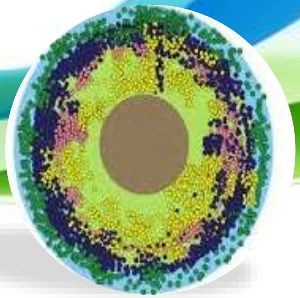
MWEA Annual Conference
June 20, 2017

Advances in Wastewater Treatment Technology

michigan water environment association
mwea
the water quality people

Nathan Cassity, Donohue

DONOHUE

Presentation Agenda

- History of Activated Sludge Process
- Advancement & Current Status
- Future Challenges
- Innovative Technologies
- Hypothetical Case Study for West Chicago, IL
- Conclusions

Early Sanitation

- Once upon a time …
  - Human waste & animal manure were simply returned to land to be used as fertilizers
- Industrial revolution of 20th century…
  - Increased population growth and urbanization
  - 'Cesspools' were constructed to treat increased sewage
  - Rivers became septic producing H2S
  - The 'Great Stink of 1858': Thames River in London

Early Sanitation

- Interceptor sewers + ‘Sewage Farms’
- Development of processes to extract nutrients from sewage for irrigation
  - ABC Process (alum, blood, and clay)
  - Septic tanks
  - Travis ‘Colloider' or ‘Hydrolytic’ Tank
  - Imhoff Tank

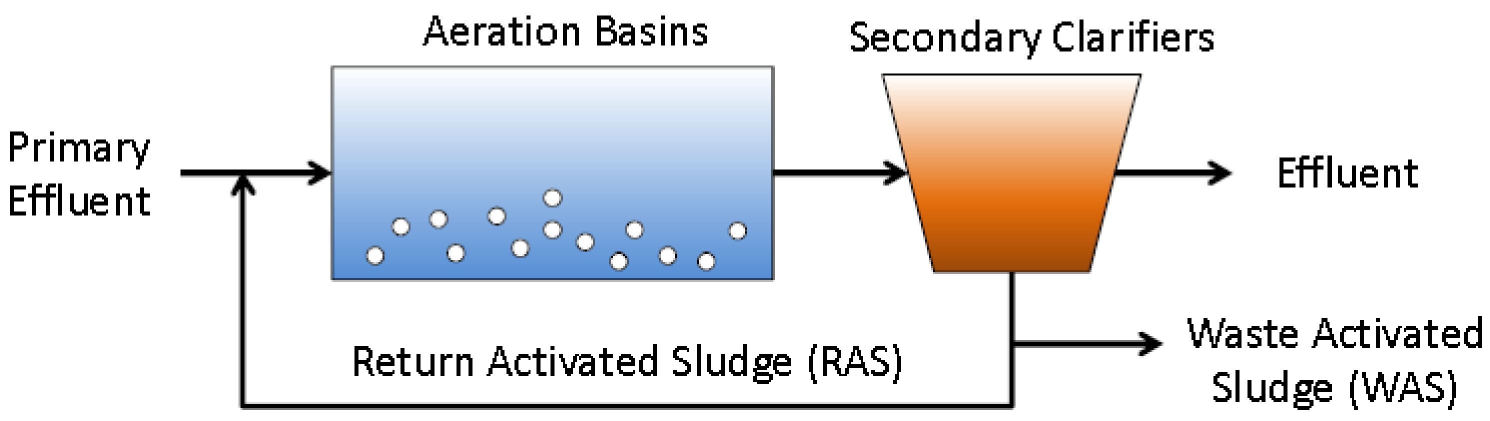
- Obnoxious and imposed health hazards
- Aerobic conditions to avoid undesirable malodors

1914 – Origins of Activated Sludge

- In 1913 Dr. Fowler (University of Manchester)
  - ‘Lawrence Experimental Station’ in Massachusetts
  - Purification of sewage in 24 hours in aerated bottles
- Ardern & Lockett repeated wastewater aeration experiments back in Manchester
  - Sludge was left in the bottle & mixed with new batch
  - Active role of sludge formed during aeration

    ‘Activated Sludge’
  - Published three papers which formed design basis

Activated Sludge - Principles



Retention of solids in aeration basin (RAS)

- Excess sludge wasting (WAS)
- Solids separation
- SRT

→

- BOD removal, nitrification
- MLSS
- Effluent

Activated Sludge – Process Advancement

BOD Removal

Nitrification – Unnecessary

High-rate systems with short SRTs

BOD Removal + Nitrification

Aquatic toxicity

Systems with longer SRTs

BOD Removal + Nitrification + Selectors

Sludge Bulking

Use of Selectors to Bio-select Microorganisms

BOD Removal + Nitrification + TN & TP Removal

Eutrophication

Unaerated zones

Increasing Process Complexities

Existing Treatment Schemes

Nitrification

- Conventional ASP
- Trickling Filters
- Oxidation Ditches
- SBRs
- BAF
- MBRs
- IFAS, MBBR
- Fluidized Beds

TP Removal

- CPR
- A/O
- PhoStrip
- SBRs
- MBRs
- Deep Bed Sand Filters

Lots of Variations

TN Removal

- MLE
- Bardenpho
- Oxidation Ditches
- SBRs
- Biological Filters
- MBRs
- IFAS, MBBR
- Deep Bed Sand Filters
- Upflow Fluidized Beds

TN & TP Removal

- A2/O
- Modified Bardenpho
- UCT/ MUCT
- VIP
- Jo'burg
- SBRs
- PhoStrip
- MBRs
- IFAS, MBBR
- Deep Bed Sand Filters

Site-specific Evaluation

Challenges

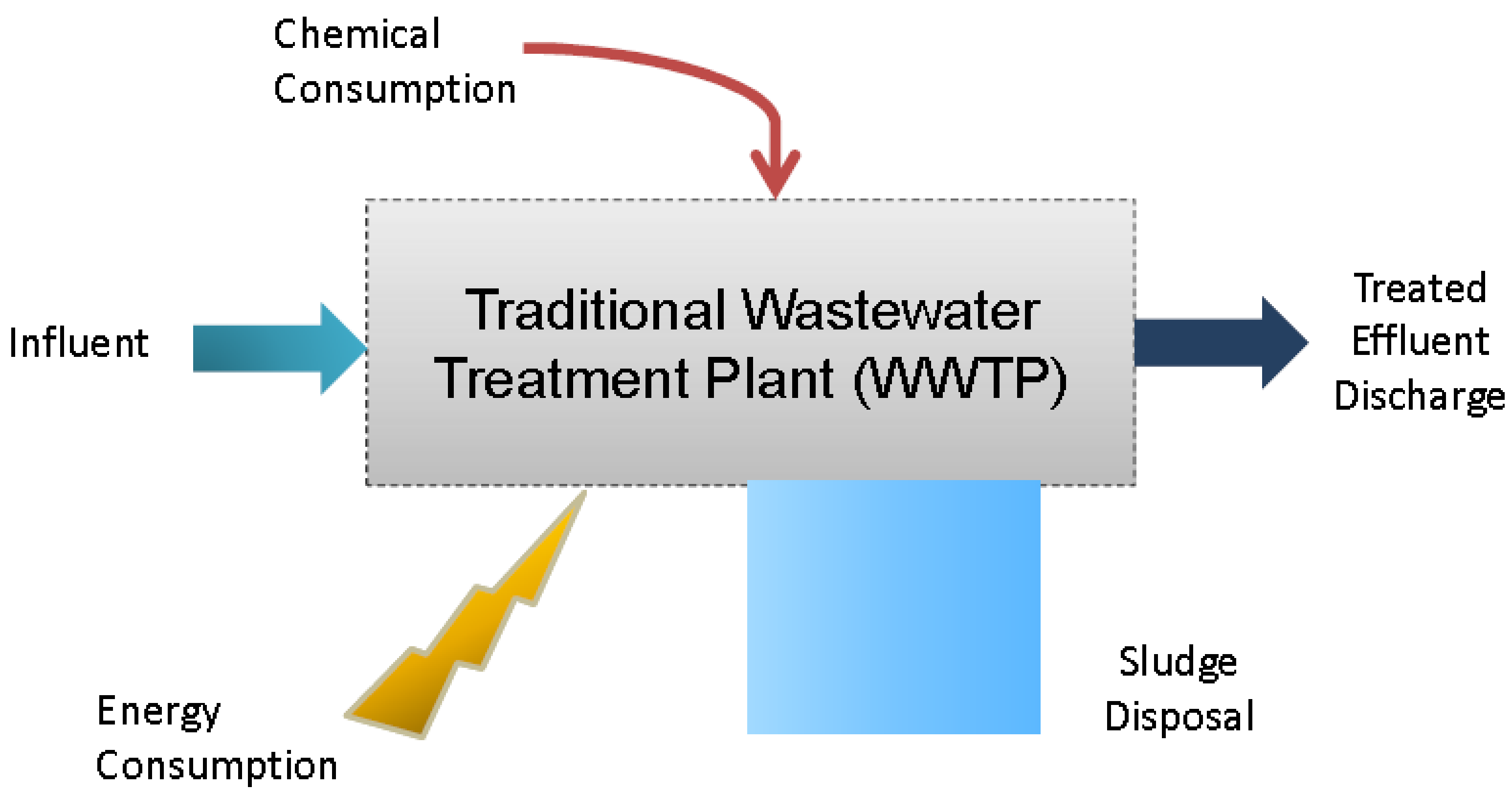
More Stringent Effluent Limits

- Limits of Technology (LOT)
  - More chemicals (ferric, alum, methanol, polymers, etc.)
  - More energy consumption (carbon footprint, GHG emissions)
  - More sludge production
  - More land requirements

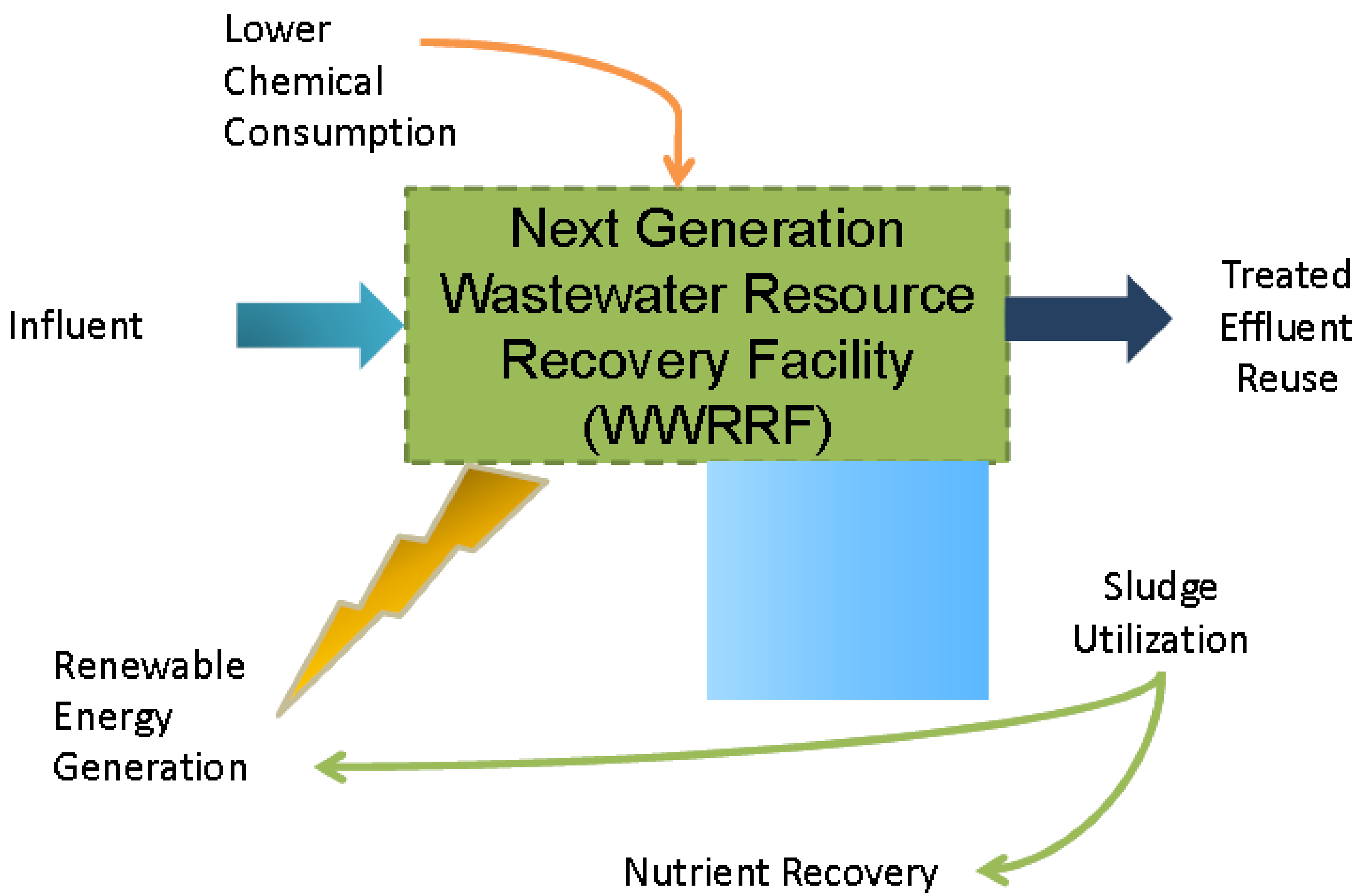
Resource Scarcity

- Increasing water demand but limited supply
  - Utilize treated effluent, gray water
- Phosphorus is limited and irreplaceable
  - 200 years supply at current consumption
- Increasing energy costs
  - Renewable energy generation

Paradigm Shift



Paradigm Shift

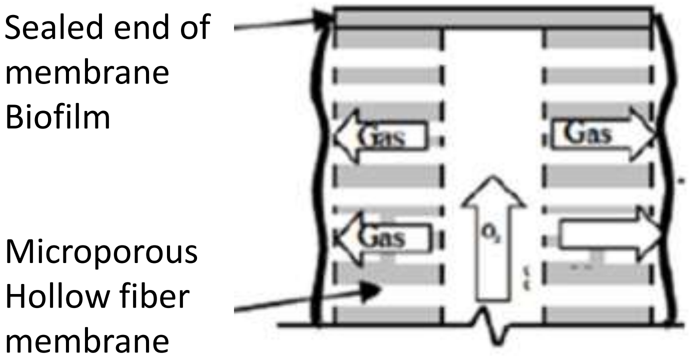


Innovative Technologies

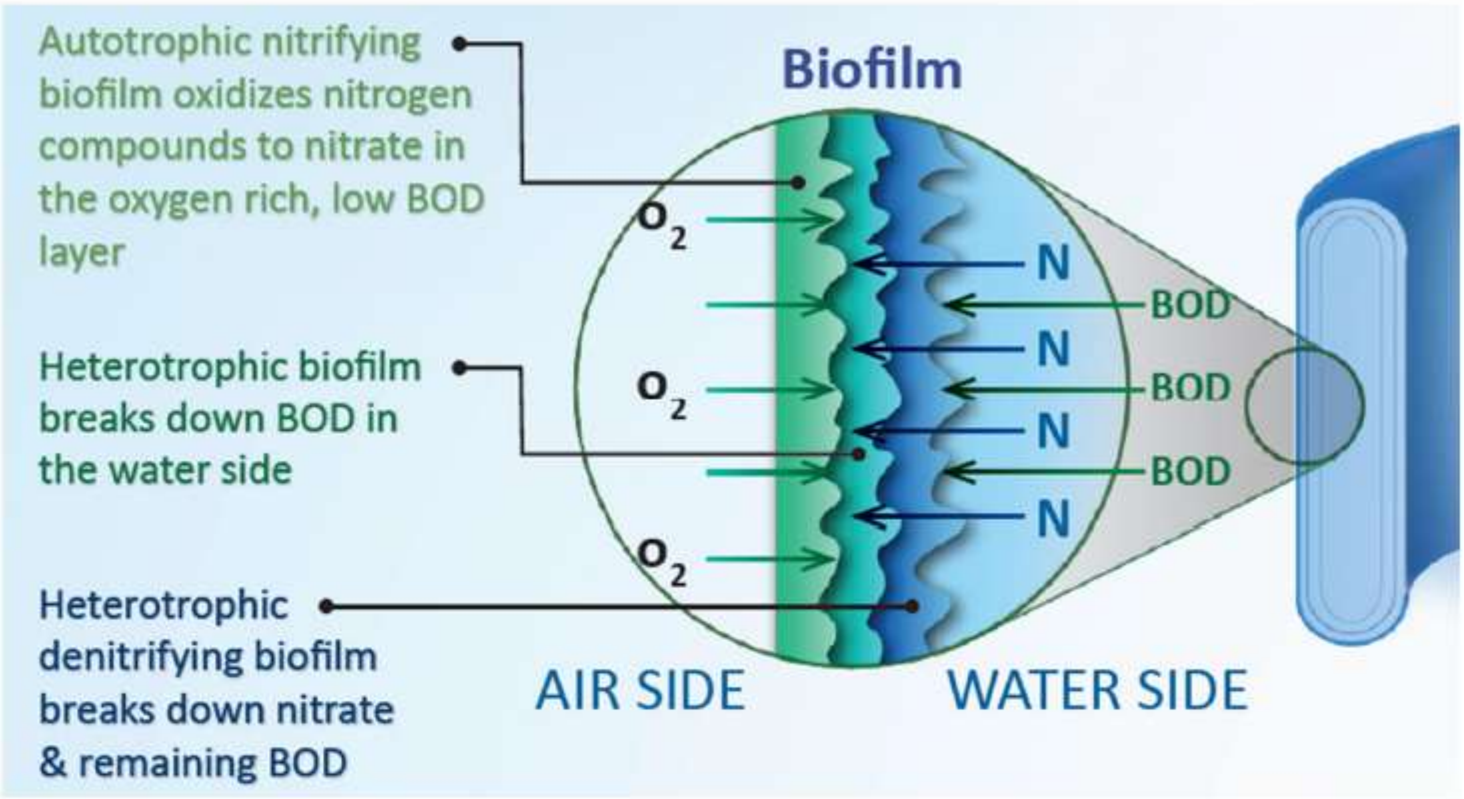
Membrane Aerated Biofilm Reactors (MABR)	✓
Anaerobic Membrane Bioreactor	
Anaerobic Migrating Blanket Reactor	
ANAMMOX Bacteria	✓
Aerobic Granular Sludge	✓
Membrane Fuel Cells	✓
Biomass Immobilization	✓
Vacuum Rotation Membrane…	
…and more	

MABR
(Membrane Aerated Biofilm Reactor)

- Oxygen diffusion through hollow fiber membrane
- Biofilm Development
  - Aerobic ... outside wall
  - Anoxic ... inside
- BOD along with SND
- ~ 95% reduction in energy
- 30%-50% reduction in sludge



MABR
(Membrane Aerated Biofilm Reactor)



Spiral Aerobic Biofilm Reactor (SABRE)

Courtesy: Emefcy

MABR (Membrane Aerated Biofilm Reactor)

Parameter	Valve	Units
Design Temperature	18 (64)	^oC (^oF)
Wastewater Flow	1000 (0.26)	m^3/d (MGD)
Influent Filtered BOD	150	mg/l
Influent TKN	52	mg/l
Effluent BOD	8	mg/l
Effluent NH-3 Req.	1.0	mg/l

MABR (Membrane Aerated Biofilm Reactor)

Process	SABRE	Activated Sludge	Units
Power Consumption	1.2	13	kW
Normalized Energy	0.06 (0.03)	1.10 (0.5)	kWh/kg BOD (kWh/lb BOD)
Normalized Energy	0.02 (0.06)	0.31 (1.18)	kWh/m^3 (kWh/1000 gal)

Power consumption reduction 95%

SABRE wastewater treatment plant 50 m^3/d (13,000G/d)

MABR
(Membrane Aerated Biofilm Reactor)

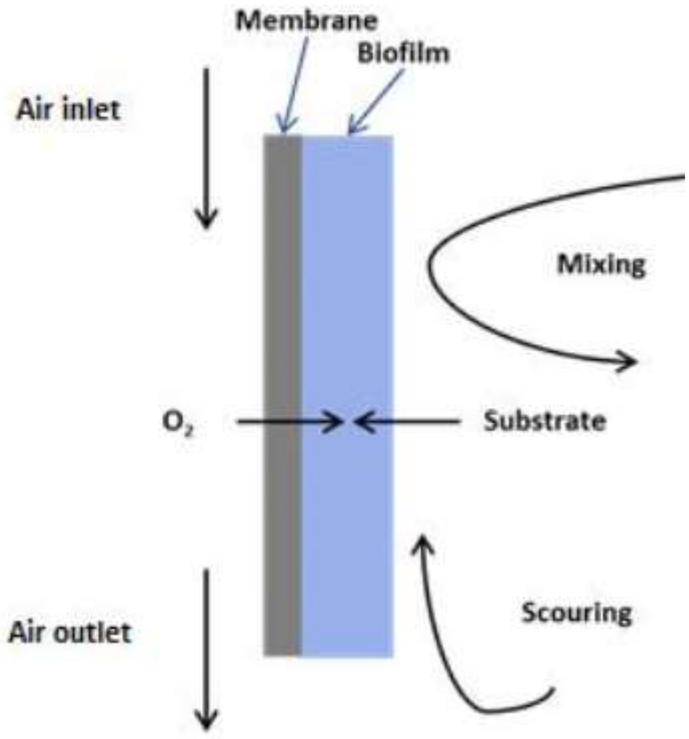


Figure 1: MABR operation principle

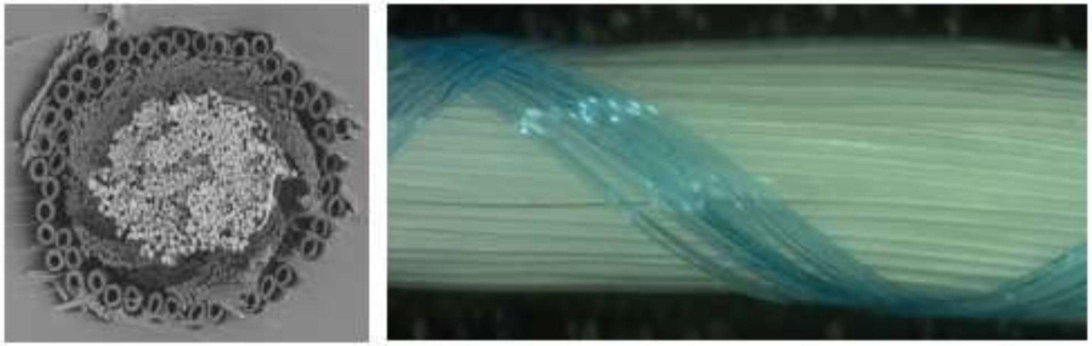


Figure 2: Scanning electron microscope image of ZeeLung cord

MABR
(Membrane Aerated Biofilm Reactor)

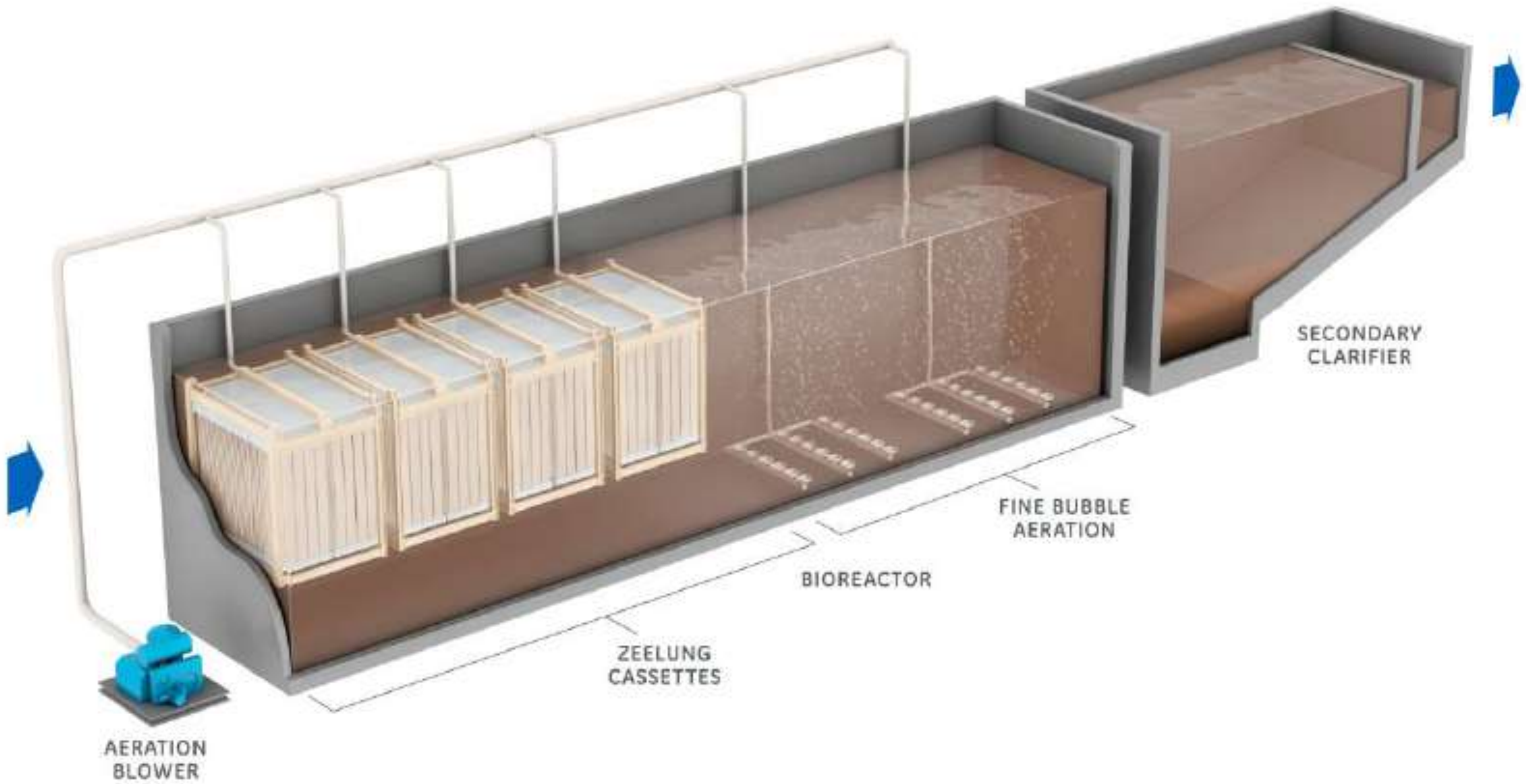
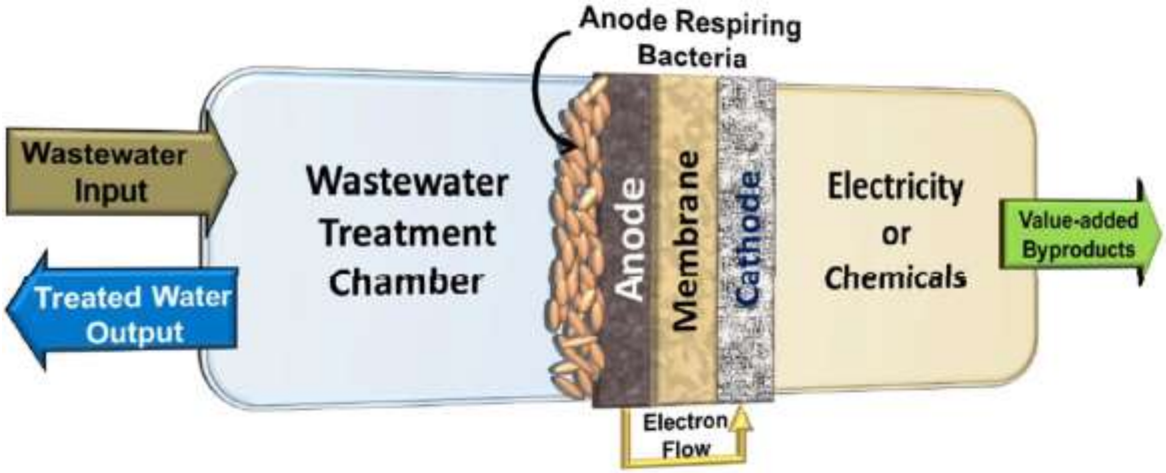


Figure 4: ZeeLung MABR process flow diagram

MABR
(Membrane Aerated Biofilm Reactor)

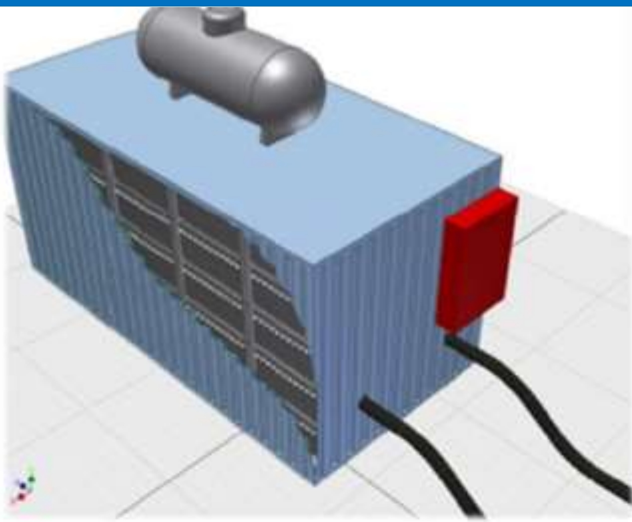
Microbial Fuel Cells

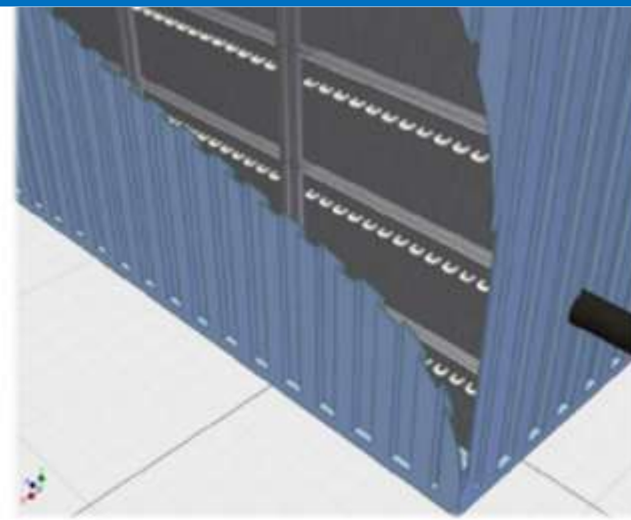
Solution: Arbcell® Microbial Fuel Cell

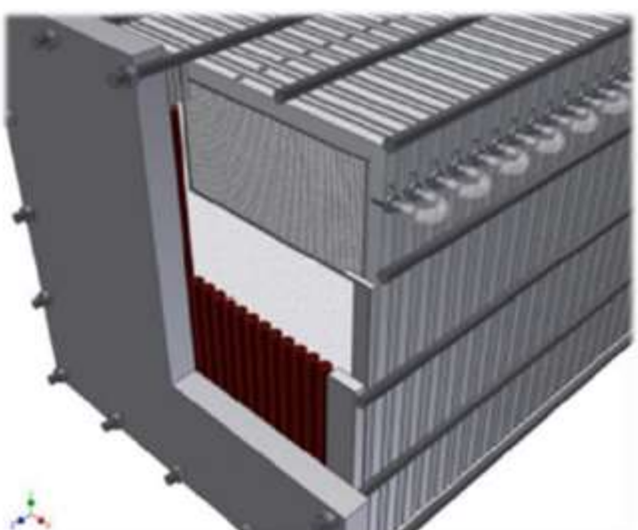


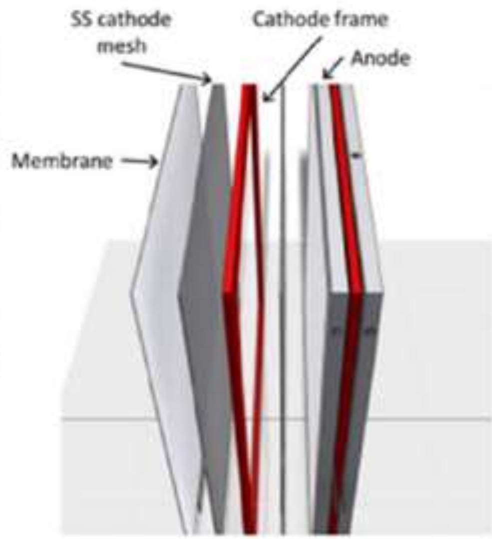
- High-throughput treatment compared to anaerobic digestion
- 700 kWh energy recovery potential per 1000 kg BOD removed
- Reduced cost through automated process control
- Small, enclosed modular design for customer facility compatibility
- BOD treatment range 1,000-10,000 mg/L influent
- Excellent way for customer to bolster green marketing initiatives

Scaled-up Design Concept

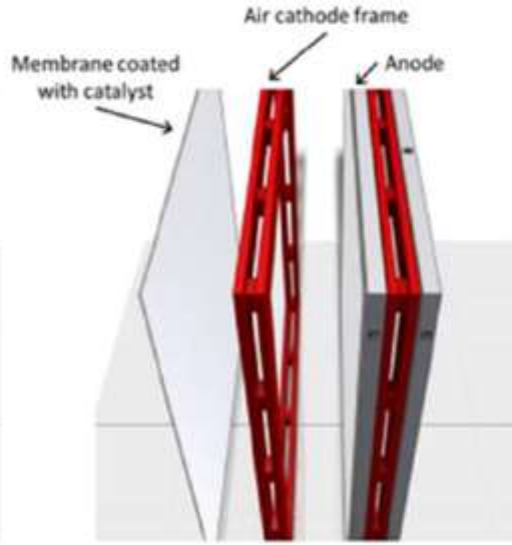






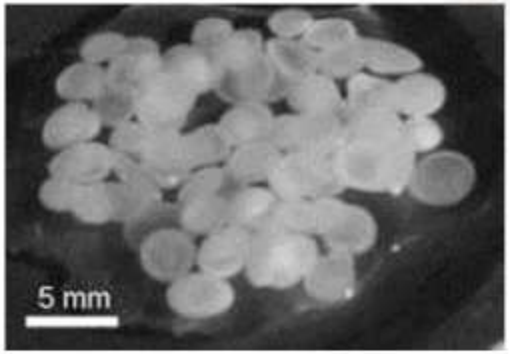


Arbcell MEC



Arbcell MFC

Biomass Immobilization



Biofilms – Attached Growth

- Current form immobilized biomass
- Sand, gravel, Plastic, etc.
- Trickling filter, MBBR, IFAS

Biocatalyst

- Capture pure cultures of microorganisms in activated sludge in gel pellets
- Use entrapped bacteria for wastewater treatment

Biocatalysts

Activated Sludge

- Mixed bacteria population
- Heterotrophs predominant
- Only ~ 4% nitrifiers (AOB, NOBs)
- Traditional Denitrification
  - 2 step process w/carbon

Conventional Design

- Nitrification
  - Long SRT More → Tank Volume
  - High Oxygen demand
  - High sensitive demand to pH, temperature
- Denitrification
  - High carbon demand

Pure Cultures

- High reaction rates
  - Nitrification … ~ 16 times
  - Denitrification … ~ 3 times
- Increased process stability
  - No washout of nitrifiers
- Low sludge production
- Low carbon source need

Biocatalyst Operation

BOD Oxidation

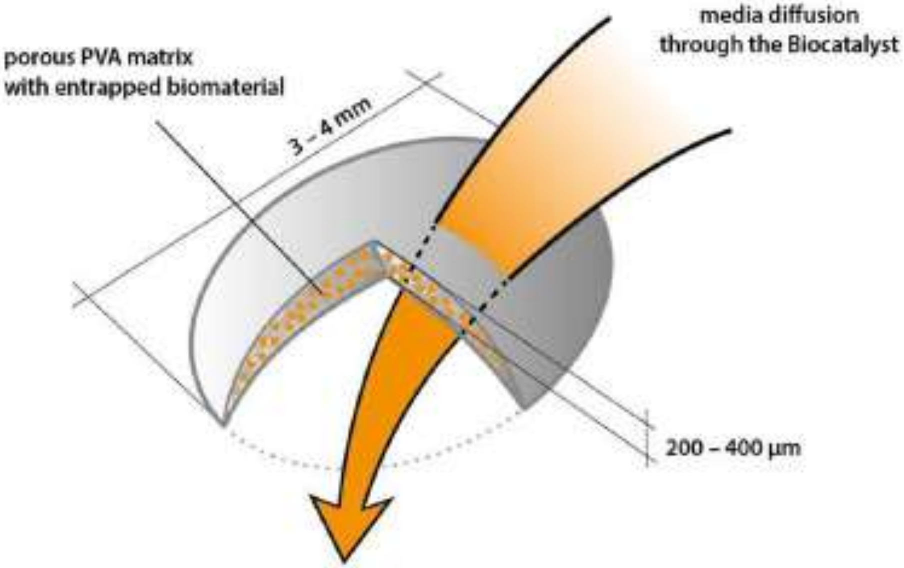
Paracoccus sp., Pseudomonas sp.

Nitrification

Nitrosomonas europaea, Nitrobacter and Nitrospira sp.

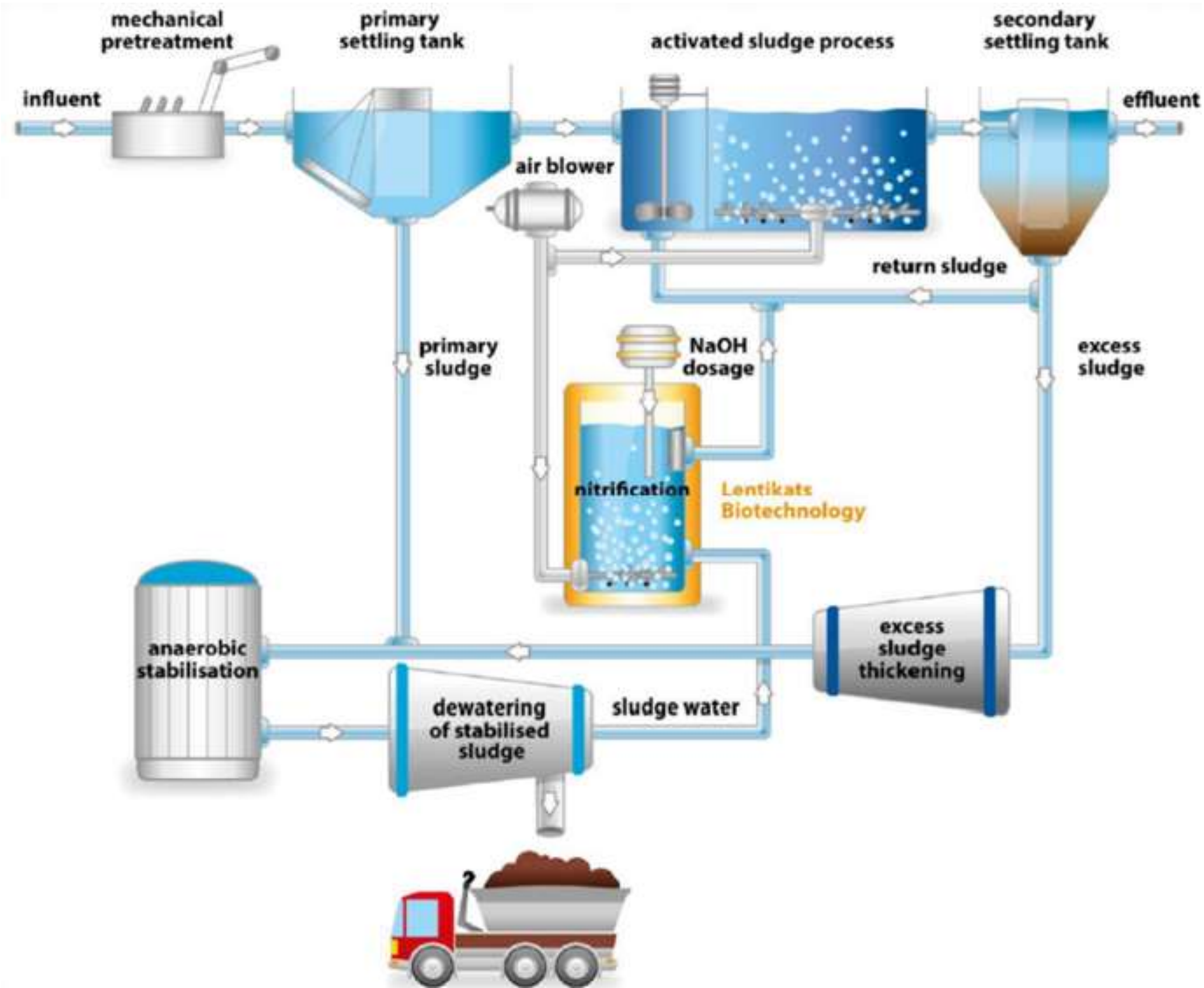
Denitrification

Paracoccus sp., Pseudomonas denitrificans

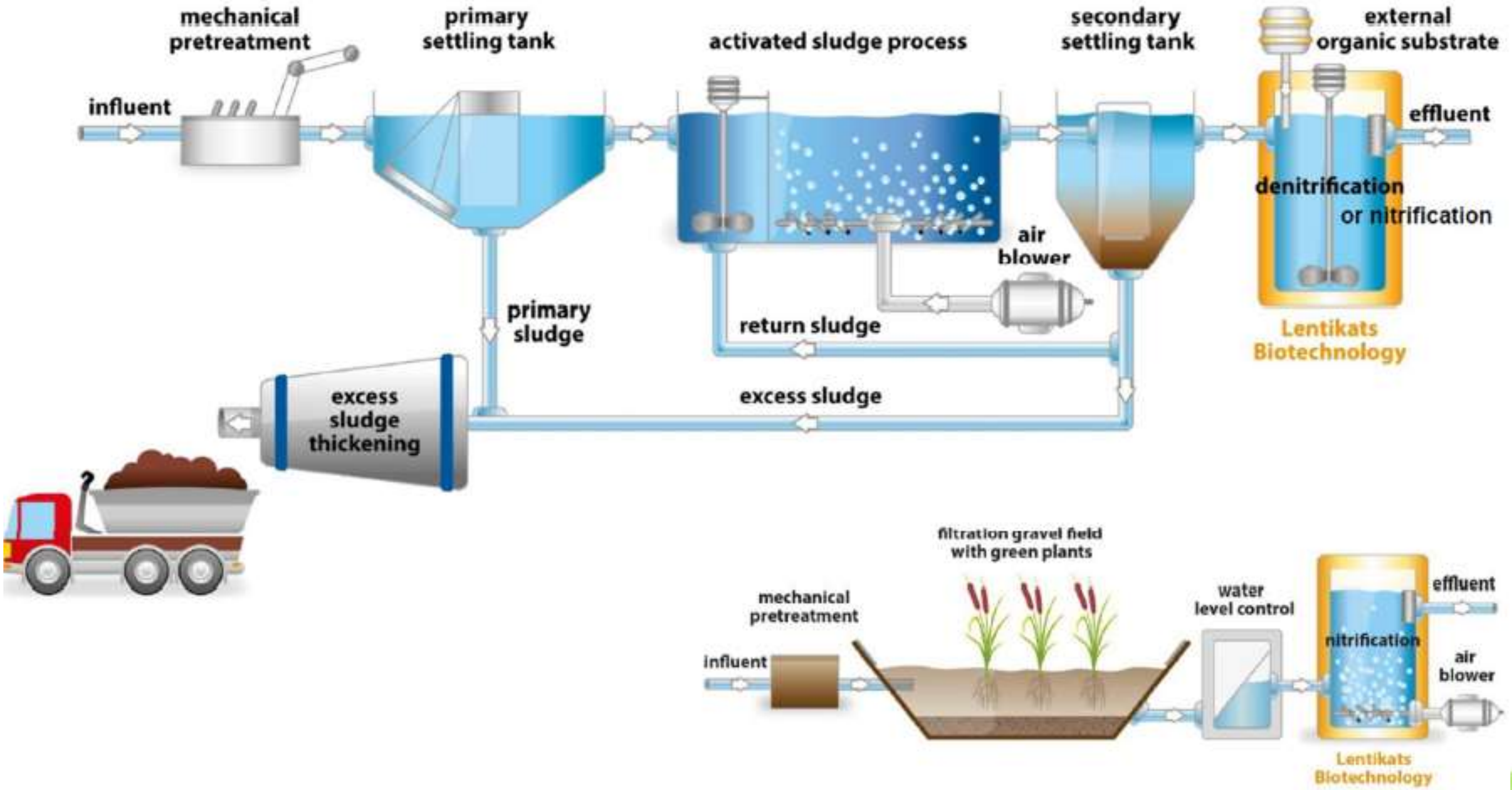


Courtesy: Lentikats Biotechnology

Biocatalysts



Biocatalysts



Biocatalysts

Project	Process	Tonnage	Year
WWTP Baxter	Denitrification (tertiary treatment)	5.4	2009
WWTP Litomerice	Nitrification (reject water)	1.5	2010
Tona	Denitrification (tertiary treatment)	0.5	2010
WWTP Ostrov u M.	Denitrification (tertiary treatment)	0.5	2011
Kyocera	BOD removal	5.5	2012
Coral-shop	Nitrogen removal (inoculation)	0.1	2012
BASF	Nitrogen removal	testing	2014
Dairy production	BOD removal	testing	2014

Biocatalysts

500 kg LB

Volume: 3 m^3

Q_d: 130 m^3/day

c(N-NO_3^-) influent - 15 mg/l

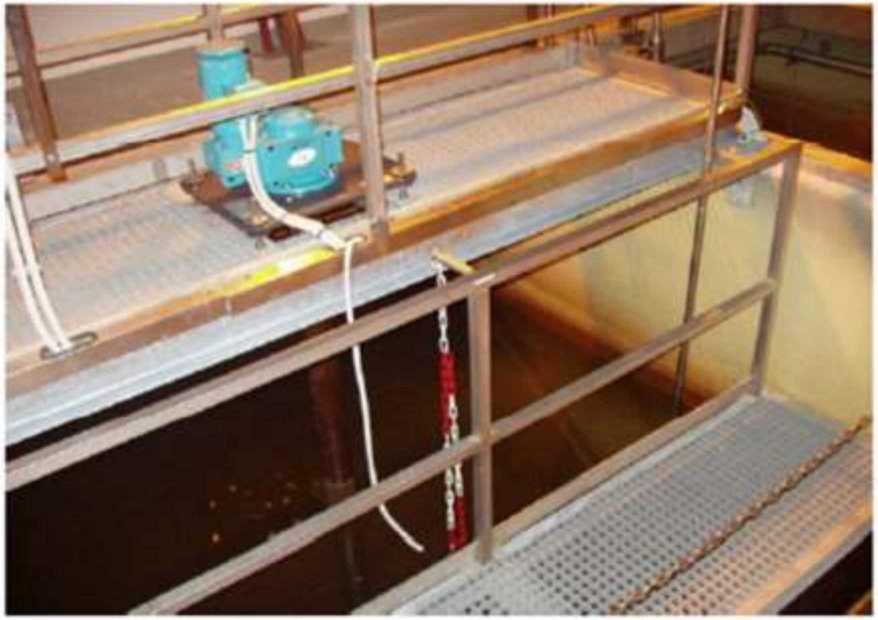
c(N-NO_3^-) effluent - 2 mg/l

Biocatalyst Usage

- Nitrification
  - Immobilized bacteria strains *Nitrosomonas europaea, Nitrobacter and Nitrospira sp.*
  - Operation in oxic conditions
- Denitrification
  - Immobilized bacteria strains *Paracoccus sp. or Pseudomonas denitrificans*
- BOD Removal
  - Immobilized bacteria strains *Paracoccus sp., Pseudomonas sp.*
  - Operation in oxic conditions
- Selective biodegradation
  - R&D – immobilized bacteria strains, fungi or enzymes

Biocatalysts

Reference – Baxter Bioscience



5400 kg LB

V: 40 m^3

Q_d: 300 m^3/day

c(N-NO_3^-) influent - 30 mg/l

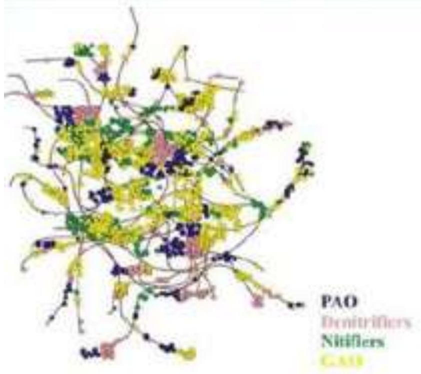
c(N-NO_3^-) effluent - 5 mg/l

Biocatalysts

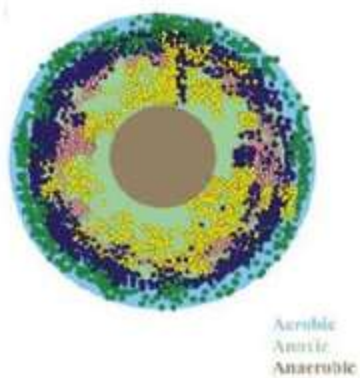
- Benefits of Lentikats Biotechnology biocatalysts
  - Pure cultures = smaller tank volumes
  - Lower energy consumption
  - Lower carbon need for denitrification
  - Lower sludge production
  - Better process stability – fluctuating influent
  - Resistant to toxic conditions (NH_4 ~ 4,000 mg/l)
  - Industrial WW w/ nutrient deficiencies

Granular Activated Sludge

- Granules - dense & compact biomass
  - No support media
- Excellent settling properties
  - High MLSS (up to 15,000 mg/l)
  - ~ 75% smaller footprint
  - No bulking sludge
- >25-35% energy savings
  - Efficient aeration
  - Lower pumping
- Lower construction, O&M costs
  - Utilize existing tanks
  - No chemicals for nutrient removal
  - Low sludge production



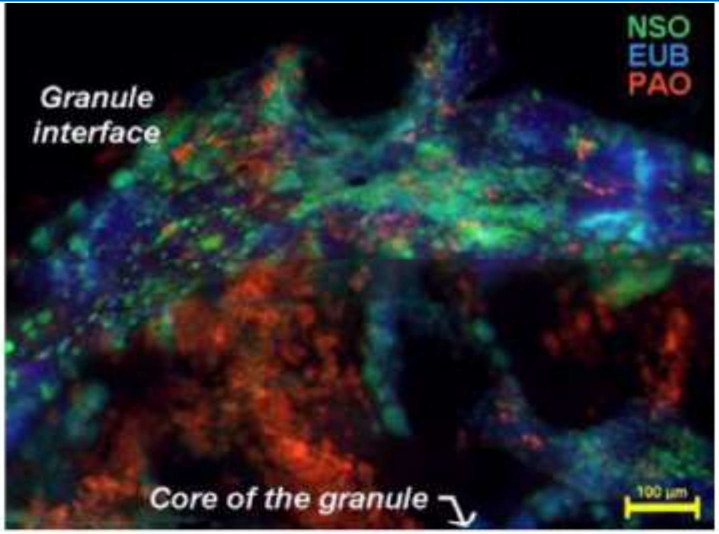
Activated Sludge



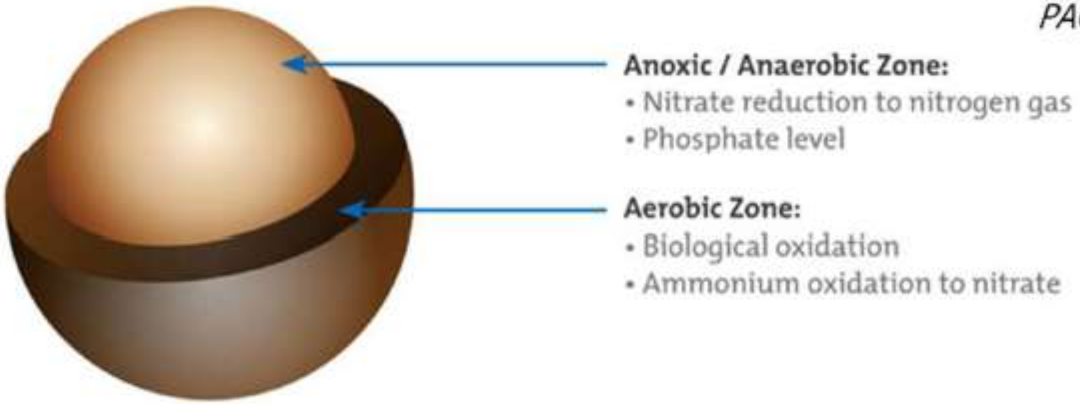
Aerobic Granules

Granular Biomass

- Oxygen gradient in granule
  - Diffusion controlled
  - Simultaneous BOD, N and P removal

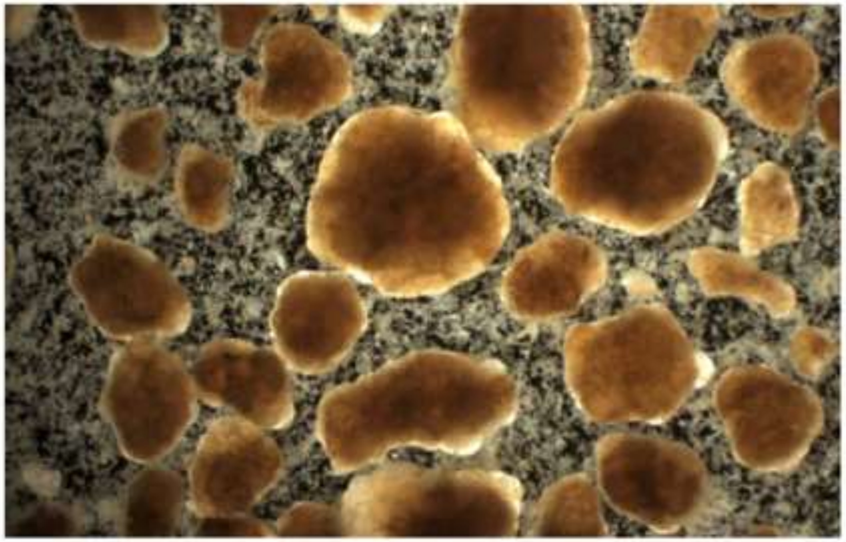


FISH analysis of a sliced granule:
NSO: nitrifying organisms; EUB: heterotrophs;
PAO: phosphate accumulating organisms



Aerobic Granular Sludge

Aerobic Granules

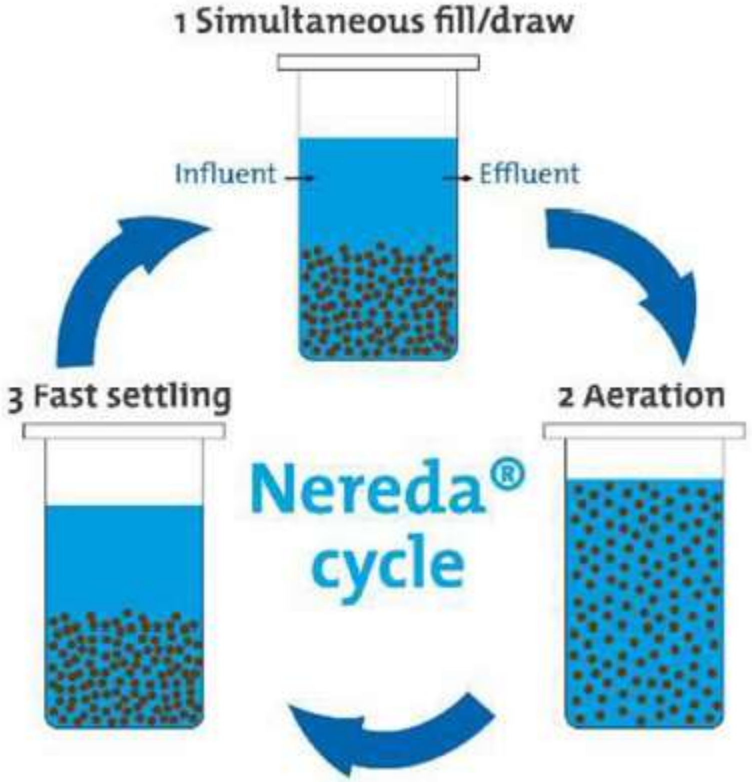


- Min. diameter 0.212 mm (0.0083 inch)

  SVI_5 of granular sludge = *SVI30* of activated sludge

- High setting rates
  - 25 – 40 ft/hr … granules
  - 1.5 – 5 ft/hr … activated sludge

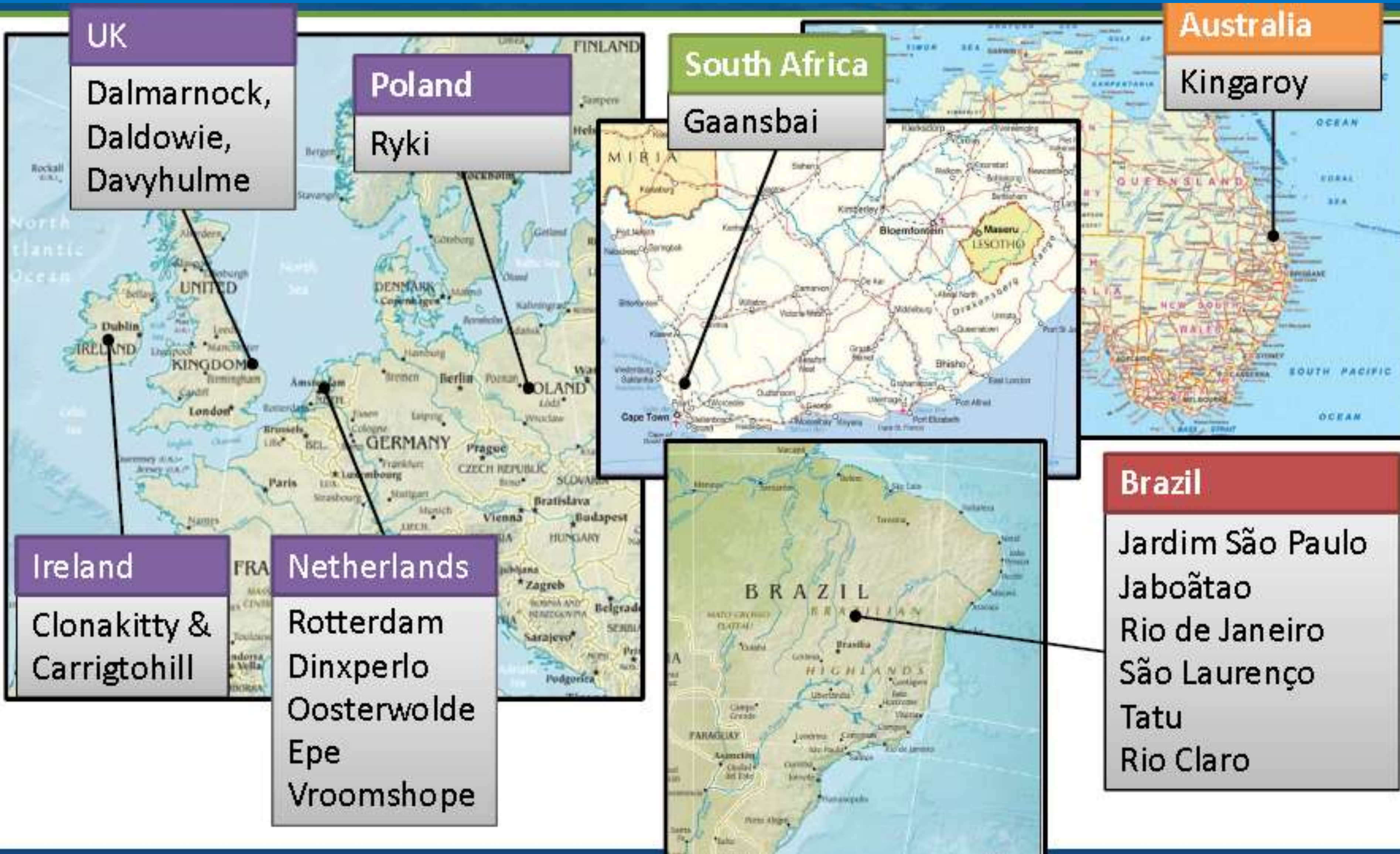
Nereda



Granule Sequencing Batch Reactor (GSBR)

- Four basins operated in series
- One basin in sedimentation mode
- One basin in fill/decant
- Continuous flow
- No moving decanter
- No mixers

Nereda Installations



Conclusions

- Stricter limits
- Energy neutrality
- Sludge minimization
- Resource recovery
- CAPEX/OPEX reduction
- Beneficial reclaimed water re-use
- Driving technological innovation

References

- “History of Activated Sludge“ http://www.iwa100as.org/history.php
- J. L. Barnard and D. H. Stensel, "The Activated Sludge Process in Service of Humanity"
- US EPA “Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management”
- Lentikats - http://www.lentikats.eu/cs/
- Emefcy - http://www.emefcy.com/
- Arbsource - http://www.arbsource.us/

Questions

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