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Department of Chemical Engineering

Queen's University

Emerging Technologies to Debottleneck Municipal Wastewater Treatment Plants

BlueGreen Innovation Group

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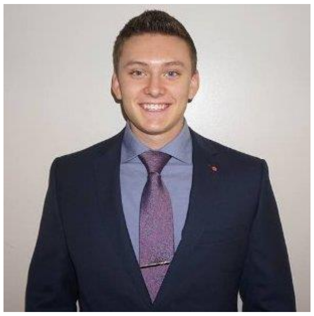

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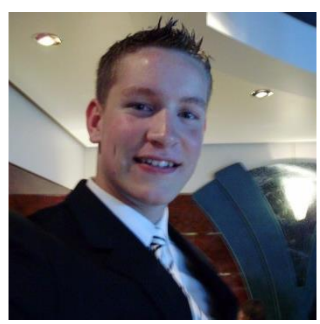


Executive Summary

Ontario municipalities are responsible for collecting and treating sanitary wastewater to quality levels as prescribed by the provincial and federal governments prior to discharge to receiving waterways. Several factors have placed onerous demands on existing treatment plants, such as population growth, regulations, and aging infrastructure. Capacity limits are hindering further economic growth and development of the surrounding community. Upgrades using traditional technologies are prohibitively expensive; therefore, there exists a need to identify new and emerging treatment technologies having performance and cost advantages over conventional technologies. A detailed research study has been completed to analyze the feasibility of augmenting and debottlenecking municipal wastewater treatment plants with emerging technologies. A total of 70 technologies were examined. Those not rejected and within the scope of the project were ranked using a weighted evaluation matrix. Finally, funding opportunities were outlined to support any finance issues. Table 1 shows the top three technologies based on the evaluation process.

Table 1: Summary of top three technologies found during this study

Technology Name	BioMag	Bio-Domes	SAGR
Vendor	Evoqua Water Technologies	Waste Water Compliance Systems	Nelson Environmental
Plant Type Application	Conventional	Lagoon	Lagoon
Description	Magnetite addition to reduce settling times	Domes to increase aeration and surface area for biofilm	Dense granular media filtration and aeration to promote contaminant removal in cold
Current Installations	Over 20 - USA	Over 30	Over 20
Capacity Increase	Up to 300%	Up to 100%	Up to 200%
Normalized Capital Cost ($/m^3/d)	290	355	400
Normalized Operating Cost ($/m^3)	0.045	0.010	0.030
Capital Cost (2,045 m^3/d)	$4,550,000	$3,650,000	$5,855,000
Operating Cost (2,045 m^3/d)	$45,000/year	$12,000/year	$28,000/year
Capital Cost (24,000 m^3/d)	$15,550,000	$42,000,000	$25,655,000
Operating Cost (24,000 m^3/d)	$265,000/year	$54,000/year	$124,000/year
GHG from Power (2,045 m^3/d) [tons CO_2/year]	21	8	14
GHG from Power (24,000 m^3/d) [tons CO_2/year]	80	35	60

In addition, a report called the Composite Correction Program (CCP), written by the United States Environmental Protection Agency (US EPA), was viewed and summarized [1]. The CCP acts as an evaluation tool for conventional waste water treatment plants (WWTP), specifically examining activated sludge and fixed film processes. Split into two parts, the CCP first evaluates and ranks the facility to determine if a major upgrade is necessary, or if the plant can simply be optimized. If it can be optimized, the second part outlines how to implement the solutions from the CCP. This tool should be used first to evaluate and possibly debottleneck the plant before implementing any new technology found in this report.

As seen in Table 1, capital cost is a significant factor to the outlook of each project. Detailed research and current plant data acquisition were performed to ensure that the initial expenditure was accurately determined for each option. This was followed by reliable quality assurance. The above values represent installation costs using a total installed cost (TIC) factor of 5. In addition, the normalized capital cost flow was calculated before the installation factor of 5.

Operating expenditure was primarily determined by using current utility costs. Additional factors such as labour, transportation, and disposal were not included.

Apart from economic analysis, the risk and safety aspects of each project were assessed to determine viability. The environmental and sustainability aspects of each project were also investigated. The report below examines the above categories in detail.

Based on Table 1, the following recommendations have been made:

Since there are many potential bottlenecks in wastewater treatment, it is recommended to first use the Composite Correction Program (CCP) to critically assess the plant and determine which infrastructure changes, if any, are necessary. If the CCP suggests that an infrastructure change is not required to increase capacity, consider improving operator training or revising standard operating procedures to ensure maximum efficiency of the plant is achieved. If the report suggests an infrastructure change is required, consider using one of the technologies in this report to augment the facility and realize extra capacity.

If the current system is a conventional plant that has an issue with settling times in clarification, then implementing the BioMag system can decrease settling times and increase capacity without requiring additional tankage or large capital expenditures. BioMag is quickly becoming a popular solution to increase capacity at conventional plants for a reasonable price.

Alternatively, if the plant in question is a lagoon system, it may require different technologies to increase capacity. If a lagoon system is at capacity and struggling to maintain compliance, Bio-Domes are an easy drop-in solution to provide increased aeration, stimulate biological activity and increase capacity at a reasonable price. Another option for small municipalities would be to augment with the SAGR system. This system employs dense granular media filtration and aeration to promote contaminant removal in cold weather. Both Bio-Domes and the SAGR system have already been employed at a number of small municipalities, making them an appealing option to increase capacity at plants.

Table of Contents

Executive Summary....iii
Table of Contents....v
List of Figures....viii
List of Tables....ix
1.0 Introduction....1
1.1 Problem Definition....1
1.2 Objectives....1
1.3 Technical Specifications....1
1.4 Constraints....2
1.5 Assumptions....2
2.0 Technical Background....4
2.1 Conventional Wastewater Treatment....4
2.1.1 Preliminary Treatment....4
2.1.1.1 Screening....4
2.1.1.2 Flow Equalization....5
2.1.2 Primary Treatment....5
2.1.2.1 Sedimentation....5
2.1.3 Secondary Treatment....6
2.1.4 Tertiary Treatment....7
2.1.4.1 Nitrogen, Ammonia and Nitrates....8
2.1.4.2 Phosphorus....8
2.1.4.3 Treatment of Toxic Components....8
2.1.4.4 Dissolved Inorganics Removal....8
2.1.4.5 Residual Handling and Disposal....9
2.2 Bottlenecks in Wastewater Treatment....9
3.0 Evaluation Metrics....10
4.0 Composite Correction Program....11
4.1 Overview....11
4.2 Evaluation....11
4.2.1 Evaluation Approach....11

4.2.2 Conducting the Evaluation 11
4.3 The Correction Program 12
4.3.1 Approach to the CCP 12
4.3.2 Implementing the CCP 13
4.4 CCP Conclusions 14
5.0 Detailed Technology Study 15
5.1 BioMag – Evoqua Water Technologies 15
5.1.1 Vendor Description 15
5.1.2 Introduction 15
5.1.3 Process Description 15
5.1.4 Additional Information 16
5.1.5 Operability and Maintenance 18
5.1.5.1 Notable Installations 18
5.1.6 Treatment Performance 20
5.1.7 Economics 20
5.1.8 Environmental, Safety and Legal Aspects 21
5.2 Bio-Domes 22
5.2.1 Vendor Description 22
5.2.2 Introduction 22
5.2.3 Process Description 22
5.2.4 Energy Requirements 23
5.2.5 Materials of Construction 24
5.2.6 Operability and Maintenance 26
5.2.6.1 Notable Installations 27
5.2.7 Treatment Performance 28
5.2.7.1 Ammonia and Total Nitrogen 28
5.2.7.1.1 Nitrification and Denitrification Results 28
5.2.7.1.2 Cold Weather Nitrification 29
5.2.7.2 BOD Reduction 30
5.2.7.3 TSS Reduction 32
5.2.8 Economics 33

5.2.9 Environmental, Safety and Legal Aspects 35
5.3 Submerged Attached Growth Reactor 36
5.3.1 Vendor Description 36
5.3.2 Introduction 36
5.3.3 Process Description 37
5.3.4 Additional Information 38
5.3.5 Operability and Maintenance 38
5.3.5.1 Notable Installations 39
5.3.6 Treatment Performance 41
5.3.7 Economics 41
5.3.8 Environmental, Safety and Legal Aspects 42
6.0 Environmental and Legal Considerations 43
6.1 Environmental Concerns 43
6.1.1 Ontario Environmental Innovation Branch (EIB) 43
6.2 Legal Considerations 43
7.0 Risk Analysis and Mitigation 46
8.0 Funding Opportunities 47
8.1 Federal Programs 47
8.1.1 Sustainable Development Technology Canada Technology Fund 47
8.1.2 Business Development Bank of Canada 47
8.1.3 Federation of Canadian Municipalities (FCM) Green Municipal Fund (GMF) 47
8.1.4 Federal Economic Development Initiative for Northern Ontario (FEDNOR) 47
8.2 Provincial (Ontario) Programs 48
8.2.1 Ministry of Infrastructure Places to Grow Infrastructure Fund 48
9.0 Recommendations 49
10.0 Acknowledgements 50
References 51
Appendix A 57
A1 – Summary of Viable Technologies 57
Appendix B 73
B1 – Word Ladder 73

B2 – Evaluation Matrix 78
Appendix C 82
C1 – Initial Rejected Technologies........ 82
C2 – Secondary Rejected Technologies........ 90

List of Figures

Figure 1: Coarse bar screen for wastewater treatment. Water flows through collecting large debris. Screens range from 6 - 150mm [2] [3]........ 4
Figure 2: Schematic of a reciprocating rake bar screen [4] 5
Figure 3: PFD showing online and offline configurations for equalization flow [5] 5
Figure 4: Examples of different sedimentation basins [3]........ 6
Figure 5: Flow diagram for a typical wastewater treatment process [9] 9
Figure 6: The BioMag system configuration [11]........ 16
Figure 7: Example of the BioMag system implemented in a reactor or mixing tank [10]........ 17
Figure 8: Working principle diagram for a single Bio-Dome. Air is bubbled up through the domes and packing from the bottom. This mixes the water and removes excess biofilm from the packing. The excess biofilm becomes part of the sludge blanket [17]........ 23
Figure 9: 7-Dome Bio-Dome [17] Figure 10: 4-Dome Bio-Dome [17]........ 24
Figure 11: Elevated view of 4-dome Bio-Dome. The air tubes are shown in green [17]........ 25
Figure 12: Bottom of Bio-Dome showing concrete base, air manifold and packing [17] 25
Figure 13: Bio-Domes being installed in a lagoon with a crane [17] 26
Figure 14: Results from glycol test at the WCS facility in Lehi, UT [17]........ 27
Figure 15: Nitrification and denitrification results [17] 29
Figure 16: Cold weather nitrification results [17]........ 30
Figure 17: Results from BOD reduction test [17]........ 31
Figure 18: Graph of BOD and water temperature over an extended time period [17] 32
Figure 19: TSS removal as a function of the number of days spent in the lagoon system [17] ... 33
Figure 20: Bio-Domes arriving on a trailer........ 35
Figure 21: Completed SAGR bed topped with mulch [21]........ 36
Figure 22: General schematic of the SAGR system [20] 37
Figure 23: Example of how the SAGR system can be incorporated into an existing facility [20]. 38
Figure 24: Example of the blowers required to operate the SAGR system [24] 39
Figure 25: Solid material collected by the BioCord substrate contained in a tank 57
Figure 26: LagoonGuard MBBR operating with a lagoon in the background........ 58
Figure 27: Baffled bioreactor working principle diagram........ 59
Figure 28: BluePro reactive sand filter diagram 60
Figure 29: WaterMiner electrocoagulation unit........ 62
Figure 30: Inclined plate clarifier 63
Figure 31: Hydro-Clear sand filtration unit........ 64

Figure 32: JET BAT reactor cross sectional view and picture in the field 65
Figure 33: Skid-mounted Puron Plus MBR.. 66
Figure 34: Membrane cross-section 67
Figure 35: Aqua Aerobic MBR system... 68
Figure 36: Leap MBR schematic... 69
Figure 37: Aqwise AGAR working principle diagram 70
Figure 38: Image of Xylem Membrane Bioreactor showing membranes.................................... 71
Figure 39: Titan membrane bioreactor in the field 72
Figure 40: AQUA-4 treatment system installed at a wastewater treatment plant 91
Figure 41: Picture of the AQUA-FER filter.. 92
Figure 42: Diagram of the operation of the Spiralift system 93
Figure 43: SubTriq Membrane Bioreactor working principle diagram 94
Figure 44: Biobed Advanced EGSB reactor schematic... 95
Figure 45: UOP Xceed bioreactor schematic 96
Figure 46: Raptor floating aeration unit 97
Figure 47: Schematic of the Aqua-EMBR system.. 98
Figure 48: Conceptual model of custom packaged treatment plant.. 99
Figure 49: Hybrid depth filtration unit installed in the field.. 100
Figure 50: Dif-Jet gas injection grid system 101
Figure 51: CAD model of Zeo-Clear packaged wastewater treatment plant 102
Figure 52: Schematic of the Aqua-Diamond cloth media filter system.................................... 103

List of Tables

Table 1: Summary of top three technologies found during this study..iii
Table 2: List of constraints identified for this project.. 3
Table 3: Aerobic and anaerobic processes [6].. 6
Table 4: Summary of processes used in secondary wastewater treatment [8] 7
Table 5: BioMag Treatment Effectiveness [10]... 20
Table 6: Economic summary for the BioMag system 20
Table 7: GHG emissions from electrical use 21
Table 8: Operation Requirements [17] 24
Table 9: Dimensions [17] 24
Table 10: Economic summary for the Bio-Dome system. 34
Table 11: Greenhouse gases emitted from electrical use 35
Table 12: SAGR Treatment Effectiveness.. 41
Table 13: Economic summary for the SAGR system [20] 41
Table 14: ECA wastewater effluent limits.. 44

INTRODUCTION

1.0 Introduction

1.1 Problem Definition

Ontario municipalities are responsible for collecting and treating sanitary wastewater to quality levels prescribed by provincial and federal government prior to discharge to receiving waterways. Population growth, increasingly stringent effluent quality requirements, plant design, societal expectations, aging infrastructure, and operator proficiency requirements have placed onerous demands on existing treatment plants. In some cases, municipal wastewater treatment capacity limits are hindering or even preventing further economic growth and development of the surrounding community.

Wastewater treatment infrastructure, including sewers, plant facilities, and discharge arrangements are in need of upgrading. However, upgrades using traditional technologies are prohibitively expensive. There is little appetite among taxpayers to pay higher taxes or fees to cover costs of adding new infrastructure. In addition to cost barriers, regulators are cautious about approving deployment of new or unproven technologies.

Therefore, there exists a need to identify new and emerging treatment technologies having performance and cost advantages over conventional technologies. These technologies must have the potential to debottleneck existing fully loaded plants allowing further economic growth and development of the surrounding community.

1.2 Objectives

This report aims to identify emerging technologies for wastewater treatment plants. The technologies will be evaluated based on a combination of technical risk, economics, and societal concerns. The report also explores the feasibility of using these technologies to debottleneck an existing fully loaded municipal wastewater treatment plant. Below is a more comprehensive list of the objectives for this study:

- Identify new and emerging technologies to treat sanitary wastewater
- Determine whether technologies can be deployed as a retrofit to existing facilities
- Identify/quantify treatment effectiveness, energy requirements, technical complexity, reliability, cost, and maintainability of the options considered
- State opportunities, challenges, and risks associated with each technology
- Locate incentives and funding opportunities
- Discuss federal and provincial regulations about effluent quality requirements and environmental standards
- Provide a screening level economic evaluation for three studied technologies

Recommendations about the technologies will be provided based on both economic and performance characteristics.

1.3 Technical Specifications

A list of specifications for the technologies was developed based on the problem statement and objectives. The following specifications were identified:

- The proposed technology must increase treatment capacity to further economic growth and community development
- The technology must be able to adapt to fluctuations in flow rates, loadings, and temperatures while still meeting the effluent water quality standards for discharge to receiving waterways

- The technology should reduce environmental impact and improve the process by reducing energy usage and/or utilizing renewable energy
- The technology must be able to be applied as a retrofit to an existing wastewater treatment plant
- The technology must be applicable for use in small scale applications, such as municipal wastewater treatment plants

1.4 Constraints

For a technology to be considered applicable, it must satisfy the technical specifications and follow the constraints dictated by the various parties who may be impacted by this project.

Table 2 contains a list of the constraints for this project.

1.5 Assumptions

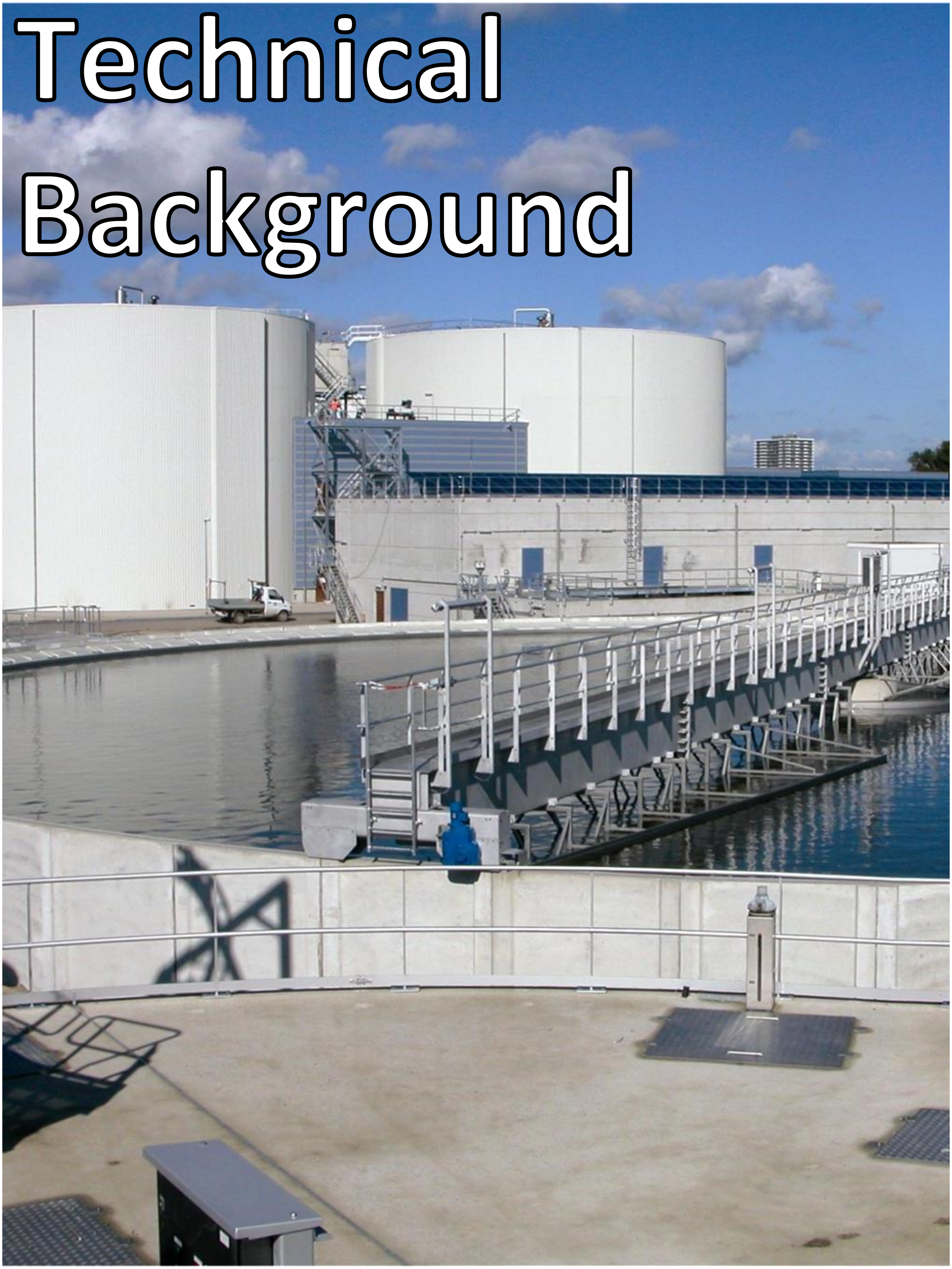
The following assumptions were made:

- The maximum number of technologies to be studied in depth was three
- The priority of objectives was assumed as follows: comply with environmental regulations, increase capacity, and reduce cost / volume treated
- It was assumed that existing plants investigated are representative of other small municipalities

Table 2: List of constraints identified for this project

Constraint	Driver	Description
Technology must be near ready and proven	BlueGreen Innovation Group	Each technology must be established or proven by use in the industry or a similar wastewater treating process. It is unlikely a start-up company in the early stages of development will be chosen or selected to improve existing wastewater treatment facilities.
The vendor must be reliable	BlueGreen Innovation Group	The vendor must be well established in the wastewater treating industry, or a similar industry for water treatment.
Environmental Regulations	The Canadian government / Ministry of Environment and Climate Change Ontario	Every technology must comply with the safety and environmental regulations prescribed by the government. Failure to meet these regulations can possibly ‘make or break’ a potentially successful solution.
The technology must be able to be applied as a retrofit	BlueGreen Innovation Group	Certain technologies may not be able to retrofit into existing wastewater plants, creating a costlier solution since the plant may need to be revamped. Identifying which technologies can be applied as a retrofit will assist with the overall evaluation.
The equipment must be affordable for small municipalities	Members of small municipalities	We must be conscious of cost when selecting a technology due to the low budget of small municipalities compared to large cities.
The technology must be applicable to small scale, municipal operation	BlueGreen Innovation Group	Each technology must be capable of treating smaller flowrates and loadings such as those in smaller municipalities.
Existing city infrastructure outside plant battery limits	BlueGreen Innovation Group	We are not considering any of the process outside of the plant limits such as sewer piping and lift stations.
The technology is only required to treat wastewater	BlueGreen Innovation Group	We are not considering treatment of incoming water supply to residential or industrial areas.
The technology must be able to operate during winter months	BlueGreen Innovation Group	The technology must be able to operate in Winter when water temperatures are decreased.
Societal concerns	Members of small municipalities	While all technologies must be safe, they may have a negative connotation with the public.

Technical Background



2.0 Technical Background

2.1 Conventional Wastewater Treatment

The current wastewater treatment industry for municipalities use similar processes across Ontario to treat the water to the required effluent regulations.

Conventionally, preliminary and primary treatment use physical and chemical processes. Primary treatment, using physical processes, reduces the load of large constituents and debris that could create problems with the maintenance and operation of downstream treatment equipment. Large constituents consist of household items such as toilet paper, rags, garbage etc.

Secondary treatment, including final effluent clarification, uses biological processes to mainly reduce total suspended solids (TSS) and degradable dissolved organic and inorganic matter. It can also be configured to reduce nitrogen and E-coli.

Finally, tertiary treatment can be a chemical process, physical process, or combination of both that removes residual suspended solids or dissolved solids remaining after the secondary treatment phase. It also specifically removes any remaining nitrogen, phosphorus, or biological oxygen demand (BOD) to meet the effluent requirements.

2.1.1 Preliminary Treatment

2.1.1.1 Screening

Preliminary treatment generally consists of screens and flow equalization. Screens are primarily used to remove coarse solids and large debris. This ensures that pipes in the facility do not get clogged so the process can run efficiently and reliably. There are two main types of screens, those that require manual cleaning and those that are automated. A picture of a manual bar screen is shown in Figure 1.

Figure 1: Coarse bar screen for wastewater treatment. Water flows through collecting large debris. Screens range from 6 - 150mm [2] [3]

The most common type of automated screen is the reciprocating rake bar screen. The machine operates as its name suggests, a rake rotates to the bottom of the screen, engaging the bar screen, and lifting debris up and out of the channel as the rake returns to the top of the unit. The garbage is then deposited into a trough. Depending on the loading of the water being treated, the screens require cleaning after a certain length of time. An example of this setup is shown in Figure 2.

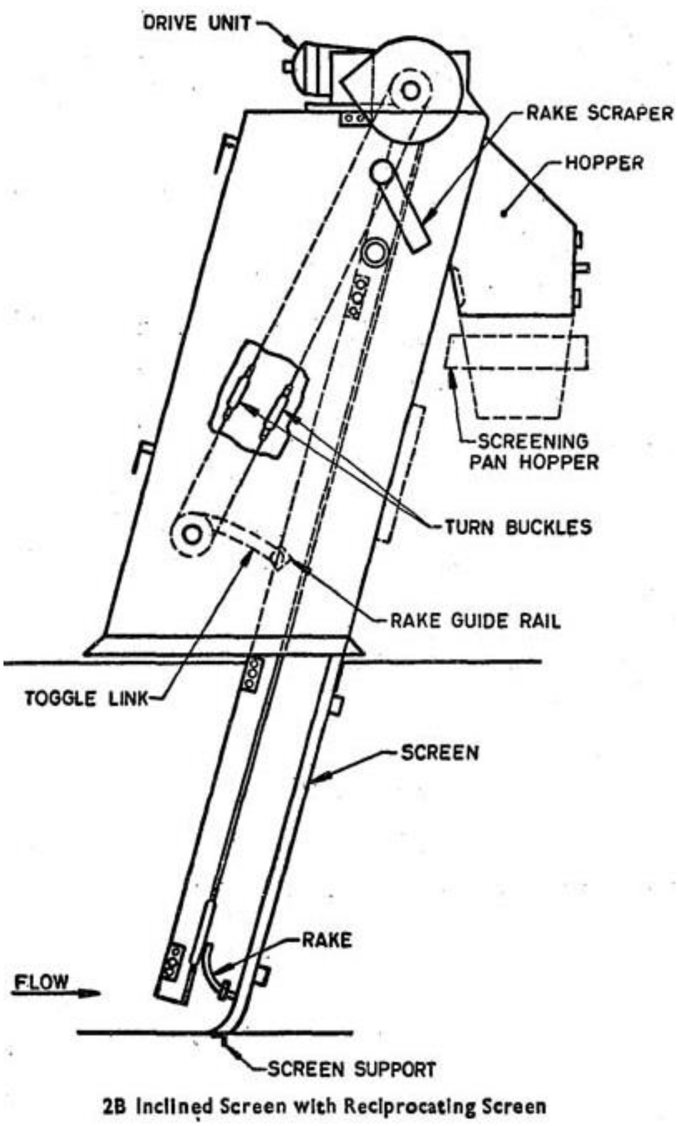


Figure 2: Schematic of a reciprocating rake bar screen [4]

2.1.1.2 Flow Equalization

Flow equalization improves gravity separation of solids by minimizing hydraulic surges or transients that upset settling in quiescent zones. It equalizes the flow and also mixes, or dampens, contaminant load transients to minimize contaminant surges in the bioreactor (chemical equalization). This can lead to rapid bug growth, which impairs settling characteristics in the effluent clarifiers. It happens before the treatment process to minimize short-term transient flow surges through the system. Figure 3 is a flow diagram that illustrates two equalization basin configurations.

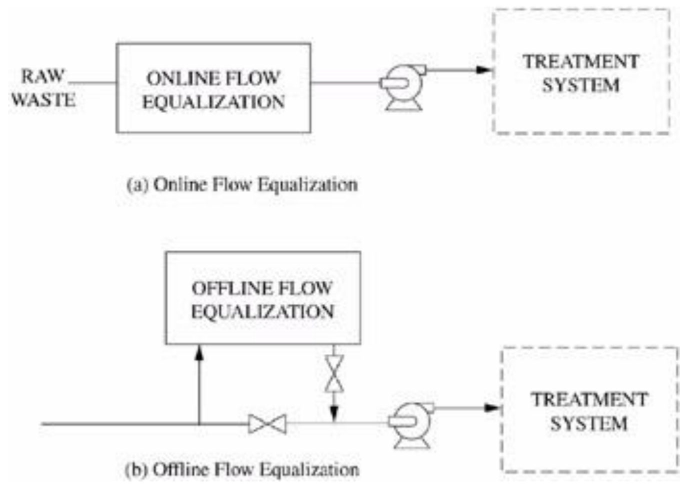


Figure 3: PFD showing online and offline configurations for equalization flow [5]

2.1.2 Primary Treatment

2.1.2.1 Sedimentation

Primary treatment occurs in sedimentation basins. Wastewater from preliminary treatment enters the clarifier at one end and effluent flows out the opposite end. Due to laminar flow equalization, the wastewater resides in the basin for a sufficient time period to remove particles of a desired size, with smaller particles requiring longer settling times. Stokes law plays a large part in these sedimentation basins, allowing larger and denser particles to settle faster. Settling basins can be rectangular, circular, or conical in nature. Figure **4** contains examples.

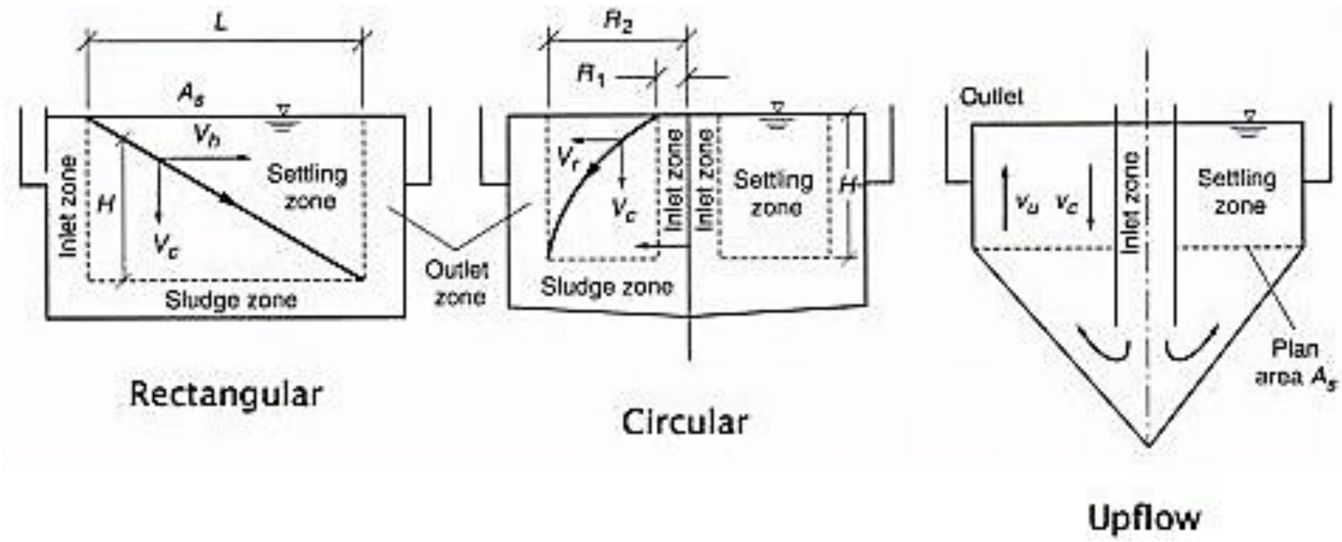


Figure 4: Examples of different sedimentation basins [3]

Another type of settling that can occur is flocculent settling using flocculent agents or chemicals. Flocculants attach to particles in the wastewater through van der Waals forces. Flocculants are typically polymers or metallic salts such as alum. As the particles coalesce, they sink faster due to their density increase [3].

2.1.3 Secondary Treatment

Depending on the water quality passing through primary treatment, it will most likely not meet effluent requirements as defined by the government. Normally, a secondary and/or tertiary treatment level is necessary. Secondary treatment uses biological processes to primarily remove dissolved organic and inorganic matter, such as sulphides, amines, ammonia, and some metals. Microbes consume the organic matter as food, converting it to carbon dioxide, water, new microbes, and energy. Typically, a biological process is used followed by additional gravitational settling to ensure effective removal of TSS [6].

Bio-Reactors are operated under aerobic or anaerobic conditions. They are normally operated aerobically, which requires the use of oxygen. Anaerobic reactors operate without the presence of oxygen. Aerobic operation provides greater benefits than anaerobic operation. Table 3 compares the two types of operation [7].

Table 3: Aerobic and anaerobic processes [6]

	Aerobic	Anaerobic
Energy	High	Low
% removal	95+	60–90
Sludge production	High	Low
Stability	High–moderate	Low–moderate
Start-up	2–4 weeks	2–4 months
Odour	Low	Potential
Alkalinity	Low	High
Biogas production	No	Yes
Nutrients	Can be high	Low

Wastewater reactors are also classified according to microbial habitats of the micro-organisms that utilize the wastewater. The design criteria include attached growth and suspended microbial growth. Attached processes provide an inert support material on which the microorganisms can attach and grow over the surface forming a dense microbial biomass layer or biofilm. The microbial population is then in contact with the wastewater as it passes over the matrix on which the biofilm develops. This system is generally used when space is limited and the biomass surface area needs extension. It is also used to clean air more than wastewater.

Table 4: Summary of processes used in secondary wastewater treatment [8]

Process	System	Reactor	Function	Configuration
Aerobic	Suspended growth	Continuous	BOD removal	Activated sludge Oxidation ditch Contact stabilization Aerobic ponds
Aerobic	Suspended growth	Fed batch	BOD removal and nitrification	Sequencing batch reactor
Aerobic	Fixed film	Continuous or fed batch	BOD removal and nitrification	Trickling filtration High rate filtration Rotating contactor Biological aerated filtration
Aerobic	Suspended growth or fixed film	Continuous	BOD removal and nitrification	Trickling filter solid – contactor process
Anoxic	Suspended growth or fixed film	Continuous	BOD removal	Secondary denitrification
Anaerobic	Suspended growth	Fed batch	Solids reduction	Sludge digestion
Anaerobic	Suspended growth	Continuous	BOD removal and nitrification	Contact process Sludge blanket reactor Anaerobic ponds
Aerobic/anoxic	Suspended growth or fixed film	Continuous	BOD removal, nitrification and denitrification	Multi stage activated sludge filter
Aerobic/anoxic/ anaerobic	Suspended growth	Continuous	Nitrification, denitrification and phosphate removal	Multi stage activated sludge

In suspended growth processes the micro-organisms are either free-living or flocculated to form suspended biomass or flocks, which contain a variety of bacteria, fungi and protozoa. These flocks are mixed with wastewater in an aeration tank by aerators that not only supply the oxygen, but also maintain the biomass in suspension to ensure contact between the nutrients in the wastewater and microbial population.

There are many types of biological processes that can be distinguished by the categories described above, such as oxygen requirements, flow type and microbial system. The most significant are summarized above in Table 4.

2.1.4 Tertiary Treatment

Tertiary treatment can be a chemical process, physical process, or combination of both. It removes residual suspended solids and dissolved solids remaining after the secondary treatment phase. This process is used to polish the water before it is released to meet discharge effluent water quality requirements. Granular media filtration and micro screens are often implemented to remove fine suspended solids (micro filterable solids) in a physical manner and the chemical processes are used for nutrient removal [3]. Lagoons are also used in smaller municipalities to combine both sediment and nutrient removal.

2.1.4.1 Nitrogen, Ammonia and Nitrates

The removal of nitrogen has been a key component of study due to the undesired growth of algae and increased oxygen consumption leading to oxygen deficient rivers and lakes and eutrophic conditions. The conversion of ammonia to nitrate through a biological process is the most common way to neutralize ammonia [8]. While this does not remove the nitrogen in the system, it turns the toxic ammonia into a less harmful nitrate. Nitrogen can also be removed in a biological anoxic zone using facultative bacteria. This is often preferred due to high efficiency, stability, easy control, small footprint and moderate cost [6].

2.1.4.2 Phosphorus

The removal of phosphorus, like nitrogen, is a highly studied process and consists of biological and chemical processes. The most common type of biological phosphorus removal is the A/O method [3]. This method involves the use of a single sludge tank that has an anaerobic section followed by an aerobic section in series. Phosphorus can also be removed through chemical addition. The chemicals added are intended to react with phosphorus to produce insoluble or low solubility salts. The typical chemicals used for this process are: alum, sodium aluminate, ferric chloride, sulphate and lime [6].

2.1.4.3 Treatment of Toxic Components

There are several methods that can be chosen for the removal of toxic components, but this will depend on the components. Carbon adsorption is one method for removal of toxic residuals in the water. Normally it is used to remove refractory organics, residual nitrogen, sulphides and heavy metals [8].

Powdered activated carbon is a method where powdered carbon is added directly to the aeration tank in the process. This causes physical absorption and biological oxidation to occur simultaneously and removes heavy metals, refractory pollutants, and ammonia from the system. It has many benefits, including improved sludge settling and system stability.

Chemical oxidation is a method that removes toxic chemicals such as ammonia, bacterial and viral content, toxic halogenated aliphatic compounds, and aromatic compounds. The compounds used in this process are chlorine dioxide and ozone [3]. Disinfection is also carried out using UV light. They are both used, as they do not form trihalomethanes and often disinfect the water.

2.1.4.4 Dissolved Inorganics Removal

There are often inorganic compounds in water such as heavy metals, refractory pharmaceuticals that must be removed. Chemical precipitation is a method similar to chemical addition for phosphorus removal. The same chemicals used in phosphorus removal can be used to cause heavy metals to precipitate.

Ion exchange involves the use of two columns. One column contains an anionic resin while the other contains a cationic resin. The overall process results in the trapping of dissolved solids and the release of hydrides and hydrogen that form water molecules. The columns then need to be backwashed to regenerate the resins that remove the suspended solids.

Ultrafiltration and reverse osmosis are often used together. The ultrafiltration uses a membrane at low pressures while reverse osmosis uses a semi-permeable membrane at extremely high pressures

[6]. While this process can remove dissolved organics to a high effectiveness, it is expensive, requires high energy, and is not highly practiced, making it difficult to implement. It also produces a brine reject steam, which is difficult to dispose of.

2.1.4.5 Residual Handling and Disposal

The residual sludge of a process remaining after treatment has to be properly disposed. There are a series of general steps that must be followed when accounting for the system residuals. These steps are: determining the type, quality, and quantity of sludge, disposal types available, regulator restrictions, sludge quantity reduction, treatment processes, and design selection.

There are several disposal methods for sludge and each contains environmental challenges. The main methods are discharge to a lagoon, landfill burial, land application, and reuse of the waste. In general, sludge is treated in an anaerobic digester to reduce the volume of sludge and to stabilize the sludge odour free. This is better known as lysis. It is then dewatered and dried into a cake that can be used.

2.2 Bottlenecks in Wastewater Treatment

There are several potential bottlenecks in wastewater treatment that need to be considered when building, designing, or augmenting a facility. Aging infrastructure and more complex chemicals, refractories such as pharmaceuticals in the system are general issues that affect all treatment facilities. Population growth is another problem occurring in most small municipalities. Once a wastewater facility reaches capacity, operators must search for alternatives to increase its capacity. Without an expansion or debottlenecking, the surrounding community cannot grow, preventing development in the local society. In Canada, the main causes of bottlenecks in wastewater treatment are the large amount of consumption per capita. Small municipalities have difficulty addressing bottlenecks through lack of resources, capital and personnel.

Another issue with wastewater treatment is the disposal of the garbage that is collected in preliminary treatment. Large debris that cannot be composted is sent to landfill. It is important that the sludge collected throughout the process is handled in an appropriate fashion that eliminates all remaining pathogens in a responsible manner. In secondary and tertiary treatment, the biological and chemical components added to the wastewater must be controlled to ensure there is not excess in the effluent.

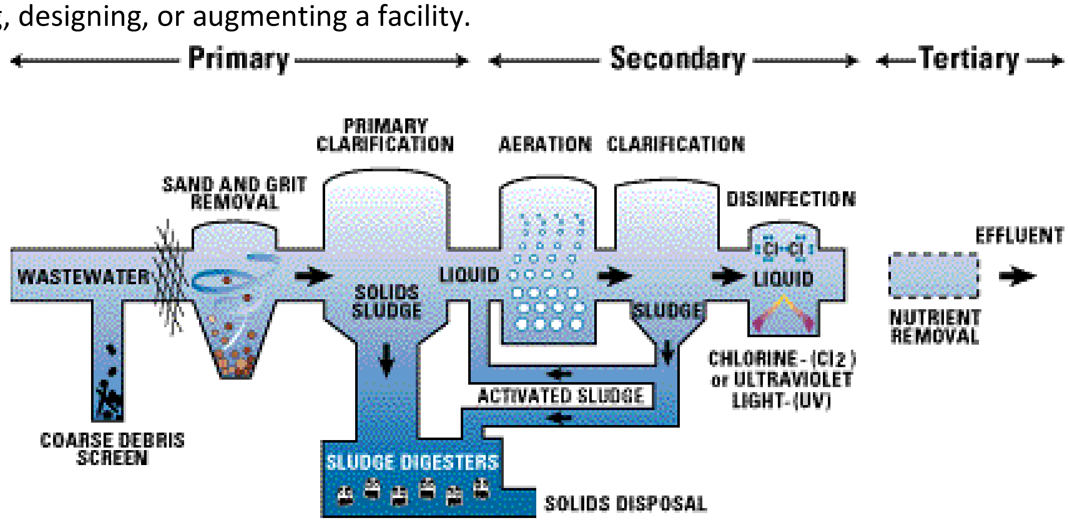


Figure 5: Flow diagram for a typical wastewater treatment process [9]

Evaluation Metrics

3.0 Evaluation Metrics

An evaluation matrix was used to rank each viable technology option. First, criteria were created to eliminate any technologies that could not operate in the cold Canadian Winter, at a small-scale operation (defined as a daily average flow of 2050m^3/d), or be installed as a retrofit. If the technology applied to small scale, could operate efficiently in cold temperature, and suitable for retrofit in existing conventional wastewater treatment facilities, then the technology was considered further. Otherwise, it was rejected and can be found in Appendix C. Each option researched was correlated against the criteria to ensure it met the initial screening requirements.

Next, the technology was reviewed to ensure it did not conflict with any of the listed technical specifications or constraints in Table 2. Important constraints include a high technology readiness level, a reliable capacity increase and capable of satisfying requirements of applicable environmental laws and regulations.

If the technology was successful in passing the first and second round of screening, it was ranked amongst several others using a word ladder and scoring system with weighting. Several important criteria were developed to assess which technologies were most valuable. Using advice from wastewater facility operators, the following criteria were used to rank each technology in order of importance: capacity increase, technology readiness level, robustness, CAPEX, OPEX, complexity, compatibility, regulation approvals, footprint, and strength of vendor.

Once the criteria were positioned in order, each was given a multiplier.

The overall objective was to identify technologies to increase capacity of wastewater plants. Capacity increase was therefore considered the most important, and was given a multiplier of ten. The other nine components were ranked based on this maximum multiplier, with the lowest multiplier assigned to the strength of vendor. It is important to recognize that the criteria were not ranked evenly, but rather unevenly. This was done purposely to ensure noticeable scoring separation between each option.

In addition, each has an associated description for the ratings of 0-5. Zero is defined as no supporting evidence or information found. One is defined as performing poorly in that category, while five is defined as exceeding expectations in that category. This word ladder was used extensively to rank each technology.

Once each category was given a ranking for a particular technology, each score was multiplied by its respective weighting. The sum of the ten criteria values was the overall score for each option. The technology with the highest score was considered to be the most valuable. The final three technologies were chosen based on this score, advice from experienced operators, and engineering judgment. The three detailed technologies were not taken solely based on their final ranking score.

Complete details regarding the scoring and ranking of each technology, including the word ladder and evaluation matrix, can be found in Appendix B.

Composite Correction Program Summary

4.0 Composite Correction Program

4.1 Overview

The composite correction program (CCP) was developed by the United States Environmental Protection Agency (USEPA). This program was instituted after a survey conducted by the USEPA noted a majority of wastewater treatment plants (WWTP) were not meeting required effluent quality. The report can be applied to a number of conventional systems such as activated sludge, fixed film and variations of these processes. The USEPA split the report into two main sections. The first part of the report is an evaluation tool called the comprehensive performance evaluation (CPE). The facility is analyzed, scored and based on the score received will determine if the facility requires a major upgrade or can be fixed by implementing the CCP. The second portion of the report details how to carry out the CCP. Despite the release of the final report being in 1998, the CCP provides a very standardized way of evaluating and correcting a WWTP without major capital expenditures.

4.2 Evaluation

The evaluation section of this report is divided into two sections. The first is a "how to" approach by conducting a comprehensive performance evaluation (CPE), following with how to proceed.

4.2.1 Evaluation Approach

The approach to conducting a CPE is to build a process to follow when performing the evaluation. The major units in the WWTP need to be assessed to determine if the CCP is indeed a valid solution to the facility's issues. This evaluation identifies performance-limiting factors, such as administration, maintenance, design and operation. The report lists 70 potential performance-limiting factors that can occur within a plant and is the basis of the evaluation. The performance limiting factors are then organized based on their priority of effect. Limiting factors are also separated into groups of those that can be fixed and others that cannot. Once the whole plant has been analyzed, it is ranked, and based on that score, the facility is given one of three categories. The three categories are:

1) Facilities whose performance is not limited by the size or capabilities of existing major unit processes. In this case the facility can be improved through the implementation of the CCP and minor facility modifications.
2) Major unit processes potentially prohibit the ability to achieve the desired performance. While a CCP may improve the plant performance, it is not guaranteed to achieve the required performance levels. The CCP implementation should be implemented with some facility upgrades to achieve maximum performance.
3) In this case the implementation of the CCP will not assist with the improvement of plant performance. The major unit processes are inadequate and thus the WWTP major facility changes or upgrades should be implemented.

Ranking the WWTP is how the implementation of the CCP is justified. The results of the evaluation are summarized in a report that covers the following topics:

1) Facility background
2) Major process evaluation
3) Performance-limiting factors
4) Projected impact of a CCP
5) CCP costs

4.2.2 Conducting the Evaluation

The report relays the method of how to conduct the evaluation and has tables and charts in the appendix that can be used when conducting the evaluation.

First, the evaluation details the initial steps that should be conducted to determine the amount of fieldwork required. It also states what basic data should be acquired. Data such as performance, irregularities and design layout should be collected here. A basic template is provided with the report.

Next steps include learning about the personnel. Plant personnel and administration for small and large facilities need to be known and contacted. The specific people and what they should provide in order to conduct the evaluation are noted in this section of the CCP. Details about what types of questions should be asked and to which personnel are also incorporated.

After meeting with plant persons and having a tour of the facilities, the sections of the water plant are evaluated. Within this section, advice is given for what should be considered for several processes. Preliminary, primary, secondary and disinfection are all analyzed. Aerated systems are also investigated. Tables and charts for collecting certain data are located in the appendices of the CCP and provide a guideline for exactly what data should be acquired.

Once data has been collected, the plant needs to be scored and evaluated. Tools, tables, calculations, the point ranking system and even examples are given for each individual section of the WWTP to determine ranking. Once points are assigned to each separate section and added, the facility can be assigned to a particular ranking. While the evaluation system criteria were based on government regulations created before the year 2000, it is assumed that the system can be modified to accommodate present regulations.

While analyzing the physical factors of the plant are important, administrative factors are also taken into account. Budgeting and staff assessment are included as a portion of the report, as these are contributing factors to the success of a treatment plant. Budget collection tables and steps are included as well as the assessment guidelines for administration.

In addition to administration factors, operation factors are also assessed. The plant may seem to be at capacity, but this can be due to improper operator training or improper use of equipment. Outlined are factors that need to be considered when observing the operations of a facility. Control systems are the main consideration when assessing operations. Significant fluctuations in areas such as aeration performance, or solids settling can be indicators of operation issues.

Once the assessment is completed, a report is written. Guidelines and report examples are included as well as information on how the data should be presented to administration.

4.3 The Correction Program

Assuming the CPE has determined that the CCP should be implemented, then it should be noted that the CCP is similarly split into two different sections. It includes how to approach conducting the CCP and then how to execute it.

4.3.1 Approach to the CCP

The CCP is a combination of implementing minor equipment upgrades and training of staff. These two overarching fixes cover the performance limiting factors identified in the CPE (administration, design, operation and maintenance). The CPE has prioritized the performance limiting factors and this is used as the guide for executing the CCP.

The CCP is typically carried out over a long period of time (approximately one year). This allows for several observations to be made in relation to the effectiveness of the CCP. When making changes to biological systems, there are inherently long response periods. To observe the full effect that the changes have, a long period of time is required. This time span also makes observations of the system in all weather and temperatures available. Physical and procedural changes also require time due to financial expenditures that need to be made, along with government approval. There is greater effectiveness of training techniques held over a longer interval, as more scenarios will arise to test training. It also allows for training modification, should the current regimen be inadequate. If other performance limiting factors are identified, there is time to correct these as well.

Personnel carrying out the CCP should have a comprehensive knowledge base of wastewater treatment and have field experience with biological wastewater treatment operations. They should be authoritative and preferably work outside the municipality to prevent bias. A long list of suggested requirements for the facilitator of the CCP are available in the report.

While the cost of the CCP can vary, there is a range from $4,500-$145,000. This is dependent on the size of the plant and the amount of work required to fix the performance limiting issues.

4.3.2 Implementing the CCP

While conducting the CCP is unique to the issues presented by each individual WWTP, there are standard techniques, schedules and guidelines that can be followed in order to ensure success. While the issues may differ, it is important to note that the objective of correcting the limiting factors is the priority.

Throughout the CCP the facilitator has a number of activities they should do to promote a successful CCP implementation. These activities can be contact through e-mail and telephone, site visits, written reports, and the final CCP report. The facilitator should have periods of onsite and offsite involvement. The first few months of the implementation should involve more onsite work that should gradually decrease over the implementation of the program.

Initial site visits by the CCP facilitator are quite important. If they were not involved in the production of the CPE report it may take time for them to confirm the conclusions made by the CPE. It is also used as the basis to begin eliminating performance-limiting factors. Control systems are usually a good starting place for adjustment. Equipment monitoring, control summaries and adjustments should be made. Laboratory testing should be standardized. These initial changes could result in immediate changes to system performance, but after time it also makes the effects of other changes more apparent.

For design limiting factors, there are several common factors identified in the appendix of the report, but minor changes to plant design may be necessary. The justification for these design changes is key. Since they have already been identified by the CPE, it is important to confirm and justify any proposed changes. Once justification for the changes have been established and all municipal and regulatory approvals acquired, the implementation of design changes can occur.

Several aspects that need to be considered by the facilitator are:

1) Purpose of the change
2) A full detailed description must be made
3) Quantitative criteria for success or failure
4) Those responsible for carrying out the change
5) Costing
6) Anticipated improvement
7) Schedule – Time allocated for MOECC approval

After the implementation of design changes, they are assessed and compared to the quantitative criteria to determine the effectiveness of the change.

To improve maintenance issues, current problems need to be reviewed. Documentation regarding lack of maintenance or equipment failure that should have been acquired during the CPE should be analyzed by the facilitator. Once there is a need for more rigorous preventative maintenance, the equipment and literature need to be acquired. From there a maintenance and inspection schedule is developed. Examples of scheduling and a materials list are available in the appendix of the report.

To improve administrative performance limiting factors the administrators need to be involved from the start of the CCP. Typically, administrators unfamiliar with the process create issues. Short lists of methods to address administrative issues are:

1) Involve the administrators from the beginning. The initial site visit should include administrators as this will help increase their understanding of the process.
2) Education of the administrators in the fundamentals of wastewater treatment, in particular, with respect to the current facility needs.
3) Understand the issues administrators pose so that they can be addressed.
4) Use technical information to support claims, but always have alternatives when possible.

Improving the operational performance limiting factors can be very technical. Thus training operators while improving process control procedures for a particular plant need to be developed. There are several processes that can be optimized through training and control changes. These processes are:

1) Suspended growth
2) Activated sludge characteristics
3) Activated sludge mass control
4) Return sludge flow rate control
5) Aeration Basin DO control
6) Process control pressure
7) Time for biological system response
8) Activated sludge testing

While many of these processes listed are for activated sludge, it should be noted that fixed film process control has also been addressed.

4.4 CCP Conclusions

While many companies have their own procedures for evaluating their facilities, the CCP provides a standardized method for testing. It provides the evaluation and correction technical aspects, as well as administrative and staff changes that can improve performance. It has a very thorough method that while intended primarily for conventional activated sludge facilities can be applied to other operations. Templates for data sheets, evaluation and scoring templates, common issues, and example reports are included within the report. The report is a valuable basis for determining if capital expenditures are necessary and how the plant can augment performance without expensive upgrades. It is recommended that before any major technology upgrades are implemented, this report be used for evaluation and correction purposes to improve plant performance. The complete CCP can be accessed online via the United States EPA website [1].

BioMag®

evoqua

WATER TECHNOLOGIES

5.0 Detailed Technology Study

5.1 BioMag – Evoqua Water Technologies

5.1.1 Vendor Description

For over 100 years, Evoqua Water Technologies has been providing leading technologies. They assist municipalities with disinfection, membrane treatment, high rate clarification, biological processes, low energy biosolids solutions, odour control, and controls across process equipment. Working with consulting engineers to purify the most precious resource is a priority for Evoqua. Their experts, experience, technologies, integrated approach, and services make them an extremely reliable source for the municipal water and wastewater treatment needs [10].

5.1.2 Introduction

Simple, reliable and proven, the innovative BioMag System from Evoqua uses magnetite (Fe_3O_4) to ballast conventional biological floc, enhancing settling rates and increasing the performance of wastewater treatment facilities, while substantially reducing life-cycle costs. It has the potential to increase capacity of up to 300%, without the need for additional tankage or energy intensive operations. It does not only remove TSS, but also Nitrogen, Phosphorus, and BOD. Primarily used to improve secondary wastewater treatment, the BioMag System easily integrates as a retrofit with planned or existing facilities. BioMag is most effective in enhancing the capacity and nutrient removal performance of activated sludge systems, including oxidation ditch, conventional air, extended air, HPO, and SBR based systems. It is hydrophobic, and naturally bonds to the chemical floc or biological solids. It is also capable of being used in primary or tertiary treatment as well. The system is located in a side stream location, without impacting the main liquid stream [11].

This chemical improves the performance of clarifiers and treatment systems because of its high density. Its specific gravity is 5.2, which is on average 5x the specific gravity of a hydroxide or biological floc. The infusion between magnetite and the floc increase the density, and therefore increasing the settling rate of the floc while also providing stability and control to the sludge blanket [10].

5.1.3 Process Description

The system starts by combining virgin and recovered magnetite with mixed liquor in a ballast feed tank. The blended slurry is fed to a single or multi-stage bioreactor for conventional processing, then onto a secondary clarifier where the solids settle quickly and reliably. The majority of the resulting underflow is returned to the bioreactor via a return activated sludge (RAS) line. Waste activated sludge (WAS) passes through an in line shear mill to liberate the magnetite, then to a magnetic recovery drum where the magnetite is recovered and re-blended with the mixed liquor in the ballast feed tank. The sludge, minus the magnetite, is wasted and with gravity thickening achieves a solids concentration of 4 to 5 percent. The result is a BioMag System that is simple and easy to operate. A high-level process flow diagram can be seen below in Figure 6 [11].

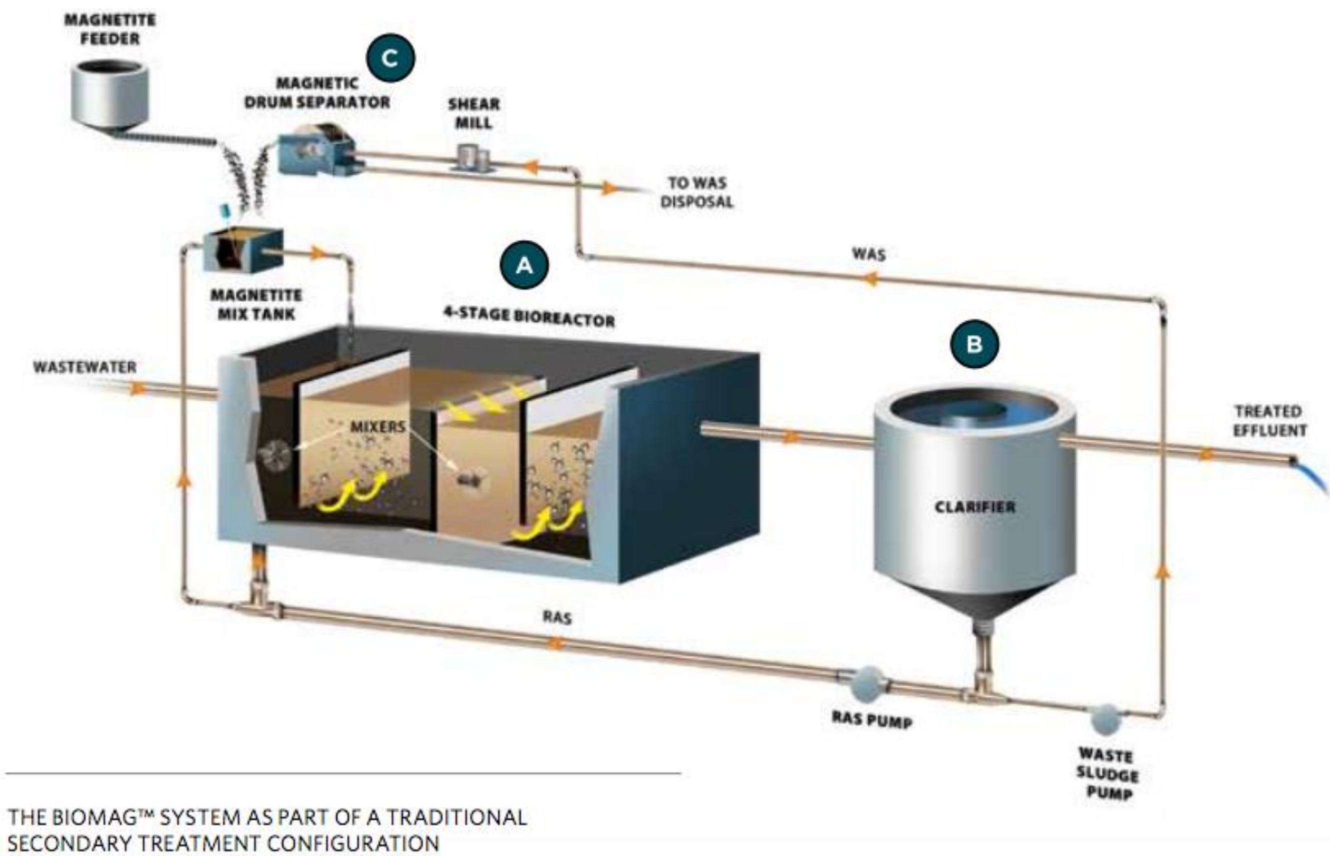


Figure 6: The BioMag system configuration [11]

It is estimated that for a larger 24,000 m^3/d (6.34 MGD) project, there is roughly 2900 kWh/d required for energy. For a smaller 2,045 m^3/d application (540,000 gpd), there is roughly 750 kWh/d required for energy.

Unfortunately, this technology has no capability to produce additional revenue for the plant. It can however reduce treatment loads and potentially reduce the existing operating cost of the plant. Treatment loads are reduced in tertiary treatment due to the early removal of phosphorus and nitrogen by the BioMag system in secondary treatment. Additionally, flocculent is not required in secondary treatment, and any chemical used in tertiary treatment may also be avoided if regulated effluent quality water is achieved.

5.1.4 Additional Information

Magnetite is an easily accessible, fully oxidized iron ore (Fe_3O_4). It is completely inert; it cannot rust; it doesn't degrade with time or usage; it has no effect on chemical or biological floc; and it is not magnetic itself, i.e., it doesn't stick to metal. Recovered magnetite can be reused over and over again without any loss in its effectiveness as a ballast. Magnetite is also not difficult to handle. Due to the pneumatic conveyance system, no direct contact is required [12].

Generally, magnetite is inexpensive, ranging from $0.30 to $0.65 CAD. In addition, due to the high recovery rates of magnetite in the BioMag system (96% recovery), daily consumption is considered low. Any magnetite not recovered is carried away by the sludge, where there has been no effect on downstream sludge processes [12].

The annual operating cost of a BioMag enhanced activated sludge system is about the same as an IFAS, MBBR, or a conventional ASP. Compared to an MBR system, the operating costs are approximately 60% less [12].

Fortunately, the magnetite is so fine that it is not abrasive and doesn't cause wear or tear on treatment pumps, valves, mixers etc. It also does not degrade itself with a fluctuation in temperature or pH. The ranges associated with most municipal plants are moderate enough to support this. Considered inert, it has no affect on the pH or the chemical characteristics of the effluent either. It also does not consume dissolved oxygen or dissolve within the fluid [12].

BioMag offers high reliability and proven performance in conventional wastewater treatment plants. It is well suited and tested for a 24-hour operation and 365 days per year. However, when a power outage occurs, due to the lack of mixing, the ballasted floc will settle to the floor of the reactor or mixer. This would happen even without BioMag. Once the power returns, the biomass is re-suspended. Mixing is required, and can be achieved in anaerobic zones with mechanical mixers, and in aerobic zones with diffused air, jet mixers, or a combination. To maintain magnetite infused biological floc, approximately 55 BHP or 11 W/m^3 of mixing energy is required [12].

Figure 7: Example of the BioMag system implemented in a reactor or mixing tank [10]

5.1.5 Operability and Maintenance

The operability of the BioMag system is excellent. It is simple to use and easy to install. Any operator is capable of working with the equipment due to its automation and simplicity, and several units have been installed within the industry. It is also fully compatible with existing conventional treatment facilities because it is only a side stream addition and does not affect the main water stream. The only equipment required is a supply tank with pump, a mixing tank, interconnecting lines, and recycling system. This technology has the opportunity to increase capacity immensely without additional tankage or high-energy operation. It has been installed in various locations with great success and very few issues.

A few of the challenges include appropriate mixing level, supplying the correct ratio of magnetite to influent parameters, and proper implementation into either primary, secondary, or tertiary treatment (whichever has the most issues). Mixing is important for the BioMag system to be effective, so supplying the correct rotational speed of the mixer and at the appropriate level is crucial to high performance. The correct ratio is also significant. Too much Magnetite addition will result in higher unnecessary operational costs, while too little will result in underperformance of the chemical and the system. These challenges can easily be resolved by working with Evoqua and supplying the correct plant information. Evoqua has completed numerous installations and solved various issues ranging from all 3 areas of conventional wastewater treatment plants.

5.1.5.1 Notable Installations

1) Sturbridge, MA; Online since 2011

Challenge: Faced with tightening phosphorus and nitrogen limits and aging infrastructure in a tight footprint, the town was planning to undergo a major upgrade of their existing conventional activated sludge plant. They based their design around membrane bioreactors until their consultant heard about BioMag, the emerging activated sludge upgrade.

Solution: BioMag for increased treatment capacity and nitrogen removal in existing treatment tanks, followed by CoMag for ultra low phosphorus effluent limits.

Advantages: BioMag allowed the town to use their existing tankage and maintain their existing footprint in a tight site with expensive to excavate ledge, surrounded by wetlands and residential development. It also facilitated a staged construction that allowed interrupted treatment over a 2 year period. CoMag allowed the town to achieve ultra low phosphorus treatment goals of less than 0.05 mg/L without filtration. The high quality effluent has excellent UV transmittance, resulting in minimized UV power usage. The town saved millions of dollars by choosing this treatment system over membrane bioreactors [13].

2) Allenstown, NH; Online since 2011

Challenge: The sewer district was faced with two big problems; a moratorium on sewer connections caused by wet weather treatment issues at the aging extended air activated sludge treatment plant, combined with a tough economic conditions and a mandate not to raise sewer rates.

Solution: BioMag upgrade to allow the existing plant to increase treatment capacity of both domestic flows and septage, with greatly improved treatment at wet weather flow conditions.

Advantages: The entire BioMag upgrade was executed for less than 2 million dollars, a fraction of alternatives capital cost that would have included additional tankage and potentially being required to purchase additional property. The plant's 7 feet deep clarifiers had proven to be a challenge for wet weather conditions, but with ballasted solids, the plant can now handle a 10x peaking factor while maintaining a steady sludge blanket.

3) Mystic, CT;

Challenge: Faced with tightening nitrogen limits and an aging infrastructure, the sewer district explored options for renovating or relocating their Mystic plant. The plant is bound on all sides by wetlands, train tracks, the mystic river, a yacht club, and a residential neighbourhood, so expanding footprint was not an option.

Solution: BioMag was demonstrated successfully in a temporary installation in the winter of 2009. The system achieved total effluent nitrogen of less than 4 mg/L versus a limit of 5.5 mg/L, with low TSS and BOD. The upgrade will utilize the existing biological reactors by conversation to a 4-stage process and no additional secondary clarifiers or need for tertiary filtration.

Advantage: BioMag had the lowest 20-year NPV analysis solution of four alternatives evaluated to address the plants challenges performed by the district's engineer. Utilizing the existing site and having the ability to reduce nitrogen load will provide the town with the opportunity to trade credits or balance the operations of their other nearby plants. The plant operations team is relieved by the observation that no additional resources are going to be required due to the operability and simplicity of the BioMag system, since the fundamentals of operating an activated sludge plant stay the same.

4) Phillipsburg, NJ; 5.36 MGD BioMag; currently under construction

Challenge: Faced with I&I and other operational treatment challenges and tightening nutrient limits, the Town of Phillipsburg was forced to consider building additional continuous flow SBR tankage to handle wet weather flows and seasonal variations.

Solution: BioMag was selected to allow the plant to improve treatment and operate with a higher biomass concentration while handling wet weather flows. BioMag was the only technology that could be installed without adding new tankage.

Advantage: BioMag was the only treatment technology proved to allow higher biosolids concentration in an existing SBR installation. The ability of BioMag to handle large fluctuations in flow without hindering treatment performance allows the plant to maintain compliance even during severe wet weather events.

Canada Installations: There are currently no full-scale installations in Canada, but there are several in the early stages of planning. Evoqua has completed an extensive and successful 3-month pilot of the BioMag system in Kemptville, Ontario (North Grenville, Ontario), and a 3-week CoMag pilot in Pottersburg, Ontario. There are currently no regulatory issues within Ontario. The MOE has not formally approved the technology, but the process is well underway. The piloting work has been submitted to the MOE in Quebec for approval for future installations.

For a full list of all projects, please see the Evoqua project document [4].

5.1.6 Treatment Performance

The BioMag System can effectively manage high wet weather flows through current clarifiers with no risk of upsets, - avoiding bypass of the biological system - relieve current tankage to meet enhanced nutrient removal effluent standards, avoid tertiary treatment for phosphorus removal, and manage high organic industrial waste. It also has the potential to increase the capacity of the plant of up to 300% [10].

Below are the claims from Evoqua that the BioMag system can reliably produce:

Table 5: BioMag Treatment Effectiveness [10]

Criteria	Concentration
BOD_5	< 5 mg/L
TSS	< 5 mg/L
NH_3-N	< 0.5 mg/L
TN	< 3 mg/L
TP	< 0.2 mg/L
Turbidity	< 1.0 NTU
Clarifier SLR	> 90 lb/d-ft^2
SVI	< 40 mL/g

5.1.7 Economics

Below is supplied information from Evoqua for the BioMag system. Note that these are estimates based on previous jobs with similar flow and loading comparison, and not a specific evaluation. An installation factor of 5 was used.

The OPEX was calculated by the sum of the required energy, magnetite, and polymer over a full year assuming ¢11.6/kWh [14], 365 days, 24 h/d, and 100% plant reliability.

All values are in Canadian dollars converted using the current exchange rate on March 14, 2016 of $1.00 USD = $1.30 CAD (quotes were provided in USD). The vendor was provided with influent and effluent quality data for a plant in Ontario. They were also provided with effluent regulation requirements, inlet flow, water temperature, dissolved oxygen, and pH level.

Table 6: Economic summary for the BioMag system

	Case 1	Case 2
Plant Flow Rate (m^3/d)	24,000	2,045
Capital Costs ($)	$15,550,000	$4,550,000
Energy (kWh/d)	2900	750
Magnetite Addition ($/d)	285	25
Polymer Addition ($/d)	104 (based on 52 lb/d at $2/lb)	9 (based on 4.5 lb/d at $2/lb)
Power and Chemical Costs ($/year)	$265,000	$45,000

5.1.8 Environmental, Safety and Legal Aspects

There are currently no environmental or legal issues with the BioMag system. The technology has been present in the industry for several years in the United States. There are currently no regulatory issues within Ontario. The MOE has not formally approved the technology, but the process is well underway. The piloting work has been submitted to the MOE in Quebec for approval for future installations. Magnetite is a non-toxic chemical that will not affect downstream operation or the environment if released as an effluent. According to its MSDS, it is not flammable, is not toxic to fish, and has no acute toxic effects. Fortunately, it is not reactive, and therefore hazardous products will not be produced in the environment [15].

When the magnetite is captured and disposed of with the sludge, there has been no evidence of hazardous effects upon disposal.

A review of its MSDS is still a necessity to ensure proper safety knowledge is distributed. There is no combustion or emissions from the technology.

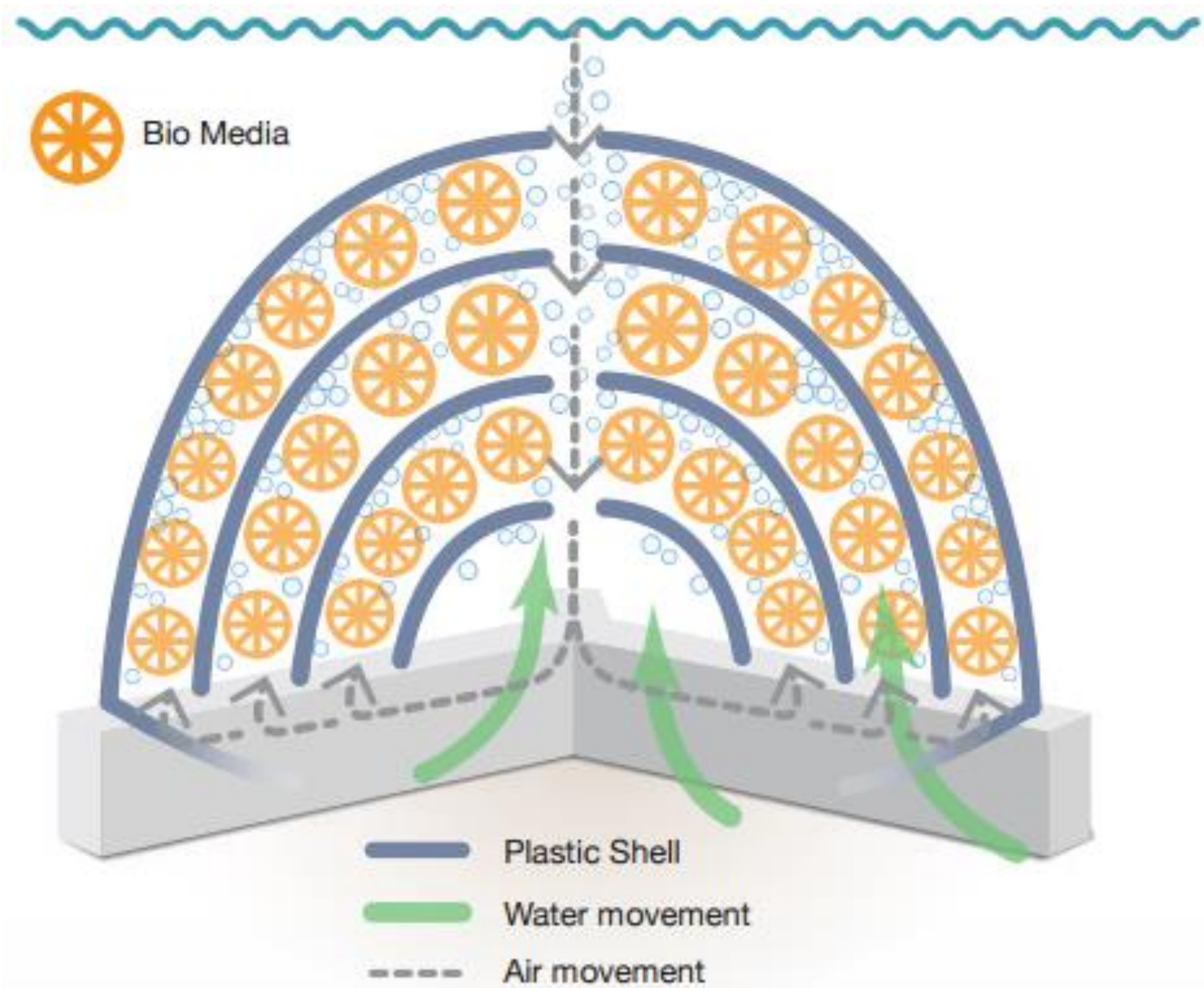
The greenhouse gases emitted from electrical use were determined for each plant size and are shown below in Table 7. The conversion used was 75 gCO_2/kWh.

Table 7: GHG emissions from electrical use

	Case 1	Case 2
Flow rate (m^3/day)	2,045	24,000
Power / Unit (kWh/d)	750	2900
Emissions (ton CO_2/y)	21	80

The above conversion value was used based on the current situation in Ontario. It is understood that this value can range anywhere from 25-128 gCO_2/kWh [16].

Bio-Domes



WCS
Wastewater Compliance Systems

5.2 Bio-Domes

5.2.1 Vendor Description

Wastewater Compliance Systems (WCS) provides submerged bio-reactors to enhance the biological activity of treatment systems to reduce ammonia, BOD and TSS concentrations [17]. Their technology helps communities comply with environmental regulations without resorting to expensive mechanical plants. Whether it is an existing system, or new construction, Bio-Domes can help minimize the expense of treatment systems.

5.2.2 Introduction

Bio-Domes are intended for increasing the naturally occurring biological activity in a water body. They sit on the floor of the lagoon and are completely submerged. The Bio-Domes enhance the naturally occurring biology by providing 2800 square feet of surface area per unit, a gas delivery mechanism capable of providing air or more specific gasses as necessary, an environment protected from UV light, and significant mixing action to ensure nutrient availability to the biology as it grows [17].

When used in a wastewater lagoon, the enhanced biology is capable of accelerating the nitrification of ammonium and the subsequent denitrification of nitrates and nitrites. Additionally, the gas delivery/aeration design helps reduce BOD levels. As organic material is consumed by the bacteria, overall TSS levels are reduced. The airlift action created within the Bio-Domes is the mechanism behind the mixing action and helps delay the build-up of sludge on the bottom of the lagoon.

5.2.3 Process Description

To significantly enhance the biological activity in a wastewater lagoon, there are two core needs: aeration and lots of surface area for biofilm development [3]. Bio-Domes simply and effectively introduce the needed air and the required surface area into existing water bodies without high capital costs. Additionally, the unique design of the Bio-Domes results in a high Oxygen Transfer Efficiency (OTE) with a minimum of energy input. Bio-Domes typically require one-third the amount of energy compared to most other aeration systems for the same performance [17].

Facilitating biofilm growth is crucial in establishing robust biological activity in a wastewater lagoon. Suspended growth bacteria are not always able to develop in sufficient quantities in a typical wastewater lagoon, nor are they capable of surviving in cold weather environments [3]. Biofilm growth allows a variety of beneficial bacteria to develop in higher concentrations than is possible in suspended growth; however, biofilm growth is limited by the amount of available surface area in the lagoon. To overcome this problem, the patented design of Bio-Domes creates additional surface area inside each unit through the use of packing [17]. This increase in surface area correlates directly to increased biological activity once the biofilm has had a chance to develop.

As effluent requirements have become more stringent over the years, many communities have had to upgrade their facultative lagoons to aerated lagoons. The increased oxygen, and to some extent the improved mixing, has helped keep communities in compliance for many years. Unfortunately, most aeration systems are incredibly inefficient and require large motors to be effective. This results in high utility bills and can increase the cost of the system over its life span. Because of its unique design and high OTE, each Bio-Dome is able to achieve the same performance as typical aeration systems for a fraction of the cost [17]. Bio-Domes are also easy to install and maintain, making wastewater aeration simple to achieve and cost-effective to maintain.

Coupling the increase in surface area with aeration and a dark environment that discourages algal competition, Bio-Domes have the perfect environment for enhanced biological activity. They are a cost effective means of reducing unwanted contaminants in wastewater treatment systems. Not only are they effective at reducing BOD, Ammonia, and Total Nitrogen levels, but because the bacteria require a carbon source for food, there is a tremendous reductions in TSS levels as well [17].

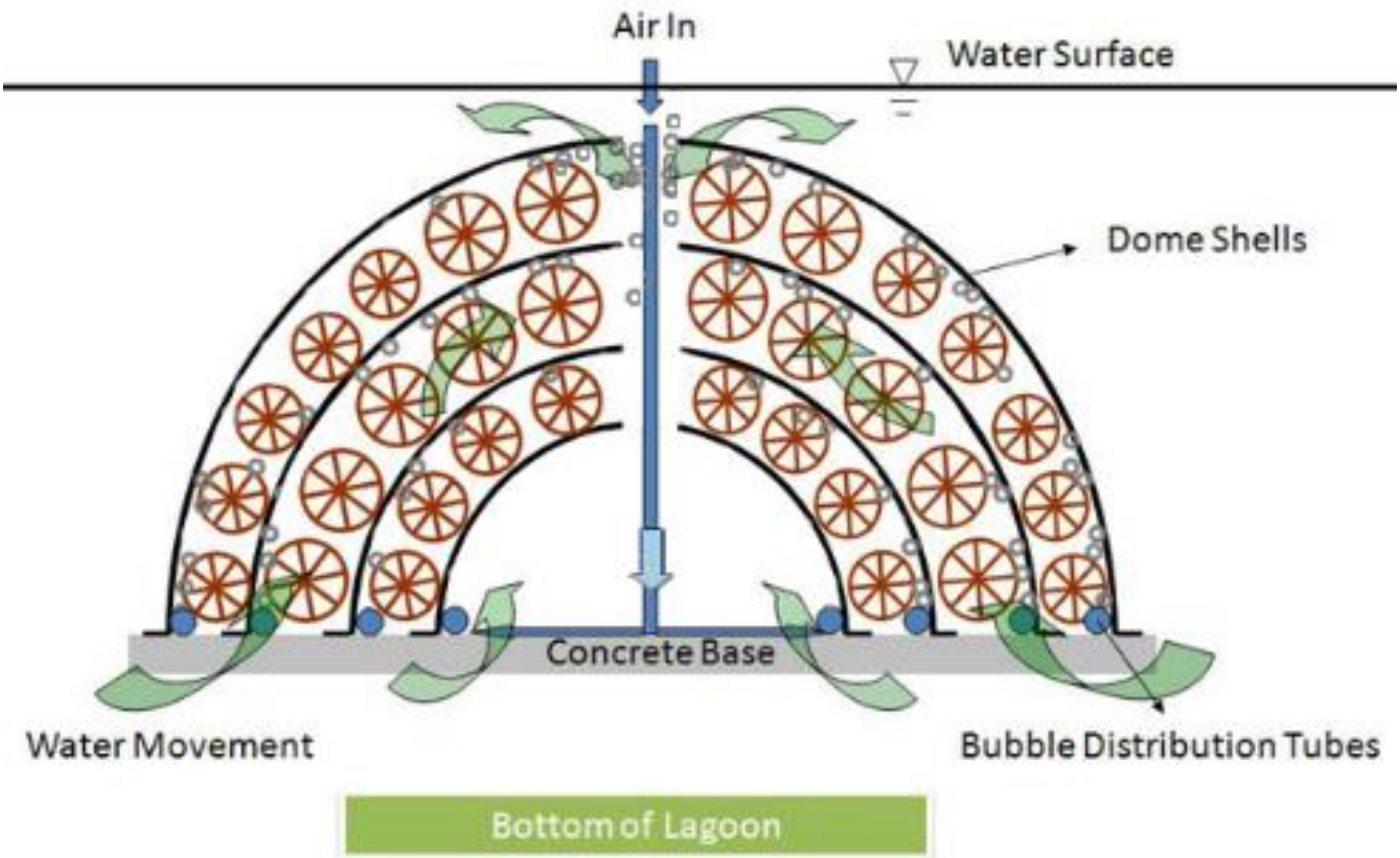


Figure 8: Working principle diagram for a single Bio-Dome. Air is bubbled up through the domes and packing from the bottom. This mixes the water and removes excess biofilm from the packing. The excess biofilm becomes part of the sludge blanket [17]

5.2.4 Energy Requirements

While Bio-Domes are more capitally expensive than a traditional aeration system such as diffusers or surface aerators, the improved performance and increased energy savings when considered over the 20 year life of the system result in a significant net savings [17]. The Bio-Domes use approximately 1/3 the energy of a comparable fine bubble diffuser system and 1/10 the energy of surface aerators while still maintaining a superior level of performance [17]. Because of the low energy needs, it is possible to design a Bio-Dome system that is completely powered by solar or wind. This makes Bio-Domes a “green” wastewater lagoon treatment system. Table 8 highlights the operating requirements for each Bio-Dome.

Table 8: Operation Requirements [17]

Airflow / Bio-Dome	1 CFM @ 5 psig
Power / Bio-Dome	75 W
Off Grid Compatible	Yes (solar or wind)

5.2.5 Materials of Construction

There are currently two variations of the Bio-Dome, the 4-Dome (Figure 9) and the 7-Dome (Figure 10). Both models consist of concentrically stacked domes secured to a concrete base with gas delivery provided under each shell (Figure 11).

Bio-Domes are designed and constructed for year round submersion. Each dome is constructed from recycled ABS plastic, concrete, stainless steel, PVC pipe, and rubber aeration hose (Figure 12). Table 9 contains the dimensions for each model of Bio-Dome.

Table 9: Dimensions [17]

Model	Dimensions	Total Surface Area (ft^2)	Weight (lbs)
4-Dome	6 ft OD x 5 ft H	2800	820
7-Dome	6 ft OD x 5 ft H	400	800

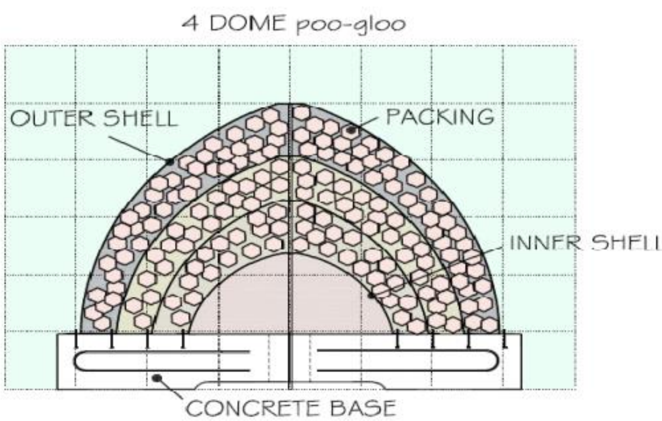


Figure 9: 7-Dome Bio-Dome [17]

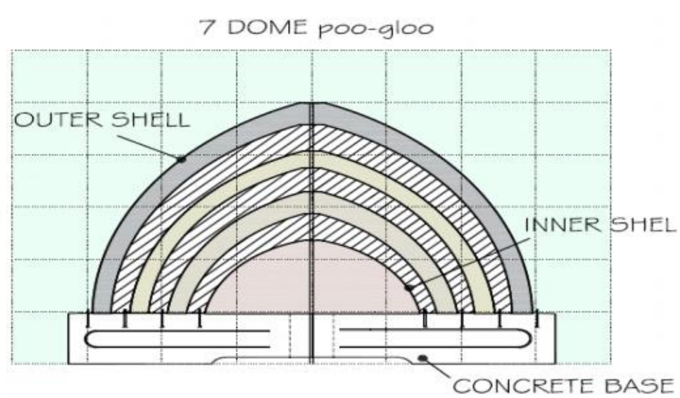


Figure 10: 4-Dome Bio-Dome [17]

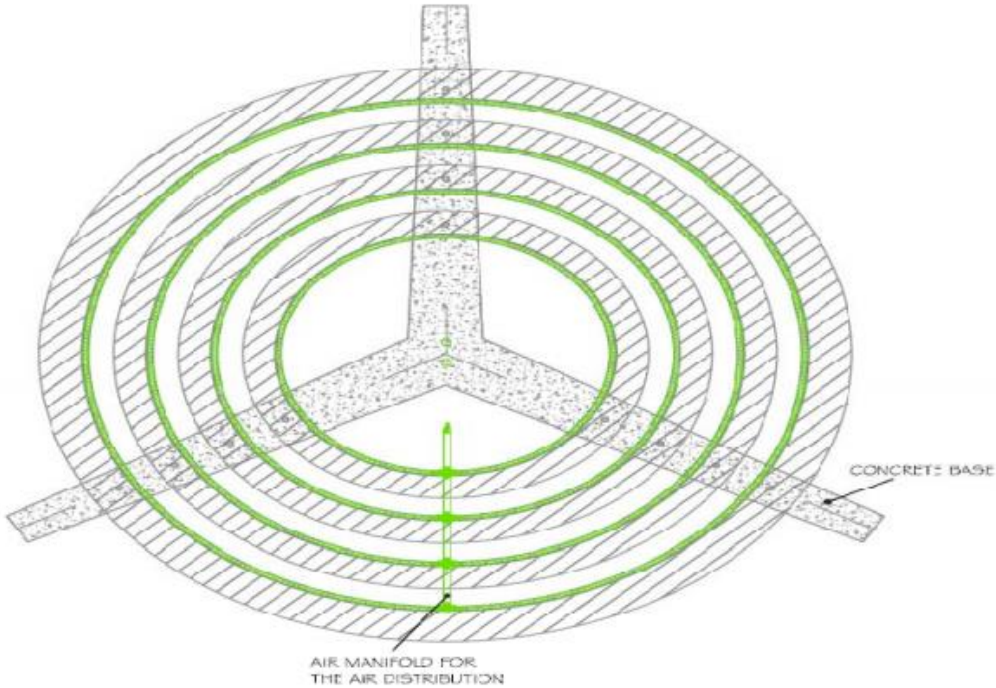


Figure 11: Elevated view of 4-dome Bio-Dome. The air tubes are shown in green [17]

Figure 12: Bottom of Bio-Dome showing concrete base, air manifold and packing [17]

5.2.6 Operability and Maintenance

Bio-Domes are constructed with no moving parts underwater and only need to be raised out of the lagoon every 20 years [17]. At the end of the 20 years, the fine bubble air hose must be replaced, then the Bio-Domes can continue to provide effective treatment. The domes can be installed in a lagoon with a crane or a barge and do not require any significant infrastructure updates to operate. Additionally, they can be installed without interrupting the operation of the lagoon [17]. This makes Bio-Domes simple to operate and maintain. The only mechanical components that require regular maintenance are the easily accessible blower that sits on the side of the lagoon and the air hoses that have an 18-month cleaning cycle that can be performed from the shore. Since the Bio-Domes have no moving parts, the reliability of the system depends only on the selected blower. Finally, since the domes are submerged on the bottom of the lagoon and require no operator intervention, adding them to a system does not increase complexity and does not require additional operator training. The simple and efficient design of the Bio-Domes results in a system that requires minimum oversight and maintenance, freeing up operators to spend their time on other projects.

Figure 13: Bio-Domes being installed in a lagoon with a crane [17]

5.2.6.1 Notable Installations

1) Calgary International Airport

Challenge: WCS made first contact with representatives of the Calgary Airport Authority (YYC) in January of 2011. The airport was looking for a solution for the glycol de-icing runoff that makes its way into their storm water storage ponds. If the concentrations get too high, YYC can experience odor problems, and if they have to send their water to the city for treatment, they can incur substantial surcharges. Having never tested the Bio-Domes in such an application, WCS was eager to work with YYC to run a pilot test on the ability of the Bio-Domes to breakdown the ethylene glycol.

Solution: After lots of planning, a Mobile Pilot unit was delivered to YYC on October 17, 2012.

Elevated glycol levels were detected in May of 2013, at which point the influent to the pilot unit had a glycol and BOD concentration of 112 mg/L and 107 mg/L respectively. The effluent concentrations were below the detection limits of 10 mg/L and 2 mg/L respectively. WCS then worked with YYC to run a series of batch reactions where the pilot unit was spiked with ever increasing concentrations of Glycol. The last test, begun May 30, showed a complete biological breakdown of the ethylene glycol from 3400 mg/L to 16 mg/L in 14 days. During this same period the BOD levels rose and the glycol was broken down but showed signs of beginning to diminish during the last sample taken before the pilot unit had to be shut down. Subsequent batch runs were performed at the WCS facility in Lehi, UT. Results are shown below.

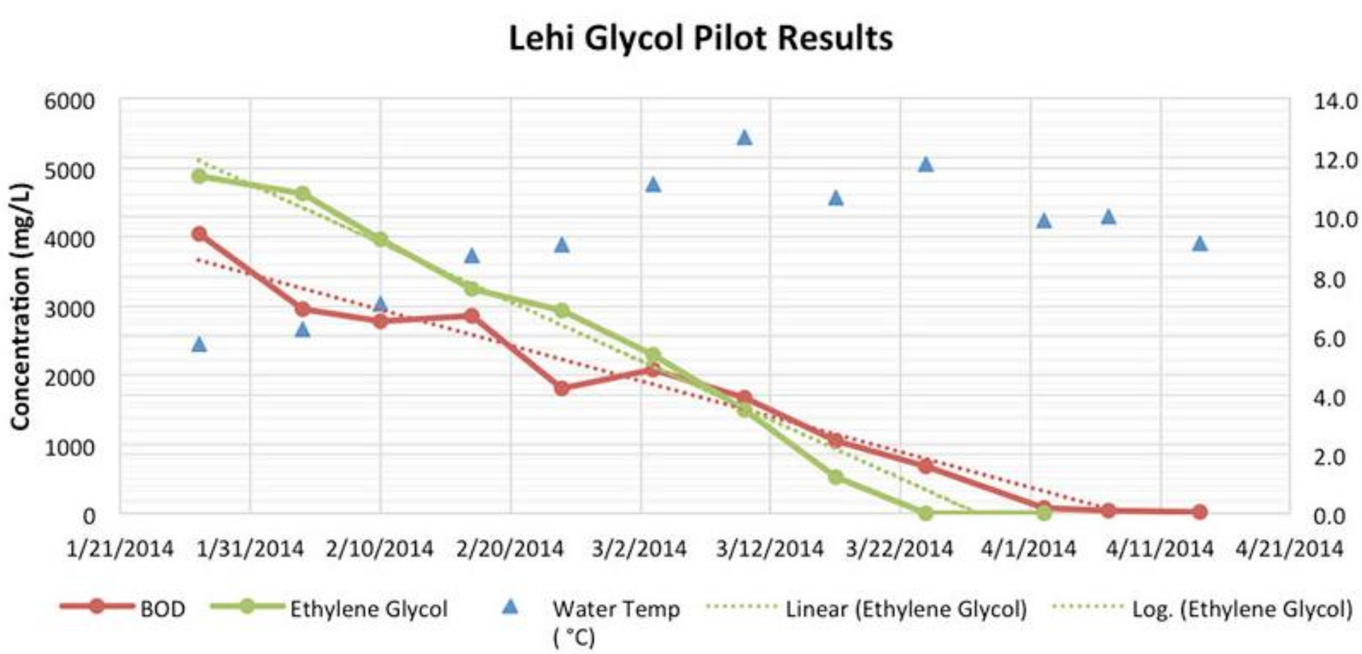


Figure 14: Results from glycol test at the WCS facility in Lehi, UT [17]

2) Coaldale, Alberta

Challenge: In August of 2012, WCS was contacted for more information on the Bio-Domes as a potential solution for their wastewater lagoons. The Coaldale lagoons currently have diffused aeration in place but it is at the end of its useful life and needs to be replaced. Additionally, Coaldale is anticipating the need for additional treatment capabilities to provide year round nitrification as that has become a bigger issue at the Federal level within Canada. In an effort to proactively address their anticipated needs, Coaldale commissioned a 12 month pilot study on site to determine the effectiveness of the Bio-Domes as a possible solution for their system.

Solution: WCS delivered the pilot unit to Coaldale on June, 19 2013 during the wettest week of the year. The pilot unit ran continuously at a one-day retention time for the next 12 months, with weekly sampling, to provide Coaldale and WCS a robust data set regarding the ability of the Bio-Domes to address BOD, TSS and Ammonia.

Note that over the past 6 years Bio-Domes have been used to treat wastewater at over 30 sites across North America [17]. In 2014, the domes underwent a 12 month study at the request of the Ministry of the Environment at a wastewater treatment facility in Brighton, Ontario, about 100 km west of Kingston. The test has since successfully finished and the municipality must vote on whether to implement the technology at full scale. For more information on previous installations please see their website or contact the company directly.

5.2.7 Treatment Performance

Upon speaking with a representative at WCS, they indicated that each standard 4-dome Bio-Dome would remove about 5.5 pounds (2.54 kg) of BOD per day, 2.16 pounds (0.98 kg) of TSS per day, and 0.3 pounds (0.15 kg) of ammonia per day. The ammonia removal is dependent on temperature, but even down to 0.5°C effluent water temp, their units will still remove ammonia at around 0.1 pound (0.045 kg) per day. The graphs shown in the following figures are results from tests conducted at previous client's facilities.

5.2.7.1 Ammonia and Total Nitrogen

5.2.7.1.1 Nitrification and Denitrification Results

Bacteria that exists naturally in most bodies of water is capable of achieving some degree of nitrification and denitrification. Unfortunately, suspended growth bacteria is not effective enough for wastewater treatment in the face of the ever increasing regulations imposed on treatment facilities. Large mechanical plants are able to achieve effective nitrification and denitrification in expensive processes such as MBBR's. Until recently, smaller treatment facilities that rely on lagoons haven't had an effective alternative for improving the nitrification and denitrification in their ponds. Hence, Bio-Domes were specifically designed for small wastewater treatment facilities. The bio-film that grows in the Bio-Domes creates a robust colony of bacteria capable of achieving treatment levels that are comparable to some mechanical systems [17]. Data shown in Figure 15 was generated in cooperation with a local wastewater treatment plant in Lehi, Utah.

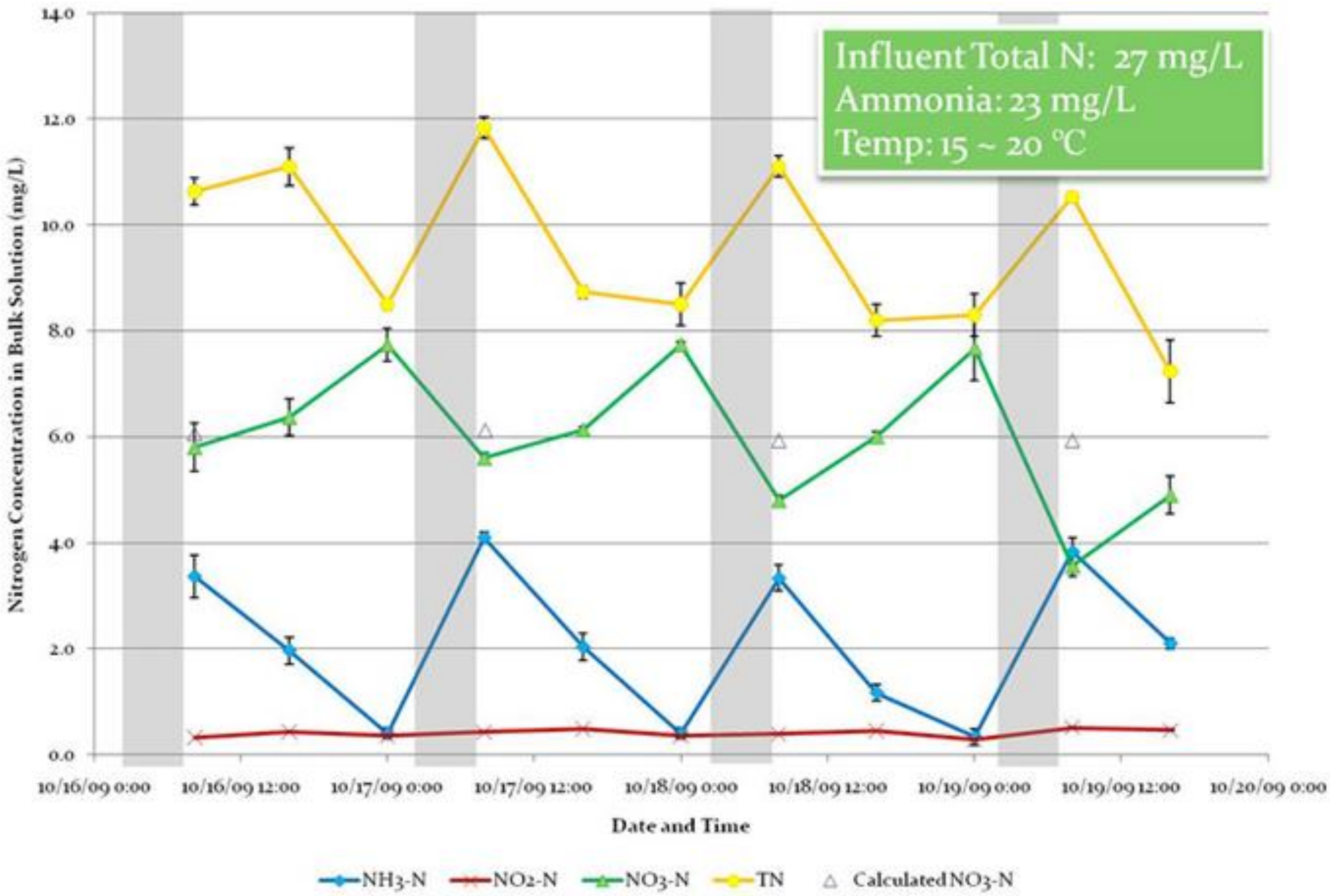


Figure 15: Nitrification and denitrification results [17]

The grey rectangles in Figure 15 indicate where the air was turned off to create an anoxic zone. As you can see, while the air is on, the ammonia is consumed and turned into nitrate. As soon as the air is cycled off, the nitrate is turned into nitrogen gas and the concentration decreases. This exhibits that Bio-Domes are capable of performing effective nitrification and denitrification.

5.2.7.1.2 Cold Weather Nitrification

The data in Figure 16 was obtained from a previous Bio-Dome customer. Bio-Domes were placed in a secondary pond adjacent to the primary lagoon. Water was pumped from the lagoon into the pond and allowed to flow back into the lagoon. Since denitrification was not a concern, the air was left on continuously. Samples were taken weekly to prove the nitrification efficacy of the Bio-Domes.

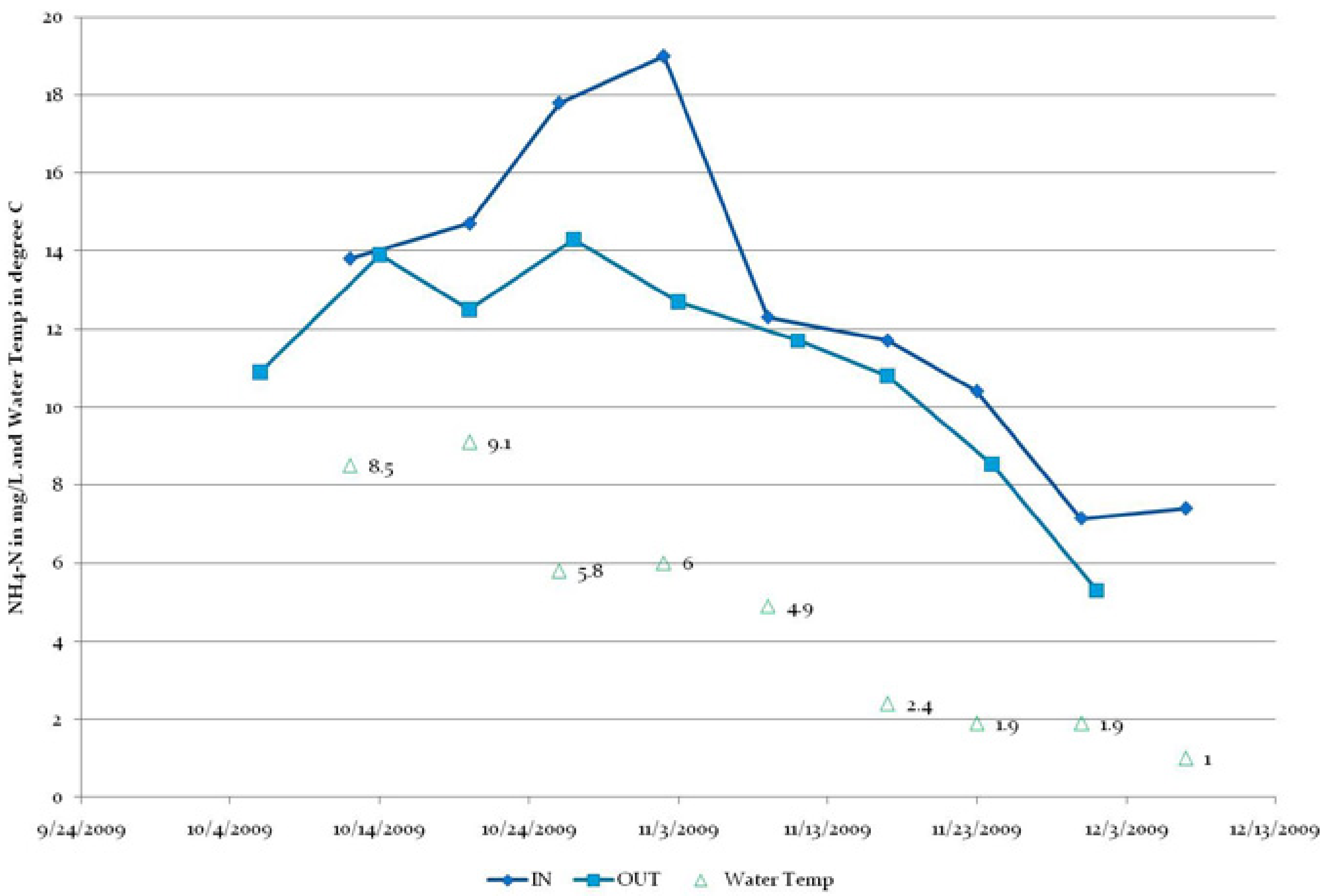


Figure 16: Cold weather nitrification results [17]

Also shown on the graph is the water temperature, as you can see, even when the water temperature drops to around 2°C, nitrification is still occurring.

5.2.7.2 BOD Reduction

BOD levels are one of the primary control parameters of every wastewater treatment facility in Ontario. In addition to the need for BOD reduction for the sake of meeting regulatory limits, BOD must also be below 40 mg / L before effective and significant nitrification removal can begin.

The data in Figure 17 was calculated using COD measurements, but since the Bio-Domes were the only addition to the lagoon, it was considered a good indicator of the effectiveness of the Bio-Domes in reducing BOD concentrations. The test was using the Bio-Domes for BOD removal in a small section of pond #2 that was sanctioned off using a hanging curtain.

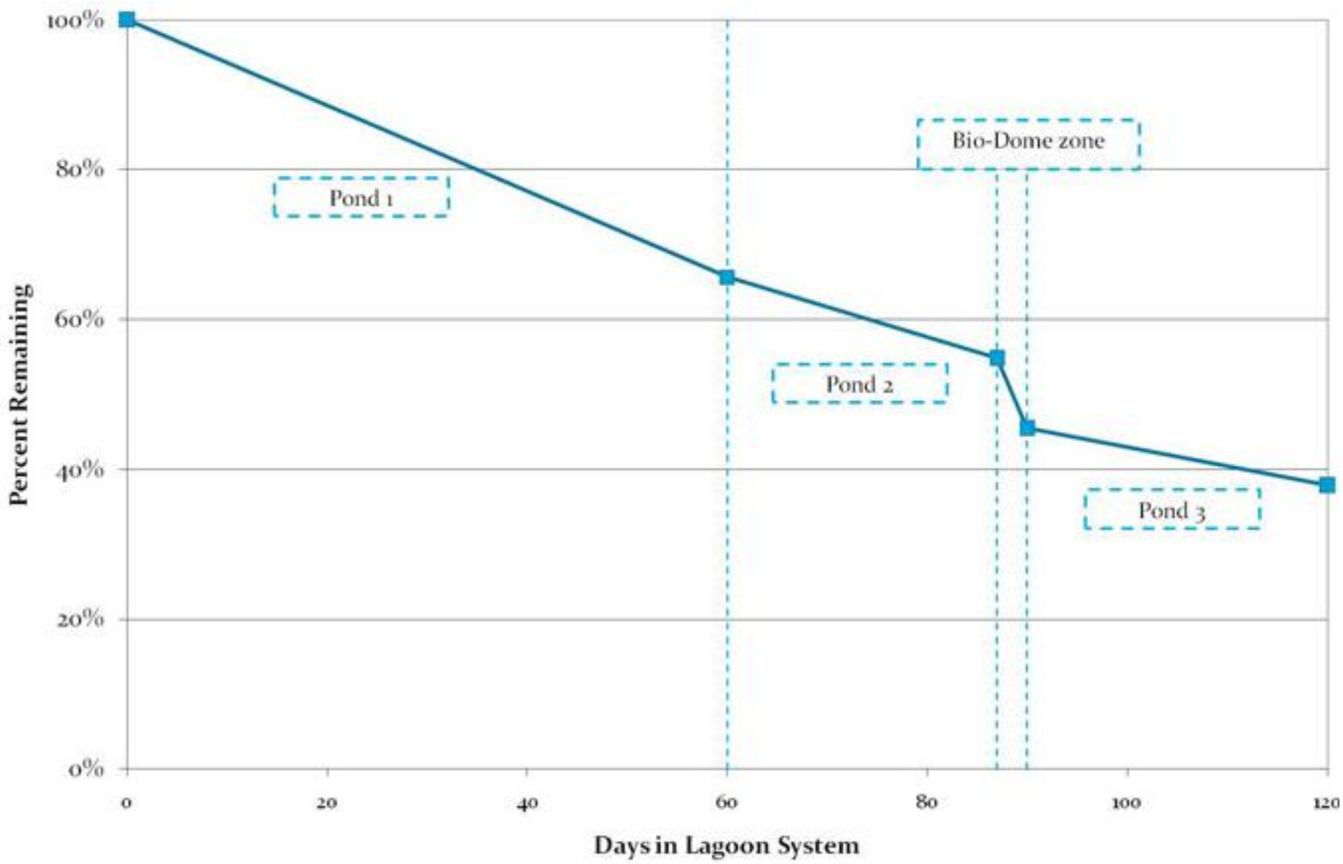


Figure 17: Results from BOD reduction test [17]

Note the steep decline in BOD when the wastewater passes through the section of pond #2 with the Bio-Domes present. Originally, the facility utilized a six-cell lagoon system to treat their wastewater. Since the installation of the Bio-Domes, the facility has stopped using three of the cells and is able to remain in compliance.

The next graph is comprised of data from an on-site study for a Bio-Dome customer. Again a number of domes were installed in a secondary pond adjacent to the primary lagoon. Water was pumped into the secondary pond and allowed to flow back into the primary lagoon. Samples were taken weekly to prove the BOD removal efficacy of the technology and the information gathered was used to create the full-scale design. The study resulted in a full-scale installation.

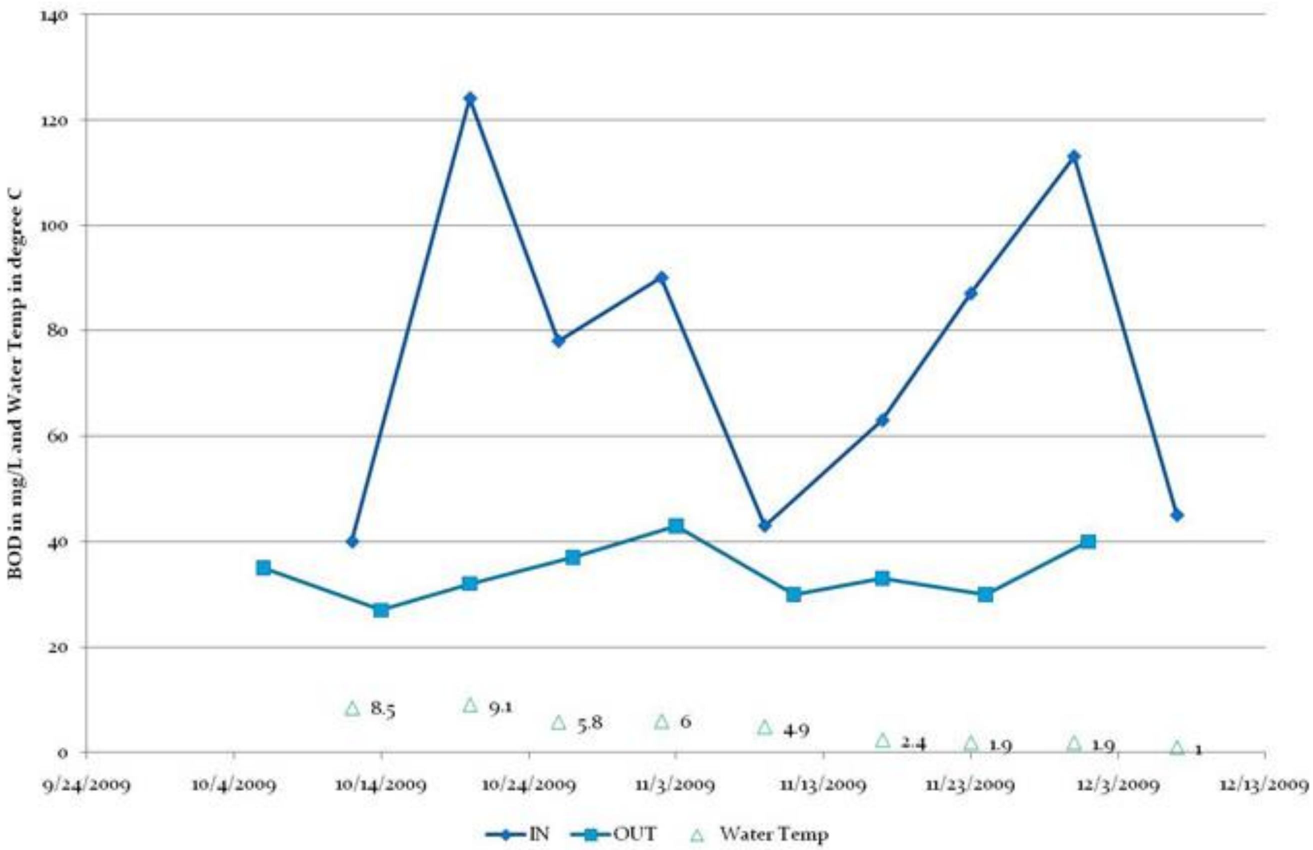


Figure 18: Graph of BOD and water temperature over an extended time period [17]

As you can clearly see, not only did the Bio-Domes significantly reduce BOD concentration but they also held the effluent BOD relatively constant.

5.2.7.3 TSS Reduction

TSS removal rates are hard to predict because of the diversity of compounds and materials that are all measured together as TSS. When TSS levels are comprised of mostly algae or other organic compounds, Bio-Domes are exceptionally effective at consuming them and lowering the overall levels of TSS in the system.

During the same test for BOD removal, the small section of pond #2 was also examined for TSS removal. Figure 19 contains the results from the test.

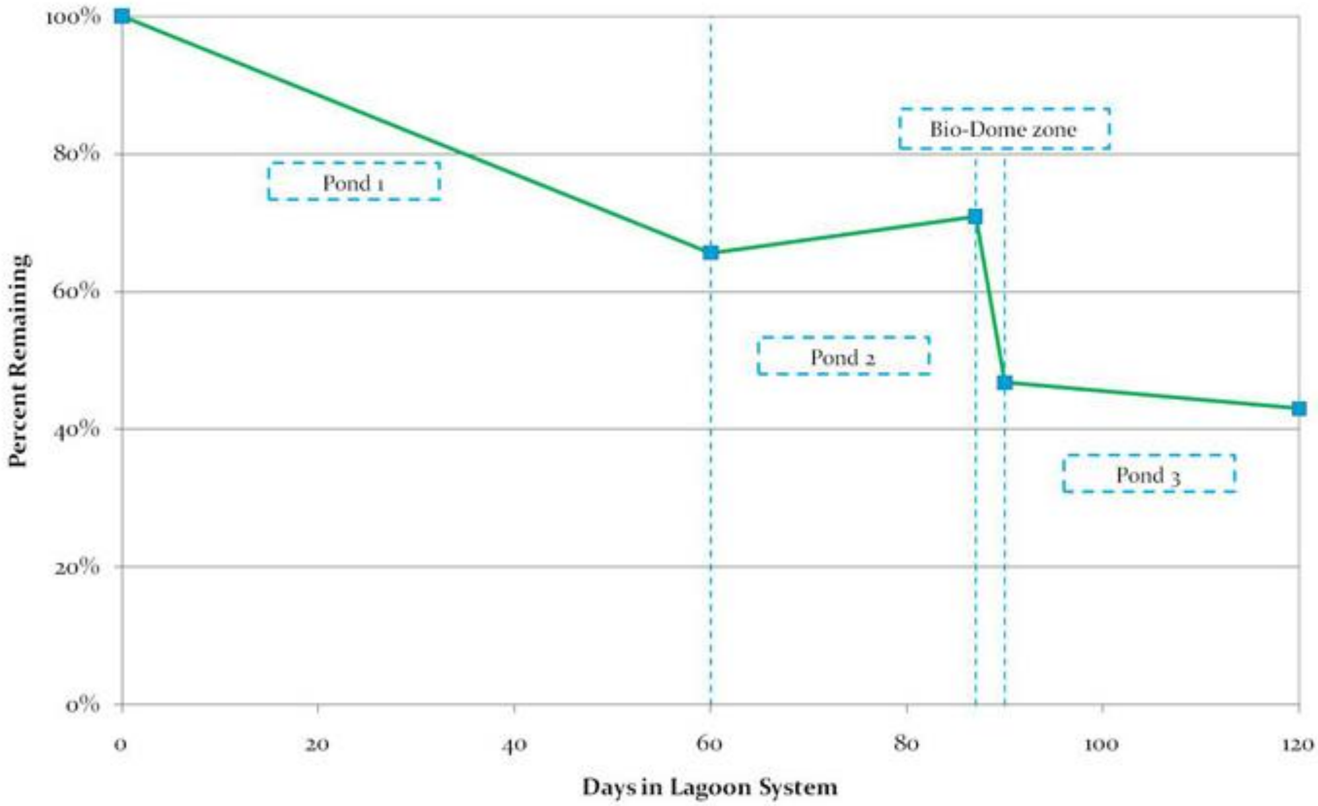


Figure 19: TSS removal as a function of the number of days spent in the lagoon system [17]

Even though the installation was originally designed for BOD removal, the TSS removal rates were equally as impressive. Recall, the facility utilized a six-cell lagoon system to treat their water. Since the installation of the Bio-Domes, the facility has stopped using three of the cells and is able to remain in compliance.

5.2.8 Economics

Below is supplied information from WCS for the Bio-Dome system. Note that these are estimates based on previous jobs with similar flow and loading comparison, and not a specific evaluation.

Table 10 contains an economic summary for the Bio-Dome system. All values are in Canadian dollars converted using the current exchange rate on March 14, 2016 of $1.00 USD = $1.30 CAD (quotes were provided in USD). Take note that these estimates do not include the installation cost. This is why Cases 2 and 3 show similar capital expenses. Presumably the installation cost for Case 3 would be lower than that of Case 2.

The information they were provided was for an average daily flow rate of 24,000 m^3/day and 2,045 m^3/day for a large and small plant respectively. A worst case scenario was provided showing an effluent BOD of about 7.2 mg/L (estimated from CBOD) and a BOD limit of 10 mg/L; a TSS effluent of 17.5 mg/L with a TSS limit of 10 mg/L, and an ammonia effluent of 13.48 mg/L with an ammonia effluent limit of 3 mg/L.

Their loading calculations indicated that 160, 4- dome units would be required to achieve these limits for the small plant flow, or about 1900 units for the large flow. At 1900 units, it was recommended to use Bio-Shells instead of Bio-Domes, which is a product they offer that is slightly larger [18]. If using Bio-Shells the number required would decrease from 1900 to 700 units. WCS indicated that the 2,045 m^3/day flow is a very reasonable, manageable flow rate that is typical of many of their installations. The 24,000 m^3/day flow rate was atypical from what they usually deal with. In order to cope with any flow surges or storms, the company said they generally include some contingency domes to mitigate the effect of surges. The number of extra domes is calculated after more detailed engineering has been done.

Each 4-dome Bio-Dome costs about $3,500 USD, and each Bio-Shell costs about $9,000 USD. An installed cost factor of 5 was used. Each Bio-Dome requires 1 cubic ft of air per minute (1 scfm) and 0.1 horse power, and about 6 pounds per square inch of pressure, based on a similar operation, inlet water quality, and flow rate.

As you can see, the Bio-Domes run on very low power, low air volume, and low air pressure. As such, it was suggested that two 15 hp blowers would provide the required air to the 160 Bio-Domes.

WCS was also able to provide operation and maintenance costs for one of their installations. The values were as follows: flow rate 0.25 MGD, 334 lbs BOD removed per day, 7.5 horse power blower, 90 Bio-Domes. Their monthly power bill was $400 USD, which makes the cost per lb BOD removed about $0.04 USD/lb BOD. Also, once the 90 units were installed and bubbling, one of their large cells was no longer required so it almost doubled the capacity of their plant.

A general estimate for utility costs was obtained using the fact that each Bio-Dome/Shell consumes approximately 75W [17]. It was assumed that the cost for electricity was ¢11.6/kWh [14], and the plant operates 365 days/year.

Table 10: Economic summary for the Bio-Dome system.

	Case 1 (Bio-Domes)	Case 2 (Bio-Domes)	Case 3 (Bio-Shells)
Flow rate (m^3/day)	2045	24000	24000
Units Required	160	1900	700
Cost / Unit ($CAD)	$4,550	$4,550	$12,000
Power / Unit (kWh/d)	1.8	1.8	1.8
Capital Costs ($CAD)	$3,650,000	$43,225,000	$42,000,000
Power Costs ($CAD/year)	$12,000	$145,000	$54,000

5.2.9 Environmental, Safety and Legal Aspects

There are currently no environmental or legal compliance issues with Bio-Domes. Over the last six years, WCS has successfully implemented Bio-Domes at more than 30 sites across North America. Bio-Domes are not made from any materials that pose a threat to being released into the environment in the effluent stream, and thus are ready for full-scale implementation immediately.

The greenhouse gases emitted from electrical use were determined for each case in Table 11. Note that a conversion factor of 75 g CO_2 / kWh was used for the calculations understanding that this value can range anywhere from 25-128 g CO_2 / kWh. Any change in this value would affect the environmental results shown above [16].

Table 11: Greenhouse gases emitted from electrical use

	Case 1 (Bio-Domes)	Case 2 (Bio-Domes)	Case 3 (Bio-Shells)
Flow rate (m^3/day)	2045	24000	24000
Units Required	160	1900	700
Power / Unit (kWh/d)	1.8	1.8	1.8
Emissions (tons CO_2/year)	8	90	35

Figure 20: Bio-Domes arriving on a trailer

Nelson Environmental Inc.

Submerged Attached Growth Reactor (SAGR)

5.3 Submerged Attached Growth Reactor

5.3.1 Vendor Description

Formed in 1997 Nelson Environmental is a company that has been focused in the area of water and wastewater treatment with a particular focus on lagoon based systems. The goal of the company is to provide cost-effective solutions for these systems while maintaining customer satisfaction. Development of cold temperature technologies is a specialty of the company allowing their technologies to be used in a wide variety of climate conditions. Nelson Environmental not only develops new technologies but they also manufacture equipment to provide optimization and restoration of infrastructure. Having completed more than 200 treatment projects Nelson Environmental provides experience to those looking for water treatment methods [19].

5.3.2 Introduction

A reliable system meant for the cold, SAGR uses a clean rock bed and aeration to promote nitrification. Nitrifying bacteria growth is promoted on the surface of the rock bed to assist in the elimination of ammonia. SAGR is as an addition to lagoon systems attaching onto the secondary lagoon to provide additional treatment. The system acts as a polishing process to lagoon based systems to reduce the ammonia levels, BOD and TSS. While SAGR's main focus is to treat the aforementioned constituents it can be fitted with an additional system to also treat phosphorus levels allowing it to meet to consumer's needs. Existing SAGR systems can handle flows ranging from 20m^3/day to 7300m^3/day making them versatile for all types of lagoon systems with the potential to significantly increase capacity. The SAGR system also has a reasonable cost for the amount of potential capacity that can be gained from using the system. The low complexity and operational costs make this system ideal for augmenting lagoons [20].

Figure 21: Completed SAGR bed topped with mulch [21]

5.3.3 Process Description

SAGR is a horizontal flow system with a gravel or rock bed consisting of one or more horizontal chambers. The bacteria uses the gravel bed as a attach point in order to grow. The gravel bed is also used to stabilize the temperature within the bed during periods of cold water. SAGR also contains multiple injection points of effluent to distribute the effluent throughout the rock media. These multiple distribution points allow for the population of nitrifying bacteria to be present within the system [22]. The feed system also produces more nitrifying bacteria than is present in a single input system [22]. The chambers are used to distribute the water throughout the system to optimize the hydraulic efficiency. A linear aeration system along the bottom of the SAGR bed provides aeration into the unit needed for the nitrification process.

There is also an increase in the heterotrophic bacteria in the first zone of the reactor due to higher CBOD at this point. This results in less ammonia treatment at the beginning of the system due to the heterotrophic bacteria competing with the nitrifying bacteria. However the nitrifying bacteria migrates to end of the system, which increases ammonia treatment at the back end of the process [22]. This is another reason for the multiple injection points as it establishes multiple colonies of nitrifying bacterial throughout the system. This ensures that the full amount of ammonia removal can occur even in cold temperatures when the process is slowed.

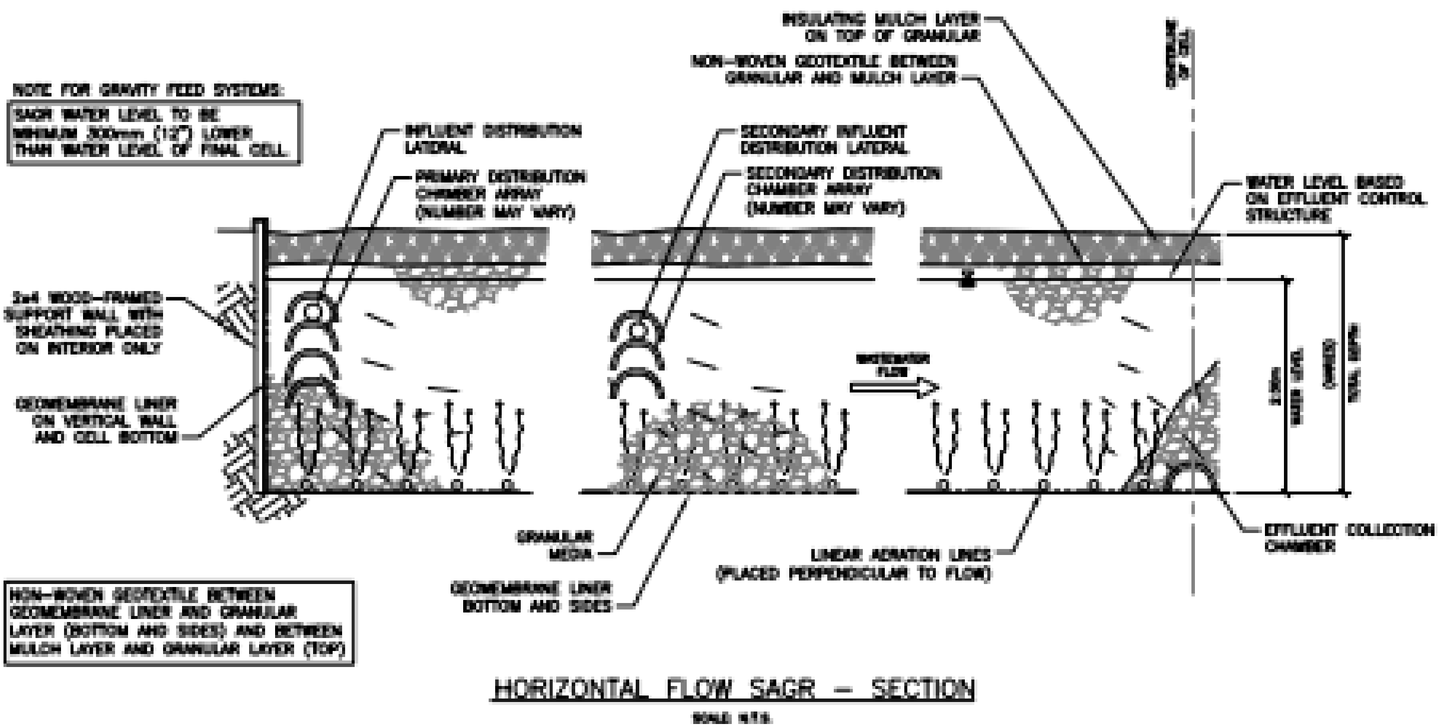


Figure 22: General schematic of the SAGR system [20]

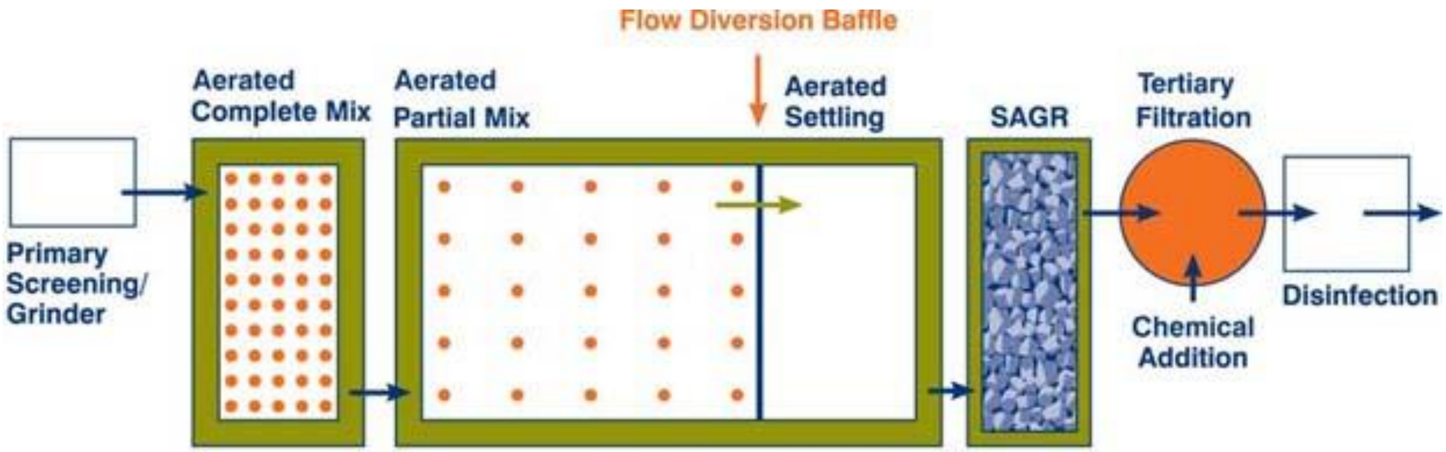


Figure 23: Example of how the SAGR system can be incorporated into an existing facility [20]

5.3.4 Additional Information

It should be noted that the SAGR system can use wood chips as an insulator for the system. This assists the process in maintaining warm water temperatures in winter months.

SAGR was revolutionary as it operates in very low, close to freezing temperatures. The reason for this is because of the discovery that ammonia levels increasing in winter months are not solely related to temperature decrease but that the bacteria may be migrating or establishing within different zones of a vessel [22]. This is why the nitrifying bacteria migrates to the end of the process in the winter months when there is higher CBOD levels entering the system allowing SAGR to still function.

There are two separate zones that are established within the reactor due to the two different types of bacteria. A BOD removal zone and a nitrifying zone [22].

A typical SAGR system is approximately 40-75ft long and 4-12ft deep. The system also has a typical retention time of 4-6 days [22].

5.3.5 Operability and Maintenance

The operability of the SAGR system is very simple. The system operates very similarly to a diffused aerated lagoon system. Operators of aerated lagoon systems should find the operations of this system easy to learn. The only moving parts to the system are the blowers for the system making maintenance and operations simple [23]. SAGR does not have any solids return so monitoring and adjusting of that system is not an issue. Sludge management and disposal for the system is also not an issue as the process. The sludge has already been treated by the preceding lagoon treatment. Operators will only spend on average 30 minutes per day doing systems checks, visual inspection and maintenance [23]. Since this system can operate in cold water temperatures of 0.5ºC it still has good continuous functionality without the need for additional heating systems.

There are a few challenges that are detrimental to the system. While the system is very good at removing nitrogen, phosphorus, which is also a nutrient that often needs to be removed, is not treated by the system. While there are systems that can be implemented with SAGR to treat this, it is an additional cost to the system. The system is also prone to issues due to power outages. If the blowers go offline there can be spikes of nitrogen and BOD_5 due to non-aerated conditions. While the system can recover it is important to note that if back up blowers are not installed (additional capital) during malfunction or maintenance there can be significant decrease in water quality [20]. The system may also run into issues with sizing. The system does have to be a particular size in order to retain heat during cold temperatures. If the system is not large enough it may require heating, which can add significant operating costs [20]. The size of the system can also pose a problem if there is limited footprint. The system can be large and if space around the lagoon system is restricted issues may arise when trying to implement the system.

5.3.5.1 Notable Installations

1) Glencoe, ON; Online since 2011

Challenge: The lagoons which had been running since 1974 in the Southwest Middlesex's WWTP had reached their maximum capacity. They required a solution that would provide additional capacity for future growth. Turning the lagoon system into a continuous operation while still meeting effluent regulations was an issue.

Solution: SAGR was implemented as an addition to increase the capacity. The capacity of the plant was almost doubled from 946m^3 to 1742m^3 per day based on a 30 year design life. The SAGR system with a FBA Linear aeration system was used to reduce the ammonia. The system was also fitted with disk filters with chemical addition to remove phosphorus.

Results: The upgraded system is able to consistently keep ammonia level below 3mg/L in the winter even at temperatures around 0.5°C. The BOD_5 and TSS are reduced below 10mg/L. In addition to the increased capacity the system also approximately reduced the footprint of the facility, which allows for future expansion.

Figure 24: Example of the blowers required to operate the SAGR system [24]

2) Shellbrook, SK; Online since 2011

Challenge: The small town of Shellbrook of 1300 residence in Northern Saskatchewan was looking to improve their aging lagoon system. The system needed to meet standards set up by the Canadian Council of Ministers of the Environment.

Solution: SAGR was implemented after the lagoon system along with 2 parallel sand filters. The process reduced the TAN from 24mg/L to 0.01 mg/L within two weeks of operation. The sand filters placed after the SAGR system incorporated alum addition to remove phosphorus for high quality water [25].

3) Dawson Creek, BC; Online since 2011

Challenge: Dawson Creek's potable water source was being put under pressure through the use of it in the oil industry. The need existed to create a reclaimed wastewater treatment facility so that the oil industry would be able to access that water supply instead of the potable water. The challenge was to meet a flow of 4000m^3/day while meeting water quality regulations

Solution: The SAGR system was chosen due to its simplicity with low operating and maintenance costs. The system was also equipped with disk filters at the end of the process to reduce TSS and turbidity levels. This system was used to meet the required BC municipal sewer regulations for reclaimed water.

Results: The system not only provided the 4000m^3/day required, but it did so well within the footprint of the existing facility. There is enough room to expand the system to 6000m^3/day. The system also reduced the TSS and BOD_5 well below the required 10mg/L and nitrogen levels were reduced well below 1mg/L within 1 year of operation [26].

4) Mentone, IN, United States; Online since 2011

Challenge: While the town was able to meet the required BOD and TSS requirements they were not able to meet the limits for total ammonia nitrogen. As a small community they lacked finances for major infrastructure changes. The challenge was to upgrade the existing facilities while keeping the cost relatively low.

Solution: The solution to this problem was to implement the SAGR system as an upgrade to the existing lagoons. Due to the minimal part requirements that the SAGR involves and the low operation costs the system was deemed ideal.

Results: The Town of Mentone has benefitted greatly from the installation of the system. The operator spends only approximately 30mins a day on the SAGR system. BOD_5 and TSS are well below the required limits operating at 10mg/L and 15mg/L respectively. They also are reaching a TAN of 5mg/L in the winter, which is 50% lower than the regulation requires. Energy savings of 50% are also estimated to have been saved by the design [27].

For a full list of all projects and project details, please see the Nelson Environmental projects page [28].

5.3.6 Treatment Performance

The main purpose of SAGR is to treat the nitrogen levels within a lagoon based system. SAGR can accomplish nitrification very effectively even in low water temperatures of 0.5°C. BOD and TSS reduction are achieved by typically below 10mg/L but when following short retention time lagoons can consistently achieve below 15mg/L for both. The system operates in a low turbidity environment, which can reduce the turbidity units of the system as well. While the total nitrogen reduction has not been a necessary metric to consider the recording of this metric has been made available for several case studies that use SAGR. While not a specific claim made by the company total nitrogen level for these studies has not breached 3mg/L within these studies and as such has been included as an effectiveness consideration [28] [20]. There are systems that can be easily incorporated/can be provided with SAGR to reduce the total phosphorus. However, phosphorus removal is not a constituent that SAGR alone is designed to handle.

Below are the claims from Nelson Environmental that the SAGR system can reliably produce:

Table 12: SAGR Treatment Effectiveness

Criteria	Concentration
BOD_5	< 15 mg/L
TSS	< 15 mg/L
NH_3-N	< 1mg/L
TN	< 3 mg/L
Turbidity	< 5 NTU

5.3.7 Economics

Below is supplied information from Nelson Environmental for the SAGR system. Note that these estimates are taken from a publically available evaluation done for the Perth, Ontario lagoon system. It was assumed that this system provides a comparable estimate for other lagoon systems. It should be noted that a reduction in the hydraulic loading may decrease the price, but SAGR relies more on the weight per liter of loadings. An installed cost factor of 5 was used.

The OPEX value is not based solely off of the energy requirements of the system. While the energy cost makes up a significant portion of the costing, the rest of the costs come from equipment replacement and maintenance costs.

All values are in Canadian dollars without tax. It should be noted that the values are just inclusive of the cost of building the system and the materials. It does not include the engineering costs associate with the project or additional costs due to unexpected events.

Table 13: Economic summary for the SAGR system [20]

Plant Flow Rate (m^3/d)	7055
Capital Cost ($)	$12,215,000
Energy (kWh/d)	996
Total OPEX ($/year)	$58,845

5.3.8 Environmental, Safety and Legal Aspects

There are currently no environmental or legal issues with the SAGR system. The technology has been implemented and tested all over North America. The system has officially been implemented in Ontario indicating that it has passed Ontario regulation requirements. Since the technology is added as a retrofit to current lagoon systems as a back end addition it does not interfere with the current treatment processes. The process has consistently been shown to improve systems to be within the regulations of their region and thus has significant scientific and testing backing. Should this system be chosen as a method of water treatment acquiring the proper approval to implement it is not considered a significant schedule risk.

The greenhouse gases emitted from electrical use was determined for the evaluated plant. Using a conversion factor 75 gCO_2/kWh, approximately 28.4 tons CO_2/year is emitted. The above conversion value was used based on the current situation in Ontario. It is understood that this value can range anywhere from 25-128 gCO_2/kWh. Any change would affect the environmental results shown above [16].

Environmental & Legal Considerations

6.0 Environmental and Legal Considerations

6.1 Environmental Concerns

The main environmental concern with preliminary treatment is the handling of the solid garbage that is deposited on the bar screens. Objects like toilet paper are biodegradable; however, other garbage such as old rags must be dealt with. This usually means addressing hygiene concerns and paying a disposal fee and sending the garbage to a landfill.

In primary treatment, it is the sludge that has the biggest environmental impact. The sludge that settles in the sedimentation basins is usually combed very slowly from the bottom of the basin to a thickening unit. In the thickening unit, water is pressed out of the sludge. From this point the sludge is processed in large tanks called digesters. These digesters are one method of stabilizing the sludge to remove pathogens, eliminate odours and prevent future putrefaction [3]. Digesters generally produce methane, which is a potent greenhouse gas. Ideally, this methane can be captured and used for energy.

There are other methods of sludge stabilization including chemical and thermal treatment. In chemical stabilization, the sludge is usually treated with quicklime [3]. This raises the pH of the sludge which then reacts exothermically with water to bring the temperature above 50°C. The high pH along with elevated temperature inactivates microbes and any larvae eggs. Thermal stabilization through incineration is the other alternative but it is very energy intensive and thus prohibitively expensive. Incineration would be difficult to get MOECC approval. [3].

6.1.1 Ontario Environmental Innovation Branch (EIB)

The Environmental Innovations Branch (under Ministry of Environment and Climate Change) advances and promotes new ways to achieve environmental results by searching out new approaches to solving challenging environmental problems [29]. The branch collaborates with environmental industries and promotes a culture of innovation across the ministry through the Ministry Innovation Action Council.

Due to the difficulty in being able to test and demonstrate new technologies, the EIB has established the Southern Ontario Water Consortium (SOWC). SOWC also receives support from Federal Economic Development Agency for Southern Ontario and the provincial Ministry of Research and Innovation [29]. The SOWC has a facility in London, Ontario that is created within the Greenway Wastewater Treatment Plant for real-world, full-scale flows. Meanwhile, a facility in Guelph, Ontario focuses on bench scale and pilot tests.

6.2 Legal Considerations

There are a number of legal issues that need to be addressed for the operation of a municipal wastewater plant to exist. However, many of these regulations are related to the protocols once the plant has been created in terms of maintenance rather than structural legal requirements.

In Ontario, each wastewater treatment plant must have Environmental Compliance Approval (ECA) from the Ministry of Environment in order to be able to build infrastructure as well as to operate. They also need an ECA, or an amendment to an existing ECA, if they are choosing to upgrade their facility. Below is a chart of the sampling, concentration, and loading requirements typically included as a term or condition in an ECA:

Table 14: ECA wastewater effluent limits

Parameter	Monthly Average Concentration see (1)	Monthly Average Loading	Sampling
Total Phosphorus	0.25 mg/L	4.9 kg/d	Weekly, composite
Ammonia - May-Sept - Oct, Nov, Apr - Dec-March	3.0 mg/L (Non-Toxic) 5.0 mg/L (Non-Toxic) 7.0 mg/L (Non-Toxic)	8.4 kg/d (Non-Toxic) 14.0 kg/d (Non-Toxic) 19.6 kg/d (Non-Toxic)	Weekly, composite
$CBOD_5$	25.0 mg/L	70.0 kg/d	Weekly, composite
TSS	25.0 mg/L	70.0 kg/d	Weekly, composite
E. coli(1)	200 counts/100 mL	-	Weekly, grab sample
(1) Monthly Geometric Mean Density			

Wastewater System Effluent Regulations (WSER) benefits Canadians and the environment because it requires continued intergovernmental partnership, and investments by all levels of government, to make its successful implementation a reality. The law applies in respect to a wastewater system that deposits a deleterious substance prescribed in the WSER to surface water via the final discharge point and that is designed to collect, or actually collects, an average daily volume of influent of 100 m^3 or more in a year.

The WSER has set out important quality standards:

- Carbonaceous biochemical oxygen-demanding (CBOD) matter not exceeding 25 mg/L (average);
- Suspended solids (SS) not exceeding 25 mg/L (average);
- Total residual chlorine (TRC) not exceeding 0.02 mg/L (average);
- Un-ionized ammonia (NH_3) less than 1.25 mg/L (maximum) expressed as nitrogen (N), at 15^0C +/- 1^0C;
- Effluent that is not acutely lethal.

The owner/operator of a continuous wastewater system must monitor the equipment using a continuous measure with a +/- 15% margin of error for the above standards each day to ensure the average is met.

The following are the Canadian Council of Ministers of the Environment (CCME) issues and Ontario's responses [30]:

1) Facilities determine risk levels of not meeting national performance standards (i.e. low, medium, high) and timeline to compliance

Ontario's Response: Facilities not meeting Wastewater Systems Effluent Regulations (WSER) may apply to Canada for authorization to deposit effluent if they do not anticipate in meeting it, and must show risk level.

2) Ensuring jurisdictions will incorporate requirements into their respective regulatory frameworks

Ontario's Response: Require the normal level of treatment shall be secondary or equivalent. Regarding total residual chlorine from the effluent disinfection process, effluent limits to control residual chlorine may be set where warranted based on site-specific receiving water assessments. In regards to acute toxicity, when warranted by site-specific receiving water assessments, environmental compliance approvals contain appropriate effluent limits and monitoring

Finally, the Ontario government is looking to increase speed of implementation for technologies through such methods as priority review for new innovative technology for normal application reviews for plants. They are also endorsing increased operational flexibility, by giving plants a greater ability to make changes without approvals. This is referred to as Limited Operational Flexibility (LOF) [31].

Risk Analysis and Mitigation

7.0 Risk Analysis and Mitigation

The risks associated with this project stem from the use of a weighted evaluation matrix to make decisions regarding the technologies. While weighted evaluation matrices are an effective tool to compare a number of potential options, they can introduce bias when assigning values to each of the options.

To mitigate this risk, a word ladder was created, which explicitly details what is required to obtain a given score in a certain category. The intent of a word ladder is that if any future work is sequential to this study, each option will be scored in exactly the same way as previously completed. In reality this is difficult because some evaluation metrics do not have strict numbers associated with them, such as compatibility and complexity. Therefore, more judgement is required when assigning a score compared to evaluating something such as the capacity increase, which is scored based on the value of the increase.

To limit the effect of this risk on the final outcome, under criteria like compatibility, very detailed verbal descriptions have been included in the word ladder for levels 0 – 5. This will ensure maximum continuity with regard to scoring. Finally, a detailed definition of the criteria was also included in the word ladder to eliminate any guessing with respect to the meaning of any of the criteria.

Another risk comes from determining the criteria and their multiplier. The ten criteria that each option was scored against were developed based on the project definition and constraints. When selecting the criteria, the risk always exists that an important criterion is omitted. This may impact the final conclusions that were made. To reduce this risk, the client was consulted, as well as other wastewater industry experts to ensure that the most important criteria were selected to critically evaluate each option. A similar method was employed when the multipliers were selected. First, the ten criteria were ranked from most to least important based on the project scope. Next, criteria were given a multiplier from one for the least important to ten for the most important.

For example, since increasing the capacity of an existing plant was the primary driver for the project, it was listed as the most important evaluation metric and received a score multiplier of 10. On the other hand, the team determined that, while still important to consider, the technology footprint was not as important to the project as increasing capacity; thus, it received a multiplier of 2.0.

Funding Opportunities

8.0 Funding Opportunities

Please note the following is summarized from the Water Tap Ontario website. For more information please visit the webpage [32].

8.1 Federal Programs

8.1.1 Sustainable Development Technology Canada Technology Fund

Type of Firms Funded: Technology development and demonstration companies

Funds Available: $590 million

Basis for Fund: Provided a financial gap for the weak links in the innovation chain that provides the development and demonstration of innovative technological solutions.

Specific investments in the wastewater treatment industry include:

i. 3XR
Location: Ontario
Type of technology: Membrane
Description of Technology: Strips nitrogen in the form of ammonia from wastewater and combines it with sulfuric acid to form ammonium sulfate fertilizer [33].

8.1.2 Business Development Bank of Canada

Type of Firms Funded: Product Commercialization and Market Development

Funds Available: $1 billion

Basis for Fund: Provides financial packages for clean technologies including – operating line of credit guarantee, flexible payment schedules of up to 20 years and targeted venture capital investment [34].

8.1.3 Federation of Canadian Municipalities (FCM) Green Municipal Fund (GMF)

Type of Firms Funded: Municipalities [35]

Funds Available: Loans up to maximum $10 million and grants up to a maximum of $1 million

Basis for Fund: Federal endowment targeting water technology projects that elicit the environmental benefit of watershed conservation and storm water management.

Specific investments in the wastewater treatment industry include:

i. Kitchener Wastewater Treatment Plant
Location: Waterloo, ON
Technology: Regional water hubs
Description of Technology: Used to improve the management of biosolids created during the water treatment process, reduce the flow of pollutants to the Grand River and address performance and capacity concerns.

ii. Rural Area Wastewater Treatment Study
Location: Ottawa, ON
Technology: Regional water hubs
Description of Technology: Created de-centralized systems that serve clusters of properties were being considered to serve rural areas.

8.1.4 Federal Economic Development Initiative for Northern Ontario (FEDNOR)

Types of Firms Funded: Northern communities [36]

Funds Available: Up to 33% of eligible capital costs and up to 50% of non-capital costs.

Basis for Fund: Supporting Northern Ontario's economy by encouraging communities and businesses to become more productive and competitive through the adoption, adaptation and commercialization of new technologies.

8.2 Provincial (Ontario) Programs

8.2.1 Ministry of Infrastructure Places to Grow Infrastructure Fund

Types of Firms Funded: Municipalities [37]

Funds Available: $2,000-$100,000

Basis for Fund: For organizations in the implementation, advancement or evaluation of growth planning within Ontario.

Recommendations

9.0 Recommendations

There are a wide range of potential bottlenecks in wastewater treatment that need to be considered when building, designing, or augmenting a facility. Aging infrastructure and population growth is an issue in many small municipalities. Once a wastewater facility reaches capacity, the municipality must search for alternatives to increase its plant capacity otherwise further economic growth and development is hindered.

Since there are many different bottlenecks in wastewater treatment, it is recommended to first use the Composite Correction Program (CCP) to critically assess the plant and determine if infrastructure changes are necessary. If the report suggests an infrastructure change is required, consider using one of the technologies in this report to augment the facility and realize extra capacity.

If the current system is a conventional plant that has an issue with settling times in clarification, then implementing the BioMag system can decrease settling times and increase capacity without requiring additional tankage or large capital expenditures. If the plant is on a larger scale and capital expense is not a primary concern, consider augmenting with a membrane bioreactor (MBR) such as the LEAP MBR made by GE. MBRs are commonly used in both municipal and industrial wastewater treatment with plant sizes up to 80,000 population equivalent [38].

If the plant in question is located in a small municipality, it is most likely operating a lagoon system, and thus requires different technologies to increase capacity. If a lagoon system is at capacity and struggling to maintain compliance, Bio-Domes are an easy, drop-in solution to provide increased aeration, stimulate biological activity and increase capacity at a reasonable price. Another option for small municipalities would be to augment with the SAGR system. This system employs dense granular media filtration and aeration to promote contaminant removal in cold weather. Both Bio-Domes and the SAGR system have already been employed at a number of small municipalities making them an appealing option to increase capacity at small plants.

Finally, if the CCP suggests an infrastructure change is not required to realize excess capacity, consider increasing operator training or revising standard operating procedures to ensure maximum efficiency of each unit operation. In some instances, a piece of technology may not be running at full capacity and it may go unnoticed if proper training has not been given. Before spending money on upgrades, always ensure that the current plant is optimized to deliver the highest possible performance.

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References

[1] United States Environmental Protection Agency, Optimizing Water Treatment Plant Performance Using the Composite Correction Program, Washington, 1998.

[2] "Coarse Screen for Wastewater Treatment," Passavant-Geiger, [Online]. Available: http://www.directindustry.com/prod/passavant-geiger/product-21060-1229597.html. [Accessed 11 November 2015].

[3] E. Metcalf, Wastewater Engineering Treatment and Recource Recovery, New York: McGraw Hill, 2013.

[4] "Specification for Sewage Screens," [Online]. Available: https://law.resource.org/pub/in/bis/S03/is.6280.1971.html. [Accessed 11 11 2015].

[5] W. &. Curran, "Waste Equalization," IHS Engineering360, [Online]. Available: http://www.globalspec.com/reference/44194/203279/waste-equalization. [Accessed 11 11 2015].

[6] T. Stephenson and R. Stuetz, Principles of Water and Wastewater Treatment Processes, New York: IWA Publishings, 2009.

[7] B. G., Wastewater Microbiology, New York: John Wiley and Sons, 1999.

[8] M. Henze, P. Harremoes, J. la Cour Jansen and E. Arvin, Wastewater Treatment: Biological and Chemical Processes, Berlin: Springer-Verlag, 2002.

[9] "Water Treatment Process," [Online]. Available: http://watertreatmentprocess.net/waste-water-treatment-process/waste-water-treatment-process/.

[10] Evoqua Water Technologies, "The BioMag System for Enhanced Secondary Treatment," 2014. [Online]. Available: http://www.evoqua.com. [Accessed 18 March 2016].

[11] Siemens Industry Inc., "Water Technologies: BioMag and CoMag Systems," 2012. [Online]. Available: file:///Users/apple/Downloads/Siemens.pdf. [Accessed 18 March 2016].

[12] Evoqua Water Technologies, "BioMag/CoMag Frequently Asked Questions," 2014. [Online]. Available: http://www.evoqua.com/en/brands/Envirex/productinformationlibrary/BC-BIOCOMAG-FAQ.pdf. [Accessed 18 March 2016].

[13] Evoqua Water Technologies, "BioMag System Smithsburg MD," 2015. [Online]. Available: http://www.evoqua.com/en/brands/Envirex/productinformationlibrary/BC-Smithburg-CS.pdf. [Accessed 18 March 2016].

[14] Ontario Energy Board, "Electricity Prices for Consumers: Tiered Pricing," 2 November 2015. [Online]. Available: http://www.ontarioenergyboard.ca/oeb/Consumers/Electricity/Electricity%20Prices. [Accessed 18 March 2016].

[15] LKAB Minerals, "Magnetite MSDS," 2015. [Online]. Available: http://www.lkabminerals.com/Documents/Product%20SDS/Magnetite%20SDS,%2012-01INT,13-09.pdf. [Accessed 18 March 2016].

[16] Gridwatch, "Carbon Emissions," 18 March 2016. [Online]. Available: http://live.gridwatch.ca/home-page.html. [Accessed 18 March 2016].

[17] K. Johnson and L. Reaveley, "Bio-Domes," Wastewater Compliance Systems Inc., [Online]. Available: http://wastewater-compliance-systems.com/. [Accessed 2016].

[18] K. Johnson and L. Reaveley, "Bio-Shells," Wastewater Compliance Systems, 2016. [Online]. Available: http://wastewater-compliance-systems.com/bio-shells.

[19] Nelson Environmental Inc., "About Us," Nelson Environmental Inc., 2016. [Online]. Available: http://www.nelsonenvironmental.com/about.asp. [Accessed 20 March 2016].

[20] Nelson Environmental Inc., "Town of Perth Environmental Services Documents," June 2014. [Online]. Available: https://perth.civicweb.net/filepro/documents/11122. [Accessed 24 March 2016].

[21] Nelson Environmental Inc., "Municipality of Southwest Middlesex WWTP Upgrade," Nelson Environmental Inc., [Online]. Available: http://www.nelsonenvironmental.com/casestudies/glencoe.asp. [Accessed 24 March 2016].

[22] M. Krocker, M. Hildebrand and B. Heppner, "Submerged Attatched Growth Reactor". United States Patent US2011/0174731AL, 19 January 2011.

[23] Nelson Environmental Inc, "SAGR data summary," Nelson Environmental Inc, 2015.

[24] Nelson Environmental Inc., "Post Lagoon Nitrification of First Nation Community," Nelson Environmental Inc., June 2012. [Online]. Available: http://www.nelsonenvironmental.com/long-plain-fn.asp. [Accessed 24 March 2016].

[25] Nelson Environmental Inc., "Post Lagoon Nitrification," Nelson Environmental Inc., May 2012. [Online]. Available: http://www.nelsonenvironmental.com/casestudies/Shellbrook.asp. [Accessed 24 March 2016].

[26] Nelson Environmental Inc., "Water Reclaimation and Reuse," Nelson Environmental, November 2011. [Online]. Available: http://www.nelsonenvironmental.com/casestudies/dawson-creek,-bc.asp. [Accessed 24 March 2016].

[27] Nelson Environmental Inc., "Town of Mentone WWTP Upgrade," Nelson Environmental Inc., March 2011. [Online]. Available: http://www.nelsonenvironmental.com/casestudies/mentone.asp. [Accessed 24 March 2016].

[28] Nelson Environmental Inc., "Projects," Nelson Environmental Inc., 2016. [Online]. Available: http://www.nelsonenvironmental.com/projects.asp. [Accessed 24 March 2016].

[29] T. Rulseh, "An Ontario Consortium Will Help Test And Prove New Treatment Technologies," *Treatment Plant Operation (TPO),* 2015.

[30] Canadian Council of Ministers of the Environement, "Canada-Wide Strategy for the Management of Municipal Wastewater Effluent," 2014.

[31] Ministry of the Environment and Climate Change (MOECC), "Building a better framework for Environmental Approvals in Ontario," 2015.

[32] "Water Technology Acceleration Program (WaterTAP)," [Online]. Available: http://www.watertapontario.com/. [Accessed 2016].

[33] "Sustainable Development Technology Canada," [Online]. Available: https://www.sdtc.ca/en. [Accessed 2016].

[34] "Business Development Bank," [Online]. Available: https://www.bdc.ca/en/pages/home.aspx. [Accessed 2016].

[35] "Federation of Canadian Municipalities," [Online]. Available: http://www.fcm.ca/. [Accessed 2016].

[36] "FedNor," Government of Canada, [Online]. Available: http://fednor.gc.ca/eic/site/fednor-fednor.nsf/eng/fn03444.html. [Accessed 2016].

[37] "Places to Grow Implementation Fund," Ontario Ministry of Municipal Affairs and Housing, [Online]. Available: https://www.placestogrow.ca/index.php?option=com_content&task=view&id=290&Itemid=96. [Accessed 2016].

[38] S. Judd, The MBR Book: Principles and Applications of Membrane Bioreactors in Water and Wastewater Treatment, Elsevier, 2006.

[39] "Biocord," Bishop Water Technologies, [Online]. Available: http://www.bishopwater.ca/node/43.

[40] "Anoxkaldnes LagoonGuard MBBR," Veolia, [Online]. Available: http://technomaps.veoliawatertechnologies.com/lagoonguard/en/?bu=doc.

[41] "Baffled Bioreactor," Frontier Environmental Technology, [Online]. Available: http://www.frontieret.com/reactors/baffled-bioreactor-bbr-for-pemanent-installations.

[42] Blue Water Technologies, "Centra-flo BluePro," 2014. [Online]. Available: https://www.bluewater-technologies.com/products/bluepro.html. [Accessed 5 MarcH 2016].

[43] Environmental Operating Solutions Inc., "MicroC Premium Carbon Sources," 2015. [Online]. Available: http://www.microc.com/products/. [Accessed 5 March 2016].

[44] Boydel WasteWater Treatment Technologies, "The WaterMiner," 2015. [Online]. Available: http://boydel.ca/boydel_waste_waters/. [Accessed 5 March 2016].

[45] Hydro Quip, "Inclined Plate Clarifiers," 2016. [Online]. Available: http://www.hydroquipinc.com/products/clarifiers.php. [Accessed 5 March 2016].

[46] Evoqua, "Hydro-Clear Sand Filters," 2016. [Online]. Available: http://www.evoqua.com/en/brands/Davco/Pages/hydro-clear.aspx. [Accessed 5 March 2016].

[47] "Jet BAT Process," Western Pump, [Online]. Available: http://www.westernpump.ca/en/wastewater_treatment_systems.html. [Accessed 02 2016].

[48] Koch Membrane Systems Inc., "Puron Plus MBR Systems," Koch Inc., 2016. [Online]. Available: http://www.kochmembrane.com/Systems-Service/Standard/PURON-MBR.aspx. [Accessed March 2016].

[49] QUA Group, "EnviQ Submerged Ultrafiltration Membrane," QUA group, 2016. [Online]. Available: http://quagroup.com/about-enviq/. [Accessed February 2016].

[50] Aqua-Aerobic Systems Inc., "Aqua-Aerobic MBR," Aqua Aerobic Inc,, 2016. [Online]. Available: http://www.aqua-aerobic.com/index.cfm/products-systems/membranes/aqua-aerobic-mbr/. [Accessed February 2016].

[51] GE Coorperation , "LEAP MBR," General Electric, 2015. [Online]. Available: http://www.gewater.com/products/leap-mbr.html. [Accessed February 2016].

[52] Aqwise Inc., "AGAR MBBR," Aqwise, 2013. [Online]. Available: http://www.aqwise.com/technologies/mbbr/. [Accessed February 2016].

[53] "Membrane Bioreactor," Xylem, [Online]. Available: http://www.xylem.com/treatment/us/products/membrane-bioreactor-mbr#item2. [Accessed 03 2016].

[54] "Titan MBR Wastewater Treatment System," Smith and Loveless Inc., [Online]. Available: http://www.smithandloveless.com/Products.aspx?CategoryUid=29&ProductUid=118. [Accessed 02 2016].

[55] *International Journal of Environmental Research,* vol. 7, pp. 963-972, 2013.

[56] *Water Science and Technology,* vol. 49, pp. 39-46, 2004.

[57] *Environmental Engineering Science,* vol. 28, pp. 639-699, 2011.

[58] *Water Engineering and Management,* vol. 138, pp. 28-29, 1991.

[59] *Environmental Pollution,* vol. 165, pp. 215-224, 2012.

[60] *Renewable and Sustainable Energy Reviews,* vol. 50, pp. 346-362, 2015.

[61] *China Water and Wastewater,* vol. 29, pp. 39-42, 2013.

[62] *Desalination and Water Treatment,* vol. 52, pp. 2388-2399, 2014.

[63] *Bioresource Technology,* vol. 102, pp. 10327-10333, 2011.

[64] *Water Quality Research Journal of Canada,* vol. 49, pp. 72-81, 2013.

[65] *Environmental Technology,* vol. 35, pp. 313-321, 2014.

[66] *Water Science and Technology,* vol. 69, pp. 177-184, 2014.

[67] A. K.-J. Hadi Falahti-Marvast, "Performance of simultaneous organic and nutrient removal in a pilot scale anaerobic–anoxic–oxic membrane bioreactor system treating municipal wastewater with a high nutrient mass ratio," International Biodeterioration & Biodegradation, [Online]. Available: http://www.sciencedirect.com/science/article/pii/S096483051530041X.

[68] C. a. C. P. Gan, "Evaluation of Passive Treatment Technologies for Septic Lagoon Capacity Expansion," World Environmental and Water Resources Congress, [Online]. Available: http://ascelibrary.org/doi/abs/10.1061/9780784479162.236.

[69] N. Chowdhury, "A Novel Liquid-Solid Circulating Fluidized-Bed Bioreactor for Biological Nutrient Removal from Municipal Wastewater," Chemical Engineering and Technology, [Online]. Available: http://onlinelibrary.wiley.com/doi/10.1002/ceat.200800564/abstract.

[70] Ingning Hongcai Electroplating Wastewater, "Internal Combustion Waste Water Treatment Device". China Patent CN102060343 A, 18 May 2011.

[71] Smith and Loveless Inc., "Aqua-4 Water Treatment System," 2015. [Online]. Available: http://www.smithandloveless.com/Products.aspx?CategoryUid=112&ProductUid=211 . [Accessed 8 March 2016].

[72] Smith and Loveless Inc., "Aqua-Fer Water Treatment System," 2015. [Online]. Available: http://www.smithandloveless.com/Products.aspx?CategoryUid=112&ProductUid=211 . [Accessed 8 March 2016].

[73] Franklin Miller, "Spiralift S," 2015. [Online]. Available: https://www.franklinmiller.com/product/spiralift-s/. [Accessed 8 March 2016].

[74] "SubTriq Membrane Bioreactor," Triqua, [Online]. Available: http://www.triqua.eu/site/subtriq-mbr.

[75] "Biobed Advanced EGSB," Veolia, [Online]. Available: http://technomaps.veoliawatertechnologies.com/biobed_advanced/Biobed-Advanced-en/.

[76] "UOP Xceed Bioreactor," Honeywell, [Online]. Available: http://www.uop.com/products/adsorbents/industrial-wastewater/.

[77] "Raptor 4002 Series Mixer," Philidelphia Mixing Solutions, [Online]. Available: http://www.philamixers.com/industries/water-wastewater/industrial/.

[78] Aquatech international Corp., "Aqua EMBR," February 2013. [Online]. Available: http://vertassets.blob.core.windows.net/download/348eba22/348eba22-42d0-4f3c-b1dd-1b72bb954fb1/aqua-embr.pdf. [Accessed February 2016].

[79] Honeywell International Inc., "industrial Wastewater," 2016. [Online]. Available: http://www.uop.com/products/adsorbents/industrial-wastewater/. [Accessed 25 February 2016].

[80] G. Omar, "Hybrid Depth filtration," *Influents,* vol. 10, pp. 22-24, 2015.

[81] "Diff-Jet Gas Injectors," Fortrans, [Online]. Available: http://fortransaeration.com/aerators/ .

[82] "Zeo-Clear Package Treatment Plant," Ecologix Environmental Systems, [Online]. Available: http://www.ecologixsystems.com/system-zeo-clear.php. [Accessed 02 2016].

[83] [Online]. Available: http://www.aqua-aerobic.com/index.cfm/products-systems/filtration/aquadisk/.

[84] P. W. C. I. A. M. V. P. W. C. I. JATIN SINGH, "Decentralized Tertiary Wastewater Treatment Plant with a Sub-Surface Disposal System for a New Residential Development in the Town of Mono," *Influents,* 2015.

[85] "Guangzhou Xintao Wastewater Treat Company". Patent CN 204034340 U, 2014.

[86] "Internat Wastewater Heat Recovery Systems". Patent CA 2809727, 2014.

Appendix A

A1 – Summary of Viable Technologies

Name: BioCord

Vendor: Bishop Water Technologies

Description / Abstract: BioCord is a substrate manufactured specifically for wastewater treatment using biofilm technology. Biofilm is a natural aggregation of a complex community of microorganisms growing on a solid substrate. This substrate allows symbiotic layers of different bacteria to develop, mirroring the process that occurs in nature. BioCord can be used to treat polluted water in oceans, rivers, lakes, as well as from municipal and industrial sources.

When used in municipal wastewater treatment, BioCord adds a fixed Biomass to the existing lagoon to increase biological treatment and provide cold weather nitrification, reducing ammonia effluent levels to meet the new wastewater systems effluent regulations. It is possible to realize up to an additional 30% increase in treatment capacity using existing infrastructure, requiring no additional tank volume.

BioCord increases the Mixed Liquor Suspended Solids (MLSS) concentration and the Sludge Retention Time (SRT) by increasing the biomass in the system.

Figure 25: Solid material collected by the BioCord substrate contained in a tank

Source: http://www.bishopwater.ca/node/43 [39]

Name: AnoxKaldnes LagoonGuard

Vendor: Veolia

Description / Abstract: Aerated lagoons are used extensively around the world for treatment of both municipal and industrial wastewaters. In North America, thousands of larger lagoons treat municipal wastewater. These systems can efficiently remove COD and BOD, but nitrification is not readily accomplished during the cold season. As municipalities with aerated lagoons are increasingly required to limit the release of ammonium to receiving waters, they are facing the hard choice of whether to build an expensive new process or to somehow upgrade the lagoon in order to obtain cold weather nitrification.

The AnoxKaldnes LagoonGuard biofilm process is a well-designed moving bed biofilm reactor (MBBR), typically after the lagoon, which can be customized to meet BOD and ammonia requirements. The upgrade is easy and economical, compact and, in the spirit of the lagoon itself, the LagoonGuard process upgrade requires a minimum level of operation and maintenance. The LagoonGuard process prolongs the usefulness of existing lagoon systems that find themselves under strict new effluent demands.

Figure 26: LagoonGuard MBBR operating with a lagoon in the background

Source: http://technomaps.veoliawatertechnologies.com/lagoonguard/en/?bu=doc [40]

Name: Baffled Bioreactor (BBR)

Vendor: Frontier Environmental Technology

Description / Abstract: Extensive research has culminated in a simplified pre-anoxic/aerobic reactor capable of advanced treatment. The unique, patented positioning of the baffles and weirs in the intermediate settler acts to automatically recycle sludge from the treatment stream while reducing the load to the final clarifier. This system has demonstrated the ability to provide excellent reduction of biological oxygen demand (BOD), total suspended solids (TSS) and ammonia-nitrogen (NH3-N), with approximately 50% nitrate/nitrite removal.

The ability of the intermediate settler to concentrate solids and immediately return them to the reactor allows for robust operation. The design of the BBR relies on air from the aerobic blowers to drive all the functions of the reactor including anoxic recycle and mixing. Minimal moving parts and electrical consumption results in a superior wastewater treatment reactor that can be operated for a fraction of the cost of conventional designs. This system was Frontier's first full design, and other BBR Technology iterations used the novelty of this system as a benchmark.

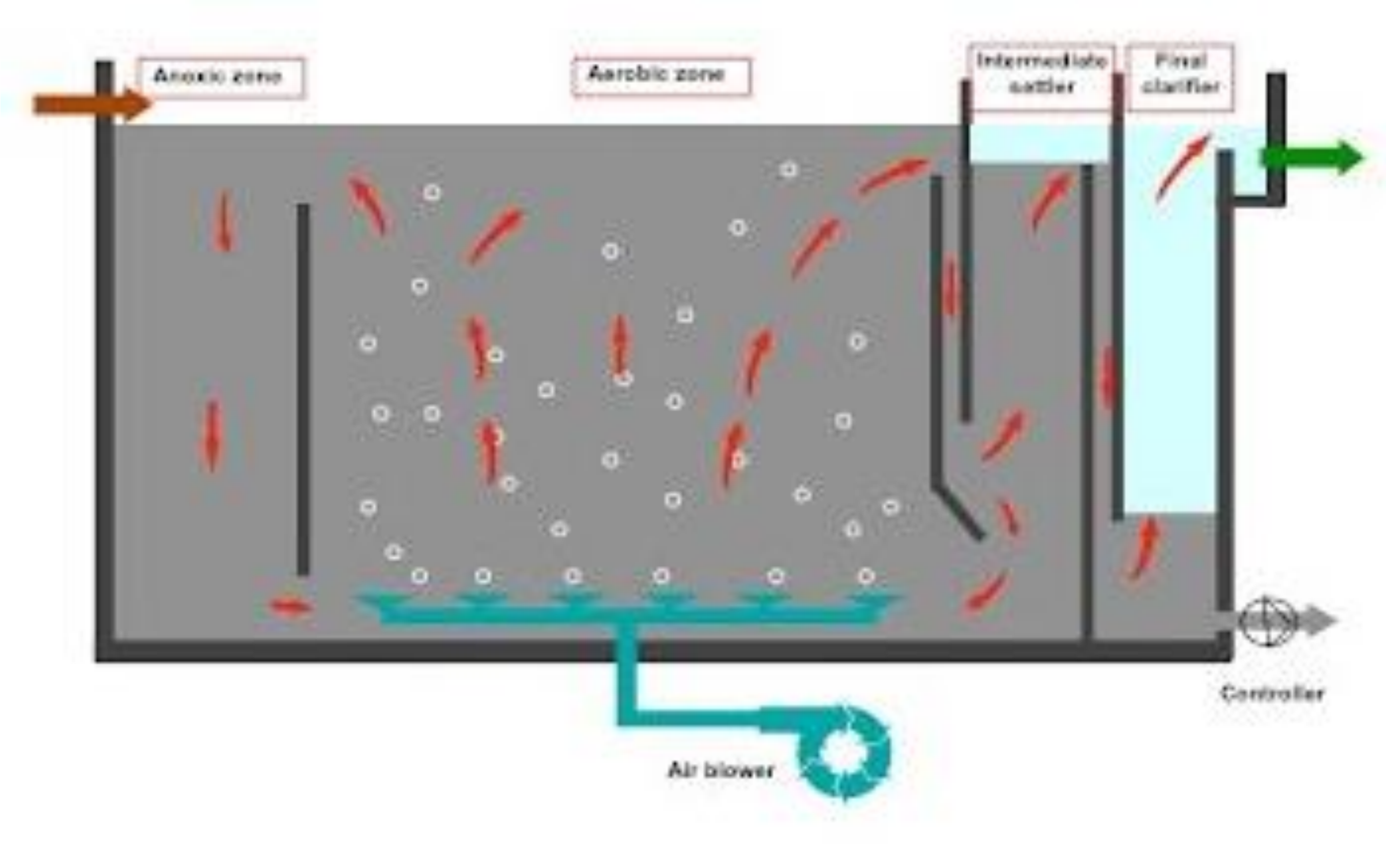


Figure 27: Baffled bioreactor working principle diagram

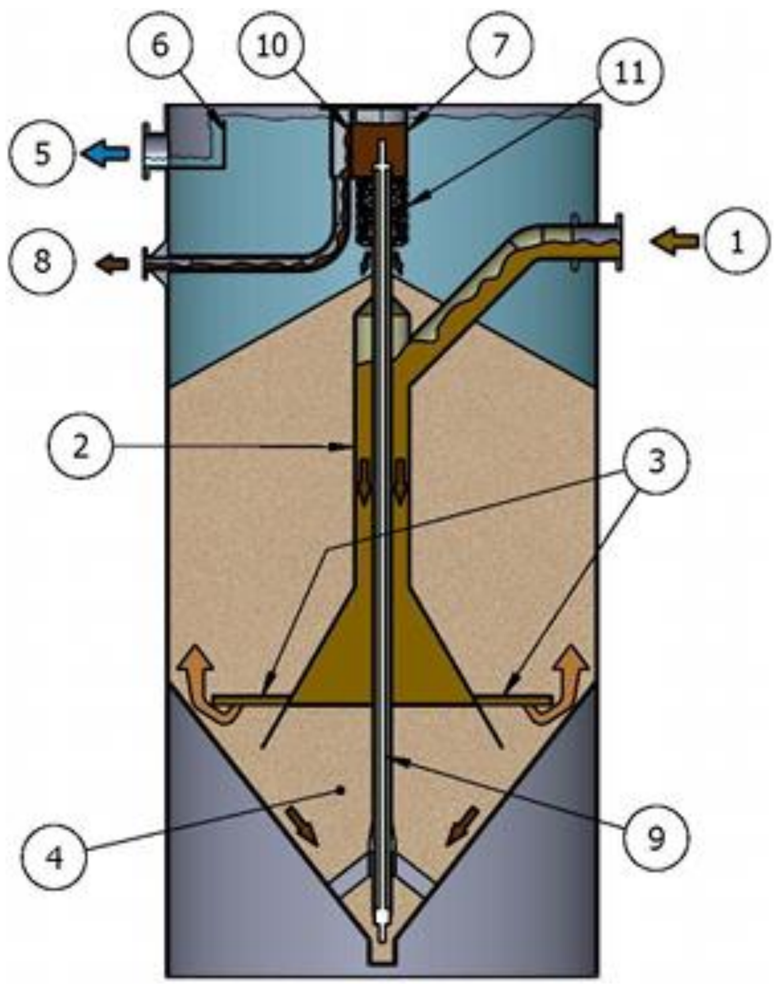
Source: http://www.frontieret.com/reactors/baffled-bioreactor-bbr-for-pemanent-installations [41]

Name: Reactive Sand Filters (Centra-flo, BluePro)

Vendor: Blue Water Technologies

Description / Abstract: Using Blue Water's Centra-flo continuous backwash gravity sand filters, a unique control system, and the patented Blue PRO process for reactive filtration, phosphorus is removed from wastewater streams through an array of processes, but most importantly by the mechanism of adsorption. No other chemical dosing is required in the plant to achieve the lowest phosphorus discharge requirements. Current Blue PRO installations are meeting permit limits as low as 0.05 mg/L with a chemical dose of only 10 mg/L as Fe.

Blue Water's reactive filtration process overcomes a critical obstacle to achieving efficient phosphorus removal in bulk aqueous solutions by providing reactive surface sites within the media bed, resulting in forced contact of chemical species with high adsorptive capacity. The adsorptive surface in Blue PRO filters is a continuously regenerated hydrous ferric oxide (HFO) coating that forms on the surface of the sand media.



1. Influent
2. Feed chamber
3. Radial arms
4. Silica media
5. Filtrate
6. Fixed effluent weir
7. Washbox
8. Reject stream
9. Airlift
10. Adjustable reject weir
11. Tortuous path

Figure 28: BluePro reactive sand filter diagram

Source: https://www.bluewater-technologies.com/products/bluepro.html [42]

Name: Micro C 2000 (as well as 1000, 3000, 4000)

Vendor: Environmental Operating Solutions Inc. (EOSi)

Description / Abstract: MicroC Premium Carbon Sources are proprietary, eco-friendly products used by water and wastewater treatment facilities to help achieve contaminant removal goals. MicroC products are liquid chemicals generally used on a recurring basis to provide an energy source to bacteria in biological treatment systems. MicroC Premium Carbon Sources are also used in Biochemical Oxygen Demand (BOD) Augmentation applications, either during wastewater plant start up or during normal operations to obtain optimum carbon to nitrogen ratios for more effective biological treatment. EOSi offers four lines of MicroC Premium Carbon Sources to meet the needs of customers large and small in a variety of markets and for a variety of applications.

MicroC 2000 is glycerin-based and non-hazardous, and it's the most cost-effective non-hazardous carbon source on the market. MicroC 2000 is widely used in denitrification, Enhanced Biological Phosphorus Removal (EBPR) and BOD addition applications. It is a proprietary green chemical designed specifically for use as a carbon source for biological contaminant removal applications in water/wastewater treatment.

Source: http://www.microc.com/products/ [43]

Name: Electrocoagulation – The WaterMiner

Vendor: Boydel Wastewater Technologies Inc.

Description / Abstract: The WaterMiner electrocoagulation (EC) technology is a process that results in a treatment similar to typical chemical coagulation. It causes dissolved pollutants in wastewater to gather into a thick mass, allowing them to be easily removed without the use of filters. This is also without the use of chemicals.

Water is pumped through the EC cell where it circulates for a few seconds. AC current is converted to DC current, which then passes through the water flowing between the cathode and anode electrodes. A positively charged iron ion is released from the sacrificial anode, attracting negatively charged dissolved colloids, resulting in the destabilization of the pollutants. This causes an agglomeration around the iron ion, and separates the contaminants from the water in a floc formation. These flocs travel out the top of the cell to a double cone clarifier. The flocs are removed from the treated water by clarification, purifying the treated water. The treated water exits via the lower cone of the clarifier. This technology is effective at removing CBOD, BOD, TSS, COD, and some metals.

Figure 29: WaterMiner electrocoagulation unit

Source: http://boydel.ca/boydel_waste_waters/ [44]

Name: Inclined Plate Clarifiers

Vendor: Hydro Quip

Description / Abstract: The Hydro Quip Inclined Plate Clarifiers are designed and manufactured to facilitate the precipitation and separation of suspended solids. The design allows the unit to perform all of the functions of a conventional solids contact clarifier at a fraction of the space and cost.

The inlet compartment receives the raw water from the process. After entering through the non-clog inlet nozzle, the water is dispersed evenly through the chamber.

The raw water passes down under the skirt and moves upward toward the plate pack. As the water moves upward, the suspended particles have their velocity interrupted by the inclined plates. These particles drop and slide down the inclined plate into the sludge hopper. Individual plates are easily installed and removed.

The clarified water exits the top of the plates and flows into the effluent trough. Then the clarified effluent flows by gravity and exits the unit through the effluent nozzle.

Figure 30: Inclined plate clarifier

Source: http://www.hydroquipinc.com/products/clarifiers.php [45]

Name: Hydro-Clear Sand Filters

Vendor: Evoqua

Description / Abstract: The Hydro-Clear pulsed-bed sand filtration system is an excellent solution when gravity filtration is needed. It features a unique underdrain system and a shallow bed of mono-media, fine-grained sand. Filter runs are extended and the filter is automatically kept on-line, despite varying loads, and changing water characteristics. The sand filter acts as an excellent tertiary treatment filter, polishing suspended solids, phosphorus, and lowering turbidity levels.

Initially, wastewater enters the filter cells through proportioning weirs and cascades into the influent distribution/wash water trough and onto the filter sand through v-notched weirs. Splash plates help distribute the water evenly across the sand. Dissolved oxygen is added to the wastewater through this cascading sequence.

As the effluent reaches the filter media surface, all but the very fine particles in the wastewater are retained on the surface of the media. The finer particles enter the interstices and become trapped.

Figure 31: Hydro-Clear sand filtration unit

Source: http://www.evoqua.com/en/brands/Davco/Pages/hydro-clear.aspx [46]

Name: Jet BAT Process

Vendor: Western Pump

Description / Abstract: The Jet BAT residential wastewater treatment plant is a compact, efficient Biologically Accelerated Treatment (BAT) plant that contains 3 compartments. The pretreatment compartment receives the wastewater and partially treats it physically and biologically before it enters the center treatment compartment. This is technically referred to as the "bio-reactor", where mixing and fresh air combine to support the revolutionary BAT process. After treatment the contents flow from the center compartment into the settling compartment, where fine particles settle and return to the treatment compartment, leaving only a clear, odorless, highly treated liquid for discharge.

Figure 32: JET BAT reactor cross sectional view and picture in the field

Source: http://www.westernpump.ca/en/wastewater_treatment_systems.html [47]

Name: PURON Plus MBR

Vendor: Koch Membrane Systems Inc.

Description / Abstract: The PURON Plus MBR is a package skid mounted membrane bioreactor technology. The system can be modified to meet any user's needs. The system can be made from just pre-screening to biological and membrane steps. The designs are pre-engineered to reduce cost and to be simple to use. The membrane uses a unique design for several benefits to the user. The membrane has free floating fibers to reduce the clogging. Fibers are made from reinforced braiding for strength. A Central air scour nozzle provides efficient air delivery and the design is meant to reduce sludging.

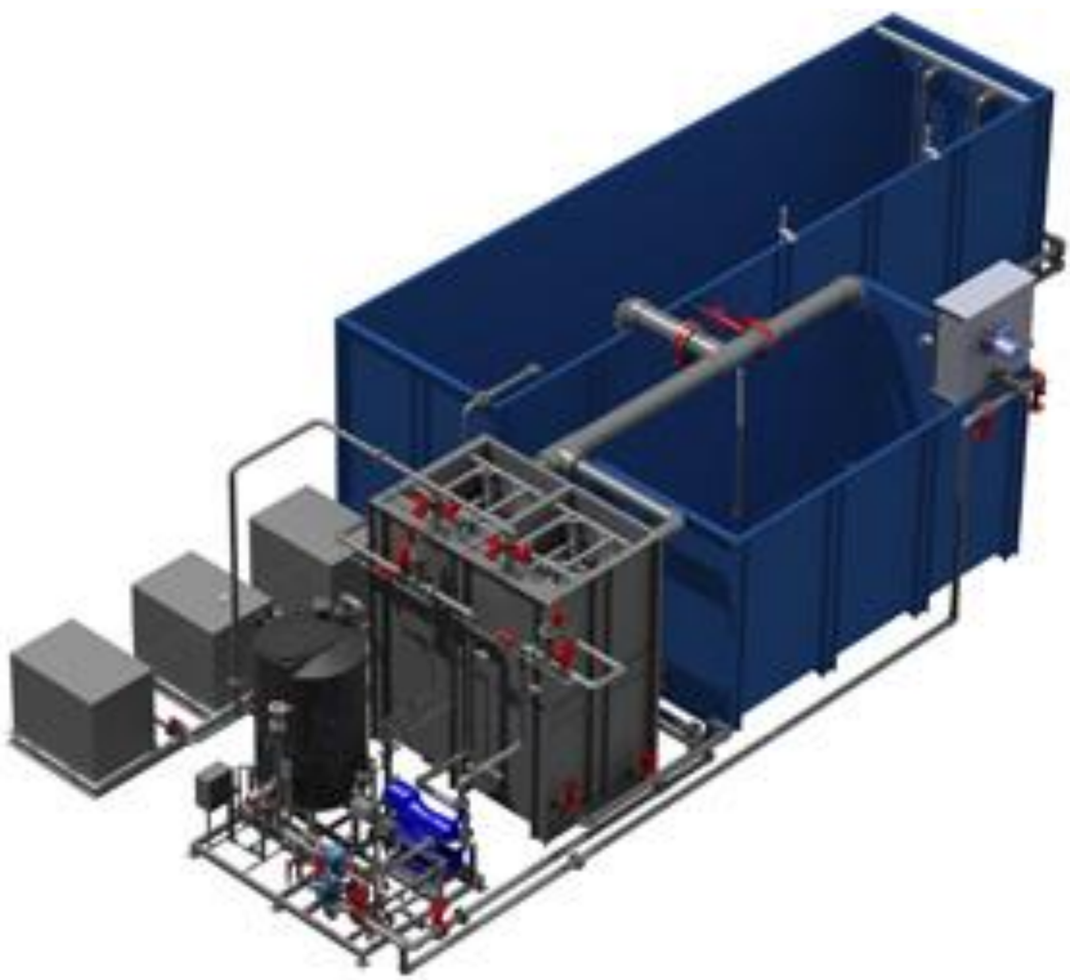


Figure 33: Skid-mounted Puron Plus MBR

Source: http://www.kochmembrane.com/Systems-Service/Standard/PURON-MBR.aspx [48]

Name: EnviQ Submerged Ultrafiltration Membrane

Vendor: QUA Group LLC

Description / Abstract: EnviQ is a flat sheet submerged membrane to be used in MBR facilities. The EnviQ membrane has pores on it that allow the water to pass through but not impurities. The water passes through the filters via suction.

There is also an air diffuser in the system which is used to keep bubble size constant and to deter settling and sticking of solids. The design is meant to lower installation costs when compared to conventional systems. The combination of this filter within an MBR is meant to significantly improve effluent quality.

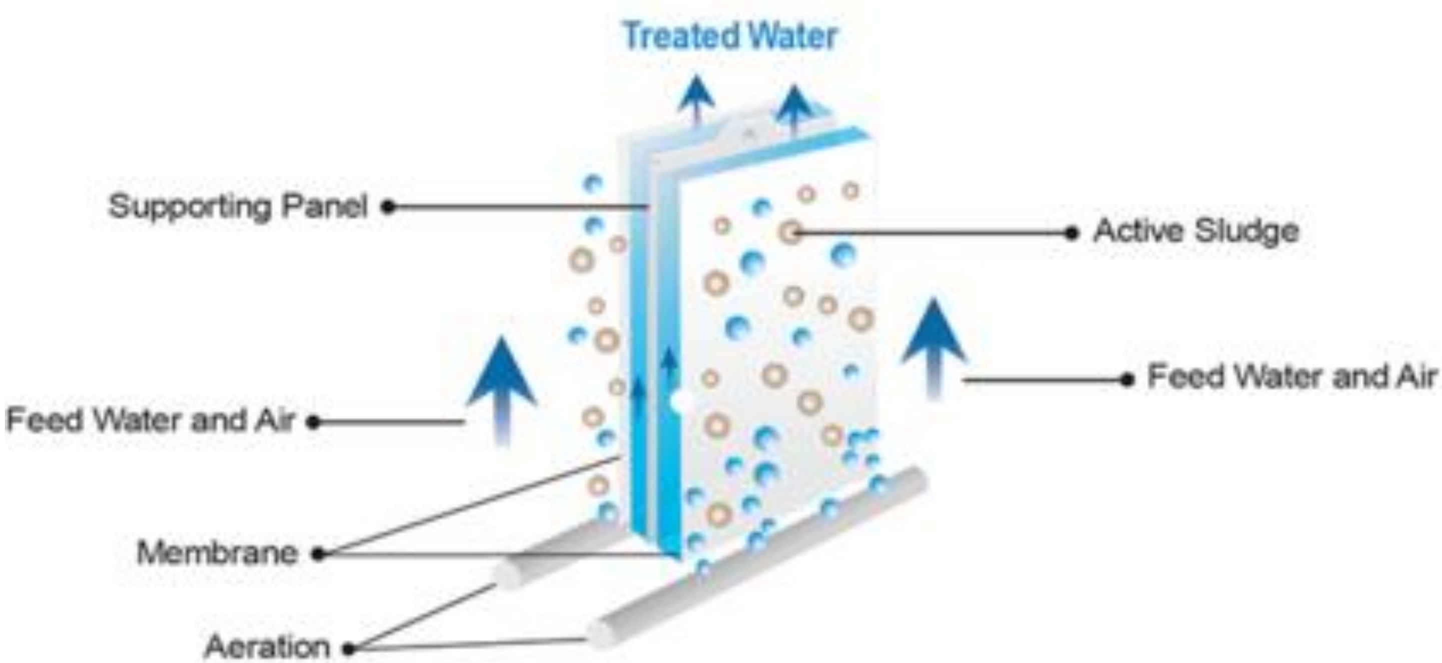


Figure 34: Membrane cross-section

Source: http://quagroup.com/about-enviq/ [49]

Name: Aqua Aerobic MBR

Vendor: Aqua-Aerobic Systems Inc.

Description / Abstract: The Aqua-Aerobic MBR system is a time-managed process which uses sequential aeration to promote biological nutrient removal in a simplified unit process. The integration of submerged membranes provides direct filtration of high-level mixed liquor suspended solids (MLSS).

The Aqua-Aerobic MBR has several features such as a modular design to assist with expansion. The time control system that comes with the system is meant to increase operational flexibility. The system is designed for enhanced biological nutrient removal to reduce the overall nitrogen and phosphorous levels.

Figure 35: Aqua Aerobic MBR system

Source: http://www.aqua-aerobic.com/index.cfm/products-systems/membranes/aqua-aerobic-mbr/ [50]

Name: LEAP MBR

Vendor: GE Corp.

Description / Abstract: The LEAPmbr is a membrane bioreactor that uses a technology called a ZeeWeed membrane. This membrane is designed to maximize surface area of the filter while keeping the system small. The purpose of this design is to have a small footprint, increase productivity, lower energy costs and be simple to operate. It has an operator interface designed to be simple to use. The system also uses a unique aeration system to reduce the energy and to keep piping simple.

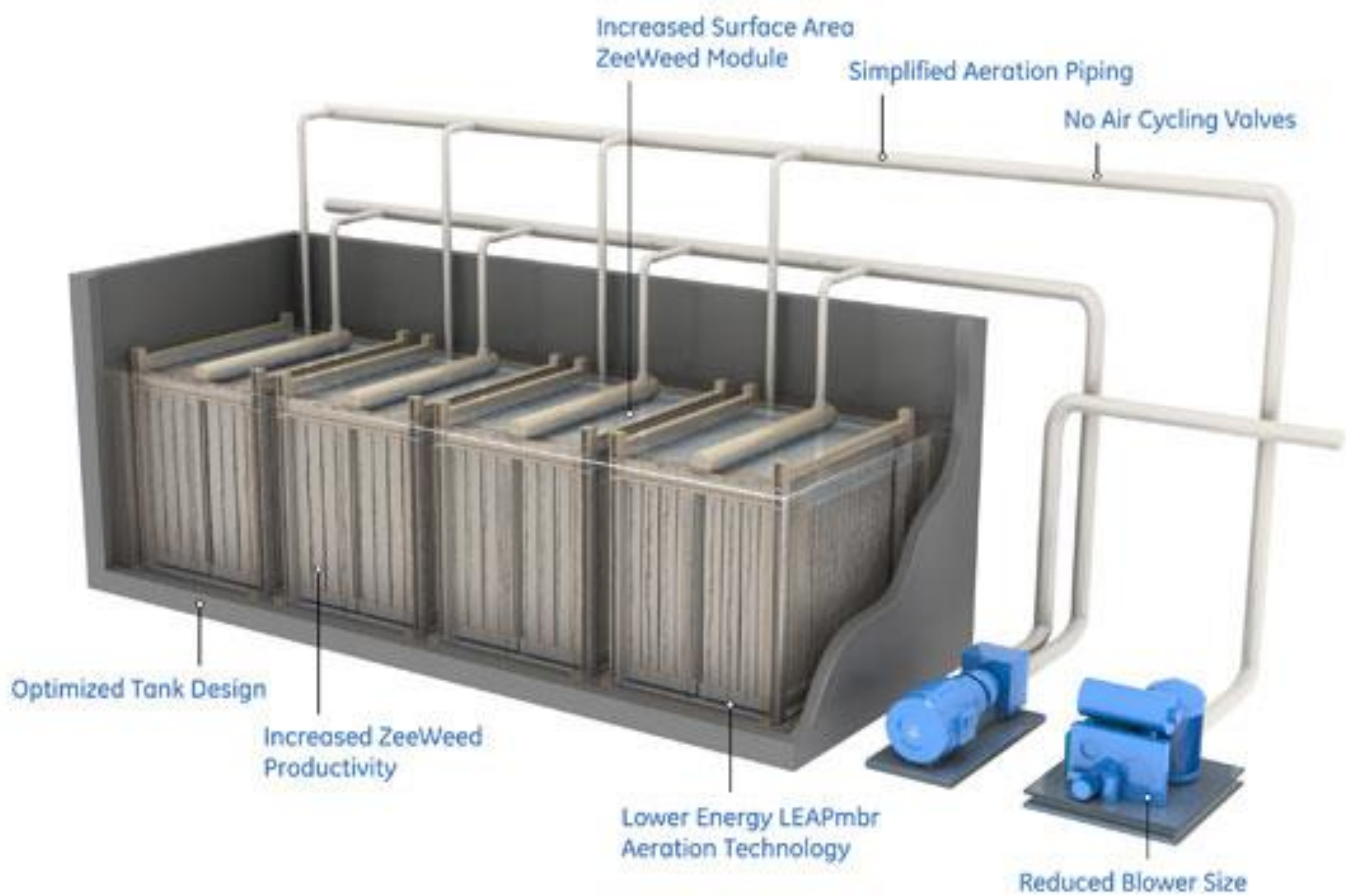


Figure 36: Leap MBR schematic

Source: http://www.gewater.com/products/leap-mbr.html [51]

Name: AGAR Attached Growth Airlift Reactor

Vendor: Aqwise

Description / Abstract: The AGAR MBBR (Moving Bed Biological Reactor) technology is a simple, single-through process, where all biological activity takes place on the biomass carriers. This process prevents sludge recycle from a secondary clarifier.

MBBR technology is robust and reduces soluble pollutants with minimal process complexity. MBBR solutions also utilize a significantly smaller physical footprint compared to conventional aerobic treatment methods. MBBR is typically used for either high load industrial applications, as stand-alone or as a buffer stage, as well as for robust simple-to-operate municipal facilities.

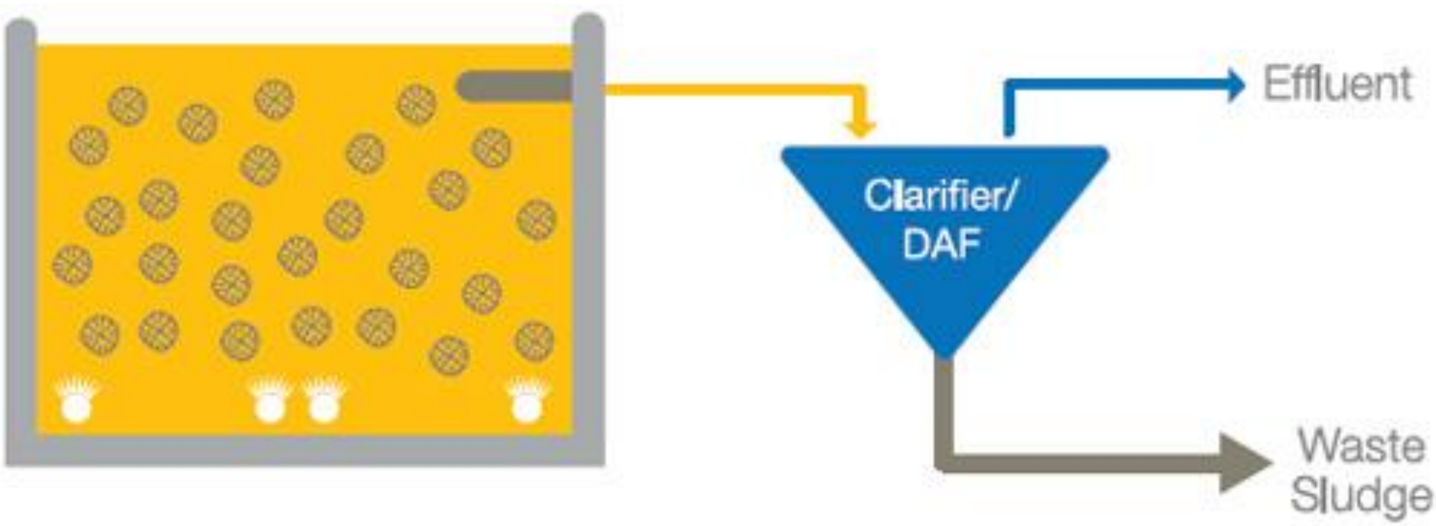


Figure 37: Aqwise AGAR working principle diagram

Source: http://www.aqwise.com/technologies/mbbr/ [52]

Name: Membrane Bioreactor

Vendor: Xylem

Description / Abstract: Membrane Bio Reactor combines diffused aeration and biological treatment with membrane filtration to produce reusable water in 8 hours. After air is added to incoming effluent, bacteria reduce organic content. Stage 2 filters water through membranes resembling rows of straws with microscopic pores that draw clear liquid into them while keeping solids out. System can be operated automatically from computer, without any human interfaces.

Figure 38: Image of Xylem Membrane Bioreactor showing membranes

Source: http://www.xylem.com/treatment/us/products/membrane-bioreactor-mbr [53]

Name: Titan MBR

Vendor: Smith and Loveless Inc.

Description / Abstract: Smith & Loveless Inc. proudly offers TITAN MBR, the latest pre-engineered wastewater treatment system for municipal, onsite and industrial applications. The innovative TITAN MBR combines the wastewater treatment engineering expertise of S&L with submerged membrane technology. The combination yields a dynamic membrane biological reactor (MBR): a system that provides end-users with high-quality treatment performance, minimal operational requirements, and a robust design that will stand the test of time. TITAN MBR delivers results with value-added engineering experience available only from S&L.

Figure 39: Titan membrane bioreactor in the field

Source: http://www.smithandloveless.com/Products.aspx?CategoryUid=29&ProductUid=118 [54]

Appendix B

B1 – Word Ladder

Criteria	1	2	3	4	5	Multiplier
Capacity Increase	The technology increases current capacity by 0-20%	The technology increases current capacity by 20-40%	The technology increases current capacity by 40-80%	The technology increases current capacity by 80-100%	The technology increases current capacity by greater than 100%	10.0
Technology Readiness Level	Unproven idea: Paper concept; no analysis or testing has been performed	Research is active at a University. This includes analytical studies, laboratory studies to physically validate the analytical predictions of the technology development. Concept design or novel features of design validated through model or small scale testing. Shall show that the technology can meet specified acceptance criteria with additional testing	Full-scale prototype built and technology qualified through testing in intended environment, simulated or actual. The new hardware is now ready for first use. Functionality has been demonstrated through testing over a range of operating conditions.	Full-scale prototype built and integrated into intended operating system with full interface and functionality tests in intended environment. The technology has shown acceptable performance and reliability over a period of time.	Technology integrated into intended operating system. The technology has successfully operated with acceptable performance and reliability. Technology is commercially available and has demonstrated success in the industry.	9.0

Robustness	The technology is not able to run and adapt in any weather conditions and not able to handle upsets (solids entering, greater flow than normal) or meet spec	The technology is able to run and adapt in some weather conditions (rain) (housing required) and handle upsets (solids entering, greater flow than normal) and still meet spec, but with more than 1 additional feature (add chemical)	The technology is able to run and adapt in most weather conditions (rain, snow, sleet) (housing required) and handle upsets (solids entering, greater flow than normal) and still meet spec, but with some additional feature (add chemical)	The technology is able to run and adapt in most weather conditions (rain, snow, sleet) (may require housing) and generally handle upsets with ease (solids entering, greater flow than normal) and still meet spec	The technology is able to run and adapt in all weather conditions (rain, snow, sleet, hail, wind) (no housing) and handle upsets with ease (solids entering, greater flow than normal) and still meet spec	8.0
CAPEX (cost/flow)	The technology costs more than $2 500 000 CAD	The technology costs between $2 500 000 and $1 500 000 CAD	The technology costs between $1 500 000 and $1 000 000 CAD	The technology costs between $1 000 000 and $500 000 CAD	The technology costs less than $500 000 CAD	6.0
OPEX ($/year)	The technology costs more than $250 000 CAD to operate per year	The technology costs between $250 000 and $200 000 CAD to operate per year	The technology costs between $200 000 and $150 000 CAD to operate per year	The technology costs between $150 000 and $50 000 CAD to operate per year	The technology costs less than $50,000 CAD to operate per year	6.0

Complexity	No system or similar system has been installed in the past, and is unlikely to be installed and operated as its features are unknown. The operation requires minutely supervision and treatment and needs manual operation, has no auto	No system or similar system has been installed in the past, and is difficult or there are still unknowns and only an experienced operator can install. The operation requires hourly supervision and treatment and is capable of running automatically, but needs manual operation as well	A similar system has been installed in the past, but is difficult or there are still unknowns and only an experienced operator can install. The operation requires daily supervision and treatment and is capable of running automatically, but needs manual operation as well	A similar system has been installed in the past and most operators with experience can install with ease. The operation requires some (weekly) supervision and treatment and runs automatically	A system has been installed in the past and any operator can install with ease. The operation requires minimal supervision and treatment and runs automatically	5.0
Compatibility	The technology is not compatible with existing and conventional waste water equipment, and needs many adjustments to operate properly	The technology is rarely compatible with existing and conventional waste water equipment, and needs several adjustments to operate properly	The technology is somewhat compatible with existing and conventional waste water equipment, it needs some adjustments to operate	The technology is almost fully compatible with existing and conventional waste water equipment, it only needs very few minor adjustments to operate	The technology is fully compatible with existing and conventional waste water equipment and no adjustments need to be made	4.0

Regulation/ Approval/ Environmental	The technology has obtained none of the required approvals and regulations and most likely cannot operate in the near future and the remaining regulations will be difficult to obtain	The technology has obtained some of the required approvals and regulations and may be able to operate in the near future, but the remaining regulations will be difficult to obtain	The technology has obtained some of the required approvals and regulations and should be able to operate in the near future, and the remaining regulations will not be difficult to obtain	The technology has obtained most of the required approvals and regulations and can operate in the near future, the remaining regulations will not be difficult to obtain	The technology has already obtained all approvals and required regulations and can operate today	4.0
Footprint	The technology has a massive footprint and requires serious land clearing (>150m2)	The technology has a large footprint and requires land clearing (<100m2)	The technology has a mediocre footprint and requires some land clearing (<70m2)	The technology has a fairly small footprint and requires no land clearing (<50m2)	The technology has a small footprint and requires no land clearing (<30m2)	2.0

Strength of Vendor	Company with inadequate technical expertise for the industry. The firm is unknown in the industry and cannot demonstrate technology development experience.	Small-to-Medium (SME) size enterprise that has technical expertise, and is financially capable of seeing the project through to commercialization.	SME that has technical expertise, financially sound and excellent service standards to support the technology offering and customization. Can demonstrate commercialization capacity through partnerships with other firms.	Large, established enterprise with good history. Firm with significant new product commercialization capability and capacity. Unknown to industry, but otherwise can demonstrate good service standards and financial commitment to new venture.	Firm with significant technical commercialization capability and capacity and has an excellent reputation within the industry for offering first class delivery of quality products and services.	1.0

B2 – Evaluation Matrix

Technology Name	Vendor	Multiplier	10	9	8	6	6	5	4	4	2	1	Final Score	Rank
		Criteria	**Capacity Increase / Unit**	**Technology Readiness**	**Robustness**	**CAPEX**	**OPEX ($/year)**	**Complexity**	**Compatibility**	**Environmental Approvals**	**Footprint**	**Strength of Vendor**		
BioMag	Evoqua		5	5	5	4	5	5	5	5	5	5	269	1
BioCord	Bishop Water Technologies		4	5	5	4	5	5	5	5	4	5	257	2
Bio-Domes	Wastewater Compliance Systems		4	5	5	4	5	5	4	5	4	5	253	3
SAGR (Submerged Attached Growth Reactor)	Nelson Environmental Canada		5	5	5	2	4	5	5	5	3	5	247	4
Reactive Sand Filters	Blue Water Technologies		2	5	5	5	5	4	5	5	5	5	240	5
Micro C - 2000	Environmental Operating Solutions Inc.		2	5	5	4	5	5	5	5	5	5	239	6
Aqua-Aerobic MBR	Aqua Aerobic Systems		2	5	4	3	5	5	3	5	3	5	213	7
LEAP MBR	GE		2	5	4	3	5	5	3	5	3	5	213	7
PURON Plus MBR	Koch Membrane Systems		2	5	4	3	5	5	3	5	3	5	213	7
Titan MBR	Smith and Loveless Inc.		2	5	4	3	5	5	3	5	3	5	213	7
The Water Miner	Boydel Wastewater Technologies		2	4	4	4	4	4	5	5	3	4	206	11
Jet Bat Process	Western Pump		3	5	5	0	0	5	4	5	5	5	191	12
Baffled Bioreactor (BBR)	Frontier Environmental Technology		2	4	3	3	5	3	3	5	4	5	188	13

Lagoon Guard Moving Bed Biofilm Reactor (MBBR)	AnoxKaldnes (Veolia)	4	5	4	0	0	5	3	5	3	5	185	14
EnviQ Submerged Ultrafiltration Membrane	QUA	2	5	4	0	0	5	3	5	5	5	169	15
Inclined Plate Clarifiers	Hydro Quip Inc.	2	5	3	0	0	5	4	4	4	5	159	16
Membrane Bioreactor	Xylem	2	5	4	0	0	5	3	3	3	5	157	17
AGAR (Attached Growth Airlift Reactor)	AqWise	0	5	5	0	0	5	3	3	0	5	139	18
SubTriq Submerged Membrane Bioreactor (SMBR)	Triqua												
Biobed Advanced Expanded Granular Sludge Bed (EGSB)	Biothane												
Dif-Jet Gas Injectors	Fortrans												
UOP Xceed Bioreactor	Honeywell UOP												
RAPTOR 4002 Aeration System	Philidelphia Mixing Solutions												

AQUA Enhanced Membrane Bioreactor (EMBR)	Aqua Tech														
Thermo ARP	ThermoEnergy Corp														
Packaged Wastewater Treatment Plant	Pollution Control Systems Inc														
Zeo-Clear	Ecologix														
Hybrid Depth Filtration	EcoWash														
Ultra-Fine Cloth Medium Filtration	Aqua-Aerobic Systems Inc.														
Tertiary Treatment Plant with Sub-Surface Disposal	WSP Canada Inc.														
Automatic Siphon Sludge Discharge Horizontal Flow Settling System	Guangzhou Xintao Wastewater T reat Company Ltd														
Waste Filtration System	Internat Wastewater Heat Recovery Systems Inc														

Internal Combustion Type Wastewater Treatment Device With Automatic Temperature Control Rotation Speed Device	Ingning Hongcai Electroplating Wastewater Treat Equipment Co Ltd													
Internal Combustion Waste Water Treatment Device	Ingning Hongcai Electroplating Wastewater Treat Equipment Co Ltd													
AQUA-4® Water Treatment System	Smith and Loveless Inc.													
AQUA-FER™ Water Treatment System	Smith and Loveless Inc.													
Spiralift® S	Franklin Miller													

* If a criteria was given a ranking of 0, this corresponded to an absence of evidence. Several efforts were made to obtain all of the required data. Some vendors were unresponsive, or unwilling to take advantage of this opportunity. Due to time constraints, any information not found was given a rank of 0. Unfortunately, this may skew the results; however, most of the higher potential technologies had plausible and reliable information.

** Each vendor provided capital and operating cost values shown above based on a small flow rate of 2,045 m^3/d. However, several MBR technologies were ranked similar due to a lack of information from other vendors. Two reliable vendors (GE and Koch) were used for both the capital and operating cost. The capital cost was generally provided in USD, and if so, the current exchange rate was used on March 14, 2016 of $1.00 USD = $1.30 CAD. If the capital cost was provided for a different inlet flow rate, the six-tenths rule (or capacity factor exponent equation) was utilized to scale up or scale down the cost to the appropriate flow rate.

Appendix C

C1 – Initial Rejected Technologies

The following list contains technologies the team did not pursue and their reason for rejection:

Name: Moving Bed Biofilm Reactors

Description / Abstract: The feasibility of upgrading and retrofitting municipal wastewater treatment plants was investigated at laboratory scale using Moving Bed Biofilm Reactor (MBBR) process. For this purpose, an aerobic pilot was operated for nearly one year in different conditions, in which a moving bed carrier with a specific biofilm surface area of 500 m^2/m^3 and a filling rate of 60% was utilized. System efficiency in removal of BOD5 and COD was examined at different hydraulic retention times (HRTs) of 1, 1.5, 2, 2.5, 3 and 4 h. The obtained results indicated high ability of the system to tolerate organic loading and to remain stable at a high food to microorganism (F/M) ratio. The system produced effluents with good quality at low HRTs and led to an average BOD5 removal efficiency of nearly 88% during the operational period. The Organic Loading Rate (OLR) applied to the system had a range of 0.73-3.48 kgBOD5/m^3.day and 2.43-11.6 gBOD5/m^2.day, at which the reactor showed a good performance and stability. In general, it was concluded that (MBBR) can be an excellent alternative for upgrading and optimizing municipal wastewater treatment plants.

Source: *International Journal of Environmental Research*, pg 963-972, 2013. [55]

Reason for Rejection: The technology has only been tested on the laboratory scale. It was not deemed technologically ready for full integration into municipal waste water treatment plants.

Name: Nitrogen removal through water recycle

Description / Abstract: The recycle water from sludge processing in municipal wastewater treatment plants causes many serious problems in the efficiency and stability of the mainstream process. Thus, the design approach for recycle water is an important part of any biological nutrient removal system design when a retrofit technology is required for upgrading an existing plant.

Moreover, the application of nitrogen removal from recycle water using the nitration process has recently increased due to economic reasons associated with an effective carbon allocation as well as the minimization of aeration costs. However, for the actual application of recycle water nitration, it has not been fully examined whether or not additional volume would be required in an existing plant. The addition of recycle water nitritation to an existing plant was evaluated based on a volume analysis and estimation of final effluent quality. It was expected that by using the reserve volume of the aeration tank in existing plants, recycle water nitritation could be applied to a plant without any enlargement. With the addition of recycle water nitritation, it was estimated that the final effluent quality would be improved and stabilized, especially in the winter season.

Source: *Water Science and Technology*, v 49, n 5-6, p 39-46, 2004. [56]

Reason for Rejection: The technology and method have not been fully tested. The results of this test were based largely on estimations. Thus it was deemed that this technology does not meet the regulation standards required for the current project.

Name: Assessing onsite waste water treatment

Description / Abstract: This study for the first time evaluated the soil suitability for onsite wastewater treatment systems (OWTS) within the Alabama Black Belt region and assessed the current status of those OWTS within this area. A local OWTS soil suitability rating system was developed based on current Alabama OWTS regulations and was compared with the existing nationwide Natural Resources Conservation Service soil limitation rating system based on their soil assessment results over the study area. Both rating systems indicate that a large percentage (52%-89%) of land within the study area should not be recommended for conventional OWTS. However, OWTS are widely used and aging in this region. Raster-based OWTS-soil suitability rating system results and US Census-derived demographics were combined in a GIS to prioritize the study area in terms of potential public health threat from OWTS. Although the results lack field verification, two parallel strategies to limit the public health risk from OWTS malfunction are suggested.

To extend municipal sewer service to high-risk city fringe areas and to subsidize system retrofit, repair, or replacement of aged OWTS with alternative engineered systems for rural households. Although this study only focused on the Alabama Black Belt area, the presented GIS and demographic methods can be referenced by other regions for similar OWTS assessment purposes.

Source: *Environmental Engineering Science*, v 28, n 10, p 693-699, October 1, 2011. [57]

Reason for Rejection: The study was evaluated on the treatment outside of the WWTP. This is beyond the scope of the current project.

Name: Heat exchangers in WWTP

Description / Abstract: With energy costs constantly on the rise and consumption closely monitored, existing plants, some of them retrofitted, and new plants alike are installing plate and spiral heat exchangers in an effort to reduce energy consumption, and so improve operating efficiencies. Each type, however, is considered for very different reasons. Plate heat exchangers may be selected for their high thermal efficiency and minimum capital investment. Spiral heat exchangers, on the other hand, are turned to for their ability to effectively handle fluids containing solids and fibers, similar to those encountered in wastewater treatment plants. First time users will want to become familiar with the basic construction features, advantages, limitations and applications of these heat exchangers. Readers familiar with the heat exchangers may find some fresh information regarding their installation or operation.

Source: *Water Engineering and Management*, v 138, n 9, p 28-29, Sep 1991. [58]

Reason for Rejection: This technology doesn't increase the capacity of the plant. It reduces overall energy use and therefore overall cost but it is not worth pursuing since no capacity increase is available.

Name: Estrogen and steroid removal

Description / Abstract: Great efforts have been made in China to retrofit and upgrade the existing municipal wastewater treatment plants (WWTPs) for enhanced removal of organic substrates and in particular nutrients.

However, the removal of trace recalcitrant or hazardous organic chemicals, e.g. steroid estrogens, one group of typical endocrine disrupting chemicals, has long been overlooked. The extensive investigations on estrogen removal rates in global and Chinese WWTPs and the estrogen biodegradation kinetics results in batch laboratory experiments are reviewed in this study. The effects of estrogen initial concentration and nitrifying activated sludge are highlighted. Challenges existing in current estrogen studies are pointed out, which are relevant for researches on fate and behavior of similar down-the-drain chemicals in both Chinese and global WWTPs.

Source: *Environmental Pollution*, v 165, p 215-224, June 2012. [59]

Reason for Rejection: The technology in this journal article doesn't specifically mention capacity increase. However, it does touch on the removal of pharmaceuticals such as steroids and estrogen which may be of interest in certain areas.

Name: Full scale biogas production for energy usage

Description / Abstract: Recently the United States Environmental Protection Agency qualified biogas from landfills and anaerobic digesters as a cellulosic transportation biofuel under the expanded Renewable Fuel Standard (RFS2). Biogas is a renewable fuel that can generate Renewable Identification Number credits for the producer. The wastewater industry may not be able to keep pace with this opportunity. Less than 10% of WWTPs in the US have currently produced biogas for beneficial use. Supporting growth of the biogas industry requires implementation of new practices and policies. In this review, the barriers, gaps, and challenges in deploying biogas production technology are identified. Issues are classified as economic, technical, social or regulatory issues. Some of the critical challenges to the economics of digester operations are the slow rate of biogas generation, the low energy content of the biogas, and the costs to upgrade the biogas. Currently there is little biogas utilization at US WWTPs. Most biogas is flared while some is used for onsite process heat and power production.

Case studies of co-digestion of biosolids with organic wastes at field-scale show the use of co-digestion could overcome significant economic challenges including higher methane yield, more efficient digester volume utilization and reduced biosolids production. These findings could provide guidance in retrofitting existing facilities or in designing new biogas production and utilization systems. The RFS2 ruling increases market certainty, hence reduces risk. The evaluation of applications of co-digestion at WWTP scales ranging from 1 million gallons per day (MGD) to 375 MGD determined its potential feasibility for different types of digester operation, organic waste and loading rate as well as effectiveness of providing energy self-sufficiency at the WWTPs. This work could improve economics of anaerobic digestion at WWTPs, enabling viable and sustainable biogas industry and offsetting costs for wastewater management.

Source: *Renewable and Sustainable Energy Reviews*, v 50, p 346-362, May 27, 2015. [60]

Reason for Rejection: This technology was looking at a retrofit idea to collect and utilize biogas as an energy resource for the WWTP. This technology, while an interesting retrofit idea, was not a method for increasing capacity in a direct way. Thus the technology didn't meet the criteria for this project. However if a bottleneck for a wastewater treatment plant is energy restraints this technology may be useful.

Name: Design and commissioning operation of upgrading and retrofitting project in a wastewater treatment plant

Description / Abstract: A wastewater treatment plant in Shandong Province was upgraded and retrofitted with a design capacity of 30 × 104 m3/d. Based on full use of the existing facilities, a set of new pre-treatment facilities was built. The A/A/O process was applied in the biological treatment stage to replace the original activated sludge process, and the advanced treatment stage consisted of chemical phosphorus removal, high-density sedimentation tank, V-style fiber filter and ultraviolet disinfection. The effluent quality met the first level A criteria specified in the Discharge Standard of Pollutants for Municipal Wastewater Treatment Plants (GB 18918-2002). The general situation, process flow, design parameters of structures and equipment configuration of this project were introduced. The experience of commissioning was summarized.

Source: *China Water and Wastewater*, v 29, n 4, p 39-42, February 17, 2013. [61]

Reason for Rejection: This was more of a case study on WWTP upgrades and retrofits. This wasn't a particular technology more like a conglomeration of technologies that were used to improve a treatment plant. It also seemed like an unfeasible upgrade for a small municipality.

Name: Electrocoagulation process with cylindrical aluminum electrodes

Description / Abstract: A series of experiments were performed in a study designed to investigate the retrofit ability of removing total soluble phosphorus (sTP) and soluble chemical oxygen demand (sCODMn) from wastewater through electrocoagulation technology utilizing cylindrical aluminum electrodes in batch-operating modes (BOMs) and continuous operating modes (COMs). By varying the operating conditions and the effects of various experimental parameters such as pH, NaCl concentration, hydraulic retention times (HRT), initial phosphorus concentration, and temperature, etc, the applied electric potentials (AEPs) range between 3, 4, and 5 volts (V), with current densities from 7.04 to 16.08 A/m2 in BOM and from 7.48 to 21.69 A/m2 in COM. Electrolysis times in the limits of 1 to 20 min were tried for different types of wastewater, including synthetic wastewater and municipal wastewater. According to experimental results, it was demonstrated that superior performance in removing phosphorus from wastewater can be achieved, with experimental data indicated that more than 99% (<0.2 mgTP/L) of phosphorus, and 75% (<10mgCOD/L) of sCODMn can be removed using this method. Additionally, it was also found that TP and sCODMn removal efficiencies were also increased with the addition of more NaCl to the wastewater. It has also been determined from the data that with optimum operating conditions and electrolysis time, this method can be used in existing municipal wastewater treatment plants to enhance treatment efficiencies of phosphorus and sCODMn when properly retrofitted.

Source: *Desalination and Water Treatment*, v 52, n 13-15, p 2388-2399, April 2014. [62]

Reason for Rejection: While this technology is fairly new and disruptive the technology readiness did not meet our required standards. This technology as only tested on the lab scale. While it may be a promising technology for the future it currently isn't ready.

Name: Upgrade for activated sludge systems

Description / Abstract: Most of 200 Activated Sludge Plant in Iran are overloaded and as a result, their efficiency is low. In this work, a pilot plant is manufactured and put into operation in one of the wastewater treatment plants in the west of Tehran. Instead of conventional activated sludge, a membrane bioreactor and an up flow anaerobic sludge blanket reactor used as a pre-treatment unit in this pilot. For the sake of data accuracy and precision, an enriched municipal wastewater was opted as an influent to the pilot. Based on the attained result, the optimum retention time in this system was 4h, and the overall COD removal efficiency was 98%. As a whole, the application of this retrofit would increase the plant's capacity by a factor of 5 and reducing the excess sludge by a factor of 10. The sludge volume index in the anaerobic reactor was about 12 after granulation occurred.

Source: *Bioresource Technology*, v 102, n 22, p 10327-10333, November 2011. [63]

Reason for Rejection: This article was more based on retrofitting a system with conventional technologies to improve performance. While the basis was that of a retrofit there did not appear to be any revolutionary technologies included within the article.

Name: Reverse osmosis and manganese greensand plants

Description / Abstract: The Water Security Agency has a legislative authority to regulate water treatment systems and enforce standards with respect to drinking water quality in the Province of Saskatchewan. A number of communities in Saskatchewan which depend on groundwater as a source for drinking water have reported high levels of naturally occurring substances, such as arsenic, uranium and selenium, in their raw water.

These communities continue to upgrade their systems by installing new or retrofitting with treatment units, such as reverse osmosis (RO) and manganese greensand (MGS) filters to reduce the levels of naturally occurring substances in finished water. In order to assess the treatment performance of these systems, a study was initiated to collect samples from 20 communities across Saskatchewan and analyse naturally occurring substances in raw and finished water. The study focused on the removal efficiency and the effect of parameters such as sulfate, total dissolved solids, and hardness on the removal efficiency. The paper includes discussion on the results and analysis of sampling/research studies conducted to assess the performance of treatment systems. Results showed that RO plants are effective in removing uranium and MGS are effective in removing arsenic from drinking water.

Source: *Water Quality Research Journal of Canada*, v 49, n 1, p 72-81, 2013. [64]

Reason for Rejection: While this technology could possibly be applied to the wastewater industry the main purpose of this technology is for drinking water. Water treatment is out of the scope of this study and thus this technology doesn't meet the criteria.

Name: PHA-based denitrification

Description / Abstract: The role of wastewater suspended solids in denitrification based on intracellular carbon storage was investigated in a biofilm sequencing batch reactor performing alternately anaerobic carbon storage and denitrification. Municipal wastewater as the feeding was compared with filtered wastewater and with acetate. The results show that the amount of PHA (polyhydroxyalkanoates) stored during a cycle was quite similar, irrespective of the substrate type used as feeding (acetate, real wastewater and real wastewater after filtration). PHA storage was limited even under excess chemical oxygen demand (COD) conditions, with a reducing power capacity enough for denitrification of only 25-26 mg/L N. However, when non-filtered wastewater was used, the denitrification capacity was about 50% higher (38 mg/L N) due to the contribution of entrapped suspended solids as the electron donor.

In addition, the involvement of the hydrolyzed wastewater suspended solids resulted in a different PHA composition containing a much higher poly-3-hydroxyvalerate content.

Source: *Environmental Technology*, v 35, n 3, 313-21, 2014. [65]

Reason for Rejection: This technology while promising still appears to be experimental. Because this technology does not meet out readiness levels it has not been chosen for further evaluation despite it looking promising as a future technology.

Name: Polyhydroxyalkanoate (PHA) production from sludge

Description / Abstract: Polyhydroxyalkanoates (PHAs) are biodegradable polyesters with comparable properties to some petroleum-based polyolefins. PHA production can be achieved in open, mixed microbial cultures and thereby coupled to wastewater and solid residual treatment. In this context, waste organic matter is utilised as a carbon source in activated sludge biological treatment for biopolymer synthesis. Within the EU project Routes, the feasibility of PHA production has been evaluated in processes for sludge treatment and volatile fatty acid (VFA) production and municipal wastewater treatment. This PHA production process is being investigated in four units: (i) wastewater treatment with enrichment and production of a functional biomass sustaining PHA storage capacity, (ii) acidogenic fermentation of sludge for VFA production, (iii) PHA accumulation from VFA-rich streams, and (iv) PHA recovery and characterisation. Laboratory and pilot-scale studies demonstrated the feasibility of municipal wastewater and solid waste treatment alongside production of PHA-rich biomass. The PHA storage capacity of biomass selected under feast-famine with municipal wastewater has been increased up to 34% (g PHA g VSS-1) in batch accumulations with acetate during 20 h. VFAs obtained from waste activated sludge fermentation were found to be a suitable feedstock for PHA production.

Source: *Water Science and Technology*, v 69, n 1, p 177-184, 2014. [66]

Reason for Rejection: This technology focuses on the utilization of waste sludge for the production of biodegradable polyesters.

While this is an interesting concept and may reduce environmental footprint and reduce sludge in the future it doesn't focus on capacity increase.

Name: Anaerobic-anoxic-oxicmembrane bioreactor (A2O-MBR)

Description / Abstract: The A2O-MBR pilot plant, with a capacity of at least 19.1 L/h, was constructed and installed at Shiraz municipal wastewater treatment plant in Shiraz, Iran. The pilot plant consisted of four reactors: anaerobic, anoxic, aerobic, and a membrane compartment containing one submerged hollow fiber membrane module.

The influent was introduced to the anaerobic tank continuously. The aerobic zone was equipped with diffusers to provide air bubbles for carbonaceous BOD removal and nitrification as well as complete mix condition. In the anaerobic and anoxic reactors, a complete-mix condition was achieved with a low speed mixer.

The pilot plant was equipped with two internal and external mixed liquor recycle (MLR) lines to enhance nutrient removal efficiency. The internal MLR line connects the aerobic and anoxic reactors and the external MLR line connects the aerobic and anaerobic reactors. In the anaerobic reactor, phosphorous release occurs under anaerobic condition, and phosphorous uptake occurs in the aerobic and anoxic reactor. In the anoxic reactor, denitrification is carried out under anoxic condition using the nitrates of the MLR and the organic matter of the influent. In the aerobic reactor, nitrification and phosphorous uptake occur.

One solenoid valve was located on the filtration line, and another on the backwash line. Two timers were then linked to these solenoid valves to adjust the periodical filtration and air backwash. The time interval for each cycle of filtration and air backwash was 10 min, with 9 min and 4 s of filtration and 18s of air backwash.

The air backwash pressure was maintained at 150 kPa by the air regulator to reduce the filtration resistance during each cycle. In order to avoid considerable membrane flux decline, the transmembrane pressure was maintained at around 30 kPa by the pressure gauge.

Source: Hadi Falahti-Marvast, Ayoub Karimi-Jashni. Performance of simultaneous organic and nutrient removal in a pilot scale anaerobic–anoxic–oxic membrane bioreactor system treating municipal wastewater with a high nutrient mass ratio. *International Biodeterioration & Biodegradation*. V 104. Pg. 363-370. [67]

Reason for Rejection: This technology was not investigated further for a number of reasons. First, the test was only conducted on a small pilot scale. This means that before scale-up to a full size trial there would still need to be further pilot tests of increasing size. Second, a vendor was not found that current sells or fabricates the tested A2O-MBR system on an industrial scale. This means that the technology is not near ready and the time to deployment will be much too long for this project. Finally, the system is too complex to be applied to an existing small municipality as a retrofit. If it were a new construction this system may be more viable.

Name: Addition of Zebra Mussels to treat WW

Description / Abstract: A pilot test was conducted in which wastewater was diverted from a lagoon to a tank containing zebra mussels before being replaced into the lagoon. Samples were taken on the outlet of the tank to measure parameter reductions. The zebra mussels were found to improve the water quality.

Source: Gan, C. and Champagne, P. (2015) Evaluation of Passive Treatment Technologies for Septic Lagoon Capacity Expansion. *World Environmental and Water Resources Congress 2015*: pp. 2403-2423. [68]

Reason for Rejection: While the zebra mussels improved water quality their effectiveness was significantly reduced in lower temperatures. In general, zebra mussels become dormant when temperatures fall below 10°C and their ability to remove particulates from water is compromised. For this reason, zebra mussels will not be a viable option for many small municipalities.

Name: Liquid-Solid Circulating Fluidized Bed Bioreactor

Description / Abstract: Biological nutrient removal (BNR) using a novel liquid-solid circulating fluidized-bed (LSCFB) bioreactor was assessed with and without particle recirculation.

The LSCFB employs attached microbial films for the biodegradation of both organics and nutrients within a single circulating fluidized-bed unit. This new technology combines the more compact and efficient fixed-film process with the BNR process that provides the additional removal of nitrogen and phosphorous.

Compared to the conventional liquid-solid fluidized bed, the liquid-solid circulating fluidized bed (LSCFB) has additional advantages. In the LSCFB, particles are entrained upwards in the riser fluidized bed by a stream of liquid having a velocity higher than the terminal velocity of the particles, and then, after a quick separation at the riser top and down flow into the downer, flow downwards counter-currently with a stream of upwards liquid in the downer fluidized bed, where the liquid velocity is lower than the terminal velocity. The LSCFB thus integrates two fluidized beds into one unit and two processes can be held in one single system, with the particles recirculating between the two fluidized beds. Liquid-solid recirculation is beneficial to biochemical processes where continuous particle regeneration and independent control of phase holdups are required. It is also efficient for bioreactors where biofilm renewal is essential. Two different zones in a single unit with different retention times can be very appropriate for the microbial processes where microorganisms require more than one substrate, especially when some of the substrates are in gas form and others are in liquid phase, and survive under different environmental conditions.

Source: Chowdhury, N., Zhu, J., Nakhla, G., Patel, A. and Islam, M. (2009), A Novel Liquid-Solid Circulating Fluidized-Bed Bioreactor for Biological Nutrient Removal from Municipal Wastewater. *Chem. Eng. Technol*: 364–372. [69]

Reason for Rejection: It was decided not to investigate this technology further for a number of reasons. Notably, the test was only conducted on a small lab bench scale. This means that before scale-up to a full size trial there would still need to be multiple pilot tests of increasing size. Also, a vendor was not found that current sells or fabricates the tested LSCFB system on an industrial scale. This means that the technology is not near ready and the time to deployment will be much too long for this project.

C2 – Secondary Rejected Technologies

The following technologies were pursued further but during more detailed research were found not to satisfy the go/no go criteria for this project:

Name: Internal Combustion Wastewater Treatment Device

Vendor: Ingning Hongcai Wastewater Treat Equipment Ltd.

Description / Abstract: The invention discloses an internal-combustion waste water treatment device which comprises a motor, a transmission device, an evaporation cylinder, an evaporation tank, a chimney, an ash discharge port, an air blower, an air valve, an air supply pipe, a fuel inlet pipeline, an ash discharge pipeline, a frame, a waste water raw material pool and a liquid transmission pipe, wherein one side of the transmission device is connected with the motor, and the other side is connected with the evaporation cylinder; the evaporation cylinder is installed inside the evaporation tank. Both ends of the evaporation cylinder are respectively provided with an opening, one opening is connected with the fuel inlet pipeline, and the other opening is connected with the ash discharge pipeline. The waste water raw material pool is positioned on the upper end of the back side of the frame. The upper end of the front side of the frame is provided with a front support and a back support; the evaporation tank is positioned between the front support and the back support; the fuel inlet pipeline is installed on the upper end of the front support; the ash discharge pipeline is installed on the upper end of the back support; the tail end of the ash discharge pipeline is provided with the chimney and the ash discharge port; the side of the fuel inlet pipeline is provided with the air blower; and the waste water raw material pool is connected with the evaporation tank.. The invention has the advantages of low heat loss, manpower saving and low cost for wastewater treatment.

Source:
http://google.com/patents/CN102060343A?cl=en
[70]

Reason for rejection: Literature written on this technology was from a different continent, and therefore presented a language barrier to understanding the operation and benefits of the technology. From the small amount of documentation presented, it was proven that the combustion aspect of the process is not environmentally friendly enough to be implemented in Ontario.

Name: AQUA-4 Water Treatment System

Vendor: Smith and Loveless Inc.

Description / Abstract: Smith & Loveless packaged water treatment plants integrate particular process steps like aeration, coagulation, oxidation, flocculation and sedimentation to provide onsite treatment of groundwater or freshwater supplies. Most applications are geared for iron and manganese removal. The AQUA-4 System from Smith & Loveless combines the processes of chemical coagulation, mechanical axial flow-assisted flocculation, tube settling and dual-media filtration in a clarifier, laminar flow setting. The AQUA-4 removes iron and manganese from surface water with the addition of a chemical oxidant.

Figure 40: AQUA-4 treatment system installed at a wastewater treatment plant

Source: http://www.smithandloveless.com/Products.aspx?CategoryUid=112&ProductUid=211 [71]

Reason for rejection: This technology is specifically for purifying drinking water and removing metals from the fluid. Efforts have been made to convert it to a wastewater treatment technology, but no recent developments have been made. It is therefore not a near-ready technology, and incapable of being deployed in the near future.

Name: AQUA-FER Water Treatment System

Vendor: Smith and Loveless Inc.

Description / Abstract: Smith & Loveless packaged water treatment plants integrate particular process steps like aeration, coagulation, oxidation, flocculation and sedimentation to provide onsite treatment of groundwater or freshwater supplies. Most applications are geared for iron and manganese removal.

The AQUA-FER Water Treatment Plant from Smith & Loveless combines aeration, chemical oxidation, sedimentation and filtration processes in a compact, integrated package. It's designed to remove soluble ferrous iron or manganese typically found in groundwater or reservoir supplies. The design consists of a downward, tortuous filtered path.

Figure 41: Picture of the AQUA-FER filter

Source: http://www.smithandloveless.com/Products.aspx?CategoryUid=112&ProductUid=211 [72]

Reason for rejection: This technology is specifically for purifying drinking water and removing metals from the fluid. Efforts have been made to convert it to a wastewater treatment technology, but no recent developments have been made. It is therefore not a near-ready technology, and incapable of being deployed in the near future.

Name: Spiralift S/SL/SLV/SC/SR

Vendor: Franklin Miller

Description / Abstract: The following provides a generic description of the Spiralift technologies, with an end focus on the Spiralift S technology. The SPIRALIFT screens, washes, transports and dewaters solids entrained in the wastewater flow. This system combines the benefits of two proven technologies into one effective system: the SPIRALIFT screening conveying system and a high-performance TASKMASTER grinder. The processed solids are washed, ground, dewatered and discharged — ideal for landfill disposal, while organics are left in the flow. Because this unit features TASKMASTER grinding technology, it offers the combined benefits of a rugged, effective grinder with enhanced screw screen performance for a uniquely effective and trouble-free system.

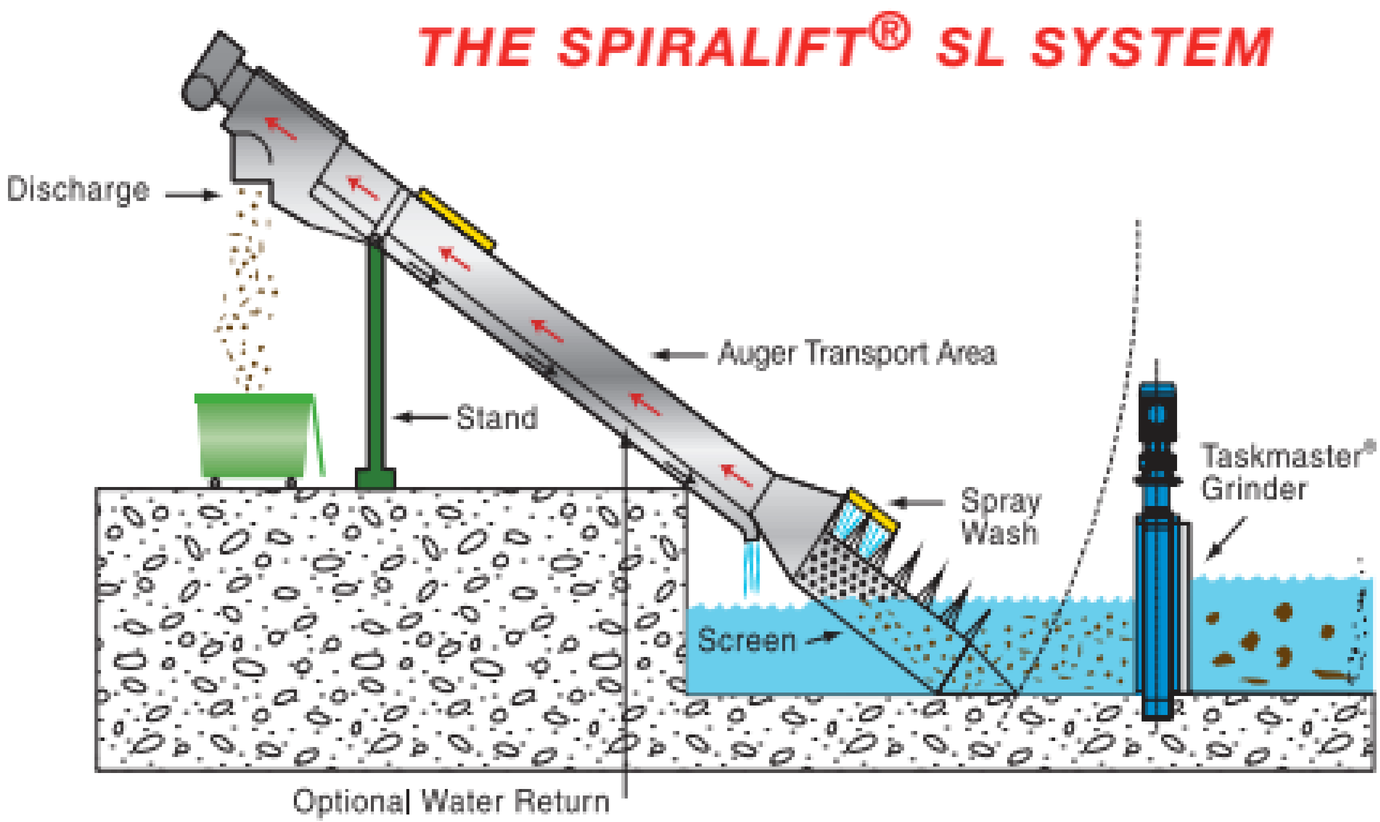


Figure 42: Diagram of the operation of the Spiralift system

Source: https://www.franklinmiller.com/product/spiralift-s/ [73]

Reason for rejection: This technology is specifically built to remove solids from the flow of wastewater. Though it is reliable and deployed in various locations, it is not designed to increase the capacity of a waste water treatment plant. For this reason, it was not considered further.

Name: SubTriq Submerged Membrane Bioreactor (SMBR)

Vendor: Triqua International

Description / Abstract: SubTriq is based on a filtration procedure with membranes that are submerged in the biomass, either inside the bioreactor itself or in a separate tank. Filtration takes place by applying vacuum to the inside of the membrane. Membrane fouling is prevented by the flow of coarse air bubbles along the membrane surface.

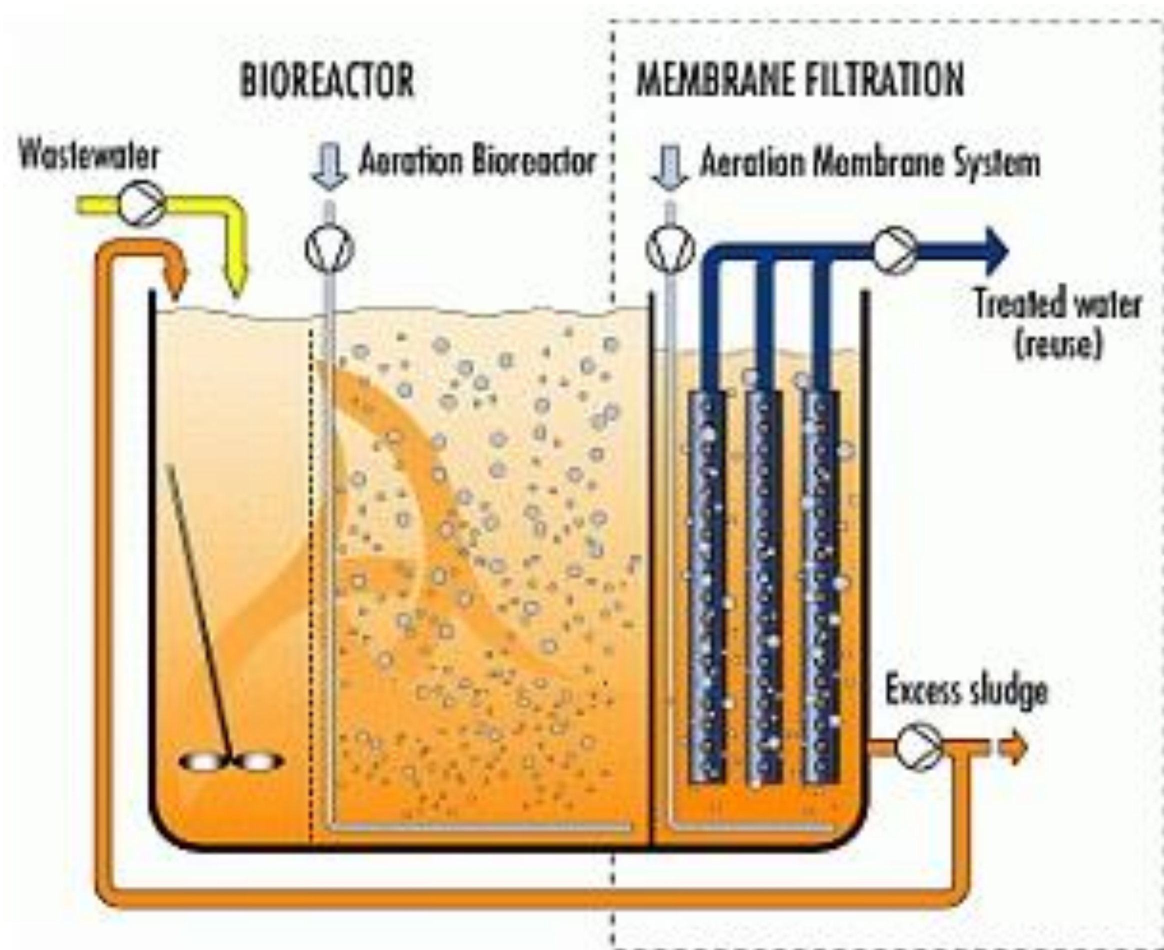


Figure 43: SubTriq Membrane Bioreactor working principle diagram

Source: http://www.triqua.eu/site/subtriq-mbr [74]

Reason for Rejection: Upon contacting the vendor they indicated that our flowrates were too high for this particular technology. They stated that this particular MBR is used on smaller scales such as accommodation barges and platforms, not for municipal wastewater treatment. This technology was not investigated further because it did not meet the go/no go criteria of being on a scale suitable for treating municipal wastewater.

Name: Biobed Advanced Expanded Granular Sludge Bed

Vendor: Veolia

Description / Abstract: The pH-value and the temperature of the wastewater are regulated in a pretreatment step in a conditioning tank. The liquid is also mixed with recycled, treated anaerobic effluent from a recirculation step to attain a homogenous body. Nutrients are added if necessary to achieve optimal growth conditions for the anaerobic biomass in the Biobed reactor.

In the following treatment step the conditioned wastewater is pumped at a constant, continuous flow to the Biobed reactor. A special influent distribution system guarantees equal distribution over the entire reactor surface area. The influent then passes a dense and anaerobic granular biomass bed where the biological treatment takes place converting the COD load (Chemical Oxygen Demand) present in the wastewater into biogas.

Biogas is collected at the top of the reactor and is piped to a biogas treatment step. Under controlled conditions it can be burned in a biogas flare or alternatively serve as a source of energy for the production site.

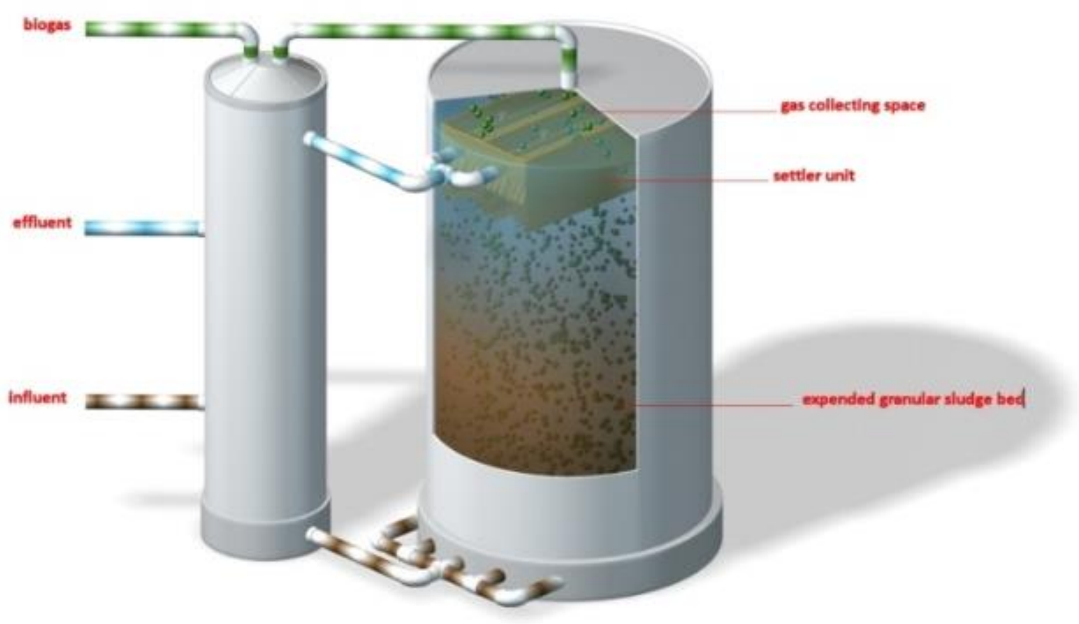


Figure 44: Biobed Advanced EGSB reactor schematic

Source: http://technomaps.veoliawatertechnologies.com/biobed_advanced/Biobed-Advanced-en/ [75]

Reason for Rejection: This technology was not pursued further because it was geared towards industrial, large-scale wastewater treatment as opposed to municipal wastewater treatment. The idea of generating Biogas is appealing; however, most small municipalities would not have the infrastructure to utilize the gas. Moreover, such a technology is a large capital expenditure for small municipalities.

Name: UOP Xceed Bioreactor

Vendor: Honeywell

Description / Abstract: UOP's XCeed bioreactor technology is an advanced, fixed-film biological treatment technology ideal for bulk contaminant removal from wastewater streams. Typical contaminants treated include simple and complex organics that contribute to high levels of biological oxygen demand (BOD) as well as the reduction of metals to stable benign forms. The system employs a unique combination of plug-flow, fixed-film modular design with a proprietary media resulting in low operations and maintenance costs. The packed bed, plug flow design also provides greater solids retention time while minimizing the hydraulic retention time. The increased solids retention time results in a high biomass to feed ratio that promotes biological oxygen demand (BOD) removal while minimizing sludge formation. High concentrations of immobilized bacteria provide natural resistance to and fast recovery from process upsets.

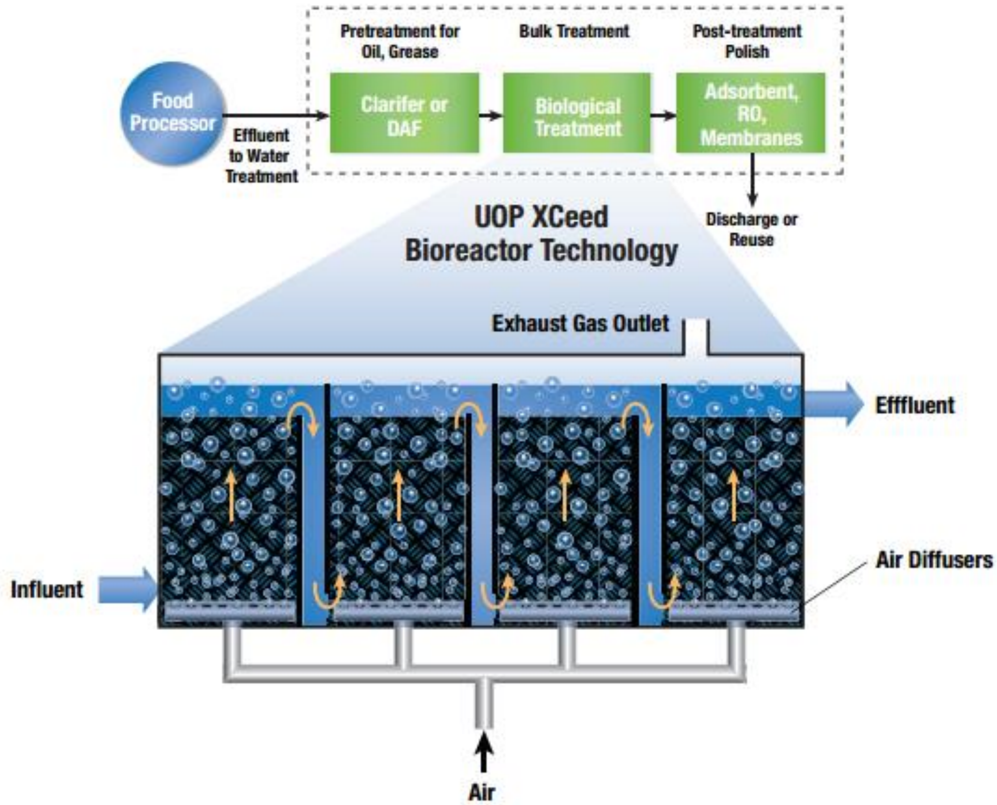


Figure 45: UOP Xceed bioreactor schematic

Source: http://www.uop.com/products/adsorbents/industrial-wastewater/ [76]

Reason for Rejection: This technology was not investigated further because it is geared towards large-scale, industrial wastewater treatment. This project is specifically focusing on inexpensive technologies for small municipalities.

Name: RAPTOR 4002 Series Aeration System

Vendor: Philadelphia Mixing Solutions

Description / Abstract: The Raptor floating directional mixer and subsurface aerator provides superior aeration and solids suspension in basins. Featuring a patented, circular rake impeller technology, the Raptor produces a focused, turbulent mix over 300 feet long. Equipped with a 4 horsepower/2.9 kilowatt blower, the Raptor injects air in front of the impeller which disperses fine bubbles that remain entrained for the length impeller plume providing improved dwell time and oxygen transfer. When configured with several units that operate in a series of loops, Raptors provide a flow pattern necessary to mix the entire basin using less equipment and energy.

Figure 46: Raptor floating aeration unit

Source: http://www.philamixers.com/industries/water-wastewater/industrial/ [77]

Reason for Rejection: While this technology has the potential to reduce energy consumption of a previously aerated lagoon, it is not likely to realize extra treatment capacity unless the bottleneck at the plant is power consumption.

Name: Aqua-EMBR system

Vendor: AquaTech International Corp.

Description / Abstract: The AquaTech Enhanced membrane bioreactor (Aqua-EMBR) consists of two main operations to treat wastewater. The system contains an activated sludge extended aeration biological treatment process and an ultrafiltration membrane system for sludge removal. The membrane for this system is located outside of the bioreactor which makes the arrangement easier and safer for contractors then typical MBR's. There is continuous air injection into the membrane system to drive the reflux stream back to the aeration tank and to sustain the permeate flux. Feed pumping energy required is reduced from typical MBR systems to make the operation more affordable. Permeate is collected from the system and is connected with a forward flushing system, periodic backwash system, and chemical dosing. Because of the separate membrane operations are controllable, optimizable, and safe.

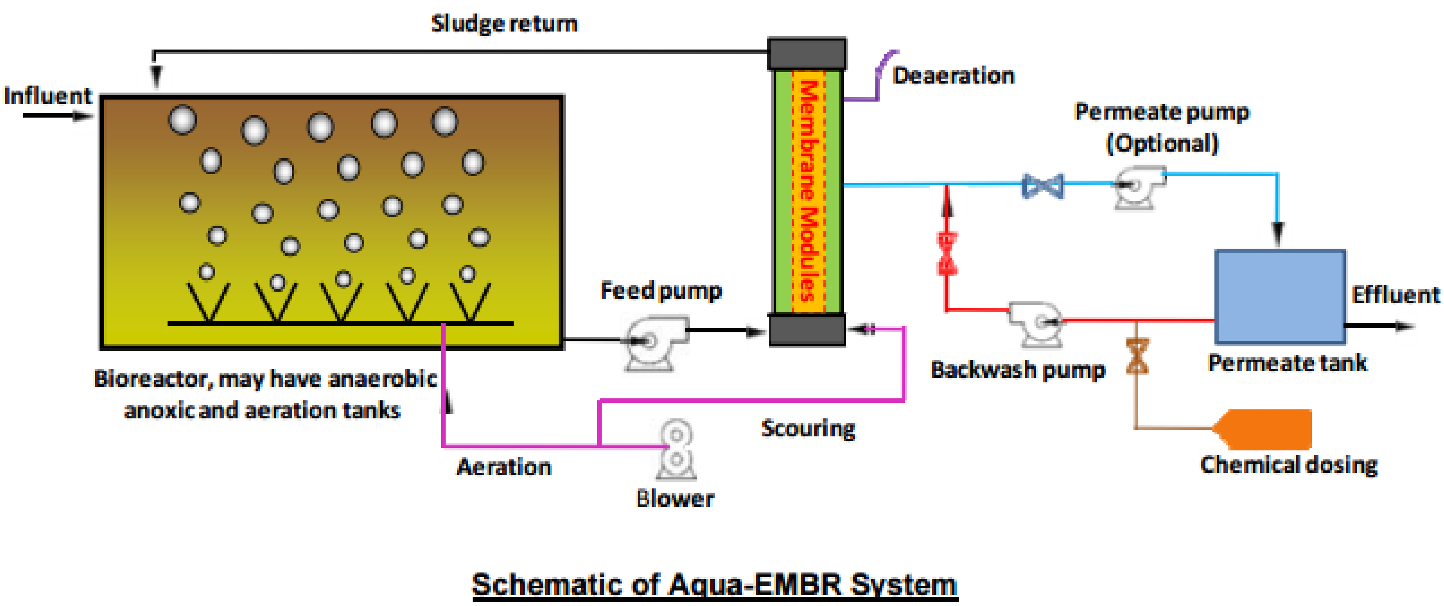


Figure 47: Schematic of the Aqua-EMBR system

Source: http://vertassets.blob.core.windows.net/download/348eba22/348eba22-42d0-4f3c-b1dd-1b72bb954fb1/aqua-embr.pdf [78]

Reason for Rejection: The reason this system was rejected was due to the insufficient data about the technology. Upon further research of this product it was difficult to discern if the technology was available for sale. The vendor had no information regarding this technology and the only source came from the article. Thus it was determined that this product may still be in the development stages and as such is not ready for implementation.

Name: Packaged Wastewater Treatment Plant

Vendor: Pollution Control Systems Inc.

Description / Abstract: Pre-engineered and pre-fabricated package biological wastewater systems are designed for treatment of domestic wastewater flows from small, and medium, municipalities. Sizes range from 500 to 100,000 GPD and larger. Steel fabricated structures feature weather and environmental resistant coatings. Units are designed to meet prevailing regulatory authorities at point of installation.

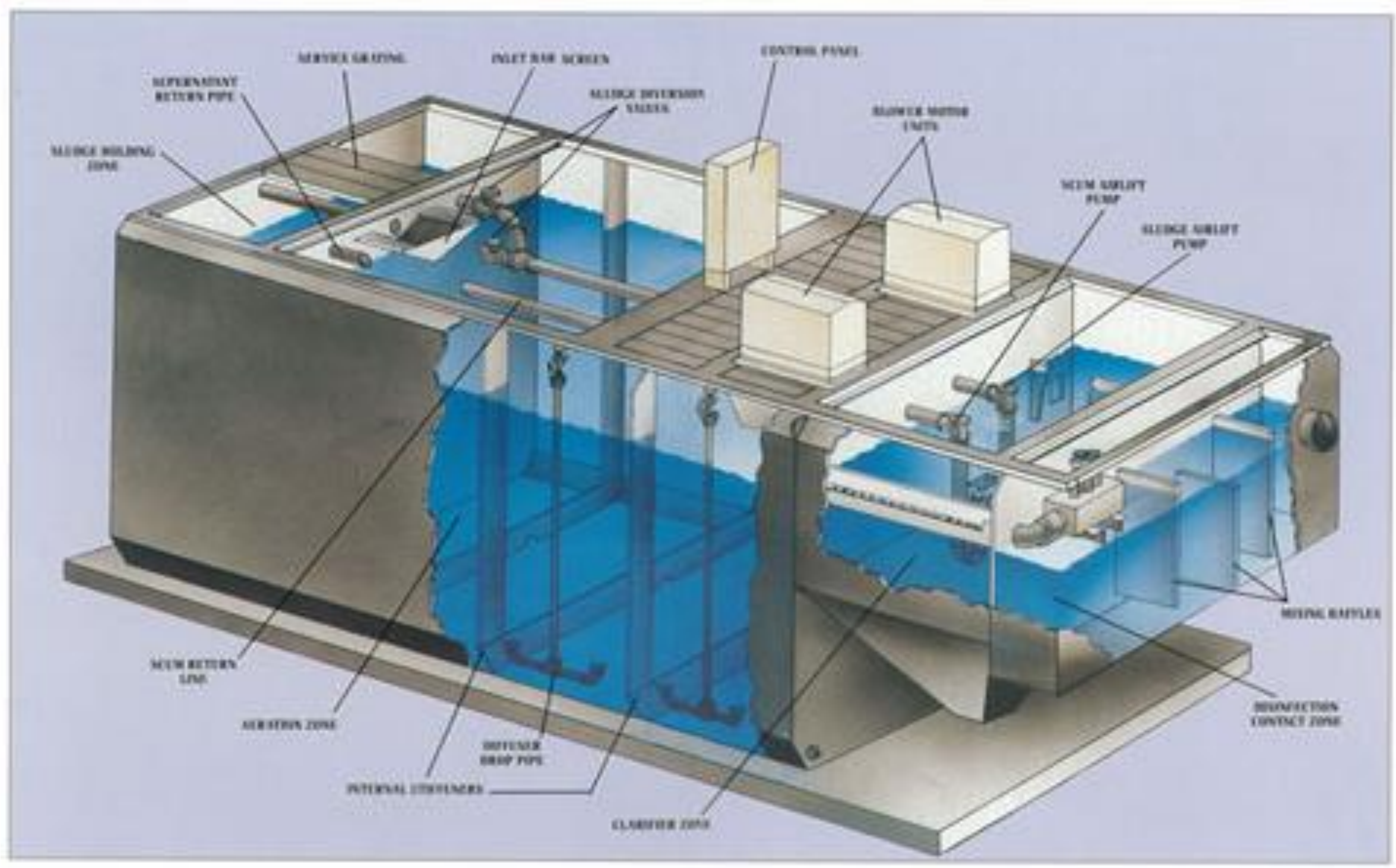


Figure 48: Conceptual model of custom packaged treatment plant

Source: http://www.pollutioncontrolsystem.com/Page.aspx/43/Downloads.html [79]

Reason for Rejection: Upon contacting the vendor of this product it was determined that the flow rates from base case wastewater facility were too high. These systems are designed mainly for small flows coming from industry, and facilities such as schools or government buildings. The systems are not designed to handle the total flow of a municipality and would not be able to increase capacity to a significant degree. Thus it was determined that this technology is outside the scope of the project.

Name: Hybrid Depth filtration

Vendor: Parskson Corp. EcoWash

Description / Abstract: This is a combination of continuous filtration and gravity filtration. The operation of the filter is up flow and continuous but the sand cleaning is intermittent. An air lift is triggered by the headloss and cleans the sand similarly to a continuous filter. The sand washing being intermittent while having a continuous filter eliminates the need for redundant filters but also reduces energy consumption. This process has also been known to increase the nitrate removal in a plant.

Figure 49: Hybrid depth filtration unit installed in the field

Source G. Omar, "Hybrid Depth filtration," *Influents,* vol. 10, pp. 22-24, 2015. [80]

Reason for rejection: While this product is a promising alternative to gravity and continuous filtration the increase in capacity is minimal. This system is easy to operate and it reduces the energy compared to the other two technologies the system is not quite within the scope of this project as it does not significantly increase capacity. It is also more applicable to facilities that already have continuous filtration as those systems provide the framework for hybrid depth filtration. As such the system is harder to implement as a retrofit.

Name: Dif-Jet Gas Injectors

Vendor: Fortrans Inc.

Description / Abstract: Dif-Jet gas injectors used in wastewater aeration systems offer a less expensive, more energy efficient alternative to conventional aeration technology for wastewater treatment. The injectors are installed on a grid system above the water surface. The wastewater is continually pumped through the grid and is oxygenated/aerated as it passes under the patented Dif-Jet™ injector. The oxygenated wastewater is then pumped to desired depth with discharge flows up to 100 GPM. The system provides deep aeration and high impact mixing. Dif-Jet™ gas injector systems available are external manifold designs, wall-mounted, floating or overlay designs. Some designs are modular drop-in systems allowing the customer to purchase the amount of dissolved oxygen they need to add to their process on a budget they can afford. Dissolved oxygen is supplied to the process at the correct depth to enhance biological activity in aeration basins and oxidation ditches. DIf-Jet™ injectors used in grid systems installed in series will establish aeration zones and flow patterns to facilitate nitrification and denitrification.

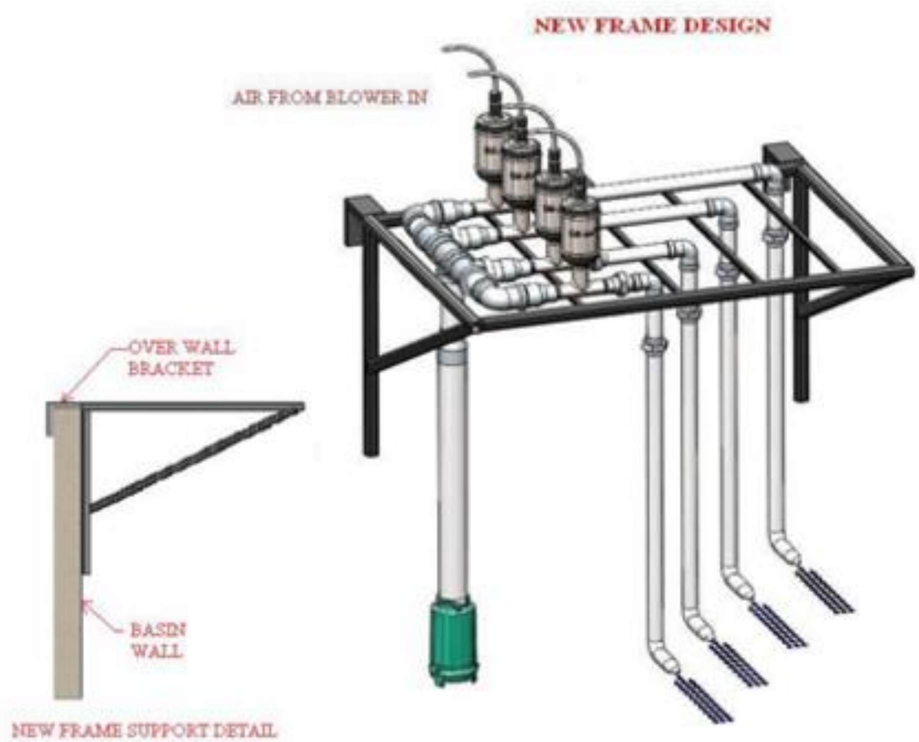


Figure 50: Dif-Jet gas injection grid system

Source: http://fortransaeration.com/aerators/ [81]

Reason for Rejection: Upon contacting the vendor they indicated that there products were used in industrial treatment only. Mainly as a way to adjust the pH of the water, not increase capacity. The vendor indicated that small bubble diffusers are more appropriate for municipal treatment.

Name: Zeo-Clear Package Treatment Plant

Vendor: Ecologix Environmental Systems

Description / Abstract: Perfect for the needs of smaller populations, communities, camps, resorts & similar sized applications, the Zeo-Clear is a one-of-a-kind biological treatment system built inside a standard ISO shipping container. Based on the activated sludge process, the Zeo-Clear produces excellent effluent quality. Zeo-Clear systems integrate secondary and tertiary wastewater treatment together in one stage with natural zeolite rock. The microporous structure of zeolite fosters the growth of a microbial population while creating microscopic anoxic zones which helps with nutrient removal. Treated effluents are typically of high enough quality to discharge to percolation fields. An extra level of filtration can be added to treat the water to levels suitable for in-home reuse or discharge to surface waterways.

Figure 51: CAD model of Zeo-Clear packaged wastewater treatment plant

Source: http://www.ecologixsystems.com/system-zeo-clear.php [82]

Reason for Rejection: The vendor indicated that their package treatment plants are for small-scale, temporary operations such as military and exploratory man camps. They are not suited for long-term use such is required to treat municipal wastewater.

Name: AquaDiamond – Cloth Media Filters

Vendor: Aqua-Aerobic Systems Inc.

Description /Abstract: A very fine cloth filter that can be used instead of a sand media or typical cloth filters. Intended to reduce total suspended solids and phosphorus. The technology currently operates at City of Brockton, Massachusetts, two surrounding towns and 20 industrial users.

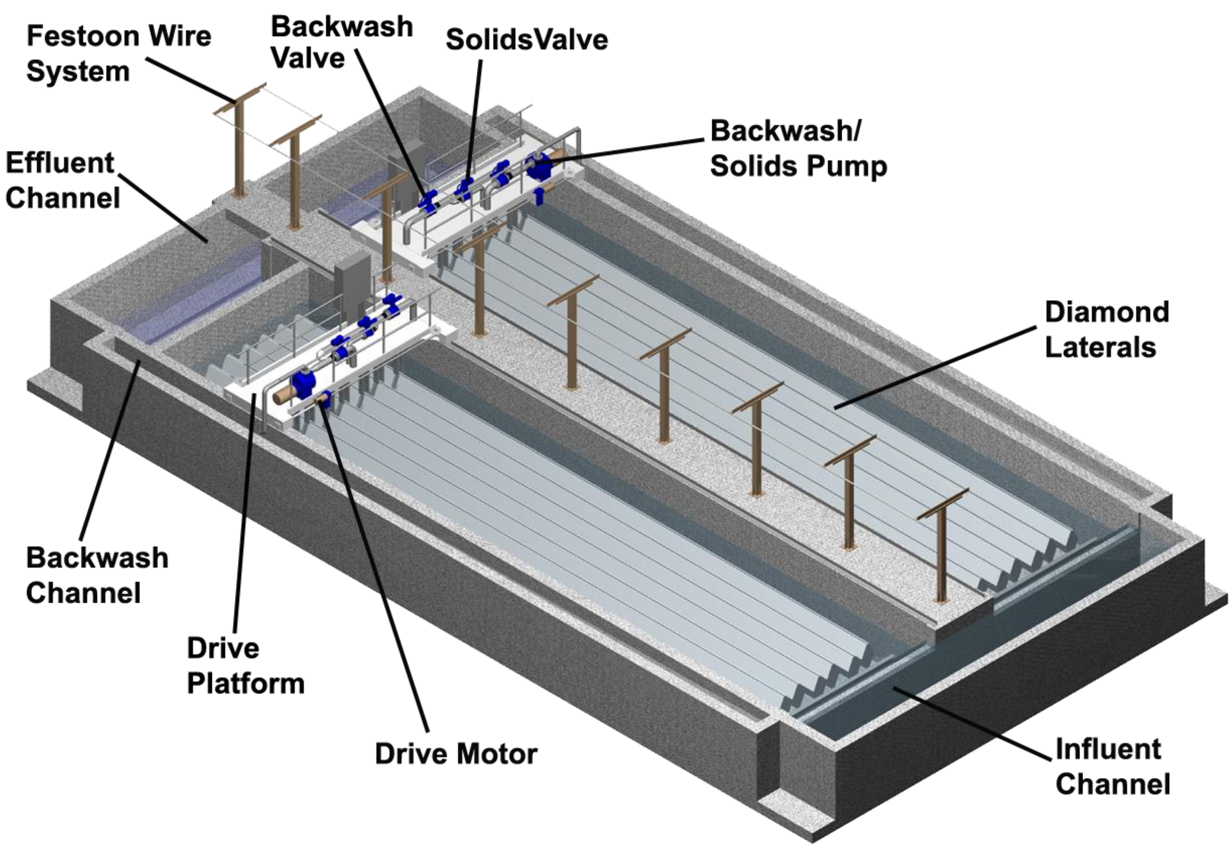


Figure 52: Schematic of the Aqua-Diamond cloth media filter system.

Source: http://www.aqua-aerobic.com/index.cfm/products-systems/filtration/aquadisk/ [83]

Reason for rejection: The scope of the project required us to focus on technologies that can be implemented within municipalities. This technology seems to have more of an industrial focus, which falls outside of our scope. Furthermore, the technology is not able to sufficiently increase capacity, another requirement of the recommendation.

Name: Tertiary Treatment Plant with Sub-Surface Disposal

Vendor: WSP Canada Inc.

Description /Abstract: A small separate tertiary facility from the main wastewater treatment plant. It is essentially its own small treatment facility with a sub-surface disposal. Was built for a 340 home expansion to the Town of Mono of approximately 7,000 people.

Source: Water Environmental Association of Ontario Magazine [84]

Reason for rejection: The scope of the project required us to focus on technologies that can be implemented within municipalities. This technology seems to have more of an industrial focus, which falls outside of our scope. Furthermore, the technology is essentially a facility on its own, not meeting retrofit requirement.

Name: Automatic Siphon Sludge Discharge Horizontal-Flow Settling system

Vendor: Guangzhou Xintao Wastewater Treat Company Ltd

Description /Abstract: Forms a vacuum pump in the siphon manner and sludge is discharged by utilizing the liquid level difference in the settling pond and the sludge discharge tank.

Source:
https://www.google.com/patents/CN204034340U?cl=en&dq=CN204034340&hl=en&sa=X&ved=0ahUKEwivn_Tah8bLAhXszoMKHYxhADUQ6AEIHTAA [85]

Patent Number: CN204034340

Reason for rejection: The scope of the project required us to focus on technologies that can be implemented within municipalities. This technology seems to have more of an industrial focus, which falls outside of our scope.

Name: Water Filtration System

Vendor: Internat Wastewater Heat Recovery Systems Inc

Description /Abstract: A waste filtration system is provided, suitable for separating waste content in a waste stream, for use in heat recovery, including a filter screen, auger and extractor pump.

Source:http://www.google.ne/patents/CA2809727A1?cl=en [86]

Patent Number: CA2809727

Reason for rejection: The scope of the project required us to focus on technologies that can increase capacity, unfortunately this technology cannot.