One Hundred Years of Activated Sludge – Is it Demise or an Even Brighter Future?

Samuel Jeyanayagam, PhD, PE, BCEE
Julian Sandino, PhD, PE, BCEE
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History of Activated Sludge

- Social & economic changes of the late 19th century triggered the problem with sewage
  - The 2nd industrial revolution resulted in technological & economic growth and better living standards
  - Increased urbanization and exponential population growth
  - Provision of safe drinking water for a growing population led to waterborne sewage and drastically increased waste volume
  - This overwhelmed traditional waste management approaches of the day

Paris Sewer (1896)

History of Activated Sludge

- Led to the use of sewage farms – large land requirements. Provided mixed results
- Increased interest in alternative treatment methods: septic tanks, Imhoff tanks, trickling filters, physical-chemical methods, etc.
- Led to the use of aeration to mitigate odors. But treatment was still inadequate

- 1890s & 1900s various researchers hypothesized that the missing ingredient in aerobic treatment were accumulated ‘humus’ (solids)
- Early 1910s: the Lawrence Experimentation Station, Lawrence, MA successfully tested aeration of accumulated biomass on wooden slats (biofilm concept).

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History of Activated Sludge

- Researchers were beginning to note the importance of aeration & solids retention.
- 1912: John Fowler of the University of Manchester, England visits the Lawrence Experimental Station. He has been experimenting with aeration of sewage.
- At Lawrence, he observed work by Clark & Gage: aeration of bottles containing sewage and algal suspension. This gave Fowler an “illuminating idea”
- On returning to the UK, he tested his idea in a flow-through reactor – reaction rates were disappointingly low.

History of Activated Sludge

- 3rd April 1914: Two of Fowlers students (Edward Ardern & William Lockett) repeated the experiment in an aerated fill-and draw reactor (SBR) - ***EUREKA!***
- By retaining the solids in the tank, reaction rates were increased. Solids were said to become ‘activated’ by retention. Fowler aptly characterized the outcome as “bombshell.”
- They published the findings in 3 papers in 1914 & 1915

History of Activated Sludge

- While Ardern & Lockett are widely recognized as the inventors of the AS system, it is obvious that
  - They leveraged previous work by others by providing the last ‘piece of the puzzle’ - a small but all-important detail of seeding – a well known concept today that we achieve via RAS.
  - Their association with Fowler, his knowledge, & his connections positioned them to make this significant contribution.

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Ardern & Lockett Publish Activated Sludge Process - 1914

History of Activated Sludge

- Typically, adoption of new technology is a 20-year process
- In the case of the AS process, although the exact removal mechanisms were not fully understood, it was immediately adopted & implemented at many plants in the UK and US.
- Why?
  - It met an urgent need
  - It was transformational with respect to public health & environmental protection

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20 AS Systems Implemented & Tested in 13 years

Year	Location	mgd	Year	Location	mgd
1914	Salford, UK	0.08	1920	Stamford, UK	0.1
1915	Davyhulme, UK	0.1	1920	Tinstall, UK	0.8
1916	Worcester, UK	2	1921	Sheffield, UK	0.4
1916	San Marcos, TX	0.1	1921	Davyhulme, UK	0.7
1916	Milwaukee, WI*	2	1921	Bury, UK	0.4
1916	Cleveland, OH*	1	1922	Des Plaines, IL	5.5
1917	Houston (North), TX	5	1922	Calumet, IN	1.5
1917	Sheffield, UK	0.8	1925	Milwaukee, WI	45
1917	Withington, UK	0.3	1925	Indianapolis, IN	50
1918	Houston (South), TX	5	1927	Chicago (North), IL	175

* Experimental

Activated Sludge, IWA

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Activated Sludge Patents

- Jones & Attwood, Ltd obtained four patents - the first in 1913 before Ardern & Lockett made their results public.
- The US licensee was Activated Sludge Ltd.
- Royalty: $0.25 per capita served
- Result:
  - Some utilities got sued
  - Some paid the royalty
  - Some delayed installation until the patent expired
  - Others implemented alternate technologies (e.g. trickling filter)

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Activated Sludge Guiding Principles

1. The bioreactor environmental conditions determine the makeup of the microbial community and the reactions they mediate.
2. SRT is the most important design & control parameter.
3. A COD balance across the bioreactor provides valuable information about the amount of electron acceptor (e.g. DO) required and the amount of excess biomass (waste sludge) produced
4. The excess biomass produced is essentially the same for all suspended growth systems with the same SRT and biochemical environment, regardless of the bioreactor configuration.

Grady et al.

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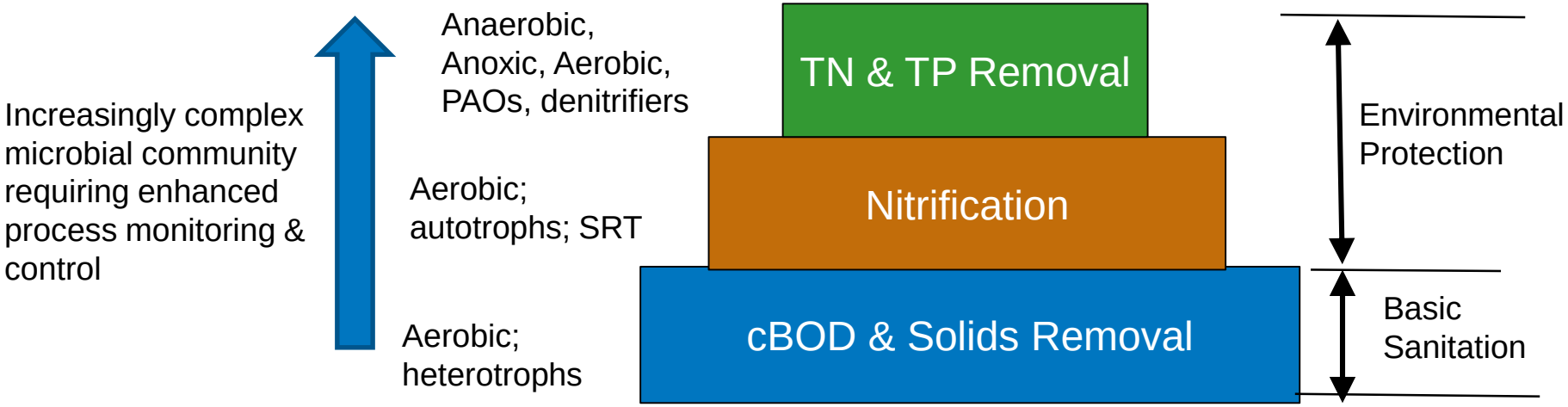
The AS System is Robust, Flexible, and Adaptable

- The AS process has served us well in the last 100 years to meet evolving treatment needs.
- By changing the bioreactor environment & SRT we have been able to select the desired organisms (Guidance Principles #1 & 2).



Can AS Continue to Meet the Needs of the 21st Century and Beyond?

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Drivers for Change in the 21st Century

- Rapid population growth & urbanization will put increasing pressure on available resources.
- Recovering water (reuse), energy, and nutrients from wastewater will take center stage.
- Research into the next generation resource recovery is already happening.
- Disruptive and game-changing approaches are needed to allow today's wastewater treatment plant to evolve as WRRF of the future
- Incremental changes maintain the *status quo* and are inadequate

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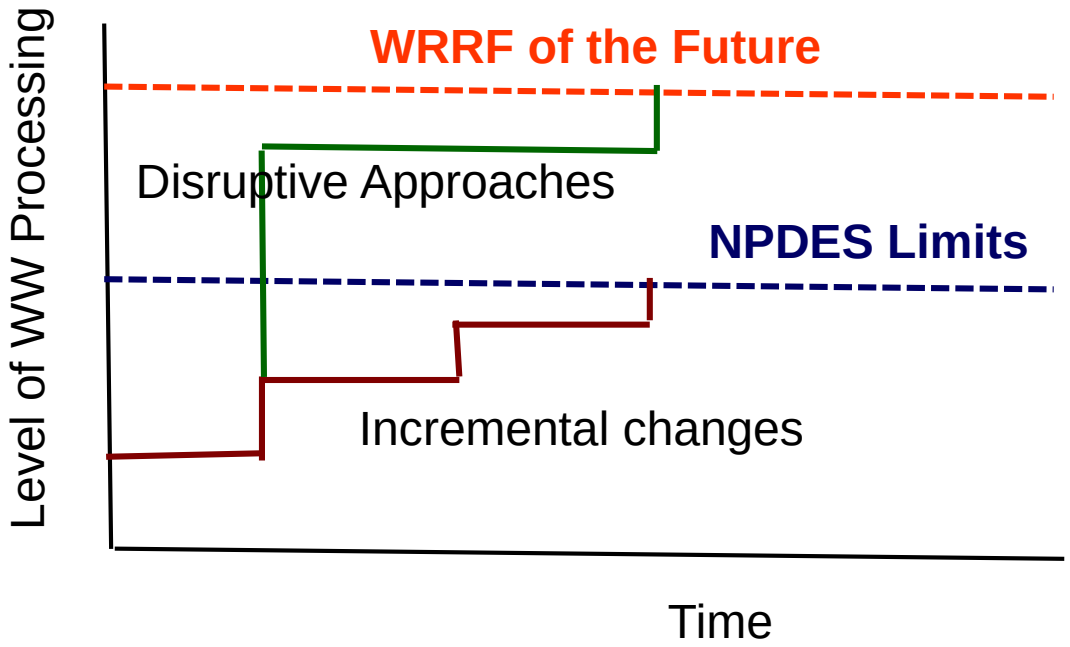
Disruption is the Name of the Game



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The Water Resource Recovery Facility of the Future

Features of the WRRF of the future:

- Continue providing environmental & public health protection
  - Achieve cBOD, TSS, and nutrient removal
- Additional requirements
  - Water reuse
  - Energy recovery
  - Nutrient recovery
  - Next generation resource recovery – WRRF as a biorefinery

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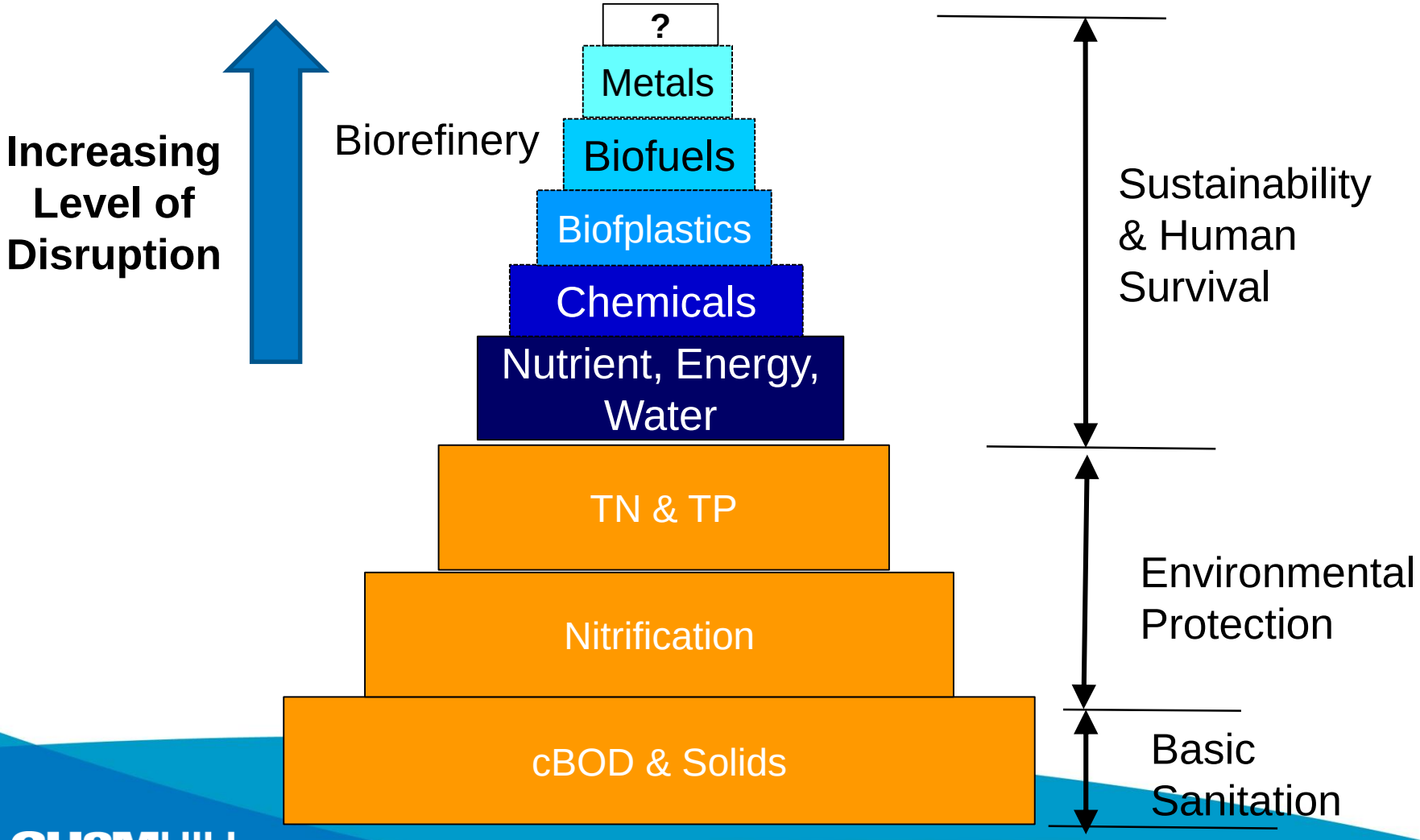
Transformational & Disruptive Approaches are Needed to go from Treatment to Product Recovery



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Processes for Reuse Application

Process	Dissolved Org. Matter	Trace Organics	TDS	Bacteria & Protozoa	Viruses
Microfiltration				X	
Ultrafiltration				X	X
Nanofiltration	X	X	X	X	X
RO	X	X	X	X	X
Electrodialysis			X		
GAC	X	X			
Ion exchange		X	X		
AOP	X	X		X	X
UV Disinfection				X	X

AS in combination with advanced tertiary treatment processes can meet the varying reuse requirements

Typical Energy Use – Secondary Activated Sludge Facility

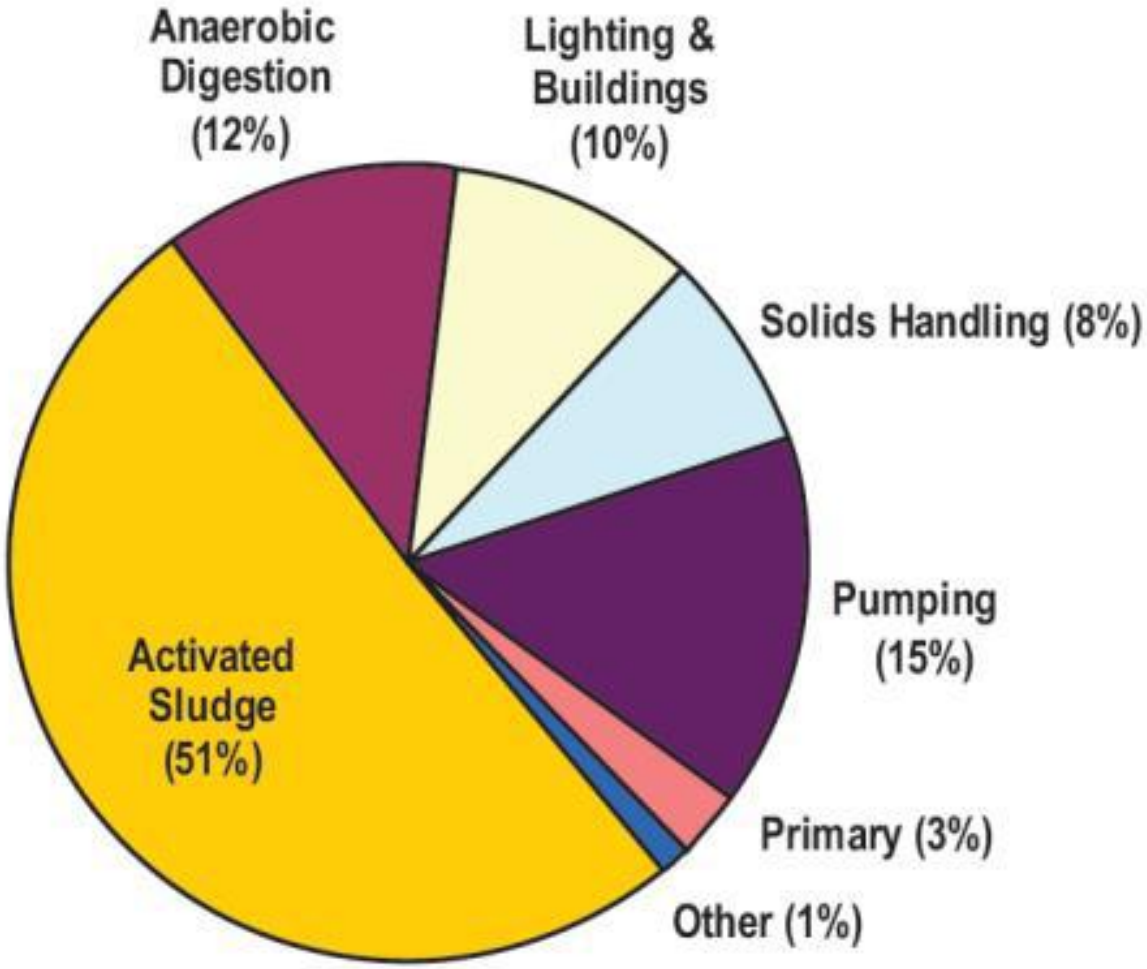


FIGURE 5.2 Typical energy use for an activated sludge secondary facility (SAIC, 2006; WEF, 2009).

Many Options for Recovering Energy From Wastewater

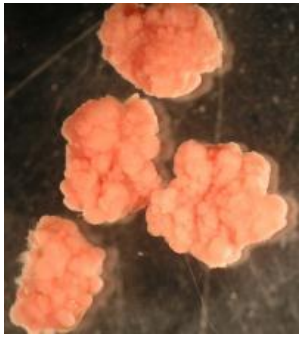
Liquid Stream

- Anaerobic Treatment
- Microbial Fuel Cells
- Effluent Heat
- Algae
- Mainstream & Sidestream Anammox
- Hydraulic Head
- Tight DO Control

Solids Stream

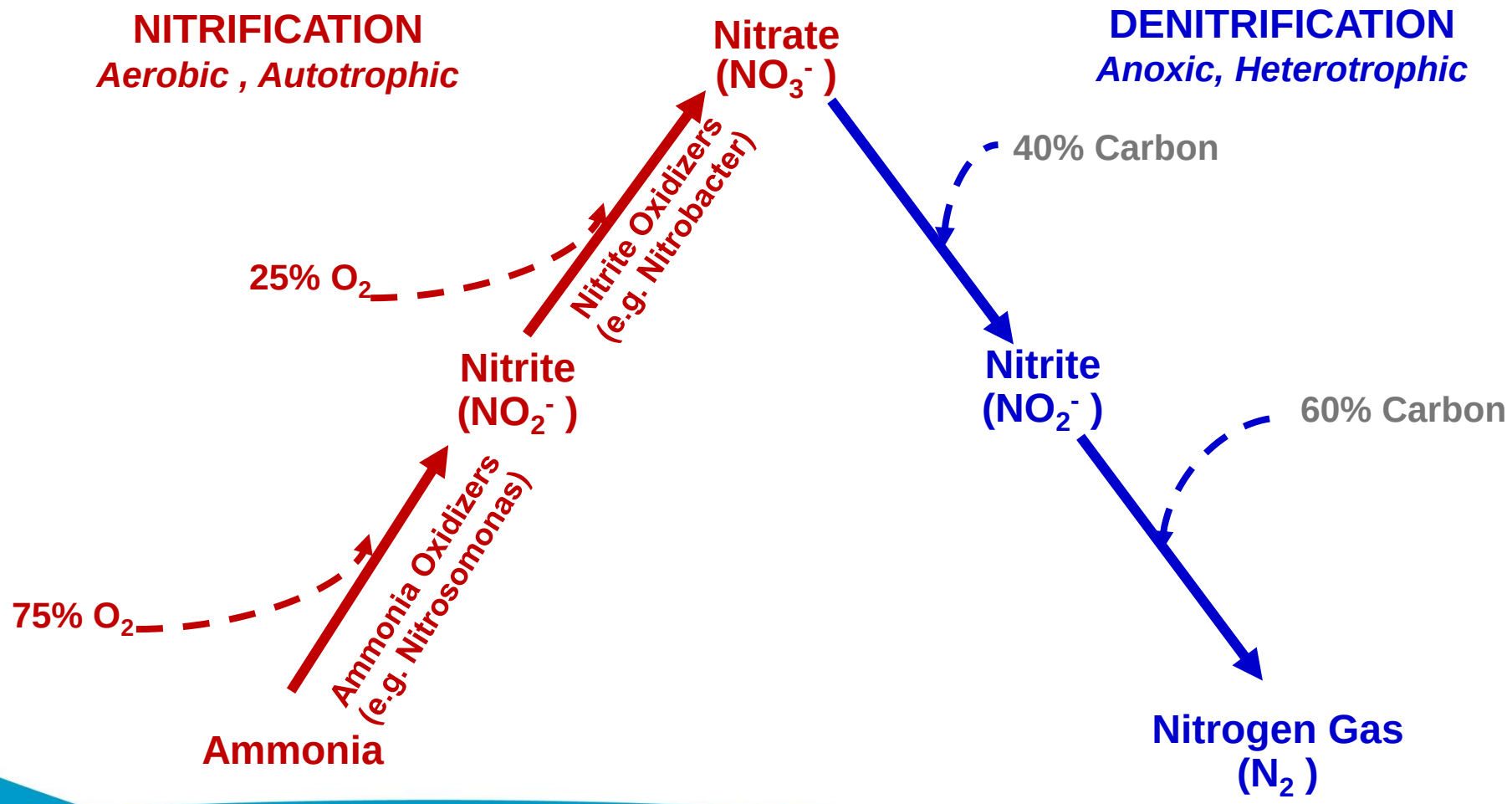
- Co-Digestion
- Thermal Oxidation
- Paralysis
- Gasification
- CHP

Anammox (Anaerobic Ammonium Oxidation) Bacteria



- Discovered in the mid 1990sin the University of Delft, The Netherlands
- Very low growth rate (1/10th that of nitrifiers!)
- Oxygen is poison!
- pH (neutral range)
- Nitrite inhibited (maintain at <40 mg/L)
- Free Ammonia inhibited (maintain at <10 mg/L)

Traditional Nitrification/Denitrification



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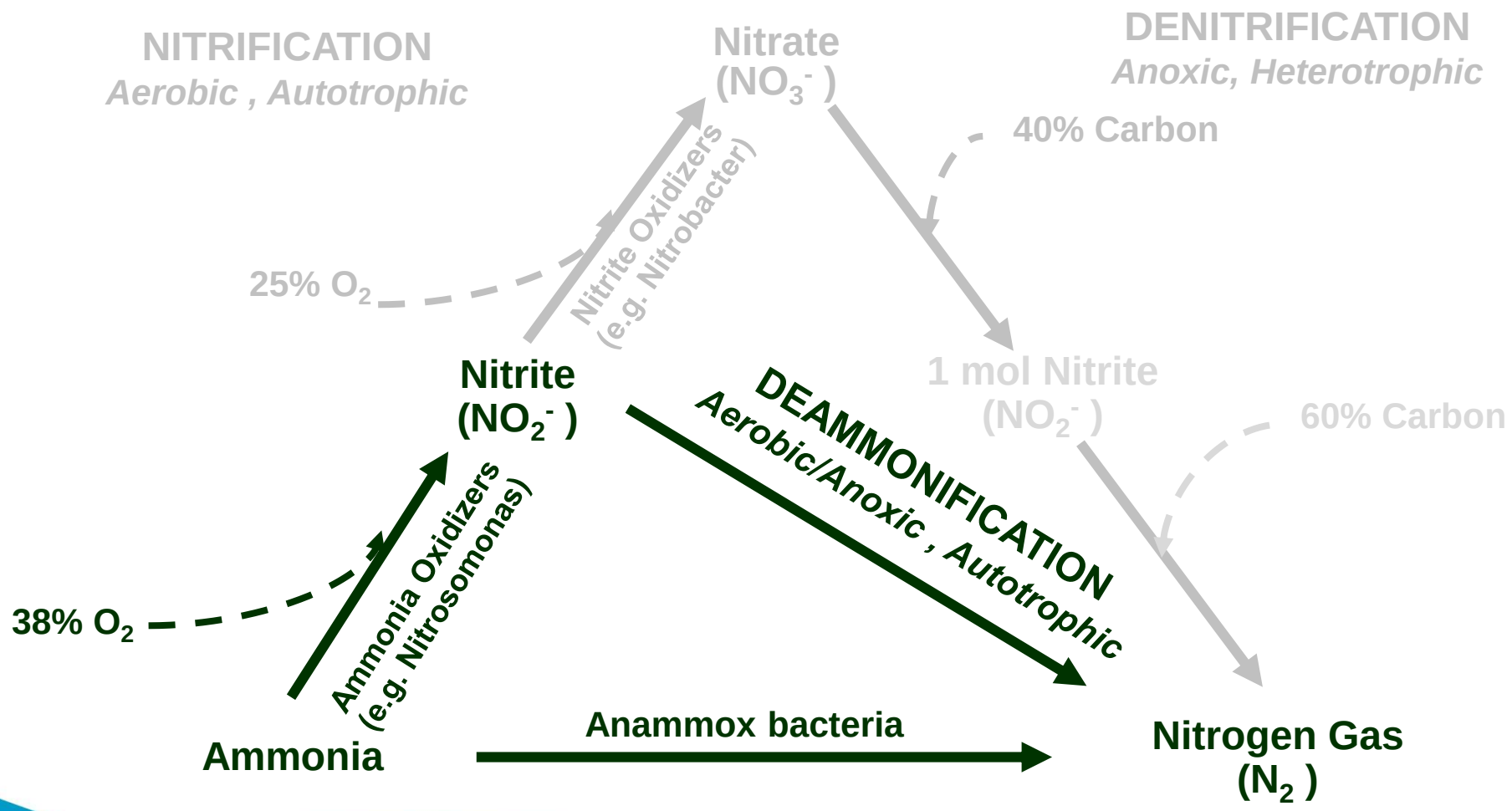
Deammonification



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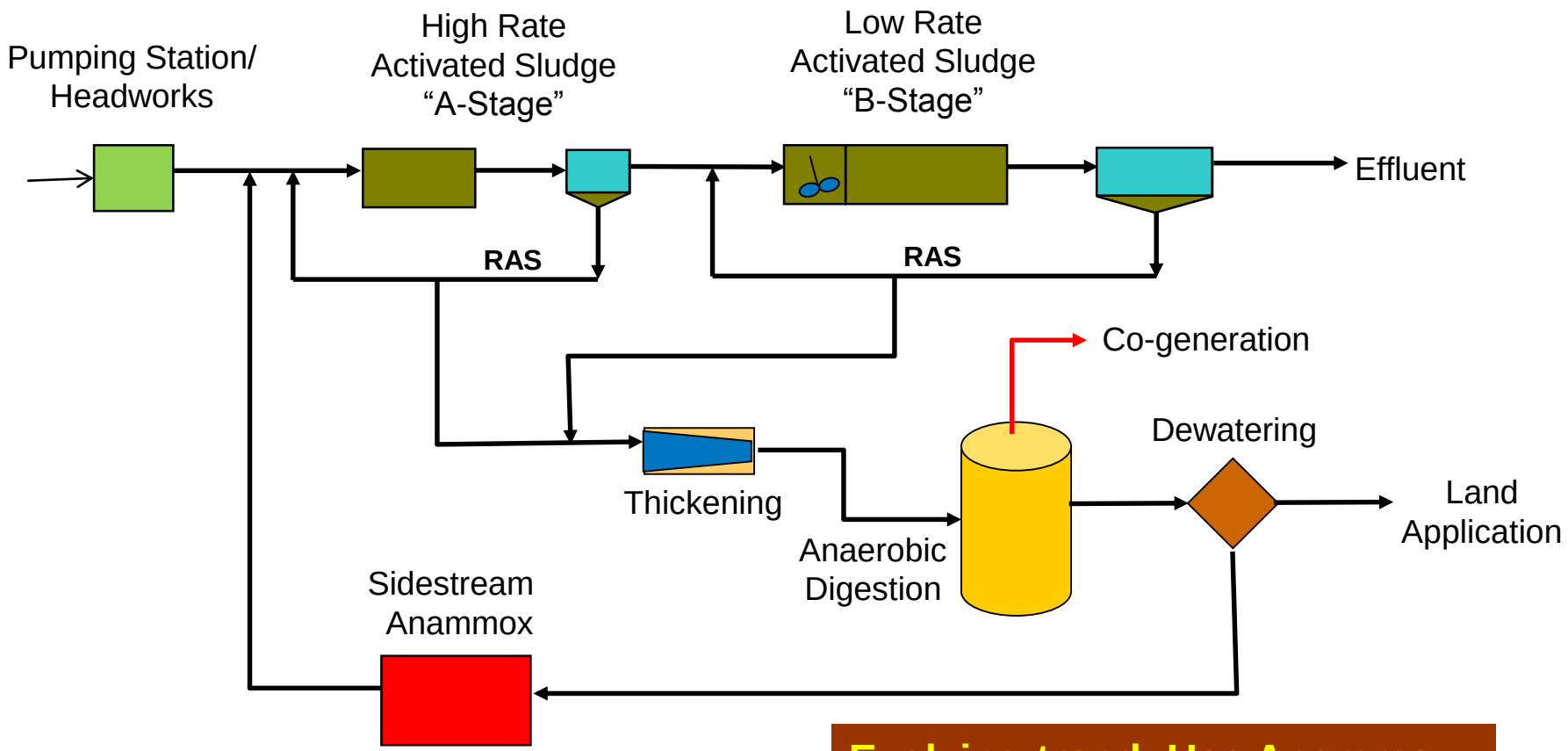
Strass WWTP, Austria

- **BOD oxidation minimized**
- **Adsorption promoted**
- **Carbon (BOD) preserved for AD – more methane**



Evolving trend: Use Anammox in the mainstream as well

Benefits of Anammox

- 63% reduction in oxygen demand
- Nearly 100% reduction in carbon demand
  - Divert carbon for energy production & reduce aeration demand
- 80% reduction in biomass (sludge) production
- No additional alkalinity required
- Successfully used for sidestream treatment
- Now being extended to mainstream to realize additional energy savings

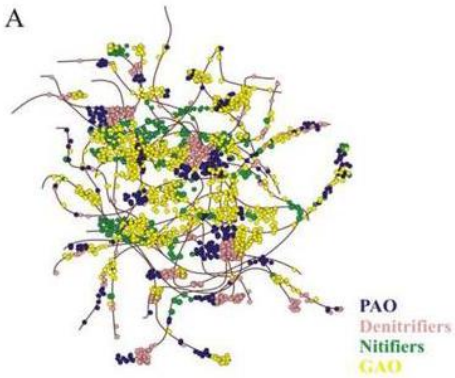
Aerobic Granular Sludge

- Granules are:
  - Special type of biofilms w/o carrier material.
  - Dense, strong & compact aggregates of biomass
- Anaerobic granules used for >40 years in Upflow Anaerobic Sludge Blanket reactors in Europe.
- It is now possible to grow aerobic granules.
- Very high settling velocities; approx. 6X that of typical AS floc. Very low SVIs. Smaller clarifier
- Higher biomass concentrations (>15,000 mg/L compared to 3,000 – 4,000 mg/L MLSS) – smaller bioreactor
- Total footprint approx. 20-25% of conventional BNR bioreactor

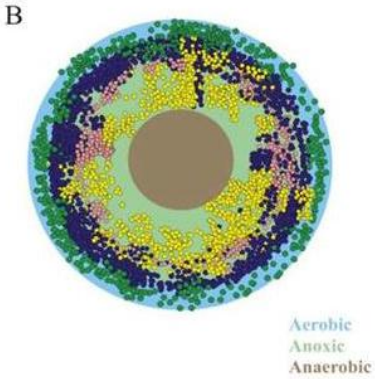
Aerobic Granular Sludge

Diffusion Gradients Transform Each Granule into a 'Bioreactor'

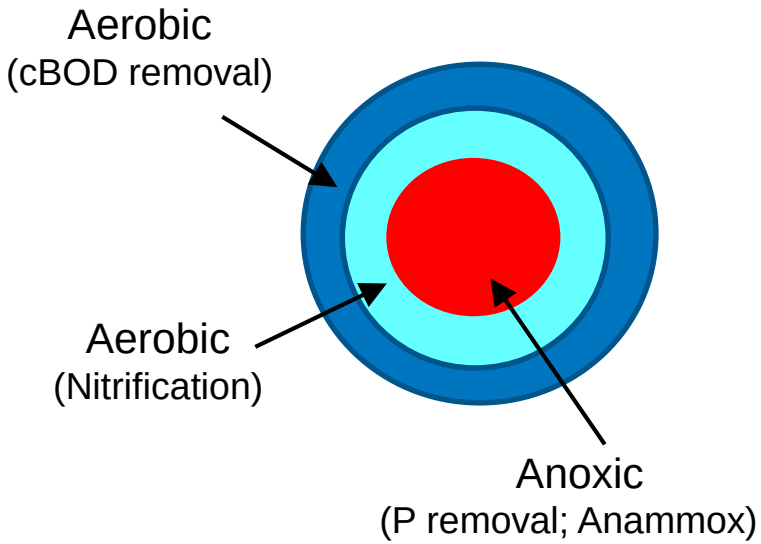
- Unique layered microbial distribution created by diffusion of the various components
- Each granule becomes a complete 'biological reactor'
  - ➢ cBOD, TN, & TP removal
- Do not need baffled bioreactor zones



Typical AS Floc

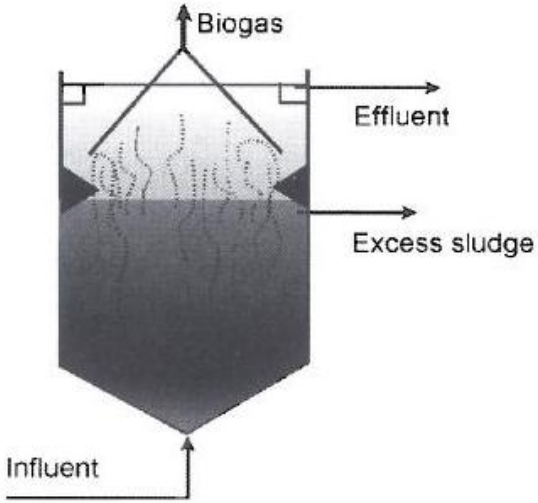


Granular Sludge



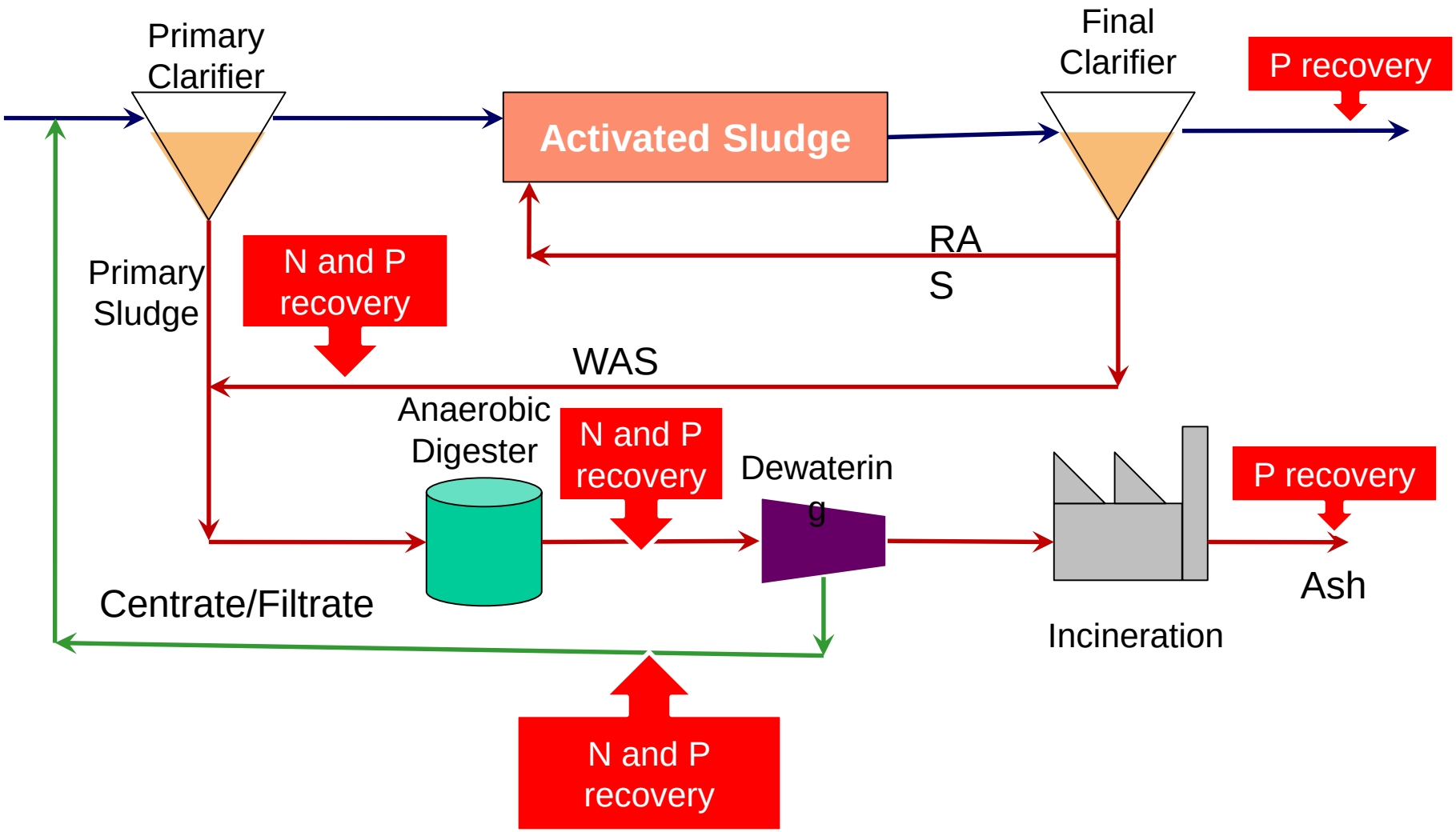
Anaerobic Treatment of Liquid Stream

- Developed by Lettinga >30 years ago in the Netherlands
- Methane production
- Elimination of aeration
- Reduced sludge production
- Nutrient rich effluent amenable to nutrient recovery

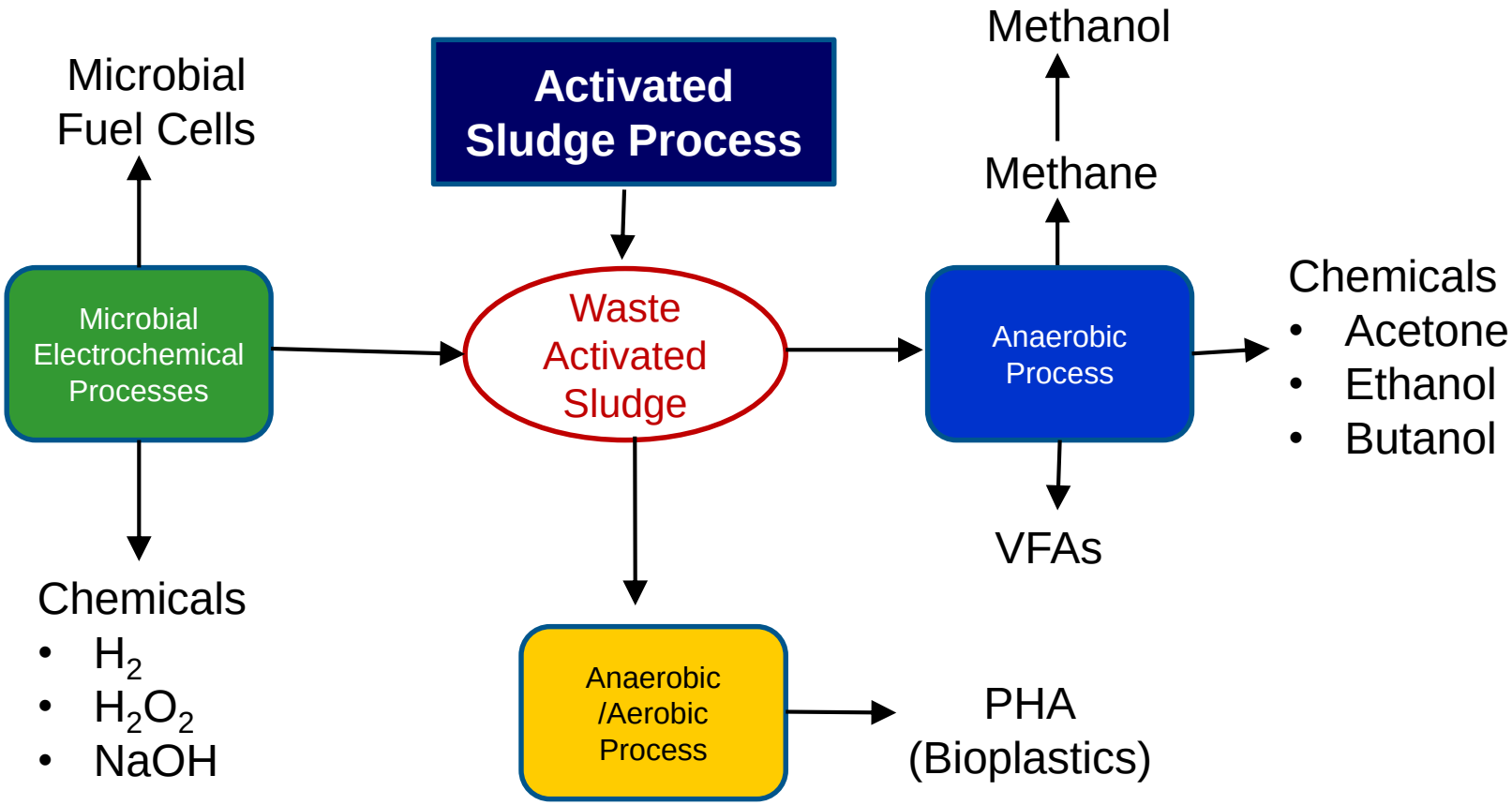


Upflow Anaerobic Sludge Blanket (UASB) reactor

Nutrient Recovery
Nuisance to Resource



AS System is Aligned with the Next Generation Resource Recovery (Biorefinery)



Gilmore, Khunjar & Jeyanayagam
WERF NTRY3R13

What is impossible today won’t be tomorrow

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Take Home Messages

- The myth about DO has been shattered!
- Experience has shown that the AS system is robust, flexible & adaptable.
- The AS is comprised of a consortium of diverse organisms. Still a black box
- By manipulating the environment we have taken advantage of naturally present niche organisms: e.g. heterotrophs, nitrifies, denitrifies, PAOs, GAO, Anammox, aerobic granular sludge, etc
- Management of the microbial community will take center stage as we strive to go from treatment to product recovery

Take Home Messages

- Microbes in the AS system will live up to expectation and do their best under the design & operating conditions imposed! They are 100% predictable!
- We are the limitation!! Our ability to monitor & control the biochemical environment will be key to realizing the full potential of the AS system.
- Tight process control will be central.
- As AS becomes more complex to meet our future needs, tools are needed for early detection of subtle changes: e.g. bio-sensing, meta-omic, etc.

Take Home Messages

Activated sludge is neither dead nor dying….it is actually alive & kicking (pardon the pun) and is ready to reveal many more hidden treasures (bugs) to serve our evolving needs for the next 100 years.

Thank You Edward Ardern, William Lockett & John Fowler!

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