BlueTech Report on LIFT Water Technology Survey: Wastewater

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1 Introduction

The Water Research Foundation conducted an innovative water technology adoption and interest survey among water facilities in the United States and abroad. BlueTech has focused on a few technologies within wastewater, taking a global approach that is useful for comparison to the U.S.-centric LIFT survey results. In particular, BlueTech uses a technology adoption model to evaluate whether technologies are above, below, or on par with an average technology adoption rate. The model is based on the Rogers Bell curve (Figure 1) that groups technologies into Innovators, Early Adopters, Early Majority, and Late Majority based on the number of installations over time. The surveyed technologies include ones that fall into each of these adoption categories, and cover applications ranging from nutrient removal and recovery to intelligent water systems to anaerobic digestion enhancement (Table 1). This report examines the potential growth of technologies based on survey results and uses BlueTech databases where available to provide context and analysis of the survey results.

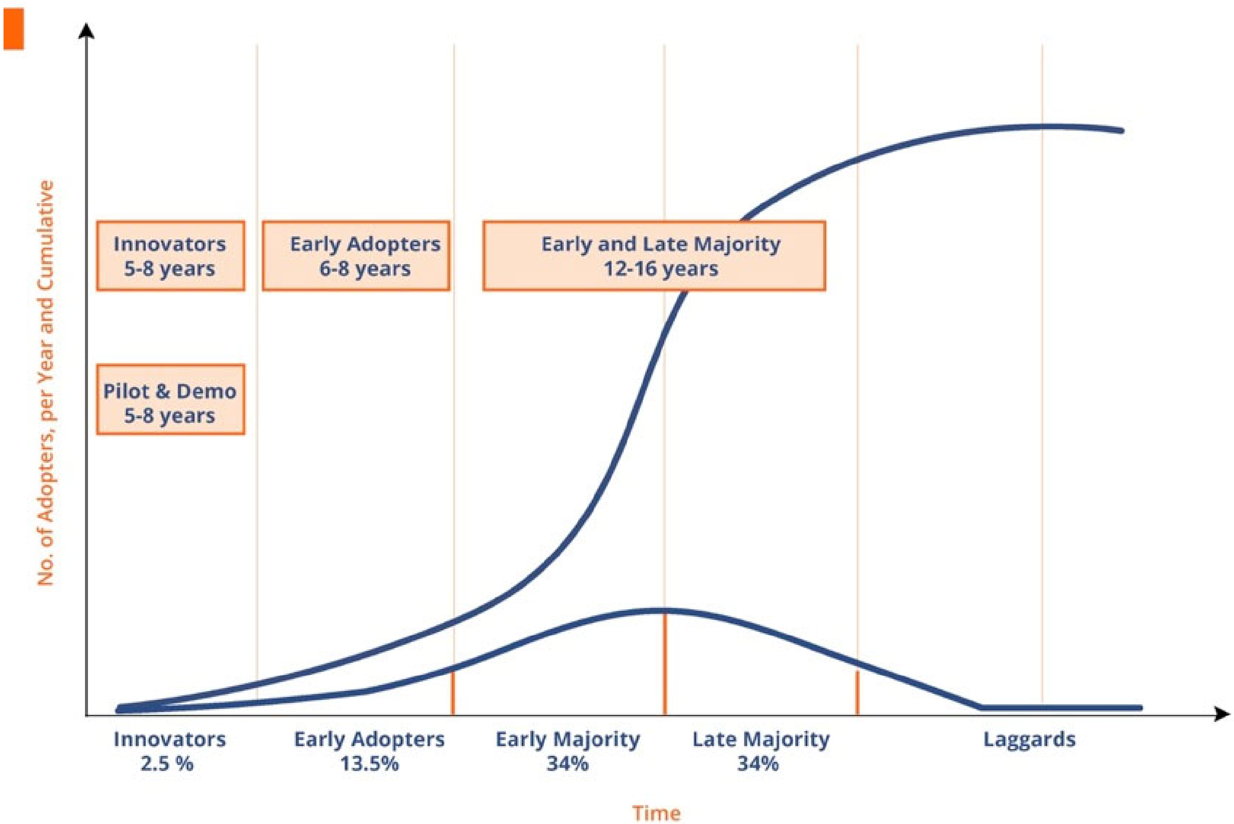

Figure 1: Rates of technology adoption according to the Rogers Bell curve, with less adoption in early and late phases. The cumulative adoption over time creates the adoption S-curve.

Table 1: The current adoption stages of technologies included in the survey among respondents.

Current Adoption Stage of Surveyed Technologies			
Nutrients	**Digestion**	**Intelligent Water**	**Disinfection**
Energy	**Collection Systems**	**Solids Management**	**Other**
Innovators	**Early Adopters**	**Early Majority**	**Late Majority**
Mainstream Deammonification	Regional Hubs For Small Systems	Techniques For Beneficial Use	Dewatering 15%-25%
Granular Sludge	Liquid Fertilizer	Dewatering > 25%	Thickening
Algae	Drying (e.g., Pelletization)	Composting For Solids Management	Class B Biosolids
Predictive Analytics	Scale Prevention	Class A Biosolids	Biological Nutrient Removal (BNR)
Internet of Things	Side-stream Deammonification	Watershed Monitoring	Biogas Recovery
Hydrokinetic Energy Recovery	Metagenomics	Phosphorus/Struvite Recovery	UV
Carbon Diversion	Decision Support Systems	Low DO Treatment	Chlorine
Biosolids to Energy	Membrane Aerated Bioreactors (MABR)	Chemically Enhanced Primary Treatment (CEPT)	
Biogas To Vehicle Fuel	Ozone	Remote Monitoring Of Collection Systems	
Anaerobic Treatment Of Low-Strength Wastewater (e.g., Fixed Film Reactors)	Two-Phase Digestion	Real Time Monitoring Of Sensors	
Anaerobic Membrane Bioreactors (AnMBR)	Sewershed Management For Contaminant Detection	Long-Term Asset Management	
Peracetic Acid	Next Generation Rehabilitation	Thermal Energy Recovery	
Thermal Hydrolysis	Next Generation Condition Assessment	Onsite Renewables (e.g., Solar or Wind)	
Temperature Phased Digestion	New Pipe Materials	Biogas Cleaning (e.g., Siloxane Removal)	
Mechanical Processes (Sonication, Pressure, Cavitation, etc.)	Managing Reduced Flows From Water Conservation	Advanced Blower Technology	
Chemical Processes (Alkaline Treatment, Hydrogen Peroxide, etc.)		Digester Mixing	
Biological Augmentation (e.g., Superbugs, Enzymatic Hydrolysis)		Co-Digestion	
Smart Pipes		Techniques for Blockages	
Urine Separation		Odor And Corrosion Control	
Micro-Pollutant Removal		Force Main Monitoring, Condition Assessment, Rehabilitation	

2 Materials and Methods

2.1 Summary of Data

There were 71 survey respondents from wastewater treatment facilities, encompassing an even distribution of small, medium, and large facilities. Twenty-four percent of respondents had small facilities, 44% had medium facilities, and 32% had large facilities.

Additionally, respondents were distributed evenly across the United States geographically with 25% of respondents from the Midwest, 25% of respondents from the West, 25% of respondents from the South, and 18% of respondents from the Northeast. Only 6% of respondents were from international facilities.

Respondents answered whether they had already installed or had interest in installing various types of innovative water technologies in the categories of nutrients issues, solids management, energy efficiency and recovery, digestion enhancements, intelligent water systems, disinfection technology, and collection systems.

2.2 Analysis Methods

Since the survey is voluntary, BlueTech has taken the type of respondent to be those already interested in new and innovative technologies, as opposed to facilities who are satisfied with status quo procedure. For that reason, rates of interest and adoption shown in the survey are assumed to be higher than average market rates for these technologies. In the Rogers model of innovation, only 2.5% of adoption indicates the transition from Innovators to Early Adopters; however, adoption of early technology was highly prevalent among survey respondents. To account for this, the following rates of adoption were used to analyze the survey results:

- Innovators – 0% to 5%
- Early Adopters – 5% to 15%
- Early Majority – 15% to 40%
- Late Majority – greater than 40%

In addition to percent adoption, a velocity model was applied to analyze the current technology adoption stage against its projected stage in five years. Early stage technologies are expected to only grow slightly in adoption within five years, while more mature technologies are expected to increase market adoption more quickly. Thus, the adoption model forms an S-curve as technologies pick up adoption towards Early Majority and slow down as the market reaches saturation after Late Majority.

In the following sections, technologies are categorized by their projected progress in the next five years compared to an expected rate of progression; technologies are expected to spend about four years in the Innovators stage (which includes pilot and demonstration scale projects), four years in an Early Adopters stage as full scale references are developed, five years in Early Majority as projects begin to pick up speed, then six or more years in Late Majority before market saturation is reached. A technology may take 11–15 years to develop from an early stage of Applied Research to reach Early Majority.

The technologies are grouped by whether they are ahead of the expected timeline (Fast Growth technologies), about the same as the expected timeline (Moderate Growth technologies), or whether projected adoption falls far behind where a technology should be in five years to be successful (Flat Liner technologies). Flat Liner technologies are not necessarily poor solutions; they may simply require market drivers that are not yet in place.

3 Results

3.1 Fastest Growth

A handful of technologies stand out as having the potential for fast growth in the near future due to high levels of interest among survey respondents. Included are several technologies relating to **nutrient management**, such as sidestream and mainstream deammonification for simultaneous nitrification and denitrification and struvite precipitation for phosphorus management and recovery. Deammonification is driven strongly by the ability to perform nutrient removal in one stage instead of multiple stages, thus reducing capital and operating costs. Phosphorus recovery is driven by the benefit of nutrient removal and reuse, and is enabled by the relative simplicity of struvite precipitation, separation, and recovery. Some solutions for **digestion** also see the potential for high growth, especially thermal hydrolysis for improving the quality and dewaterability of biosolids and to a lesser extent the potential for bio-augmentation to assist in digestion. Similarly, post-digestion technologies for **energy recovery**, such as the upgrading of biogas to vehicle fuel or the use of pyrolysis, gasification, hydrothermal liquefaction or supercritical water oxidation to harvest energy from biosolids, have high potential for adoption. Lastly, technologies for **intelligent water systems** are gaining traction in the water industry following developments in other industries, especially solutions for decision support systems such as big data processing, predictive analytics tools, and products that are part of the Internet of Things (i.e., connecting previously unconnected hardware and components).

A few technologies overlap with where BlueTech has focused in the past few years, confirming that the drivers and trends are seen by technology providers and end users alike, including:

- **Sidestream shortcut nitrogen removal**
- **Mainstream shortcut nitrogen removal**
- **Thermal hydrolysis**

Table 2: Current and potential adoption stages of fast growth technologies.

Technology	Current Stage	Potential 5-year Stage
Sidestream shortcut nitrogen removal	Early Adopters	Early Majority
Mainstream shortcut nitrogen removal	Innovators	Early Majority
Phosphorus/struvite management	Early Adopters	Late Majority
Thermal hydrolysis	Innovators	Early Majority
Decision support systems (e.g., big data)	Early Adopters	Early Majority
Predictive Analytics	Innovators	Early Majority
Internet of Things	Innovators	Early Majority
Biogas to Vehicle Fuel	Innovators	Early Adopters
Biosolids to Energy	Innovators	Early Adopters
Biological augmentation [for digestion] (e.g., superbugs)	Innovators	Early Adopters

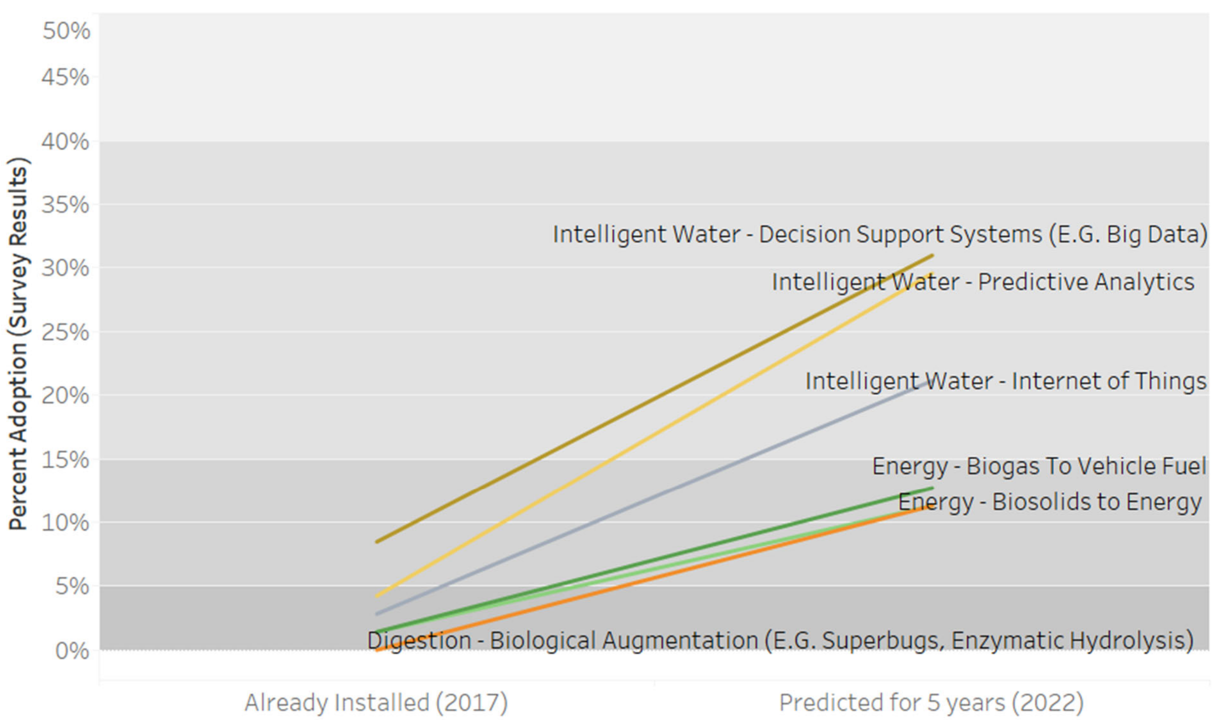

Figure 2: Select technologies identified as poised for fast growth in the near future.

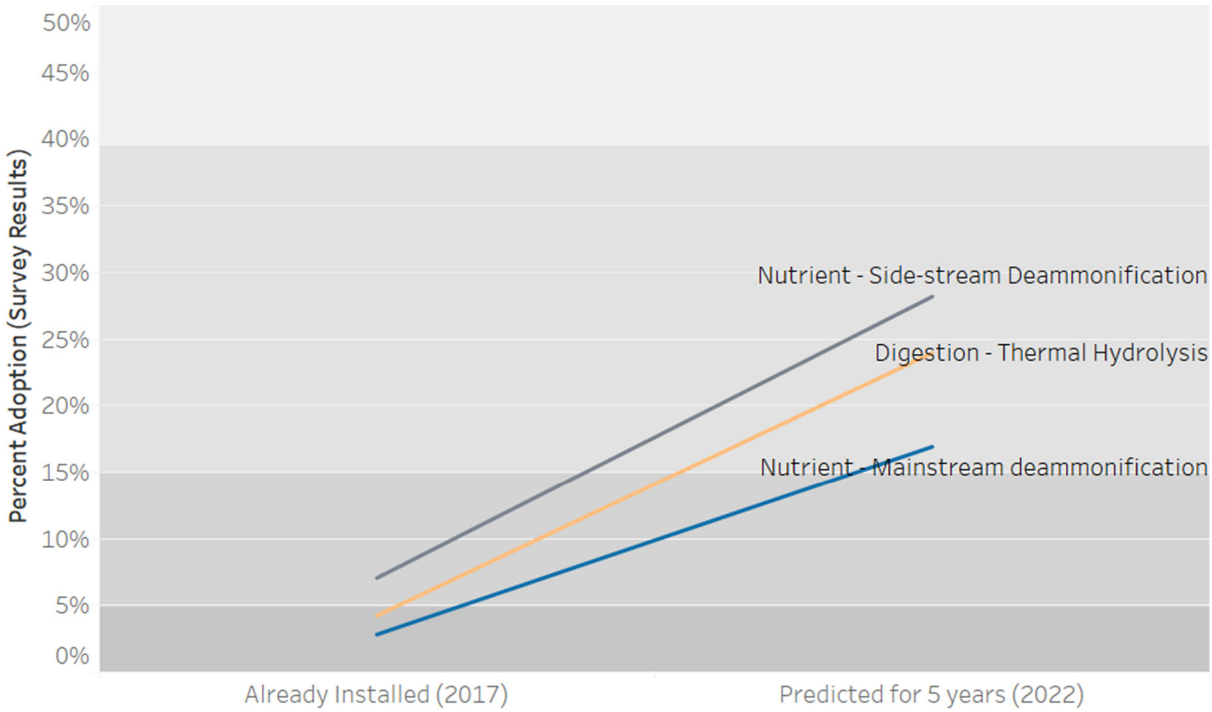

Figure 3: Select technologies identified as poised for fast growth in the near future that BlueTech has also analyzed for historical and future growth.

3.1.1 Sidestream and Mainstream Shortcut Nitrogen Removal

As an alternative to nitrification-denitrification biological nutrient removal, deammonification accomplishes both steps simultaneously, which is made possible by specific annamox bacteria that can metabolize ammonia to nitrogen gas. Sidestream treatment, where deammonification is applied to a separate stream of high strength wastewater, has been adopted ahead of mainstream treatment due to difficulties in applying the process over entire flows. The survey results indicate that the potential for deammonification overall is strong. In fact, current growth potential is stronger in mainstream deammonification than sidestream, likely due to adoption of sidestream treatment paving the road for adoption of mainstream treatment. While mainstream treatment is currently in an Innovators stage of adoption, it is expected to enter an Early Majority stage among survey respondents in five years, a process which would ordinarily take 5-7 years. For more information on mainstream deammonification, see the WERF report *Mainstream Deammonification* (O'Shaughnessy 2015).

BlueTech has found that sidestream deammonification has enjoyed wide adoption, particularly in Europe and Asia, and is into the Early Majority stage globally, where references are predominantly in Europe and Asia (Figure 4). Since this technology has a high number of references worldwide, there should be little in the way of adoption by interested North American facilities.

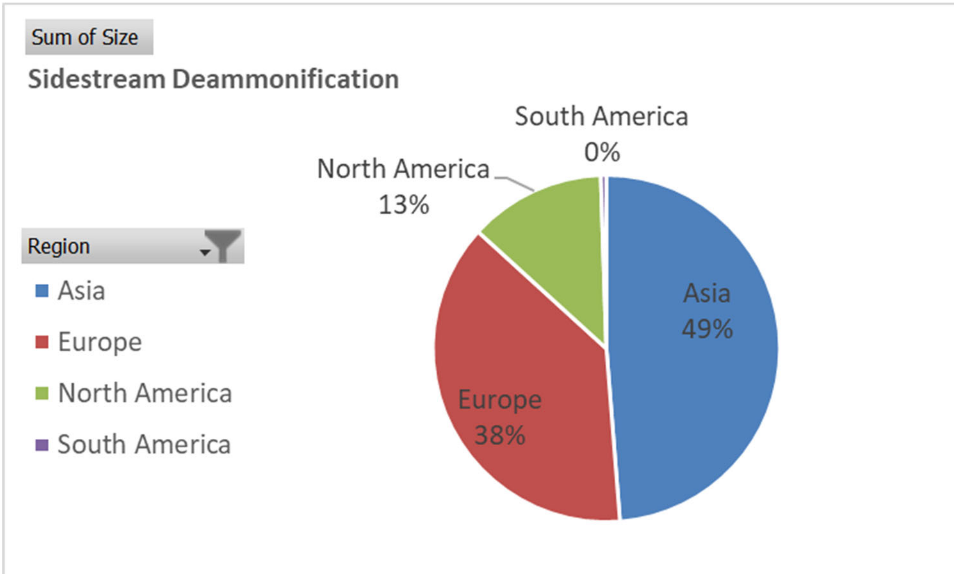

Figure 4: BlueTech tracking of global installations of sidestream shortcut nitrogen removal (deammonification) showing geographic distribution by cumulative installation size.

3.1.2 Thermal Hydrolysis

The second technology deals with digestion enhancement. The survey showed a general high interest in improved digestion technologies. Thermal hydrolysis uses heat and pressure followed by rapid depressurization to make sludges amenable to aerobic degradation, allowing for either direct land application or more efficient anaerobic digestion. As an installation, it can be added as retrofit to existing digesters.

BlueTech has identified the U.S. municipal wastewater market as a difficult contender for this technology due to more complicated operations. Rather, it is a desirable technology for industrial wastewater markets. However, federal limitations on biosolids usage and disposal drive adoption of technologies that can produce Class A biosolids, such as thermal hydrolysis. The LIFT survey respondents (solely municipal facilities), reveal that thermal hydrolysis is currently utilized in two U.S. municipalities and has high interest among other municipalities of all sizes.

The survey results predict that installations for thermal hydrolysis digestion enhancement will jump into an Early Majority stage within five years from a current Innovators stage of adoption. Globally, there are already numerous installations in both industrial and municipal markets. BlueTech estimates that the global market has a reached a Late Majority stage of adoption (Figure 5). As with sidestream deammonification, the large number of existing references abroad will pave the way for high-speed adoption in North America.

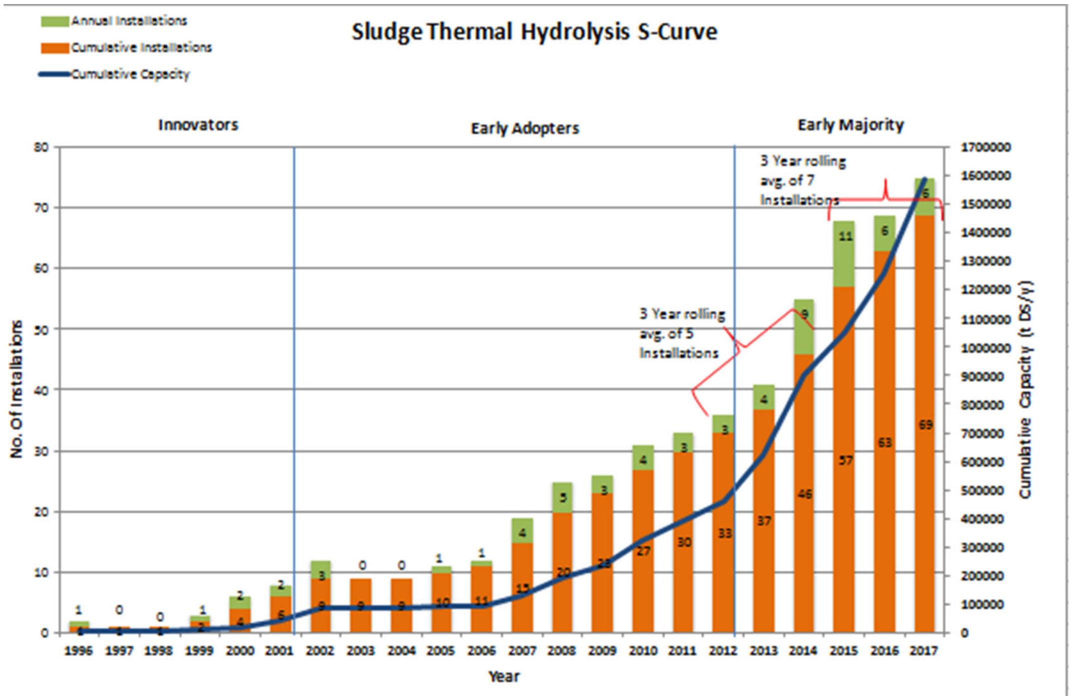

Figure 5: BlueTech technology S-curve for thermal hydrolysis sludge pre-treatment in both municipal and industrial markets.

3.2 Rapid Growth

Several technologies were identified through the survey as slated for fast growth in the near future, but not advancing quite as quickly through adoption stages as the first group of technologies. Each of these technologies demonstrates a different point in the adoption cycle, and the time it takes to reach the next point in the adoption cycle. Each of these projections follows an average estimated time for progress, although linearly, they appear to be on different trajectories.

Carbon diversion and struvite management are both budding technologies; co-digestion and long-term asset management continue on a path to maturity; and advanced blower technology continues to grow despite high adoption rates likely due to an economically wise trade-off in installation costs versus energy savings. Interestingly, these are all driven by **circular economy and sustainability** initiatives.

Struvite precipitation and recovery, described further below, removes phosphorus from wastewater in a form applicable to agricultural fertilizer. Carbon diversion is a relatively new idea for diverting carbon-rich solids from activated sludge to an anaerobic digester, which simultaneously reduces biological oxygen demand and prevents creation of carbon dioxide. Potential technologies for carbon diversion include enhanced primary treatment, filtration, or high-rate systems. LIFT has screened primary effluent filtration technologies as part of its *Intensification of Resource Recovery* program, which looks at technologies that can reduce capital costs for treatment plants.

Digestion enhancements and smart water systems were well-represented in the fastest growth group by thermal hydrolysis, biological augmentation, predictive analytics, decision support systems, and Internet of Things technologies. Next are co-digestion for digestion enhancement and intelligent long-term asset management. Co-digestion is a precursor to carbon diversion, as it uses additional high-carbon waste streams such as fats, oils, and grease (FOG) for digester supplements instead of diverting within wastewater itself. Intelligent solutions for asset management reduce energy and material waste by using data to drive decisions on repairs and replacements.

Table 3: Current and potential adoption stages of rapid growth technologies.

Technology	Current Stage	Potential 5-year Stage
Digestion - Co-Digestion	Early Majority	Late Majority
Energy - Advanced Blower Technology	Early Majority	Late Majority
Energy - Carbon Diversion	Innovator	Early Majority
Intelligent Water - Long-Term Asset Management	Early Majority	Late Majority
Nutrient - Struvite management	Early Adopters	Early Majority

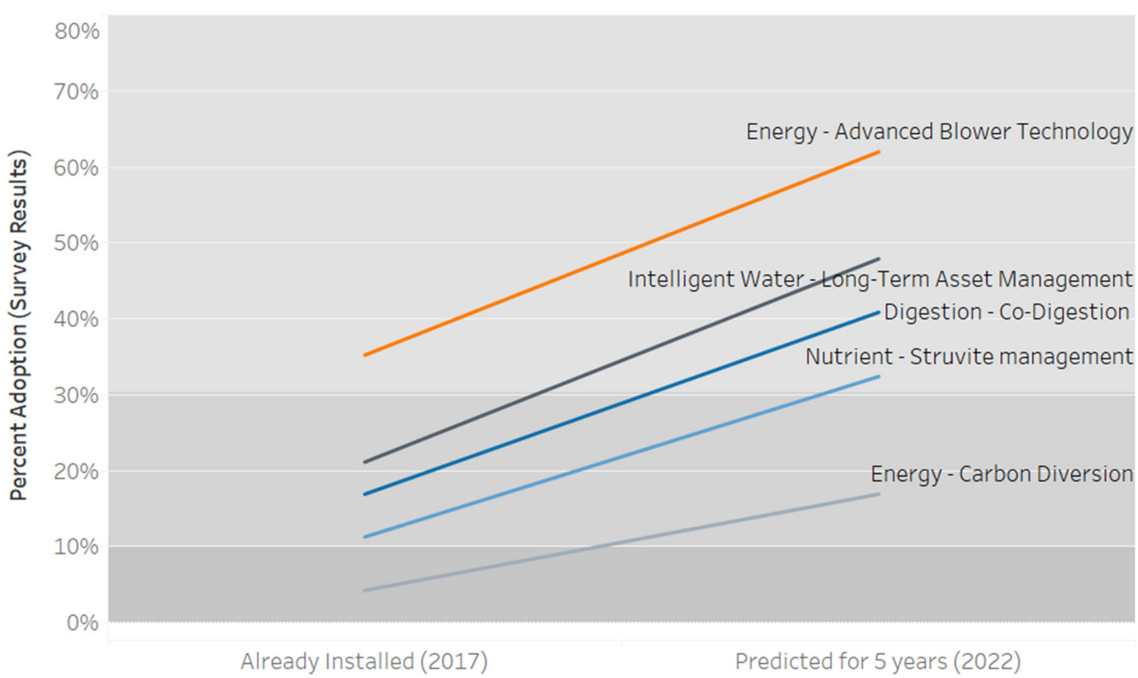

Figure 6: Technologies poised for rapid growth in the near future.

3.2.1 Struvite Management (for Phosphorus Recovery)

Multiple technologies exist for the recovery of phosphorus from wastewater and wastewater sludge. One of the hurdles to adoption of such technologies is the gap between cost of implementation and the value of recovered minerals, either phosphate or the phosphate compound struvite. Removal of struvite is also of interest since it can result in scaling of equipment. Struvite as a phosphorus recovery technique is arguably the most straightforward, however, it typically has low recovery efficiency. Other techniques of phosphorus recovery first combust sludge to ash and recover phosphorus from the ash content. Struvite recovery is now a competitive option with companies such as Ostara improving technology performance.

BlueTech tracking of struvite installations has seen steady adoption of the technology over time, differing in pattern from the predicted technology adoption curve, but the number of total installations show that the technology is still in early stages of adoption, thus matching with LIFT survey results. The higher rate of adoption compared to other technologies is likely due to a lower hurdle to adoption since the technology can be installed easily among existing unit processes and is simple to operate. The high level of growth indicated in North America by the survey results is likely driven by the ease of adoption rather than a high number of existing references globally, with a prediction of reaching Early Majority in five years.

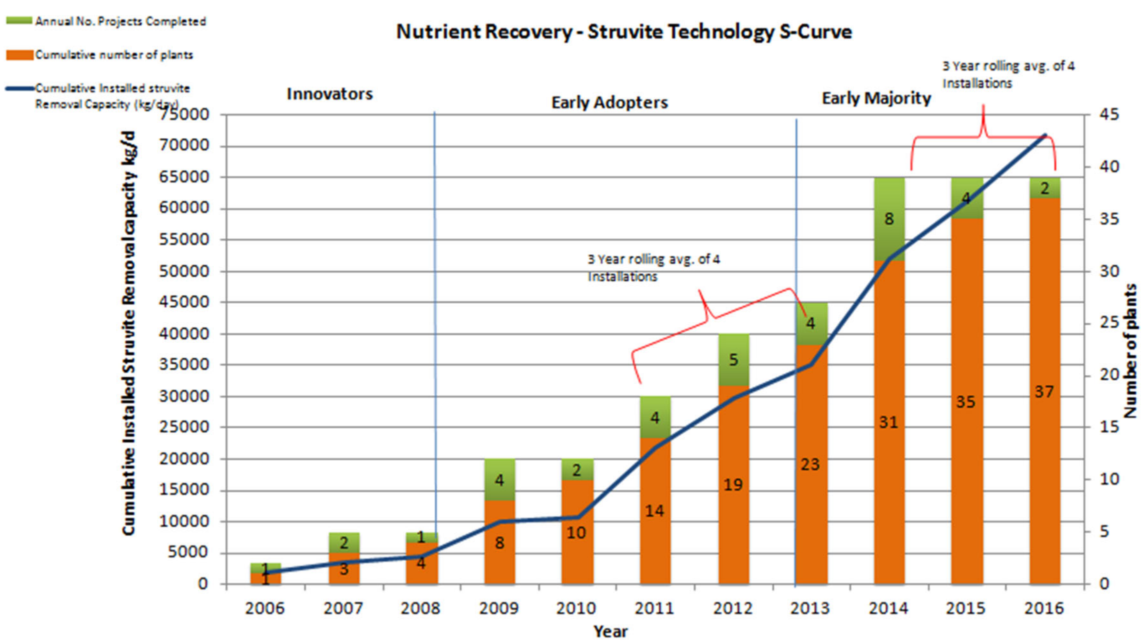

Figure 7: BlueTech technology S-curve for struvite recovery installations.

3.3 Moderate Growth

Most of the technologies included in the survey are predicted to undergo moderate growth in the near future, that is, growth at rates at or just below the average growth model. Those in the Innovators stage would move into the Early Adopters stage in five years, and those in the Early Majority stage would move into a Late Majority stage in five years. These are technologies that are not driven or enabled significantly, but are instead typically growing primarily due to a value proposition.

- Class A biosolids
- Real time monitoring using sensors
- Sludge dewatering >25%
- MABRs
- Granular activated sludge
- Anaerobic membrane bioreactors (AnMBRs)
- Biogas cleaning (e.g., siloxane removal)
- Onsite renewables
- Thermal energy recovery
- Biological enhancements (e.g., metagenomics)
- Temperature-phased digestion
- Mechanical digestion enhancement

The moderate growth technologies include solids management technologies for Class A biosolids and dewatering above 25% dry solids. These technologies provide more options for biosolids management and disposal, including reduced cost of transportation or even revenue generation from the sale of fertilizer quality biosolids. These are examples of value propositions since the processing is not required in the United States. Similarly, technologies for the on-site generation and use of renewable energy, upgrading of biogas, and recovery of thermal energy are value-driven via energy generation and recovery.

Other technologies include real-time monitoring using sensors, anaerobic membrane bioreactors (AnMBRs), metagenomics for biological process optimization, and digestion enhancement via temperature phasing or mechanical digestion. Each provides value through increased efficiency, either through data-supported decision making, a robust energy-generating process with a small footprint, selection of optimal microbial communities, temperature optimization of anaerobic digestion, or ease of digestion through mechanical pre-treatment. However, even with value propositions, these technologies are not the front runners in their respective areas. For example, the survey respondents showed less interest in real-time monitoring than decision support systems or predictive analytics, although sensor networks used in real-time monitoring would be necessary for technologies using predictive analytics or providing decision support.

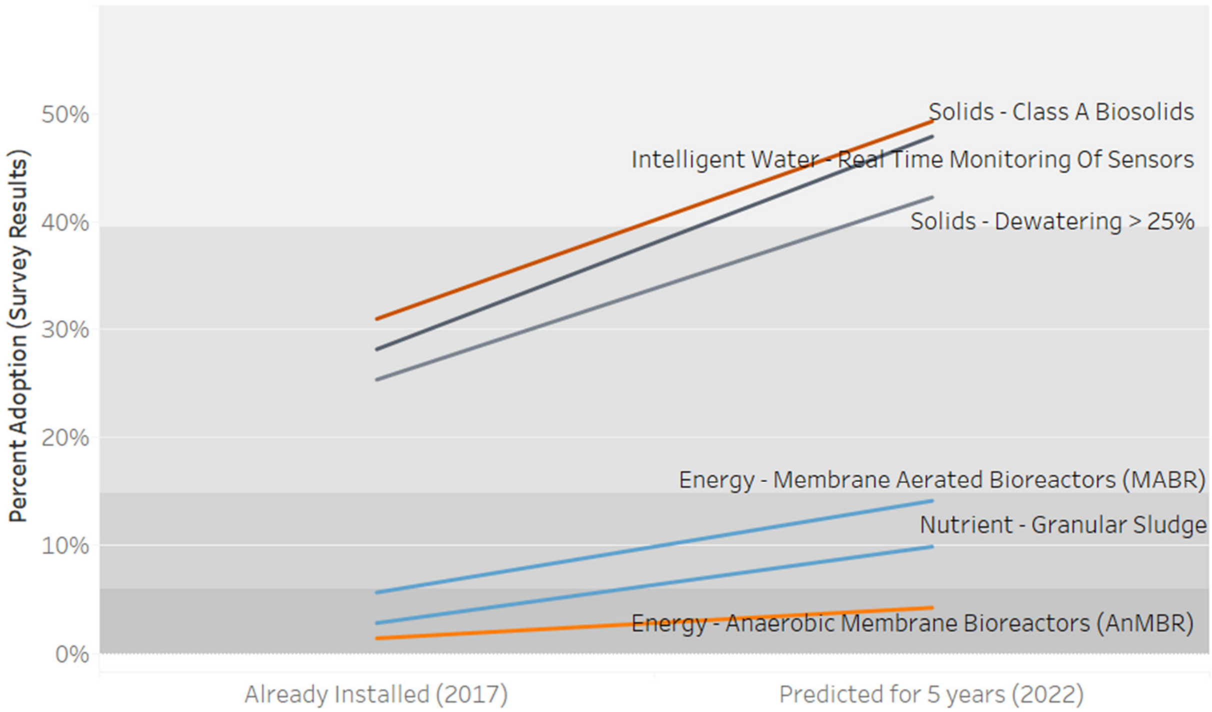

Figure 8: Select technologies identified for moderate growth in the near future, including Granular Sludge and MABR which are tracked closely by BlueTech Research.

A spotlight on two of the technologies—granular activated sludge and MABRs—provides examples of moderate growth technology adoption in North America in context of global adoption tracked by BlueTech Research.

3.3.1 Granular Sludge

Granular activated sludge harnesses sludge microbial communities into granules, forming aerobic, anoxic, and anaerobic zones that simultaneously achieve multiple types of biological treatment. In effect, it is similar to sidestream and mainstream deammonification. A benefit of the granules is that the process, which replaces activated sludge, does not require clarification since the granules can be removed by coarse filtration.

Nereda, the first major technology of this type, came out of The Netherlands and, likely for this reason, has seen higher adoption in Europe than North America. BlueTech estimates that granular sludge is in the Early Majority stage globally (Figure 9). The LIFT survey predicts a transition from an Innovators stage to an Early Adopters stage within the United States, where currently few installations exist. Similar to deammonification, the adoption of granular sludge in North America will be supported by references abroad.

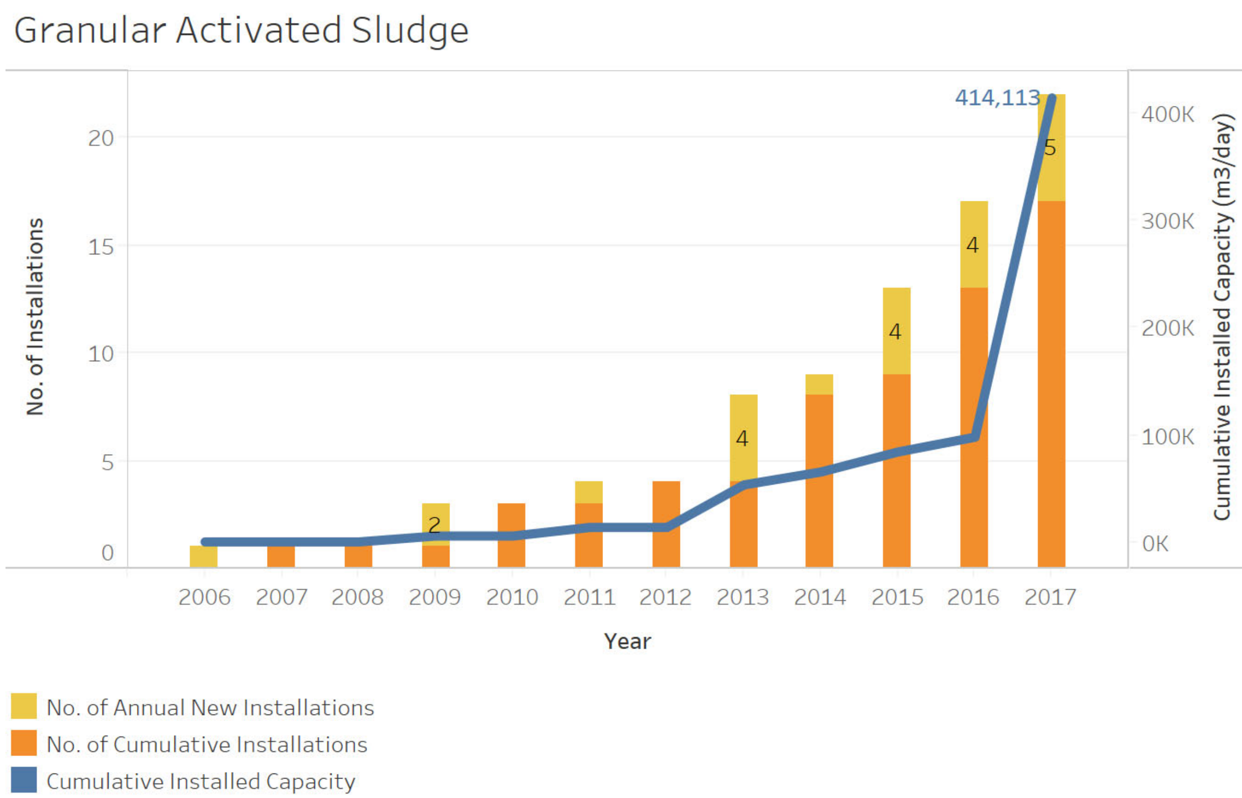

Figure 9: BlueTech technology S-curve for granular sludge.

3.3.2 Membrane Aerated Bioreactors (MABRs)

MABRs are a lesser known technology often confused with membrane bioreactors (MBRs). The technology reduces costs of aeration by passively aerating through air-permeable membrane material. The process increases the surface area and contact time between air bubbles and microbial communities, thus more efficiently utilizing supplied air. Additionally, MABRs can be designed so that little oxygen is transferred into the bulk mixed liquor, creating both aerobic and anoxic microbial communities in the same tank.

MABR providers include GE's Zeelung (now Suez), Fluence, and Oxymem. Additionally, BioGill produces a ceramic membrane trickling filter that results in passive aeration, putting it in a similar category to MABRs. Globally, there are few installations and North America has the largest installation to date. BlueTech data and LIFT survey results are in agreement on MABRs, finding that installations are distributed evenly worldwide, with the current status on the brink between Innovators and Early Adopters. If the LIFT survey results hold for global installations, then MABRs will be entering Early Majority in five years.

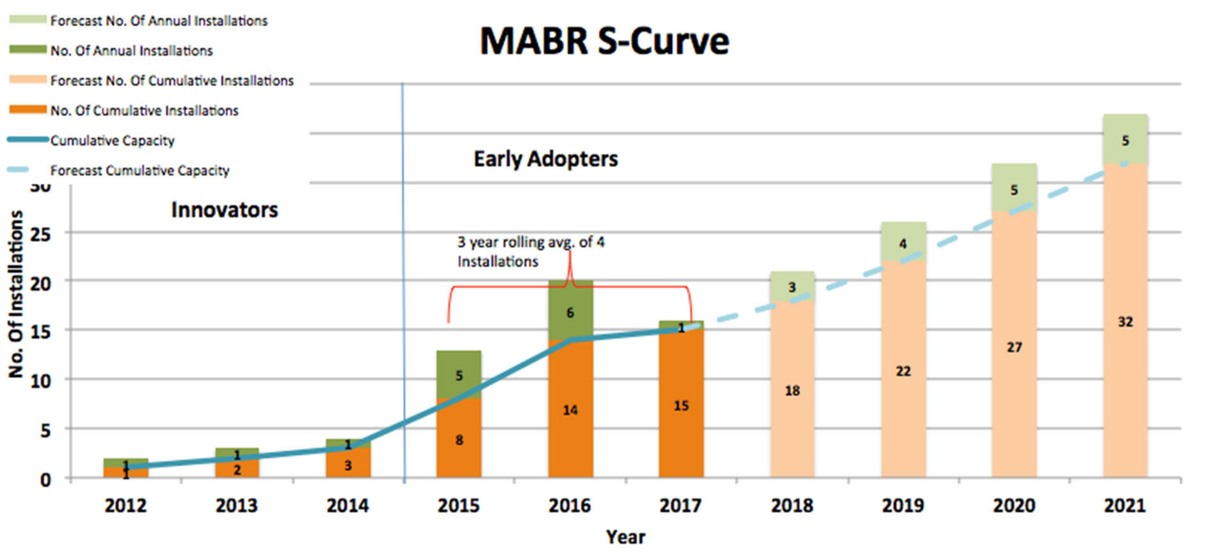

Figure 10: BlueTech technology S-curve for MABRs.

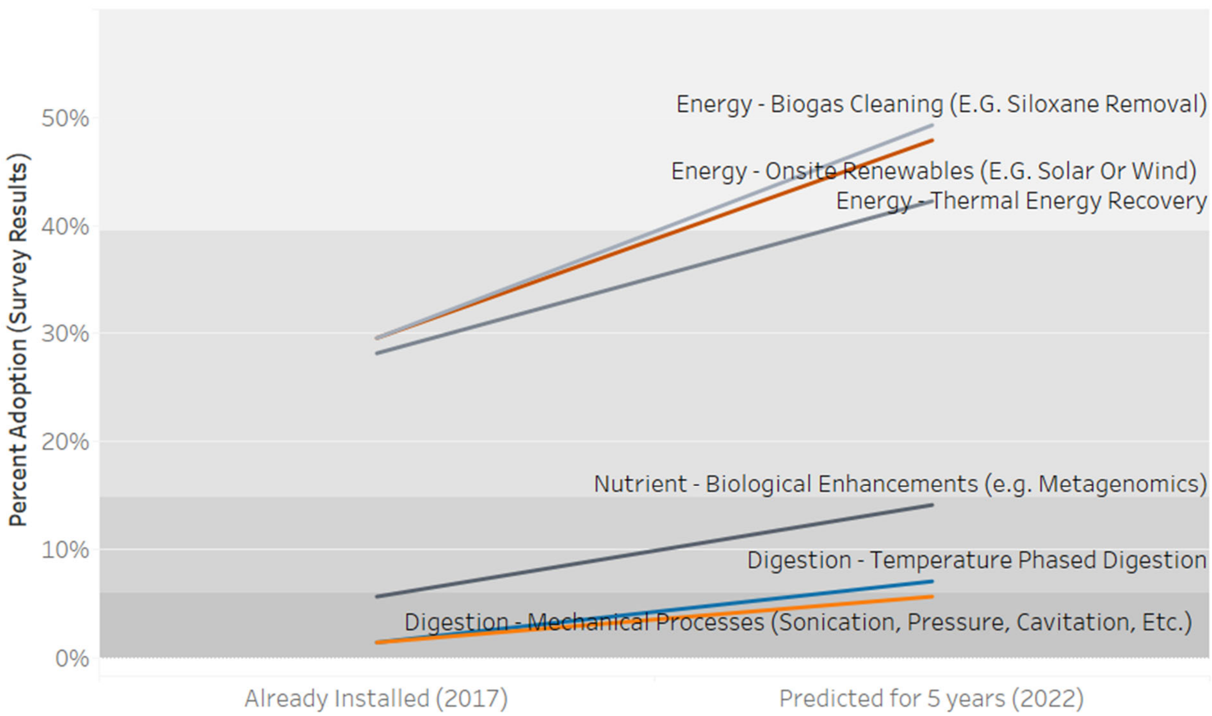

Figure 11: Additional technologies identified for moderate growth in the near future.

3.4 Flat Liners

Several technologies presented as flat liners—technologies with no potential growth based on survey results that are either stalled or will not take off (Figure 12). Flatlining technologies are not necessarily poor or flawed technologies. A lack of interest from survey respondents may speak to poor timing or a non-ideal market.

- Hydrokinetic energy recovery
- Chemical digestion enhancement
- Anaerobic treatment of low-strength wastewater
- Sludge as liquid fertilizer
- Ozone disinfection
- Two-phase digestion
- Sludge drying to pelletization
- Composting for solids management
- Low dissolved oxygen treatment
- Chemically enhanced primary treatment

Some technologies are process inhibited, such as anaerobic treatment of low-strength wastewater where the ability to efficiently grow microorganisms is limited. Others may be unsuitable for wastewater application, such as hydrokinetic recovery from collection infrastructure where the amount of energy to be recovered is too small to significantly cover the cost of installation and upkeep. Lastly, some technologies are too costly with little additional trade-off compared to competitor technologies, such as ozone disinfection. Ozone is slightly more established than the other two technologies due to positive benefits such as avoiding disinfection byproducts, though all three are in early stages.

Some technologies have higher rates of adoption but are still expected to see limited growth soon. For example, sludge pelletization, a process where sludge is dried to 90% dry solids, has enough current installations to put it into Early Adopters, but is expected to only grow slightly in the next few years. A likely reason is that pelletization is an energy intensive process and the trade-off is positive only when the energy of sludge disposal is also high, such as off-site transport to permissible land application.

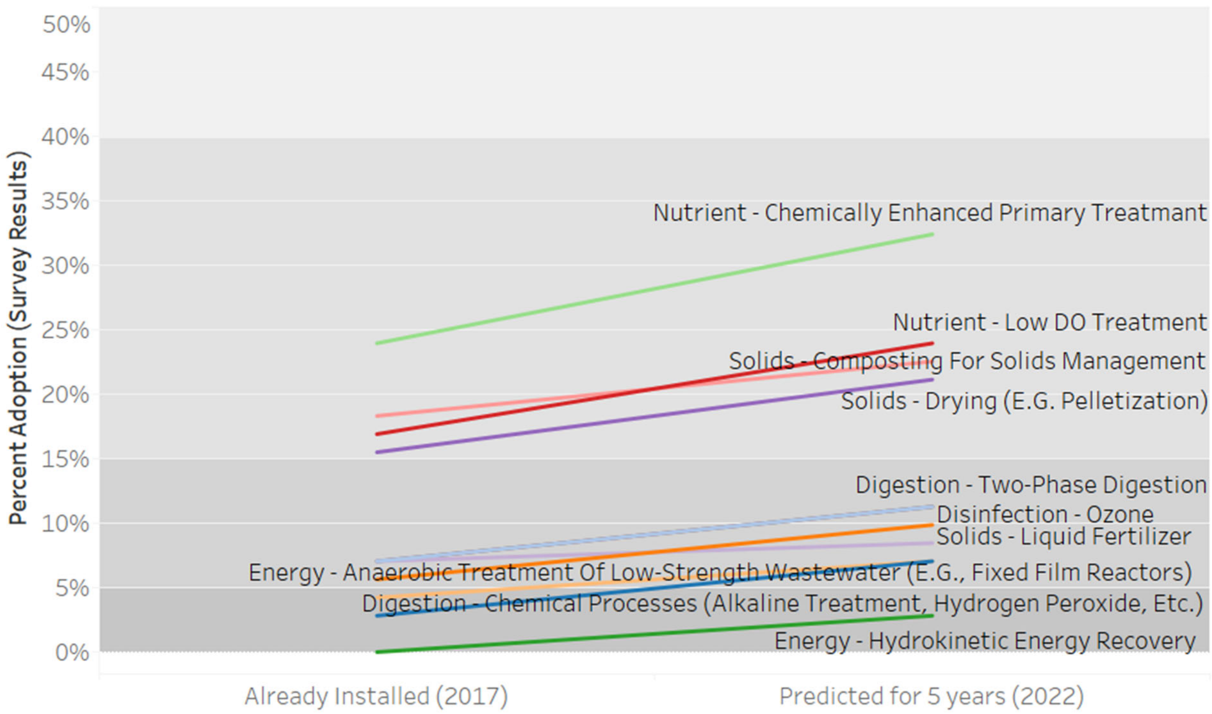

Figure 12: Technologies with limited or stalled growth in the near future.

4 References

O'Shaughnessy, M. 2015. *Mainstream Deammonification.* Project INFR6R11. Alexandria, Va.: Water Environment Research Foundation.