Business Opportunities for Water Pollution Remedies using Microbiomes

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Abstract
Water pollution occurs for many different reasons, both anthropogenic and natural. According to the U.S. Environmental Protection Agency in 2008/2009 "46% of our rivers and streams are in poor biological condition. Poor biological condition can lead to loss of fishing and recreational opportunities." The decreased water quality of the US water bodies is a growing public cost. The EPA has multiple grants to help municipalities treat water bodies and water treatment is a multi-billion dollar industry. Microbiome is a promising treatment option due to advanced processes such as CRISPR technology that edit genes to create the desired outcome. With the ability to create specialized solutions, microbe technology companies must analyze the market opportunities within the water pollution industries to determine if the research and development costs are worth expected future returns. This report will look at three water treatment industries; hydrofracking wastewater, wastewater reuse and recycling, and nutrient pollution in freshwater. The analysis will determine if there is an opportunity for a biological treatment in these industries and if there is a financial benefit to the R&D and commercialization of such a product.

Introduction
Water pollution occurs for many different reasons, both anthropogenic and natural. NRDC defines water pollution as "harmful substances-often chemicals or microorganisms- contaminating a stream, river, lake, ocean, aquifer, or other body of water, degrading water quality and rendering it toxic to humans or the environment[i]." The public's increased awareness of how water pollution is affecting us, from hydrofracking wastewater disposed into streams to dead zones from agriculture run off, is creating a business opportunity to find a cost effect solution to remedy or reduce the severity of water pollution. There are many reasons why an entity would pay for a remedy; such as a reducing the cost for regulated water treatment, or increasing the recreational and economic benefit, and thus revenue, such as a lake or river for fishing and real estate vale.
According to the U.S. Environmental Protection Agency in 2008/2009 "46% of our rivers and streams are in poor biological condition. Poor biological condition can lead to loss of fishing and recreational opportunities[ii]." Roughly one-third of our lakes are polluted from excess nitrogen and "40% have excess pollution, increasing the likelihood of algal blooms, and low levels of oxygen[iii]." Nutrient pollution from fertilizer, animal manure, sewage treatment plant discharge, etc. is the leading type of contamination in our water[iv]. The decreased water quality of the US water bodies is a growing public cost. The EPA has multiple grants[v] to treat the water bodies used for recreation and drinking water, but it can still be a significant financial strain on local government.
This report will review three water pollution treatment markets; hydrofracking, wastewater reuse and recycling, and freshwater nutrient pollution. The analysis will determine the ability to use microbiomes to treat pollution and the size of the market to calculate Net Present Value of the investment for development and commercialization of a product using microbiomes. The market analysis includes current commercial remedies and problems, size of the current market and expected growth. The financial analysis will determine the cost of research, time value of money and expected revenue for the life of the project to calculate an NPV.

Microbiome Technology

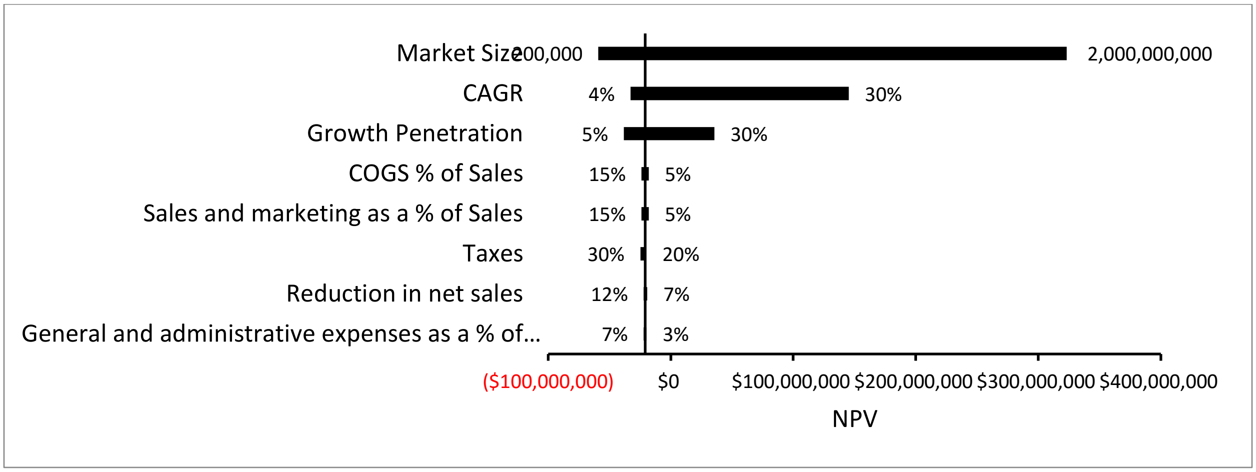
Microbiome research has been growing in interest as a biological solution for multiple issues due to the substantially decreased cost of DNA sequencing. "The findings have generated knowledge on the roles that populations of microorganisms play in determining human health and also in defining soil fertility, crop performance and defense against disease and stresses in agriculture[vi]." Microbiome research includes solutions for human health, animal health and agriculture inputs from microbes found around the world. For example, biological fungicide is now being marketed as an organic replacement with results equal or greater than synthetic fungicides for agriculture. Additional research is going beyond finding current microbes to using technology such as CRISPR to enhance the results of the microbe. In an interview with the Chief Innovation Officer for one microbiome company, she said the opportunities to use microbiomes are endless and gave an example of modifying a microbe to change color in the presence of a harmful substance such as uranium or *E. coli,* thus creating a real-time monitoring of water quality. With such a versatile scientific field and over $1.5 Billion of private and public investment[vi] the opportunity to find a microbial solution to treat different water pollution issues seems likely in the near future.

Financial Modeling Method

NPV stands for Net Present Value. This is a common formula to determine if the cost of research and development will give a positive return on investment over the life of the project. This analysis assumed a cost of $100MM over 10 years, with commercialization starting on year 11. The patent would protect the product for the first 10 years of commercialization, after which market penetration would be stagnant. The product would be discontinued after year 25.

To calculate NPV, certain assumptions need to be made for each market opportunity; specifically, size of the market, penetration into the market and CAGR. Company discount rate, cost of capital (sometimes referred to as the opportunity cost of capital) is assumed to be 11%. Sales and Marketing Costs and General and Administrative costs are assumed to be 5% each except in highly infiltrated markets. Taxes are 22% and COGS is 10% of sales. Reduction in net sales refers to drop in sales when a generic product enters the market in year 21. A sensitivity tornado chart was used to determine which assumptions were most critical to a positive NPV. (Figure 1) The overall size of the market in 2020 was the greatest indicator of NPV, followed by CAGR and then penetration into the market. The other factors are not considered material.

Figure 1: Tornado Sensitivity Chart for determining NPV of biological commercialization.



To further understand what market size and CAGR is necessary for a positive NPV, a simple sensitivity chart was created. The market penetration was placed at 10%, a low expected growth over 10 years. All reasonable CAGR would still result in a negative NPV for any market size below $75MM (Table 1). Even with a market size of $275MM, a high CAGR of 15% would be necessary for a positive ROI.

Table 1: NPV sensitivity analysis of Market Size and CAGR with 15% Market Penetration over 10 years.

	Market Size (10% Market Penetration)						
CAGR	**30,000,000**	**50,000,000**	**75,000,000**	**125,000,000**	**200,000,000**	**250,000,000**	**275,000,000**
4%	$ (56,099,839)	$ (54,110,201)	$ (51,623,155)	$ (46,649,061)	$ (39,187,921)	$ (34,213,827)	$ (31,726,780)
5%	$ (55,889,646)	$ (53,759,880)	$ (51,097,672)	$ (45,773,256)	$ (37,786,633)	$ (32,462,218)	$ (29,800,010)
7%	$ (55,413,942)	$ (52,967,040)	$ (49,908,412)	$ (43,791,157)	$ (34,615,273)	$ (28,498,018)	$ (25,439,390)
9%	$ (54,853,323)	$ (52,032,674)	$ (48,506,864)	$ (41,455,243)	$ (30,877,812)	$ (23,826,191)	$ (20,300,381)
11%	$ (54,192,334)	$ (50,931,027)	$ (46,854,393)	$ (38,701,126)	$ (26,471,224)	$ (18,317,957)	$ (14,241,323)
15%	$ (52,493,449)	$ (48,099,552)	$ (42,607,180)	$ (31,622,436)	$ (15,145,321)	$ (4,160,578)	$ 1,331,794
20%	$ (49,408,691)	$ (42,958,289)	$ (34,895,286)	$ (18,769,280)	$ 5,419,729	$ 21,545,735	$ 29,608,738
25%	$ (44,761,433)	$ (35,212,859)	$ (23,277,140)	$ 594,296	$ 36,401,451	$ 60,272,887	$ 72,208,605
30%	$ (37,788,648)	$ (23,591,550)	$ (5,845,177)	$ 29,647,568	$ 82,886,686	$ 118,379,431	$ 136,125,804

To emphasize the importance of market penetration, we did the same sensitivity analysis with a market penetration of 25% by year 10 (Table 2). With a greater share of the market, any CAGR would be acceptable in a market size over $275MM. Therefore the development of a strong marketing and sales strategy is just as important as the development of the microbiome product for commercial success.

Table 2: NPV Sensitivity Analysis for Market Size and CAGR with market penetration of 25% by year 10.

	Market Size (25% Market Penetration)						
CAGR	**30,000,000**	**50,000,000**	**75,000,000**	**125,000,000**	**200,000,000**	**250,000,000**	**275,000,000**
4%	$ (52,089,977)	$ (47,427,099)	$ (41,598,501)	$ (29,941,305)	$ (12,455,511)	$ (798,315)	$ 5,030,283
5%	$ (51,500,062)	$ (46,443,907)	$ (40,123,713)	$ (27,483,326)	$ (8,522,744)	$ 4,117,643	$ 10,437,837
7%	$ (50,153,918)	$ (44,200,334)	$ (36,758,353)	$ (21,874,391)	$ 451,551	$ 15,335,512	$ 22,777,493
9%	$ (48,551,476)	$ (41,529,596)	$ (32,752,247)	$ (15,197,548)	$ 11,134,501	$ 28,689,200	$ 37,466,549
11%	$ (46,644,810)	$ (38,351,820)	$ (27,985,583)	$ (7,253,108)	$ 23,845,604	$ 44,578,079	$ 54,944,316
15%	$ (41,683,223)	$ (30,082,508)	$ (15,581,614)	$ 13,420,173	$ 56,922,854	$ 85,924,641	$ 100,425,534
20%	$ (32,535,524)	$ (14,836,344)	$ 7,287,632	$ 51,535,583	$ 117,907,509	$ 162,155,460	$ 184,279,436
25%	$ (18,570,204)	$ 8,439,190	$ 42,200,932	$ 109,724,416	$ 211,009,643	$ 278,533,128	$ 312,294,870
30%	$ 2,601,297	$ 43,725,025	$ 95,129,685	$ 197,939,005	$ 352,152,984	$ 454,962,304	$ 506,366,964

Hydrofracking Wastewater

Hydrofracking for natural gas has become more popular in the United States due to improved technology and historically high oil prices. Hydrofracking requires large amounts of water[vii] at the beginning of the process as high-pressure water is what breaks the rock, releasing the gas. When the water is removed, it has high salinity and pollution making the company unable to discard the wastewater directly in the environment. It has been standard practice to reinject the water into the site after it has been closed, but increased regulations are reducing that practice. Many hydrofracking sites are in remote locations without standard sewer or water infrastructure, requiring water to be trucked to the site and then removed via truck. Water reuse is popular to reduce trucking costs. Many fracking sites have an onsite recycling truck for that purpose. When water is removed from the pipes, it is put in a holding pond until it can be treated and then used again. The waste brine is trucked out from the site, as well as any residual water when the site has been closed.

Due to increased pressure from local municipalities and other water users, increased water treatment for hydrofracking wastewater is growing in demand[viii]. This is due to the inability of municipal plants to process such highly polluted water and the constraints of water access for other users such as industry or agriculture. When the state of Pennsylvania required hydrofracking wastewater to be treated before it could be sent to a municipal wastewater treatment plant in 2011[ix], almost all fracking activity in the state came to a complete halt until the technology could be delivered to the hydrofracking site. The treatment and disposal of hydrofracking is critical to the operation of the site.

The treatment of hydrofracking wastewater is very generalized for primary and secondary treatment, but requires specialize solutions for tertiary and advanced treatment. All hydrofracking wastewater has high salinity, but individual concentrations of other compounds vary from site to site based on the geography, source of original water and proprietary chemical compounds to create the slurry. Furthermore, treatment standards are set by state and local governments, added to the need for specialization of the treatment.

Primary treatment reduces large sediment from the water, often by letting the water settle and large particles sink or float for removed. Secondary treatment clarifies and removes ions such as barium, calcium magnesium and strontium. Tertiary treatment for fracking is pretreatment for reuse by removing chloride and reducing TDS to an acceptable level for hydrofracking reuse. Advanced treatment is for surface discharge or beneficial use by meeting PADEP effluent standards of TDS below 500 ppm[x].

Bacteria that can be modified to remove contaminates can be used in the second, tertiary and/or advanced treatments. Due to the variability among locations, each site will need a personalized blend of microbiomes to create the correct chemical composition for fracking reuse. Thus, more than one bacteria is necessary for research in this area, decreasing the likelihood of positive return on investment. For advanced treatment, a central wastewater treatment plant can be less specialized and has economies of scale, allowing greater flexibility of treatment and discharge or reuse options.

Financial Analysis of Hydrofracking Wastewater Treatment

The market for fracking water treatment has a few large firms with well-established products and processes for primary and secondary treatment[xii]. A few firms also offer tertiary treatment equipment, but smaller firms are increasingly entering the fractured market due to the large size and demand. CAGR for advanced treatment is expected to grow 3x faster than tertiary or primary & secondary treatment (Table 3). In my analysis I assumed the value add for microbiomes would be 10% of the overall market size. For example, the total market size for tertiary treatment is expected to be $103MM per year in

2020. If microbiome technology is able to offer benefits that reduce the overall cost of the system by 10%, and increase benefits to current technology, they have value added worth 10% of the market, or $1.03MM/year. In the table, I assume one firm controlling 53% of the $1.03MM as it grows 9.3% year over year for the 15 years the product is in the market, with a NPV of negative $49.35MM, not making the required return of investment to justify research and development for a microbiome product in the tertiary treatment market. With the high capital expense and need for specialized solutions for all levels of treatment the NPV is negative, therefore it is not a promising market to use microbiome technology.

Table 3: Estimated hydrofracking wastewater microbiome market size, CAGR and NPV for microbiome products with an estimated market penetration after 10 years. Divided by level of treatment.

Level of Treatment	2020 Market Size (10% of total market)	CAGR	Market Penetration (10yrs)	NPV
Primary & Secondary	$2.12MM	8.5%	25%	($38.34MM)
Tertiary	$1.03MM	9.3%	53%	($49.35MM)
Advanced	$0.35MM	31.2%	53%	($49.17MM)

Wastewater Recycling and Reuse

Water recycling and reuse from industrial and/or municipal wastewater treatment plants is becoming more popular as freshwater demands outpace supply, especially in arid areas[xii]. There is rising demand for wastewater treatments to use less harmful chemicals, increasing the desirability for a product such as microbiomes. As with hydrofracking wastewater, the treatment for industry and municipal wastewater recycling starts with separating large particles, often by adding a flocculant to bind the particles together. A corrosion inhibitor is also added to protect the equipment. By genetically altering bacteria, either of these additives could be replaced with microbiomes. The secondary treatment breaks down organic compounds usually using aerobic or anaerobic digestion which differ on need for oxygen and biogas output as well as other features (Table 4). Aerobic and anaerobic digestion use naturally present bacteria that either need oxygen and are extremely efficient at breaking down waste, or can not be exposed to oxygen but creates a biogas that can be captured and used.

Table 4: Aerobic and Anaerobic Differences

Aerobics	Anaerobic
Needs Oxygen	Can not be exposed to oxygen
Operation temperature and pH finicky	Inefficient in temperatures below 90°F
Extremely efficient at breaking down waste	Medium reduction breaking down waste
No foul odor when designed correctly	Causes odor issues by creating hydrosulfide if not properly managed
More expensive to operate	Creates biogas
Lower Capital Costs	Complex operation and maintenance
	If overloaded, can wash out bacteria. May need holding ponds to keep production stable

To replace current anaerobic and aerobic bacteria, the most promising technology would operate in a wide range of temperatures and pH, have no foul odor, create biogas and rapidly breakdown solids to minimal sludge left over. Currently anaerobic and aerobic treatment takes 15-40 days to break down the organic material successfully. Microbiome is expected to reduce that time to 1-3 days[xi]. In essence, a new bacteria that combines the positive attributes of both anerobic and anaerobic technology while removing the negative attributes has a very strong likelihood of being accepted in the industry. Since current aerobic and anaerobic bacteria are natural occurring, the new bacteria would need to create economic value to justify the expense of adding the bacteria to the treatment process. In addition, this new process may require additional capital expense in the form of updated treatment plant or a new treatment facility. Aerobic and anaerobic treatments have different capital expense, mostly due to capturing the biogas, so a new bacteria process would most likely be similar to an anaerobic facility. This technology is part of MBR (Membrane Bioreactor) that is becoming increasingly popular.

Financial Analysis for Wastewater Recycling

The flocculant and corrosion inhibitor markets are extremely mature with a few large companies. These companies are often a “one stop shop” for wastewater treatment plants to order all the chemicals and often provides consultants and other expertise to manage the plant[xii]. To enter this market, a new microbiome company would need a higher sales and marketing budget and should expect a lower market penetration after 10 years. It might only be possible to enter the market in a meaningful way by partnering with one of the large firms, reducing the expected profit margin.

The MBR overall market is growing, but is a very small market size of $13.8MM in 2020. Using the same assumptions of capital expense, only 10% of the market is available for microbiome technology in the analysis. In addition, the analysis assumed sales and marketing would be 10% of sales compared to 5% for the other industries. The flocculant and corrosion inhibitor market size are promising areas to receive a positive net present value on the investment to justify the research and development into those areas (Table 5).

Table 5: Estimated wastewater treatment microbiome market size, CAGR and NPV for microbiome products with an estimated market penetration after 10 years. Divided by level of treatment.

Type of Treatment	2020 Market Size (MBR 10% total)	CAGR	Market Penetration (10yrs)	NPV
Flocculants	$10,740MM	5.9%	7.75%	$1,203MM
Corrosion Inhibitors	$12,992MM	6.2%	7.75%	$1,495MM
MBR	$1.38MM	15%	37%	($48.33MM)

Nutrient Overload in Freshwater

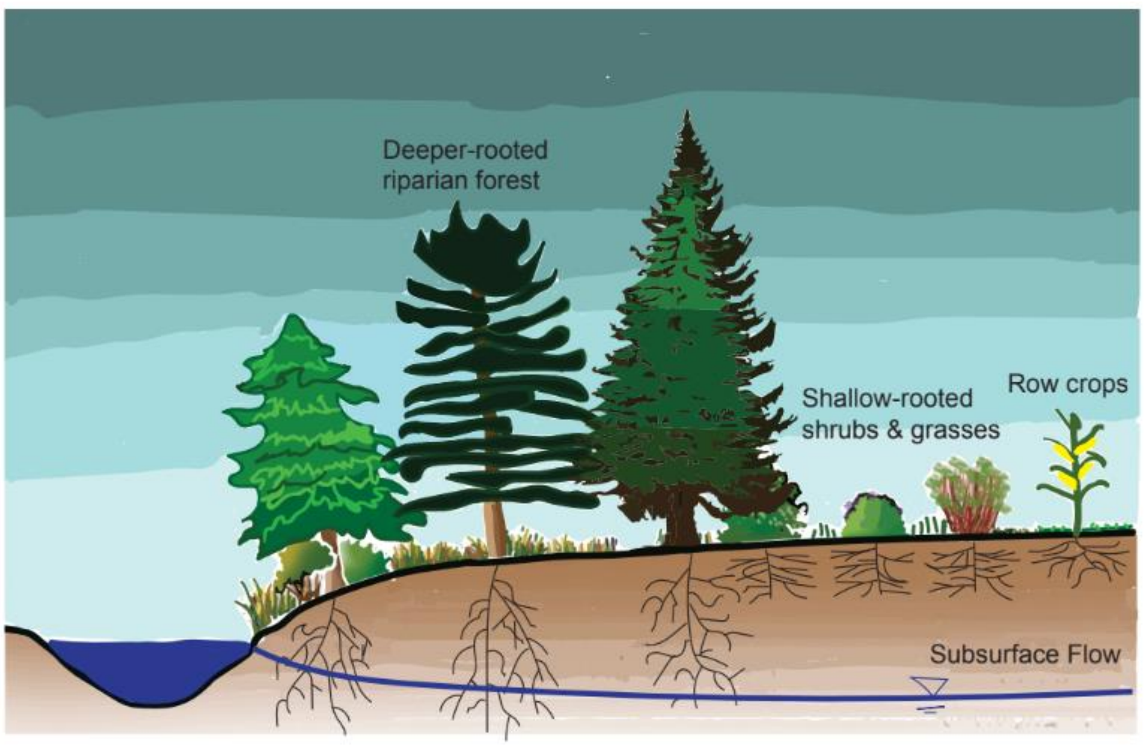
Nutrient overload, most notably nitrate and phosphorus from agriculture runoff, affects our freshwater streams, rivers and lakes reducing recreational and aesthetic value by create more favorable conditions for algae blooms and invasive aquatic plant overgrowth. Algae blooms can become toxic, endangering humans and animals that come in contact with the water or drink it. The algal toxins can enter the food chain, affecting the seafood industry and poisoning livestock, wild mammals and birds[xiii]. Invasive aquatic plants cause eutrophication by blocking light from penetrating into the water, reducing natural plant growth thus depriving the ecosystem of oxygen resulting in fish kills. A 2010 United States Geological Survey (USGS) study found that nitrates were above recommended levels in 64 percent of surface water and shallow groundwater monitoring wells throughout the United States[xiv].

Algae blooms have become national news in a number of freshwater lakes in recent years. Most notably, Lake Erie has larger and longer algae blooms that threaten the freshwater for cities in the area[xv]. Record-setting algal blooms in Lake Erie caused by agricultural trends are consistent with expected future conditions[xv]. In 2014, Toledo, Ohio issued a boil water notice of all drinking water for 500,000 residents after over 100 people became ill from the water due to algae blooms. The city has spent over $600MM reducing the nutrients in its water source and upgrading the drinking water treatment plant to meet EPA water standards[xvi].

Non-point source pollutions are not regulated by the EPA. Therefore, any reduction in nutrient runoff is due to voluntary change in behavior by the agriculture industry. Multiple methods to reduce nutrients from entering the waterways include nutrient trading to incentivize farmers to actively reduce nutrient runoff and riparian buffers to absorb excess nutrients before they enter the waterways. Nutrient trading attempts to create a market where municipalities can pay farmers to change their farming techniques to scientifically proven methods that reduce nutrient runoff, thus reducing the costs to clean the water downstream for drinking. Unfortunately, the method needs a majority of the farmers to participate and there is the chance other municipalities further downstream could reap the benefits, but not pay the cost making it even more burdensome for one municipality without full watershed coalitions. Riparian buffers infiltrate runoff making nutrients available to plants and microorganisms instead of entering the waterways[xvii].

A case study was conducted on riparian buffers for the watershed that fed the drinking water supply for Des Moines, Iowa to determine the cost compared to upgrading the drinking water treatment plant. The Des Moines Water Works utility serves more than 500,000 people. The nitrate levels for the Raccoon River Watershed are some of the highest in the nation, with Des Moines downstream from 6 counties of agriculture farmland. The study determined the cost to install and maintain riparian buffers that consisted of native trees and brush (Figure 2) was $1.8MM/hectare plus paying opportunity costs for the farmer for a total cost of $155-$185MM. This is assuming the majority of the farmers would participate to make a noticeable difference in nutrient runoff. In contrast, to update the current treatment plant and build a nitrate removal plant in the next 10 years would costs $184MM and have a higher rate of success than buffers, especially when run-off is exasperated by flooding shortly after fertilizer is applied[xviii].

Figure 2: Multi-species riparian buffers include trees, shrubs and prairie grasses. Grasses attenuate surface runoff and filter out contaminates[xvii].

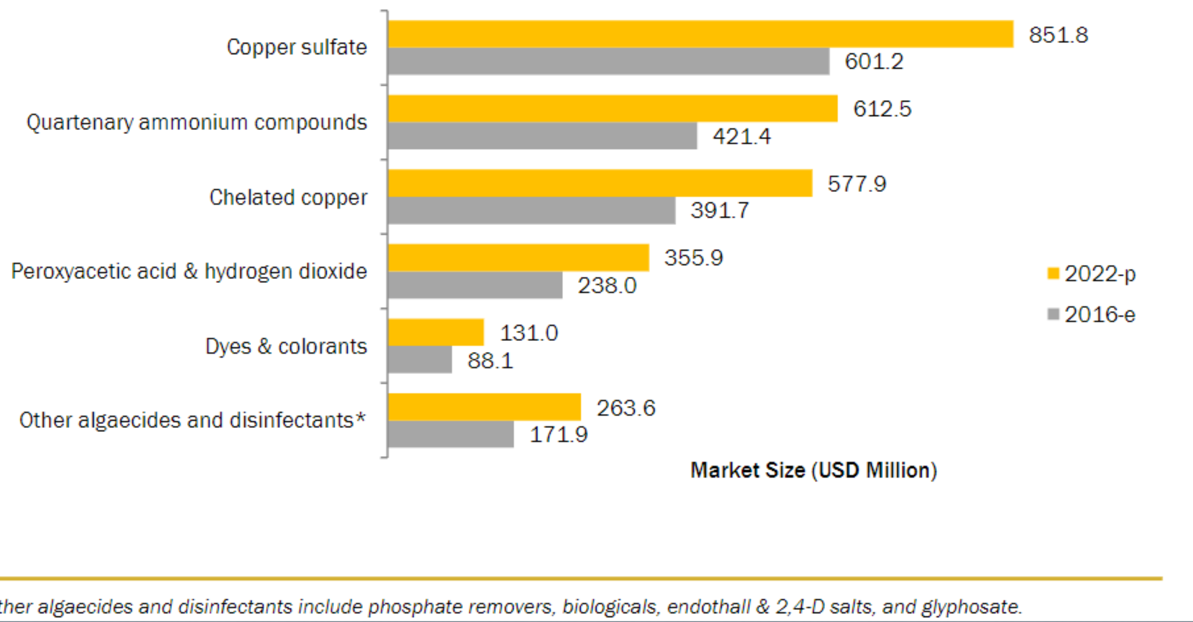


Another method to control for over-nutrient is using chemical treated alum or clays to bind with phosphate, forming a thin barrier at the bottom of the lake. This has worked in small water bodies, but risks having the phosphate released if the bottom of the lake is disturbed[xix]. The most common way to treat algae or plant overgrowth is to apply chemicals that kill the plant and algae directly. Cooper sulfate and Ammonium compounds have the highest market penetration (Figure 4) due to ease of use and wide range of species. This benefit is also a hinderance as it is effective for a broad range of plants, beneficial and harmful (Table 6). The "Other algaecides & disinfectants" includes phosphate removers and biologicals. Biologicals and phosphate removers can indirectly control algal blooms without lethal effect on fish species. It is expected to have a CAGR of 7.39% from 2016-2022.

Table 6: Benefits and Negative outcomes of commonly used algaecides[xx].

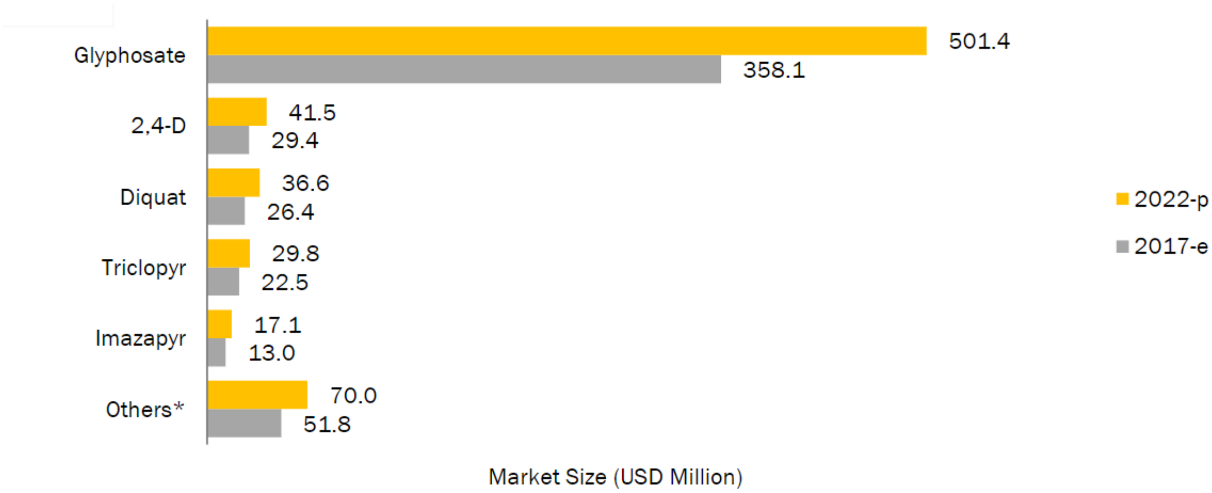
	Copper Sulfate	Ammonium compounds	Chelated Copper	Peroxygacetic acid & Hydrogen Dioxide	Dyes & colorants	Other algaecides & disinfectants
Benefits	wide range of species	Low cost, availability, easy to apply, considered an alternative to copper-based products. Most effective on stem and flowering, stunting plant height.	Effective against “tougher species”, low precipitation rate (longer contact time with targeted vegetation)	Low toxicity compared to copper products, selective control of blue-green algae at lower application rates.	not persistent in the environment, Effective in various alkalinity and pH, working together they are effective on all forms of algae.	Compounds that eliminate the source of important ingredients for algal growth, no negative effect on fish or wildlife. Can be selective or non-selective, lasts 1-3 months in still ponds or lakes
Cons	Toxicity to aquatic ecosystems, not biodegradable	Have antibacterial activity, resulting in disruption to the aquatic ecosystem. Less effective on leaf growth.	Risky in waters with low alkalinity, noxious to invertebrates and fish (less so than copper sulfate)	Not effective on all algae	Dye the water to reduce sunlight, do not affect algae already present in the water, cannot be used in waters for human consumption	

Figure 3: Algaecides Market Size, but Type, 2016 vs. 2022[xx].



The aquatic herbicide market is divided into foliar and submerged. Foliar is applied to the plant after its leaves have grown above the water line. Submerged is applied to the water and is thus in a higher concentration until it is diluted in the water body. Foliar is much more popular with glyphosate the most popular herbicide[xxi]. Glyphosate is one of the most common herbicides in the world, its commercial name is RoundUp and is know to be extremely effective at killing all plants it is applied to. Due to the wide efficacy and effect on the ecosystem, there is a demand for products that do not affect the native flora.

Figure 4: Aquatic Herbicides Market Size, but Type, 2016 vs. 2022[xxi]Error! Bookmark not defined.**.**



Financial Analysis of Nutrient-overload Treatment

Algaecide and Aquatic Herbicides are under increased pressure to reduce the environmental impact of treatment while the demand for clear and safe water for drinking and recreation is growing, especially in developing countries. Both markets are controlled by large chemical companies with intense market and political power**Error! Bookmark not defined.**. As research and regulations about algae blooms reach the same intensity as brackish and salt water research and regulations, these large companies will have more lobbying power to influence what treatments can be used in the future. Regardless, these large companies are resorting to acquisitions to broaden their offerings into the growing biological segments. With the increased pressure to not use glyphosate, there is a large market opportunity for an effective and environmentally safe replacement. A biological product that breaks down phosphate and nitrate will have a competitive advantage to the current methods of control by treating the cause and not the symptom. While such a solution would most likely be a submerged product, it would be a substitute for both foliar and submerged products, so controlling 7.75% of the combined market would result in an NPV of $27.6MM. The biological and phosphate removers could have a greater market penetration with a superior product and strong marketing resulting in an NPV of $46.9MM. Both the aquatic herbicide and algaecide market are promising industries to develop a biological to remove nitrogen and phosphate from freshwater reserves.

Table 7: Estimated nutrient overload microbiome market size, CAGR and NPV for microbiome products with an estimated market penetration after 10 years. Divided by current treatment type.

Aquatic Herbicide	**2020 Market Share**	**CAGR**	**Market Penetration (10yrs)**	**NPV**
Foliar	$548MM	6.8%	7.75%	$18.3MM
Submerged	$75.1MM	6.9%	34%	($18.9MM)
Combined	$623MM	6.8%	7.75%	$27.6MM
Algaecides	**2020 Market Share**	**CAGR**	**Mkt Penetration**	**NPV**
Biologicals & phosphate removers	$228.6MM	7.39%	34%	$46.9MM

Conclusion

The technology advancements in microbiome development are opening market opportunities in multiple industries, including water pollution management. While not all pollution can be currently addressed with microbiomes, there are specific opportunities where the technology in microbiomes is promising. This report looked at 3 different ways water pollution is addressed and how microbiomes could be used as well as a financial model to determine if the market penetration and size would lead to favorable financial returns. Flocculates, Corrosion inhibitors, and nutrient overload are three promising industries for microbiome research and product development.

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