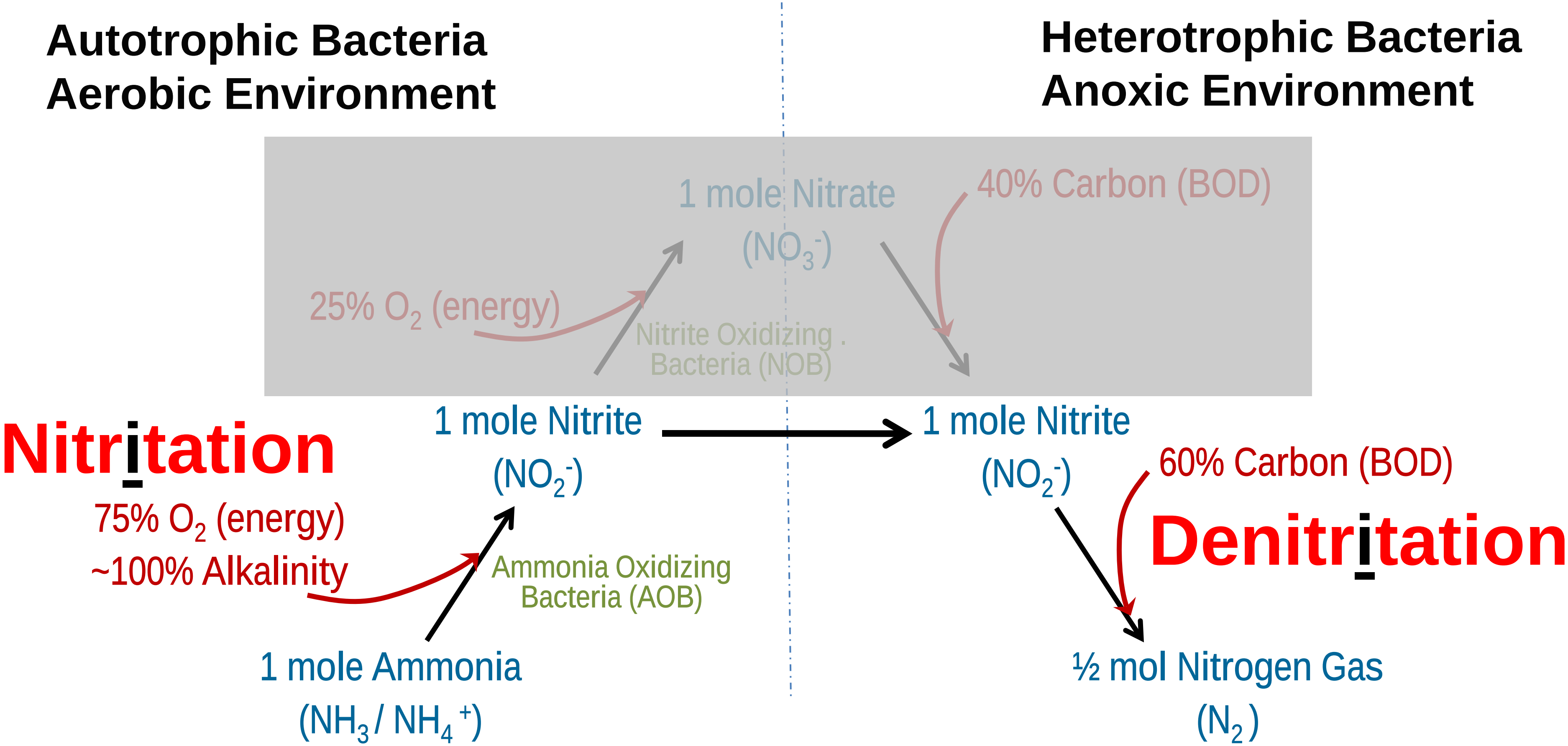


WHY???

Ammonia-based aeration control

- **Limiting aeration:**
  - Reduce energy consumption
    - less NH4 converted, aerating at lower DO, less COD oxidized aerobically
  - Increase denitrification – SND
  - Improve usage of sbCOD, reduce need for supplemental carbon
  - Decrease ALK demand
  - Decrease chlorine demand – NH4 is present
  - Maybe improve bio-P performance
- **Decreasing effluent ammonia peaks:** Reduce the extent of effluent ammonia peaks

Nitritation-Denitritation = "Nitrite Shunt" (2.0)



Advantages:

- 25% reduction in oxygen demand (energy)
- 40% reduction in carbon (e^- donor) demand
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Aerobic Environment

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½ mol Nitrogen Gas (N_2) + a little bit of nitrate (NO_3^-)

Advantages:

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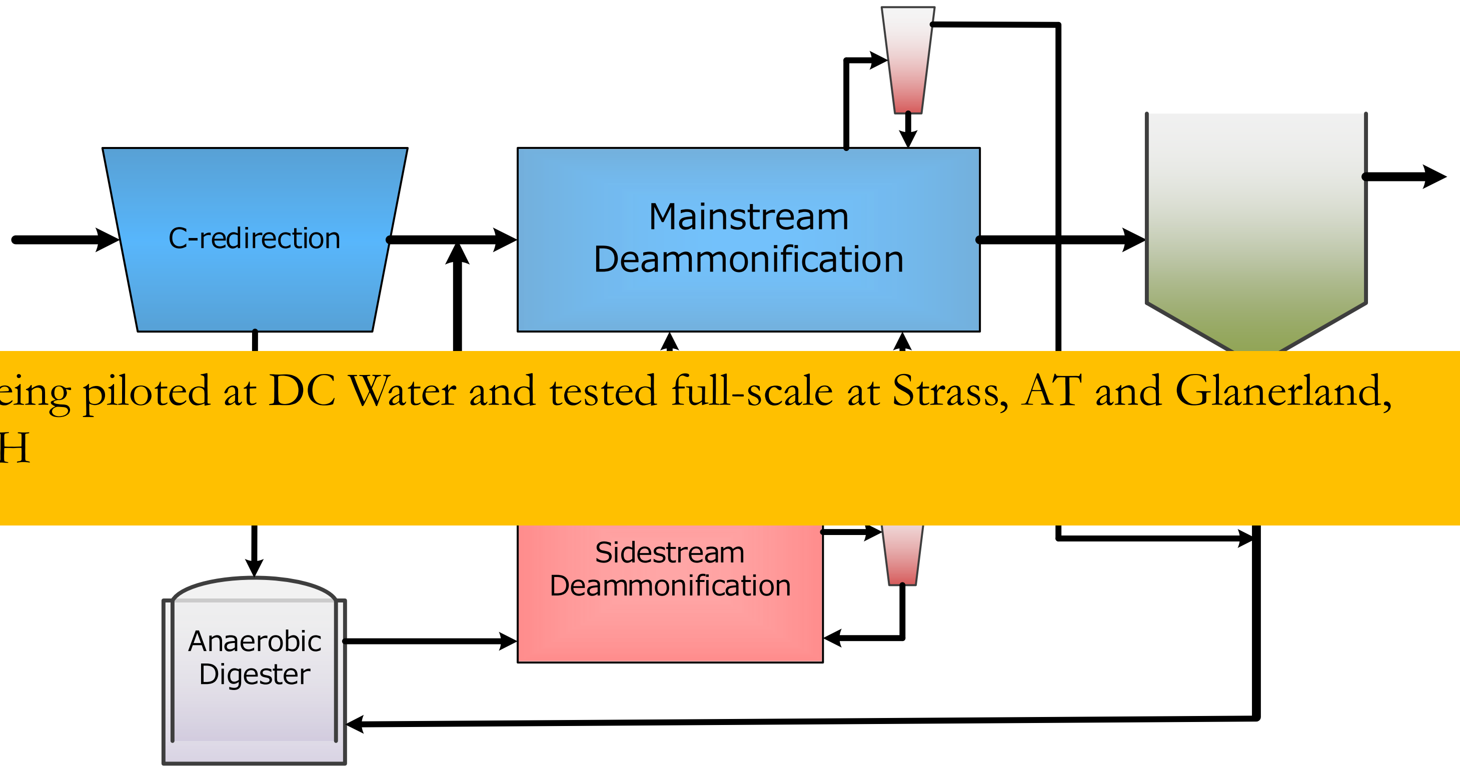
- No additional alkalinity required

Plants with Anaerobic Digestion

- Incentive for C-redirection

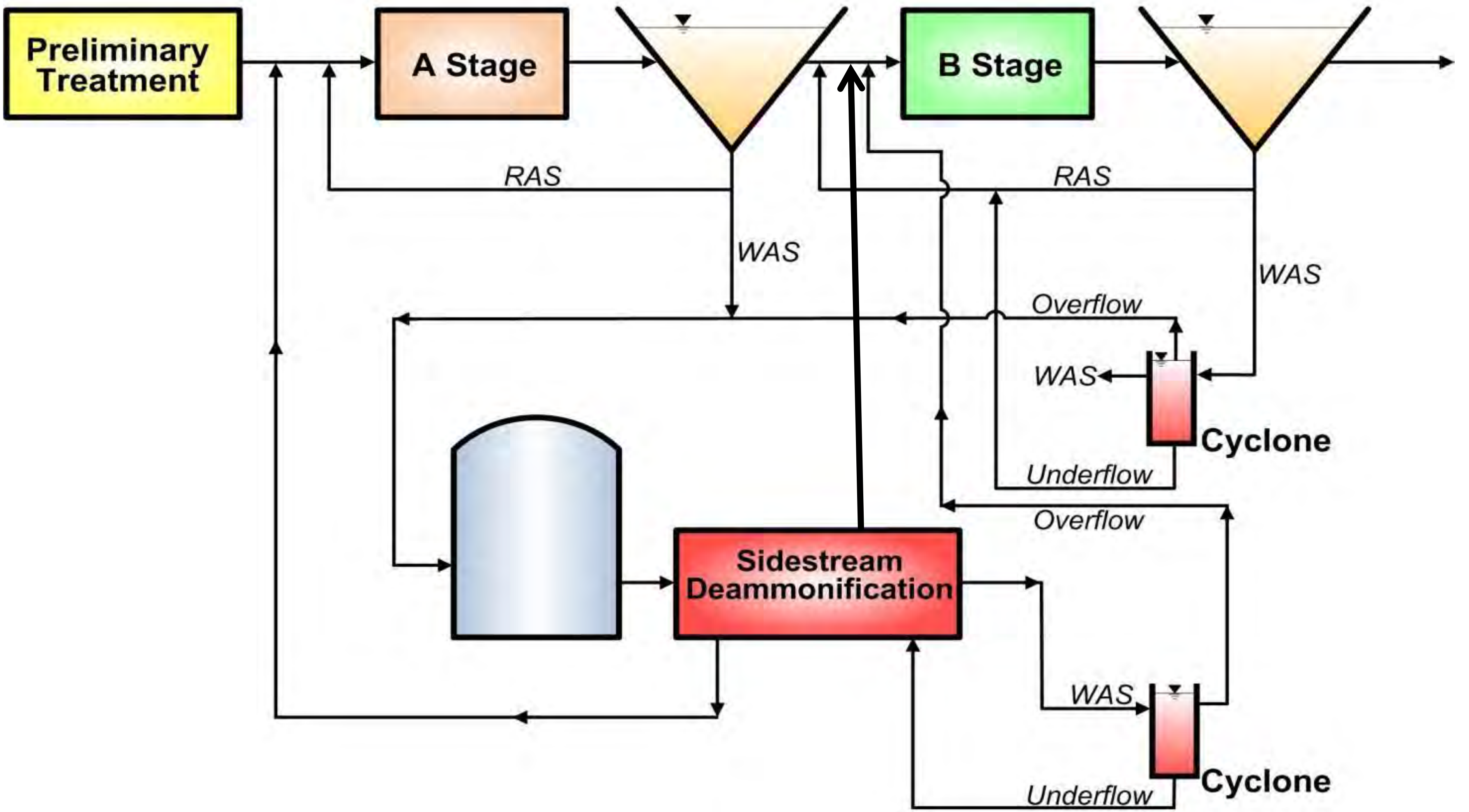


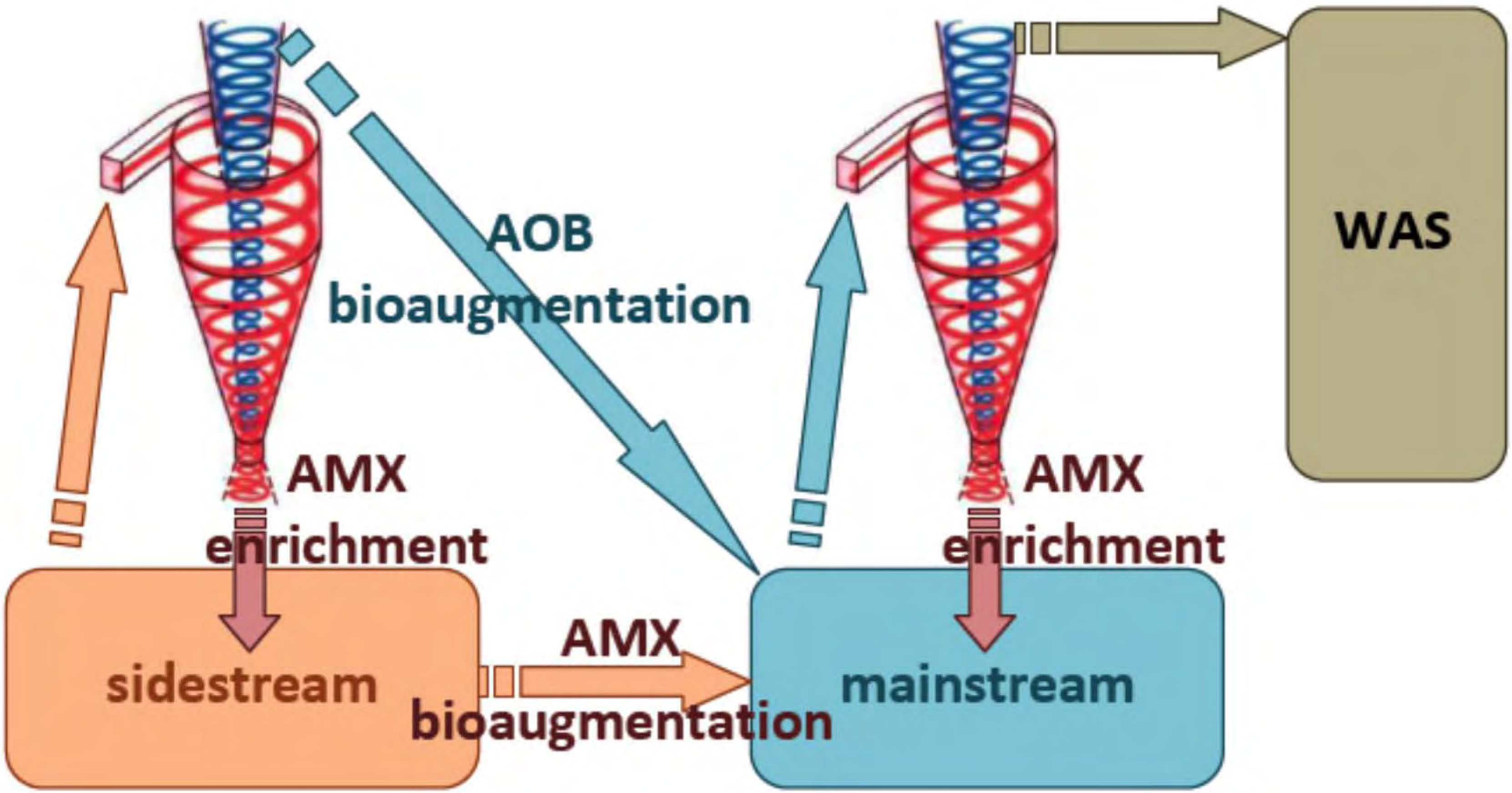
Being piloted at DC Water and tested full-scale at Strass, AT and Glanerland, CH

Key Features:

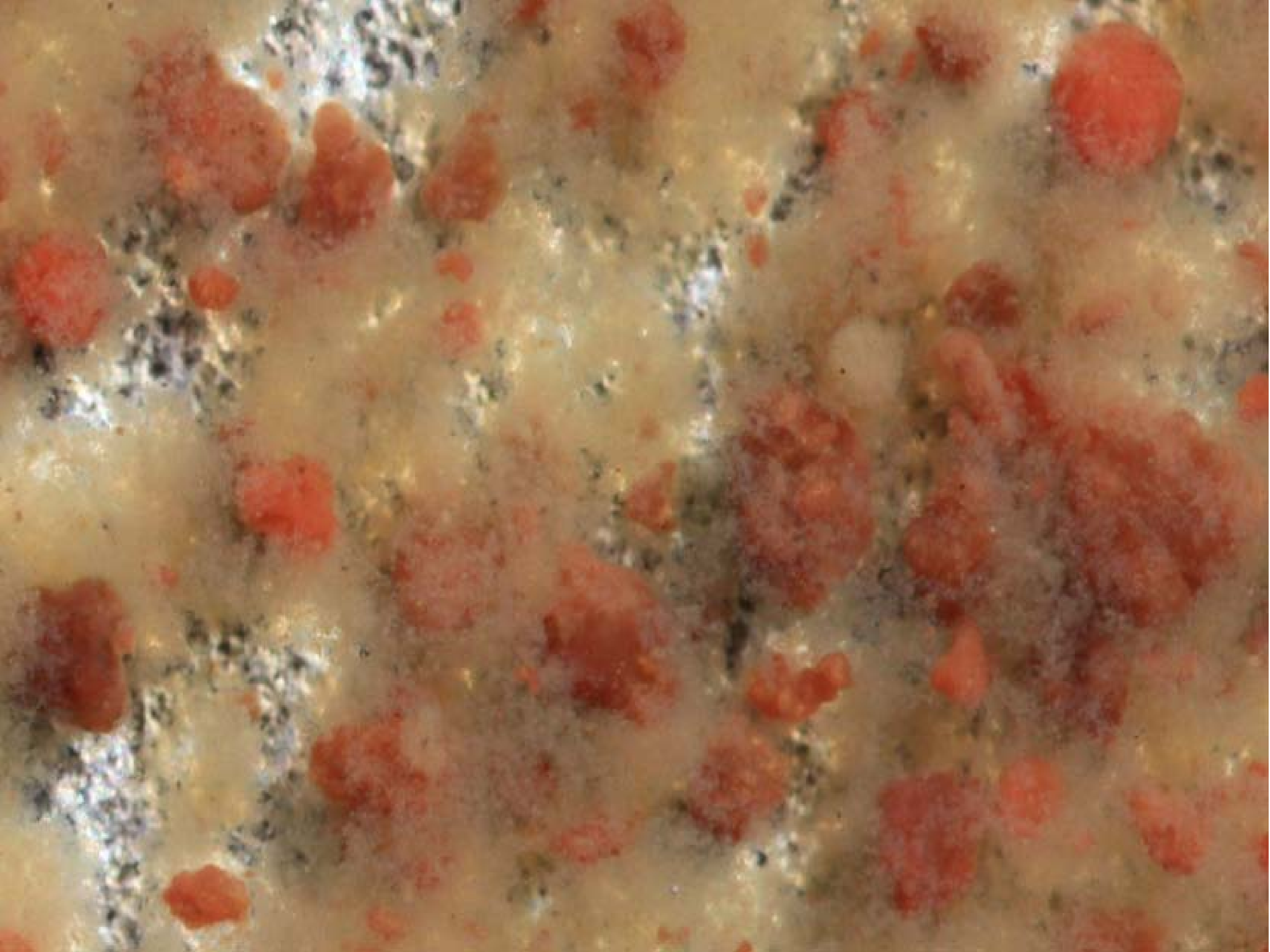
1. Bioaugment AOB in the sidestream cyclone overflow to the mainstream
2. Bioaugment anammox from sidestream to mainstream
3. Cyclone for anammox retention in mainstream
4. Repress NOB in mainstream (and sidestream)

STRASS WWTP DEMONSTRATION (Full-Scale)

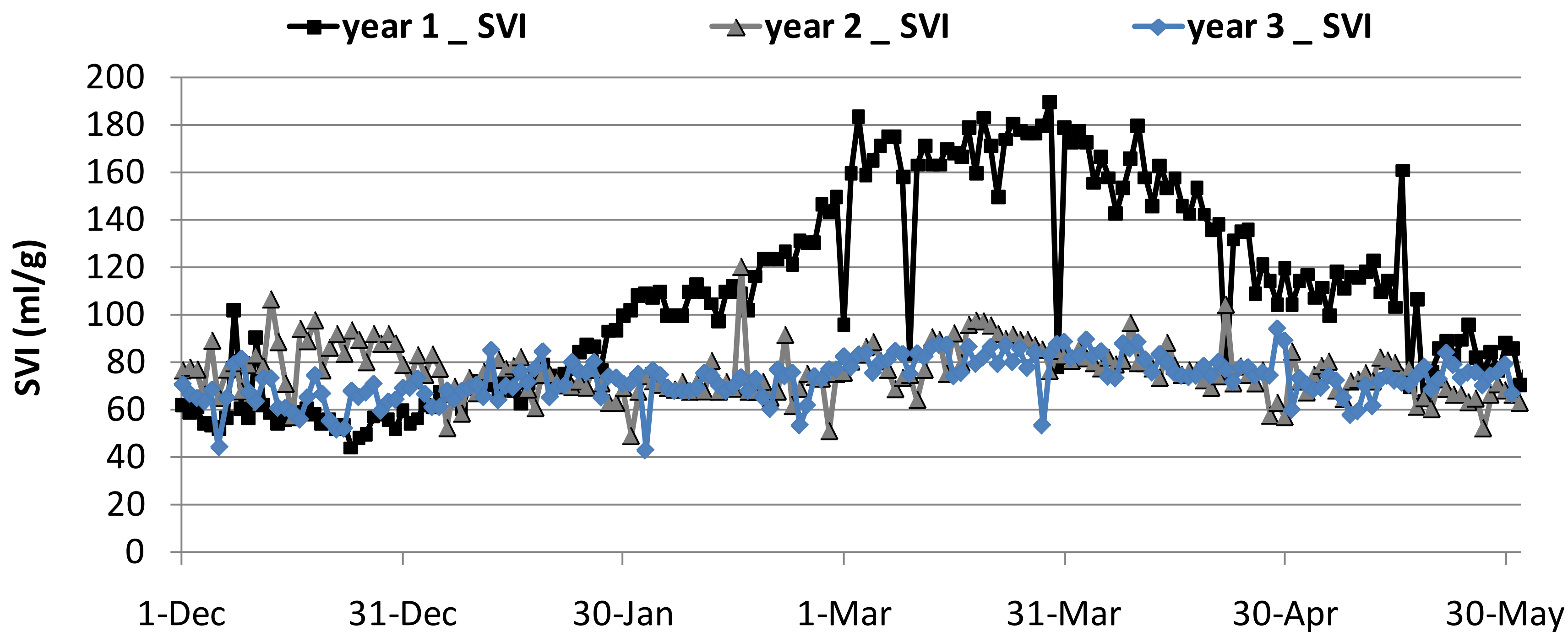




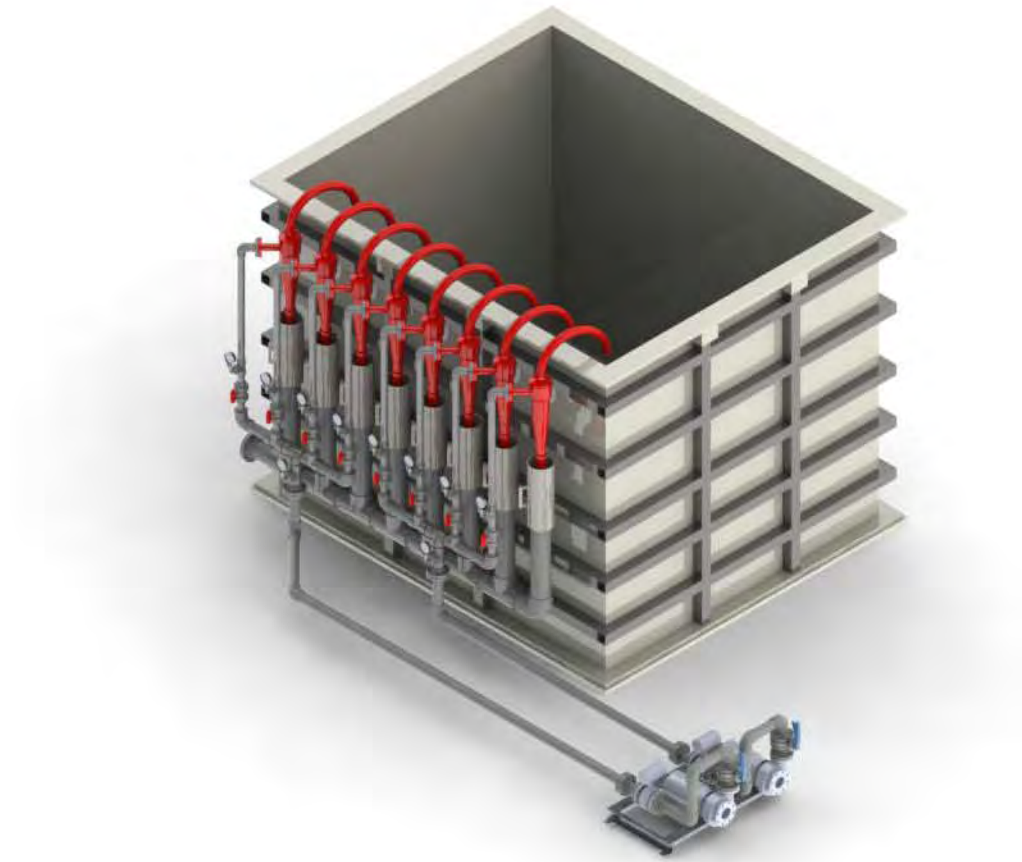
AOB
bioaugmentation
WAS
AMX
enrichment
AMX
enrichment
sidestream
AMX
bioaugmentation
mainstream



S-select – Cyclone installation for settleability improvement



HRSD James River Plant - S-Select



HRSD Mainstream Approach

Anaerobic digestion is not necessary

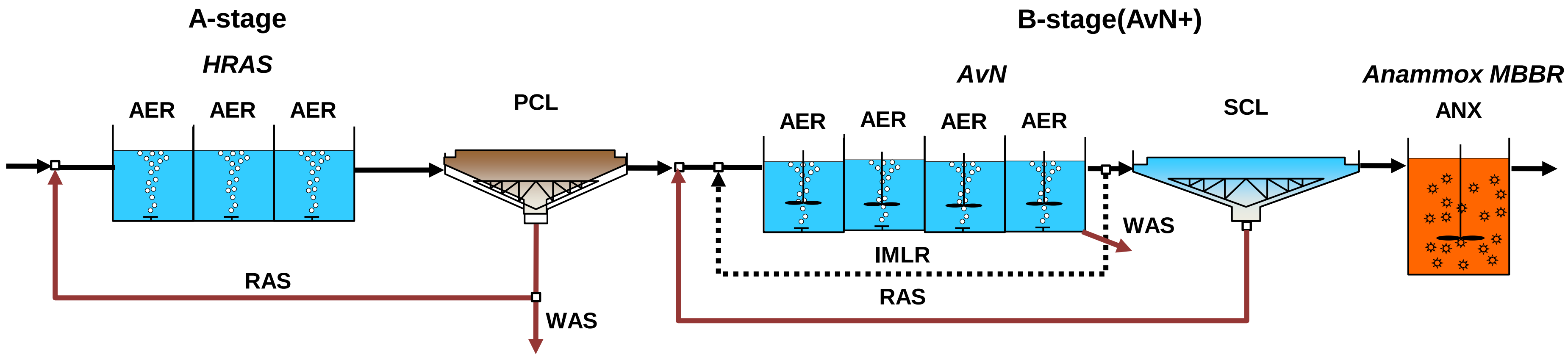
- **Minimum aeration and volume for C-removal**
- **Reduce volumetric requirement for nitrogen removal**

- **Promote nitrite shunt pathway to achieve more nitrogen removal for a given influent C/N**
- **Produce effluent containing ammonia and nitrite for anammox polishing**
- **AVN control system for NOB out-selection**

- **Remove remaining nitrogen autotrophically without additional aeration energy and supplemental carbon**
- **Meet very low effluent TIN limits**

https://vimeo.com/92084803

Pilot 2.0



Mainstream 2.0 & 3.0
A Few Conclusions…

- NOB out-selection is possible in mainstream (sensors and novel control systems are unavoidable)
- Separate stage C and N removal is back…
  - Energy benefit
  - BNR volume and footprint benefit
- Anammox polishing in the mainstream is feasible and simple
- NOB out-selection is really tough…
- The AVN control strategy provides excellent N removal even in conventional 1.0 nitrification-denitrification mode – **technology is adequately incremental and transferable to existing infrastructure**

Questions?

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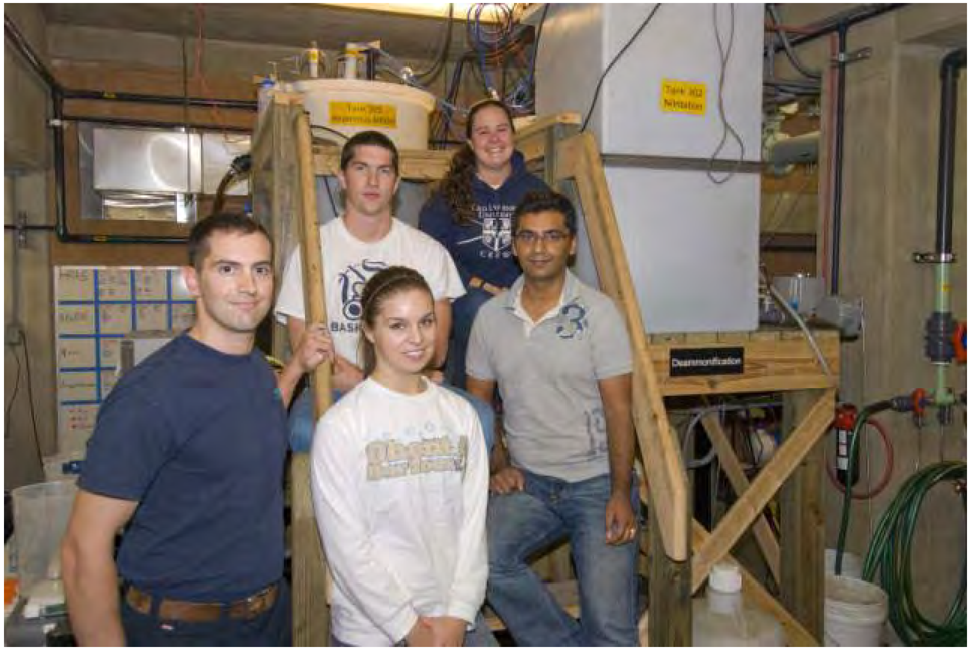

HRSD