DEFYING CONVENTIONAL

An overview of advanced intensification nutrient removal technologies

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Long solids retention times, high carbon-to-nutrient ratios, unaerated zones (anoxic and/or anaerobic), additional chemicals for phosphorus removal, proper solids separation or clarification processes, and so on are all typical requirements of conventional nutrient removal processes that require large tank volumes to accommodate slow-growing nitrifiers. These factors make conventional approaches costly to employ, both in terms of initial investment and ongoing maintenance. Since energy consumption has a direct bearing on operating costs and contributes to global warming, it is imperative that appropriate nutrient removal technologies be implemented in the future as nutrient discharge limits grow more restrictive.

A growing number of advanced nutrient removal methods that also reduce energy use have become more popular in recent years. Recent advances in nutrient removal techniques are developing with a focus on low energy and chemical consumption and reduced supplemental carbon. They include intensification/densification, simultaneous nitrification/denitrification (SND), denitrifying phosphorus uptake, and phosphorus removal using metal hydrides. Reduced aeration demands (low dissolved oxygen operation), smaller reactor sizes (running at high mixed liquor suspended solids [MLSS]), lower external carbon requirements, and lower biosolids production are all ways in which emerging technology may be able to achieve low-energy optimum nutrient removal.

The term *low-energy intensification biological nutrient removal (BNR) applications* currently encompasses a wide range of technologies. Similarly, this article aims to encompass a wide range by providing a high-level summary of three intensification technologies: aerobic granular sludge (AGS), membrane aeration biofilm reactor (MABRs), and microbial immobilization technology (MIT) by looking at several specific products available on the market.

It is important to note that this list of technologies and the products shown here does not cover all of the potential intensification technologies that exist. It is possible that different systems have equivalent removal performance, but when it comes to removing nutrients, they all have significant differences in performance, hydraulics, cost, operation, and maintenance.

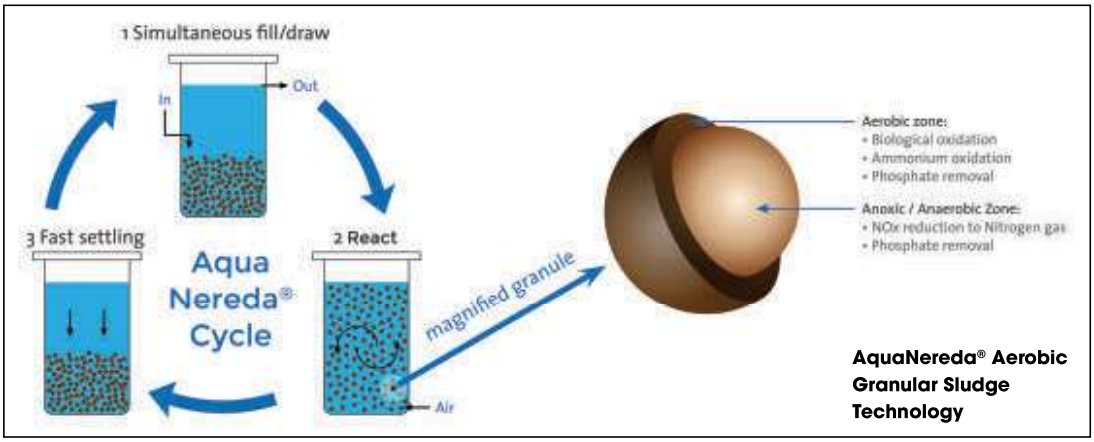
The advantages and disadvantages of different intensification strategies may differ significantly from conventional BNR. Analyzing treatment requirements, removal efficiencies, operational performance, and cost comparison is essential when considering the usage of different enhanced nutrient removal systems for different types of water resource recovery facilities (WRRFs).

Aerobic Granular Sludge

Recent developments using dense granular biomass particles, known as AGS, are gaining popularity as a nutrient removal intensification technology. In this single-sludge, single-reactor system, the formation of large (~250-500 µm in diameter), fast settling, dense granule biofilm particles simultaneously remove carbon, nitrogen, phosphorus, and other contaminants. Currently, only a single patented method offers treatment for sequencing batch flow regime in AGS. However, a number of academic institutions, research institutes, and forward-thinking utilities are attempting to produce AGS in a continuous flow regime by modifying biological and physical characteristics (internally and externally).

AquaNereda AGS Technology

The AquaNereda® Aerobic Granular Sludge Technology is a groundbreaking biological wastewater treatment system that provides



AquaNereda® Aerobic Granular Sludge Technology

advanced treatment using the unique features of the aerobic granular biomass.

The biomass is composed of compact granules that consist of layered microbial communities. These granules provide superior settling compared to conventional activated sludge. Within a single tank, the batch-based process creates the proper conditions to develop and maintain a stable granule population without the need for a supplemental carrier.

Aerobic, anoxic, and anaerobic conditions occur within different areas of each granule. This enables enhanced biological phosphorus removal and nitrification/denitrification to occur simultaneously.

The unique process features of the AquaNereda technology translate into a flexible and compact process that offers energy efficiency and significantly lower chemical consumption than conventional treatment culminating in a low life-cycle cost. The technology is suitable for a variety of WRRFs, including new construction and retrofits of existing tankage for both municipal and industrial applications.

Operation description. Based on the unique characteristics of the granular biomass, the AquaNereda technology uses an optimized batch cycle structure. There are three main phases of the cycle to meet advanced wastewater treatment objectives. The duration of each phase is based on a site's specific waste characteristics, flow, and effluent objectives.

AquaNereda® Aerobic Granular Sludge Technology

AquaNereda: Potential Benefits

- Improve Settling: Settling properties at sludge volume index values of less than 60 mL/g allow for high MLSS concentration.
- Compact: Significantly less footprint compared to conventional activated sludge systems
- Energy Savings: Significant energy savings compared to conventional activated sludge processes
- Chemical Savings: Significant reduction or elimination of chemical addition for nutrient removal due to the layered structure and biopolymer backbone of the granule
- Resilience: Robust granule structure withstands fluctuations in chemical spikes, load, salt, pH, and toxic shocks

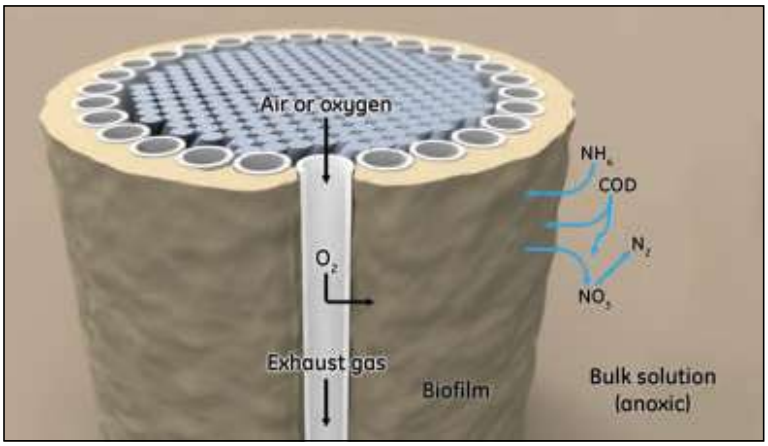
Installations. The first Nereda system was started up in the Netherlands in 2005. Today, there are 95 facilities around the globe in more than 20 countries of which 60 are in operation. Installations ranging from 378 m^3/d (0.1 mgd) to 624,593 m^3/d (165 mgd) and across a variety of municipal and industrial applications demonstrate the flexibility of the technology. In North America where the technology was introduced in 2018, there are a total of 11 facilities with five operating; the remainder are in construction or startup phases. All of these facilities have met or exceeded performance criteria.

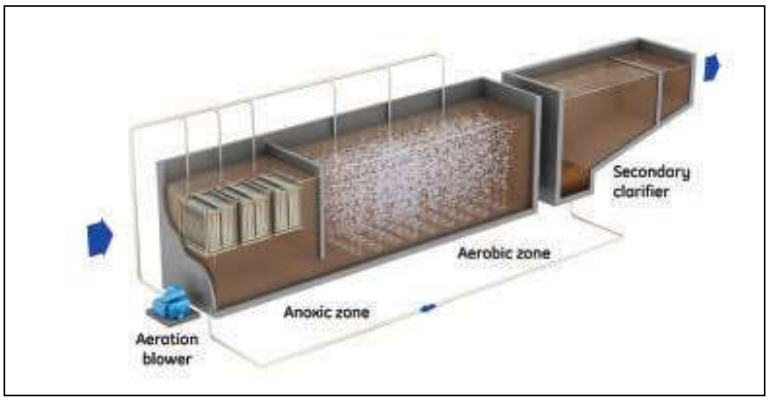
About the company. For more than 50 years, Aqua-Aerobic Systems Inc. has led the water and wastewater treatment industry by providing advanced solutions in aeration and mixing, biological processes, cloth media filtration, membranes, disinfection, and process control serving both municipal and industrial customers.

Membrane Aerated Biofilm Reactor (MABR)

MABR is an emerging intensification process where oxygen diffuses through gas-permeable membranes that function as a highly efficient aeration device and attachment media for biofilm growth. This differs from conventional biofilm reactors — for example, integrated fixed-film activated sludge — because there are multiple active layers within the biofilms. Each active layer's location plays a specific role in nutrient removal dynamics.

Currently, at least three companies — Veolia (formerly SUEZ), Fluence, and Oxymem — provide this technology.





Veolia Water Technologies & Solutions ZeeLung

Veolia Water Technologies & Solutions MABR (ZeeLung)

ZeeLung enables simple, sustainable, and modular process intensification of activated sludge facilities for capacity expansion and/or nutrient removal upgrade. It is a next-generation BNR technology that uses a biomass carrier to support the growth of a biofilm that increases the inventory of biomass in an activated sludge system.

MABR media "breathes" — transferring oxygen to the biofilm at very high efficiency without the use of bubbles. The counter-diffusional biofilm — where substrates and oxygen enter the biofilm from opposite sides — delivers high nitrification rates

ZeeLung: Potential Benefits

- Due to process intensification, this process can significantly increase treatment capacity and improve nutrient removal performance in existing tank volumes.
- Due to the process resiliency, nitrifying biofilm performs even during extreme events.
- It can be easily retrofitted in the existing tanks. Also, no civil works are required, and this solution can be implemented quickly.
- This system offers significant energy savings compared to conventional activated sludge systems.

Veolia Water Technologies & Solutions ZeeLung

and SND. This technology can be easily and flexibly integrated into existing activated sludge facilities.

Operation description. ZeeLung cassettes are installed in the bioreactor to increase biomass inventory. The oxygen diffuses through gas-permeable membranes that function as a highly efficient aeration device and attachment media for biofilm growth. Aeration efficiency of MABR is 4 times higher than conventional fine bubble aeration. The counter-diffusional biofilm provides selection pressure for nitrifiers. Installation of ZeeLung cassettes in an anoxic zone enables SND.

Installations. Currently there are more than 20 contracted installations globally. The size range varies from small, decentralized facilities (less than 500 m^3/d [0.14 mgd]) to medium/large conventional activated sludge upgrades (greater than 95,000 m^3/d [25 mgd]). The longest existing facility in the U.S., at the Yorkville-Bristol (Illinois) Sanitary District, has been operating for 5 years. It handles 13,7000 m^3/d (3.6 mgd). The largest facility in construction is greater than 95,000 m^3/d (25 mgd).

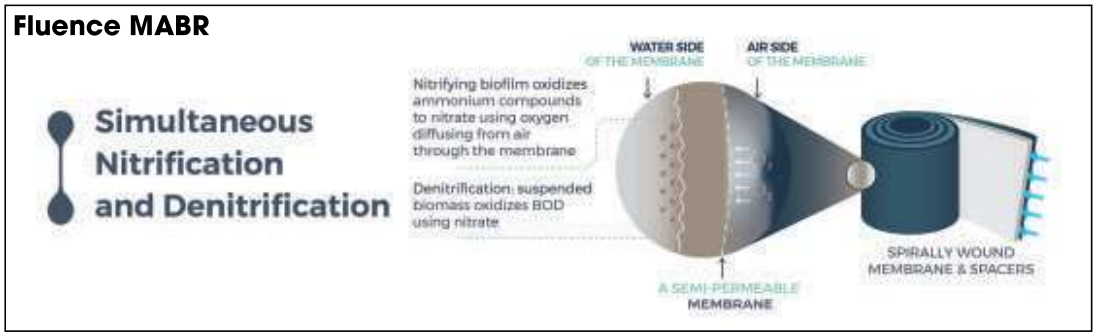
About the company. With operations in 130 countries and more than 10,000 employees, Veolia Water Technologies & Solutions solves the toughest water, wastewater, and process challenges around the globe, leveraging a comprehensive set of chemical, equipment, and digital-enabled services and products.

Fluence MABR

Fluence's MABR is a patented, spirally wound flat-sheet membrane technology that provides highly efficient biological nutrient removal.

The semi-permeable membrane is submerged in the wastewater tank while low-pressure air is blown through the air side of the membrane. Oxygen is constantly supplied to the fixed nitrifying biofilm that develops on the wastewater side of the

Fluence MABR



Fluence Treatment Options

Product	Description	Application
Aspiral™ Micro	A packaged, single-stage reactor	Individual homes
Aspiral™	Decentralized facilities	Municipal wastewater from communities, hotels, resorts, shopping malls, highway service areas, worker camps, ponds upgrade, etc.
SUBRE	Retrofits and greenfield facilities	Centralized municipal facilities
Nitro	Shortcut nitrogen removal	High nitrogen streams from anaerobic digestion, co-digestion, leachate, compost, swine or cow farms, or fertilizer

Fluence: Potential Benefits

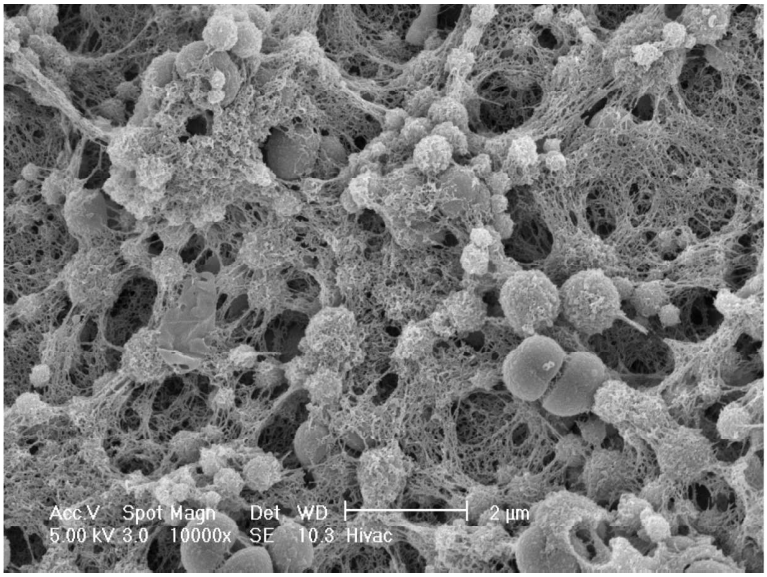
- High-quality Effluent: The biofilm supports simultaneous nitrification and denitrification (SND) for high nutrient removal. The effluent meets Class 1A (China) and Title 22 (California) standards for reuse.
- Energy Savings: The low pressure, passive aeration offers significant energy savings over conventional, high-pressure aeration. This low energy consumption allows for decentralized treatment off the power grid.
- Low Maintenance and Operation Costs: There is no need to clean the membrane since biofilm growth is desired for treatment. Fluence's MABR products can be remotely operated.
- Easy to Deploy: The packaged solutions are prefabricated and "Ikea-like", requiring minimal effort and resources to install.
- Minimal Footprint: The module contains aerobic and anaerobic areas, so nitrification and denitrification can take place simultaneously in the same basin. There is also no need for large diffusers due to the MABR's passive aeration.
- Robust Performance: Thanks to the resilient biofilm, the system demonstrates stable performance regardless of seasonal changes or storm-weather events.

membrane while denitrification occurs in the anoxic bulk liquid.

Operation description. Fluence's MABR facilities are designed to run automatically. All of the facilities are single-pass, and the settings are defined during the startup period. Parameters can be monitored and changed remotely from the control room. To manage the MABR facility, operators do not need special skills beyond the typical skills needed for the maintenance of activated sludge systems. Neither chemical cleaning nor biofilm control are needed.

Installations. Fluence installed its first MABR facility in Israel in 2016. Since then, Fluence has expanded to have more than 330 MABR projects around the world. Projects range in capacity from 5 to 20,0000 m^3/d (0.0013 to 5.3 mgd). More than 200 installations are currently operational, while the remainder are at various stages of production, installation, and commissioning. The table on p. 36 describes the different treatment options.

About the company. With more than 330 MABR wastewater facilities worldwide and more than 120 water treatment units sold, Fluence Corporation is a leader in the decentralized treatment space.



Microvi Technology MIT

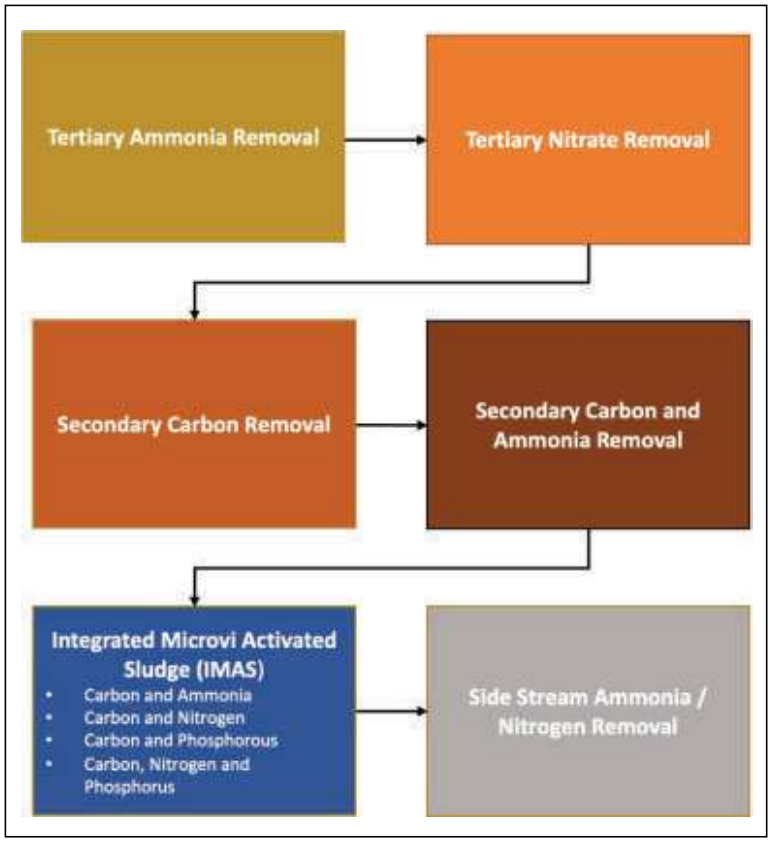
Fluence is a global company with headquartered in Minneapolis, Minnesota, listed on the Australian Stock Exchange.

Microbial Immobilization Technology

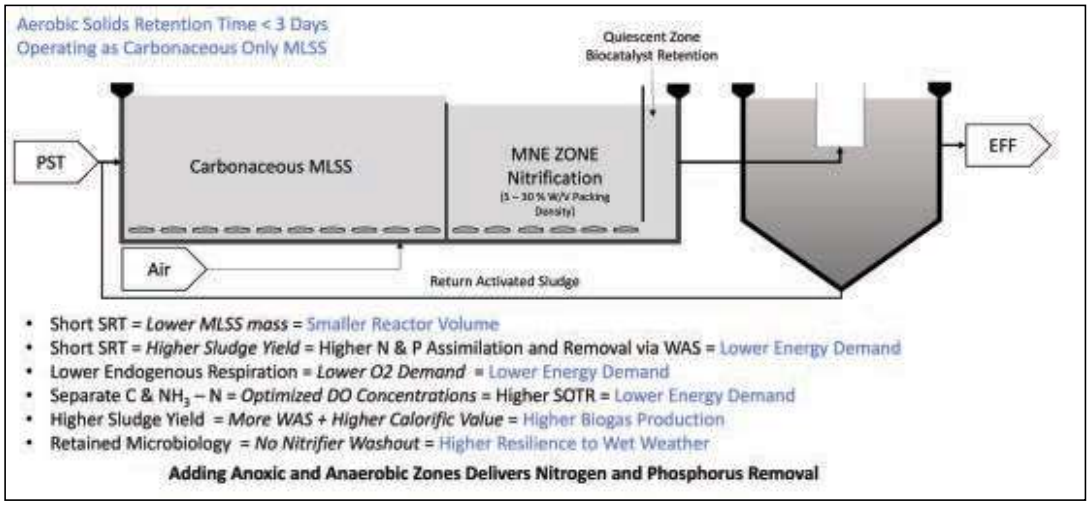
MIT is a novel technique that uses microorganisms that have been immobilized. This technology has been quickly evolving since the late 1960s.

Users can keep cells or enzymes alive and

Microvi Technology MIT



Microvi Technology MIT



utilize them again and again by isolating them in a confined space (cubes or spheres), either chemically or physically. Immobilized microorganisms have been the subject of extensive study and use in the field of wastewater treatment due to their high microbial density, quick response, minimal sludge generation, resistance to environmental effect, and the convenience of their easily controlled reaction process.

Currently, two technology providers — Microvi and PEGASUS — offer this technology.

Microvi

The Microvi technology introduces a new paradigm. Using a materials science platform called MicroNiche Engineering™ (MNE), the Microvi technology decouples growth from degradation, such that wastewater treatment is no longer reliant on the growth and solids residence time (SRT) of indigenous microorganisms.

The Microvi technology intensifies bioconversion processes using biocatalyst composites, containing pregrown, specialized monocultures at high densities within super hydrophilic composites. The composites are designed with defined pore and cavity structures optimized for the transfer of dissolved substrates and provide a protective microenvironment against external environment changes, for example, toxins.

Few biological solids are produced across the biocatalyst as the composites promote key microbial mechanisms to control their population size — that is, quorum sensing, autophagy, and cryptic growth. The unique nature of the MNE platform distinguishes it against the simplified and inferior practice of encapsulation within generic polymer structures.

Operation description. The biocatalyst composites are typically deployed within completely mixed reactors, where they are fully retained through use of an integrated settlement zone within the reactor. For many applications the system is applied as a single-pass process, with no MLSS or biofilm inventory requiring no solids recycling and reduced downstream solids separation.

Microvi has two commercially available biocatalysts. Nitrate removal (Denitrovi™) and combined or separate chemical oxygen demand and ammonia removal (Aerovi™). These biocatalysts can be coupled in separate reactors in series to provide complete systems. Stand-alone applications include

- groundwater nitrate removal,

Microvi: Potential Benefits

- Footprint and Energy Savings: The Integrated Microvi Activated Sludge benefits include a significant reduction in required reactor volume and energy consumption.
- Increased Biogas: The system significantly increases biogas production (via anaerobic digestion of secondary solids).
- Low Nitrogen Oxides Production: By virtue of maintaining nitrification within a discrete reactor, thus avoiding exposure of autotrophic nitrifiers to transient stress conditions, this system removes a mechanism associated with potential nitrous oxide production.
- Low Cost: Due to reduced requirements of pre- and post-process needs, simple operation and maintenance, and significantly low-waste residuals produced, the system has lower capital and operating expenses than conventional treatment.

- tertiary nitrate removal,
- tertiary ammonia removal, and
- anaerobic digestor liquor ammonia removal.

Biocatalysts can be added to existing activated sludge systems termed Integrated Microvi Activated Sludge (IMAS). These systems have the distinct advantages of divorcing solids retention time from nitrification and allowing operation at reduced solids inventories. The IMAS process can operate as straight nitrification or full biological nitrogen and phosphorus removal.

Installations. California holds the longest running groundwater nitrate removal system; it has been in continuous operation for 6 years. The digestor liquor ammonia removal system, which is also in California, has been operating continuously for 1.5 years. At press time, a new groundwater nitrate removal system was slated to start up in Arizona in November 2022.

About the company. Microvi is a transformative biology company based in the San Francisco Bay Area delivering next-generation biotechnologies for the water and wastewater industries. Microvi offers commercial technologies globally to reduce waste, increase productivity and provide disruptive economics across the value chain.

Final Thoughts

In summary, emerging intensification processes can reduce capital construction costs and operation and maintenance costs by retrofitting existing tanks with intensification processes. These technologies offer the change to increase capacity, achieve efficient oxygen transfer rates (and, therefore, reduce blower sizes and energy needs), reduce or eliminate external carbon, reduce internal recycle pumping, reduce the need for chemical phosphorus removal, and lower greenhouse gas emissions.

However, if a WRRF wishes to investigate this technology, the authors strongly advise doing more investigation to see whether an intensification technology is suitable for your treatment facility. Additionally, the authors strongly encourage using pilot studies of intriguing technologies prior to implementation.

Put simply, when considered thoughtfully and implemented carefully, intensification technology will become the future leader in wastewater treatment for nutrient removal.

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