Sorption Oxidation Commercialization

A Major Qualifying Report Submitted to the Faculty of Worcester Polytechnic Institute

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4/30/2009

The water treatment industry is steadily growing in size due to pollution and climate changes, population growth and concentration, urbanization and industrialization, and ever-growing awareness and evidence of harmful water contaminants. There is an increasing demand for potable and industry-usable water, as well as increasing standards for water quality in both withdrawal and discharge. The patent pending Sorption Oxidation (SOx) process developed by Dr. John Bergendahl and Dr. Robert Thompson could be an effective treatment technique for the removal of a myriad of organic contaminants in both consumer and industry water treatment applications. This report addresses the state of the technology, as well as promising applications for SOx. It also contains detailed information about the domestic and international water treatment markets and possible opportunities for commercialization of the SOx process. After in-depth product, industry, and market analyses, it has been concluded that there is a market opportunity for SOx and that with product tailoring there are opportunities in a wide range of applications and sectors.

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Sorption Oxidation Commercialization

Sorption Oxidation (SOx) is a technology developed by two Worcester Polytechnic Institute professors, Dr. John Bergendahl and Dr. Robert Thompson, who originally designed the technology to remove organic impurities from drinking water. The initial design was proven effective and the provisional patent was submitted in 2005 and is currently pending. The market for this type of filtering technology is a rapidly growing field as more and more harmful water contaminants are being identified. The objective of this project is to assess the viability of Sorption Oxidation technology as a marketable commercial water treatment solution and determine the most advantageous opportunities for SOx, as well as begin the actual commercialization process.

Executive Summary

This report investigated the the patent pending Sorption Oxidation (SOx) process developed by Dr. John Bergendahl and Dr. Robert Thompson and assessed its viability as a treatment technique for the removal of organic contaminants in both consumer and industry water treatment applications. In order to do this an in-depth investigation into the state of the technology, as well as promising applications for SOx, was conducted. Detailed information about the domestic and international water treatment markets and possible opportunities for commercialization of the SOx process were also established. After in-depth product, industry, and market analyses, it was concluded that there is a market

opportunity for SOx and that with product tailoring there are opportunities in a wide range of applications and sectors.

Once this research was completed it became possible to initiate the actual commercialization process and target and contact potential strategic allies or buyers that might be interested in Sorption Oxidation technology. A strategic ally would be valuable to WPI, the inventors, and the actual SOx technology. Using customized, technical and marketing materials over fifty-six companies were contacted and informed of the SOx technology. As will be discussed in this report, there are a number of interested parties that the WPI research and technology transfer teams are in contact with.

Based on the findings of this project, it is recommended that The WPI Bioengineering Institute Center for Water Research concentrate more resources on developing Sorption Oxidation process and technology. It has been established to be a viable technology, and there is a large and growing market for this type of treatment technology. By focusing efforts on creating a working proof of concept, further contaminant testing, and continuation of initiated, commercialization efforts, Sorption Oxidation can provide marketable, cost-efficient treatment of a wide variety of organic contaminants.

The WPI Bioengineering Institute Center for Water Research

The WPI Bioengineering Institute Center for Water Research is led by John A. Bergendahl,[1] Nikolas Kazantzis,[2] Robert W. Thompson,[3] Ayşe Erdem-Şenatalar,[4] Arjan Giaya,[5] and James F. Hauri.[6] They are currently focusing their research and testing efforts on the numerous organic compounds that have been found in US and foreign water supplies in varying concentrations. Among these contaminants are: pesticides, insecticides, pharmaceuticals, antibiotics, personal care products, solvents and organic additives, disinfection by-products, and natural compounds such as hormones. Many of these have been proven to detract from water taste, appearance, and scent quality. They are also toxic, carcinogenic, or cause other various negative health issues, even in very low concentrations.

The BioEngineering Center for Water Research at WPI uses an effective integrated approach to address, understand, and solve water remediation problems involving these harmful organic compounds. This unique approach, illustrated in the figure below, takes advantage of the team's broad range of experience and expertise in computational chemistry techniques in order to understand molecular interactions between organic compounds and potential adsorbents, predict adsorption affinities, and modify adsorbent structures to enhance separations. Theoretical predictions are then tested in their laboratories through adsorption experiments, coupled with advanced analytical

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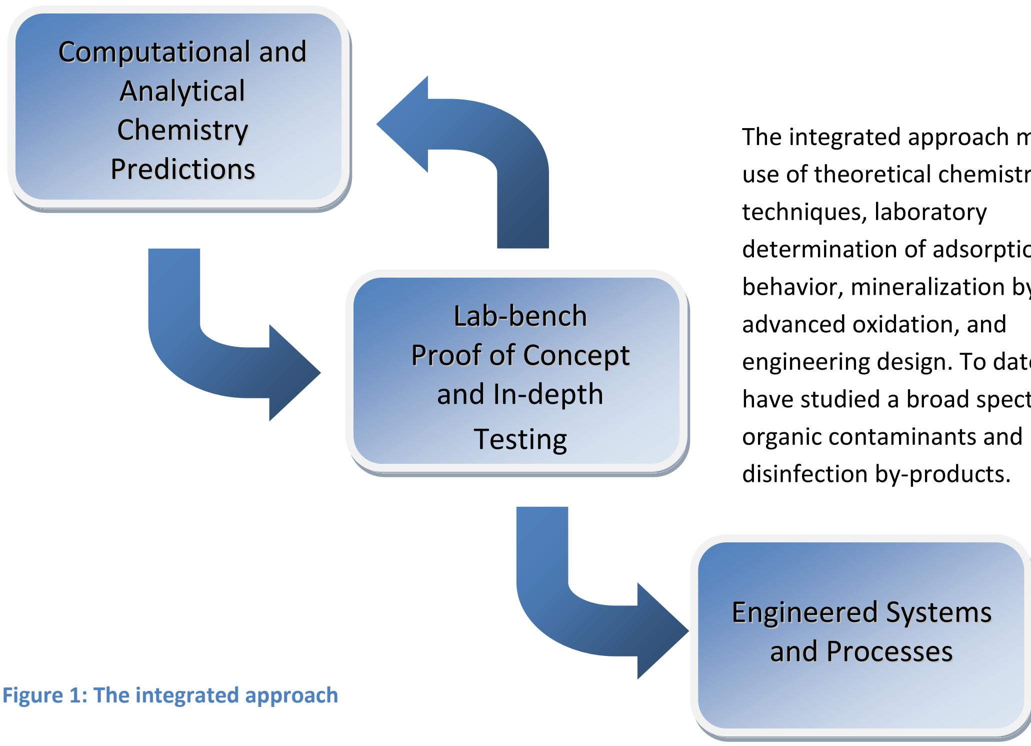
[5] Triton Systems, Inc, Chelmsford, Massachusetts
[6] Assumption College, Department of Chemistry, Worcester, Massachusetts

techniques. Activated carbons, molecular sieve zeolites, and other hydrophobic adsorbents are tested and compared. Advanced oxidation techniques are used to destroy the organics in the adsorbent pores, thus regenerating the remediation medium.



The integrated approach makes use of theoretical chemistry techniques, laboratory determination of adsorption behavior, mineralization by advanced oxidation, and engineering design. To date we have studied a broad spectrum of organic contaminants and disinfection by-products.

Figure 1: The integrated approach

This project outlines Sorption Oxidation's most promising potential applications as well as the corresponding market demands. The inventors proved to be an invaluable resource for insight into SOx's advantages and disadvantages as a water treatment solution. Once these were established, it became easier to determine the most promising uses for the technology. For each application, the NABC approach was taken to establish Need, Approach, Benefit, and Costs.

The market analysis portion of this project consisted of a multifaceted, broad range study of the water treatment market's past, present, and potential future trends and figures. Once the most promising markets were established, an updated SWOT analysis was conducted in order to show the inherent Strengths, Weaknesses, Opportunities, and Threats associated with the SOx technology.

Porter's Five Forces Industry Attractiveness analysis was used to establish SOx's competitive advantage in the market. A suggested marketing mix and possible promotion needs were shown. Also, a spreadsheet was created that contains over fifty of the most promising companies for marketing SOx, and includes their contact information, website locations, and a brief description of their operations. This was be used to target specific potential strategic allies or buyers. Contact and level of interest was tracked throughout the process.

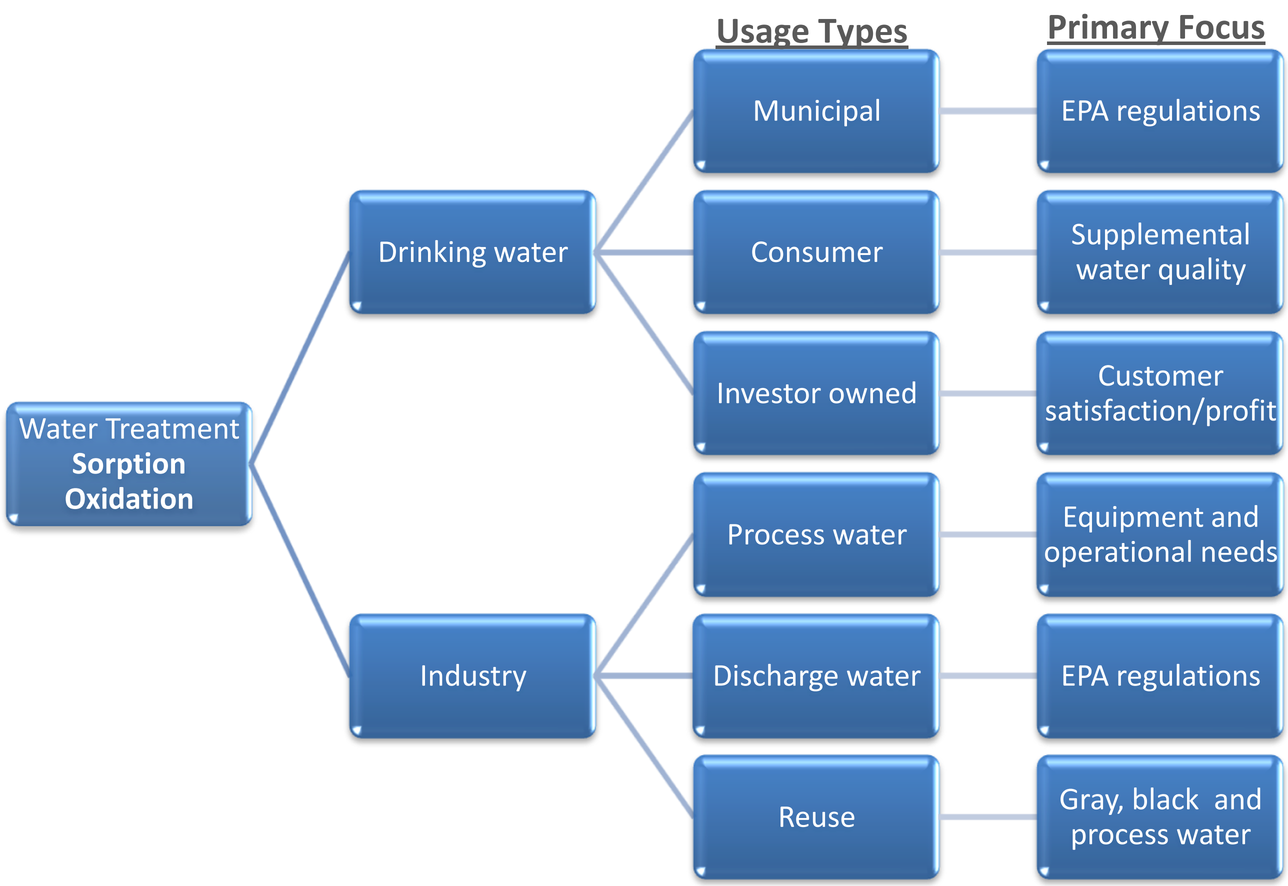


Figure 2: Stage I project scope

Water and Its Future

The water purification, remediation, and transportation industries are predicted to experience promising growth over the coming years, and the market for related technologies is expanding. Water availability is more and more of a concern every year and water is being viewed as an increasingly valuable resource. Due to steady population growth and relocation to concentrated areas, combined with limited resources, newly protected environmental areas, displacement of normal water patterns, and cycles from climate and weather changes, water shortages are unfortunately likely to increase.[7]

According to the U.S. Census Bureau, the world's population is currently under seven billion, yet is projected to reach approximately ten billion within 50 years.[8] Not only is the general world population continuing to grow, but also the number of people living in water-stressed countries is expected to rise two-thirds by 2025. Even though water is the most common substance in the world, only three percent of it is freshwater and only one percent of the world's water can be used for human consumption. If spread evenly throughout the world this amount would be adequate, but water availability is concentrated in specific regions and nonexistent in others. Also, every year water quality deteriorates due to pollution and other environmental concerns.[9]

[7] Tenny, Edward. The Road Ahead for Water & Wastewater. Source: *Water & Wastes Digest* January 2007 Volume: 47 Number: 1. 2009 Scranton Gillette Communications

[8] http://www.census.gov/ipc/www/idb/worldpopgraph.html 2009

[9] Singh, Rajindar. Hybrid Membrane Systems for Water Purification: Technology, Systems Design and Operation USFilter PWS, Inc., 2005. Colorado Springs, USA. Elsevior, NY

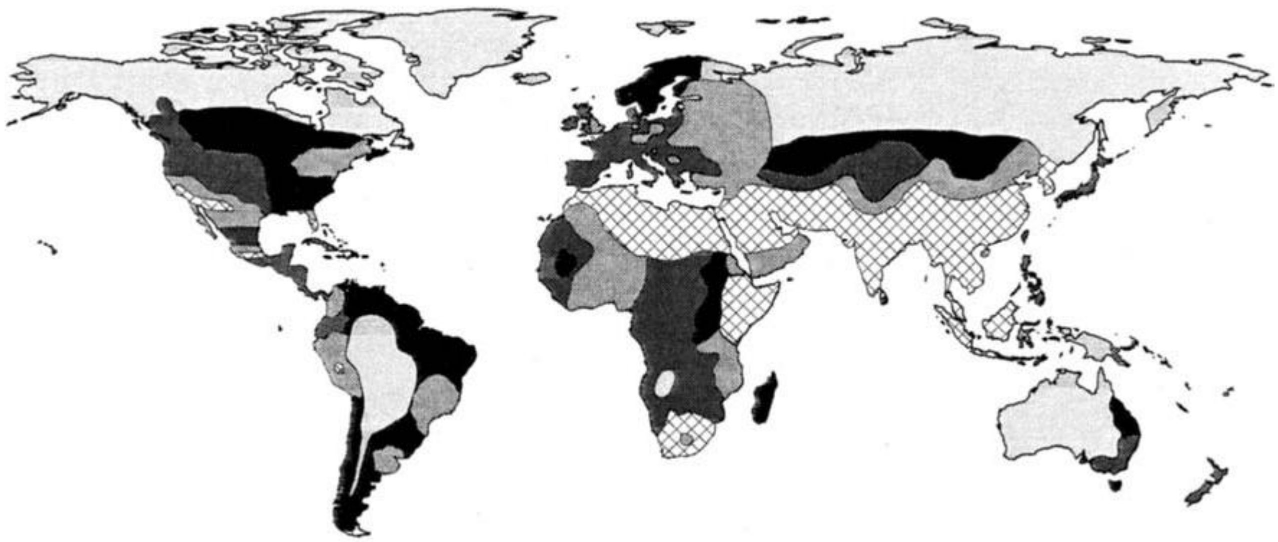


Figure 3: Projected worldwide water scarcity through 2020. Source: USFilter. 2005.

- Sparsely populated
- Water Abundant
- Water Concerns
- Water Stressed
- Water Scarce

According to the senior vice president for HDR Engineering Inc., Edward Tenny, “Water in the United States has been both undervalued and underpriced, but with a shrinking supply or fresh water, the need for infrastructure repair, increasing standards and regulation needing new, and more expensive treatment, one should expect the cost to steadily rise.” As water becomes more expensive and people become accustomed to paying more for it, they will also want a better, purer product.[10] According to Dr. Alan Leff, “The greatest issues will be dealing with aging distribution systems and the biofilms contained within.”[11]

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[10] Tenny, Edward. The Road Ahead for Water & Wastewater. Source: *Water & Wastes Digest* January 2007 Volume: 47 Number: 1. 2009 Scranton Gillette Communications

[11] Leff, Dr. Alan. Projections for 2001 … and Beyond. *Water Quality Products* January 2001 Volume: 6 Number: 1. 2009 Scranton Gillette Communications

Organic Water Contaminants

It is currently estimated that over 5,000 new organic compounds are brought to market every year. There are currently over 150 drinking water contaminants either proposed, listed, or finalized for government regulation, and at least 100 of these are organic compounds.[12] Anything already regulated by the EPA has been proven to have negative side effects with certain doses of exposure, yet many other contaminants are not yet regulated, despite the fact that they have not been proven safe. When humans are exposed to many of these organic contaminants, potential health effects can include: problems with the cardiovascular system, reproductive organs, digestive system, nervous system, eyes, liver, kidneys, blood, adrenal glands, and an increased risk of cancer.

Chlorination Risks

As stated by Dr. Joseph Price, one of the first researchers to look into the negative effects of chlorinated water and the author of *Coronaries/Cholesterol/Chlorine*: "Most large poultry producers now use water that has been dechlorinated because of the discovery that birds drinking water without chlorine grew faster and larger and displayed more vigorous health. If chlorinated water is not good enough for chickens, it is probably not good enough for humans."[13] More importantly, according to the US Council of Environmental Quality: "Cancer risk among people drinking chlorinated water is 93 percent higher than among those whose water does not contain chlorine." However, chlorinated water has played a huge role in the 50 percent increase in life expectancy (from around 45 years in the early 20th century to about 76 years now), as well as the elimination of once lethal waterborne diseases such

[12] HDR Engineering Inc. Handbook of Public Water Systems 2nd Edition. March 23, 2001. Omaha, NE. John Wiley & Sons Inc. New York, NY and Canada
[13] Fox Ph.D., Martin. Chlorination: A Link Between Heart Disease and Cancer. http://www.purewatergazette.net/chlorinationfox.htm

as cholera, typhoid, and dysentery.[14] Like many technologies, the chlorination disinfection technique is a double-edged sword with both benefits and risks.

Disinfection By-products

Disinfection by-products (DBP's) are trace amounts of substances that result from the reaction of chlorine and organic matter often found in feed water and are resistant to environmental degradation. They are formed by three separate reactions[15]:

- Substitution onto the organic molecule (chlorine onto methane to form chloroform)
- Oxidation to form new organic (ozone reacting to form formaldehyde)
- Most DBP's are halogenated, meaning produced by free chlorination

The most commonly occurring of these DBP's are trihalomethanes (THM's). THM's, like chloroform, are the reason that chlorinated water is linked to increased cancer rates and birth defects and they can be very problematic to remove. In 1979, Swedish researchers proved that THM's are created by the chlorination process. The most harmful known THM's are as follows, with the first three currently unregulated:[16]

- Bromochloromethane: Tests on animals show this to be mutagen and toxic to fetuses.
- Bromodichloromethane (Dichlorobromomethane): Animal tests have shown it to cause kidney and liver damage. It has limited mutagenic results.

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[14] Chlorine and Drinking Water: Here's to Your Health. Water Quality & Health Council. http://www.waterandhealth.org/drinkingwater/before.php3

[15] Gilbert, Charles E. and Calabrese, Edward J. Regulating Drinking Water Quality. Chapter 13: Regulating Disinfection By-Products. 1992 Lewis Publishers Inc, 121 South Main Street, Chelsea, Michigan 48118

[16] Coffel, Steve. But Not a Drop to Drink. 1989 Rawson Associates New York, NY.

- Bromoform (Tribromomethane): Bromoform is used in fire retardants and as solvent and it also results from chlorination. It is a suspected mutagen and teratogen in humans. It is estimated that lifetime exposure to 1.9 ppb is sufficient to cause one cancer death per 100,000 people.
- Chloroform (Trichloromethane): Chloroform is often used in drugs and plastics, refrigerant and propellant, and pesticide and solvent. Most chloroform is caused by a reaction between chlorine and humic material in water. A 1975 EPA survey of 80 cities found chloroform in all city waters. It is also a suspected human carcinogen and has been proven to cause damage to kidneys, liver, thyroid and immune system and hinders fetal/embryonic development.

Chloroform and Its Dangers

Toxicology studies show that chloroform causes cancer in a least one strain of both rat and mice.[17] Since 1984, American drinking water utilities have spent over $23 million researching disinfection by-products such as THM, as well as their associated risks and available methods of treatment. An additional $150 million has been spent by the top 300 largest water utilities in order to gather information for the EPA's Information Collection Rule, which is the largest study of DBP's ever conducted in the United States.[18]

EPA studies, such as the Information Collection Rule, have yielded shocking statistics. Not only was it found that residents in cities with chlorinated water have a 93 percent greater chance of contracting rectal cancer, but also a 53 percent greater chance of contracting colon cancer.[19] Colon and rectal cancer are responsible for over 56,000 deaths per year, second only to lung cancer.[20] THM's such

[17] Gilbert, Charles E. and Calabrese, Edward J. Regulating Drinking Water Quality. Chapter 13: Regulating Disinfection By-Products. 1992 Lewis Publishers Inc, 121 South Main Street, Chelsea, Michigan 48118
[18] Swichtenberg, Bill. Chlorination: The Love/Hate Relationship. *Water Engineering & Management,* April 2003, Volume: 150 Number: 4. Copyright © 2009 Scranton Gillette Communications
[19] Coffel, Steve. But Not a Drop to Drink. 1989 Rawson Associates New York, NY.
[20] http://www.coloncancerprevention.org/

as chloroform have been found in drinking water in almost every city in the country. It has been shown that chloroform is not only a carcinogen, but also causes damage to the kidneys, liver and thyroid, as well as the immune system, and hinders embryonic and fetal development as well. Out of all THM's formed from chlorination, approximately 90 percent are chloroform, and the resulting 10 percent consist of bromodichloromethane (CHCl2Br), dibromochloromethane (CHBr2Cl) and bromoform (CHBr3).[21] The EPA has estimated that exposure to concentrations as small 1.9 parts per billion of chloroform yields a 1 in 100,000 risk of cancer. However, the World Health Organization standard is 30 ppb and the United States is 100 ppb.[22] At chloroform concentrations in this range, the chances of experiencing associated negative health risks greatly increase.

Removing DBP's

There are a number of strategies for reducing disinfection by-products in finished drinking water supplies. There are three methods for removing the DBP's after they are formed: oxidation, aeration, and adsorption. However, oxidation is ineffective for removing the harmful THM's, aeration is only partially effective and cannot remove any nonvolatile DBP's (HAA's), and until now adsorption used granulated activated carbon (GAC) and required frequent and costly regeneration. Another option to reduce DBP's is to use a disinfection substitute such as chloramine, a weaker agent that results in fewer government regulated DBP's, but also increases exposure to contaminants and other DBP's such as N-nitrosodimethyl amine (NDMA) and iodinated DBPs.[23] Currently chlorine is the most effective method

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[21] McClean, Jon. Using UV for Dechlorination. *UV proves to be an effective dechlorination technique without drawbacks. Water & Wastes Digest* November 2007 Volume: 47 Number: 11 © 2009 Scranton Gillette Communications

[22] Coffel, Steve. But Not a Drop to Drink. 1989 Rawson Associates New York, NY.

[23] Stage 2 Disinfectants and Disinfection Byproduct Rule (Stage 2 DBP rule) http://www.epa.gov/ogwdw/disinfection/stage2/basicinformation.html

of disinfecting drinking water. Lastly, the natural organics that are precursors to DBP's, such as chlorine, can be removed before disinfection, but this proves both difficult and costly.[24]

The Stage 1 Disinfectants and Disinfection Byproducts Rule has resulted in as many as 140 million people receiving increased (but not full) protection from DBP's, and a 24 percent national average reduction in TTHM levels. However, the total annual cost of Stage 1 implementation is over $700 million. The EPA estimates that the majority of households will incur costs under $1/month, but some will incur costs as high as $33/month if they choose to install treatment.[25] Many houses will spend even more than this in order to have broad range filtration devices removing many different contaminants and organics.

One of the newer and more effective water treatment methods is membrane treatment through reverse osmosis, nanofiltration, and some ultrafiltration. These techniques use semipermeable membranes to separate contaminants such as aqueous salts, metal ions, as well as organic molecules. Ultrafiltration and microfiltration use physical straining to remove colloidal and particulate contaminants including microbial pathogens like bacteria, Giardia, and Cryptosporidium cysts. Electrodialysis uses electrically charged membrane dialysis to remove dissolved ions. However these membrane treatments cannot remove organic contaminants, which actually can result in the plugging or fouling of the membranes. This decreases membrane performance due to adsorption and blocking of pore spaces.

[24] HDR Engineering Inc. Handbook of Public Water Systems 2nd Edition. March 23, 2001 . Omaha, NE. John Wiley & Sons Inc. New York, NY and Canada
[25] http://www.epa.gov/ogwdw000/mdbp/dbp1.html

These organics can even promote biofouling by providing conditions that enhance organism growth. These effects are often irreversible.[26] Operationally, a well designed system includes an effective pretreatment system that minimizes membrane fouling, resulting in lower required system feed pressure and cleaning frequency. These are important factors for maintaining low running costs by reducing system downtime and minimizing need for expensive cleaning, while maximizing membrane lifetime and requiring fewer replacements.[27]

Currently the only available methods for organic pretreatment removal are coagulation, flocculation, sedimentation, and granular-bed filtration. There are some cleaning agents available that can be used to remove organics, but like many of the other available processes, have had little success. Due to the relatively recent discovery of the dangers associated with contaminants such as THM's, experience with treating/removing organic contaminants is relatively limited and there are not many effective technologies to address the problem.[28]

Harmful Synthetic and Volatile Organic Compounds

Synthetic organic compounds are synthesized by the scientific, medical, and chemical industries and include antibiotics, pain medication, pesticides, plastics, synthetic fabrics, dyes, gasoline additives, and solvents. Volatile organic compounds (VOC's) include chemicals such as benzene, vinyl chloride, and carbon tetrachloride. They are produced during the manufacture of various pharmaceuticals, pigments, refrigerants, and industrial chemicals. More and more are produced every year and are

[26] HDR Engineering Inc. Handbook of Public Water Systems 2nd Edition. March 23, 2001. Omaha, NE. John Wiley & Sons Inc. New York, NY and Canada
[27] Majamaa, Katariina; Peter, Aerts; & Gomez, Veronica. Ready for Reuse? *Integrating membrane systems to increase water safety, reduce footprint and fouling.* *Membrane Technology* October 2008 Volume: 7 Number: 2 © 2009 Scranton Gillette Communications
[28] HDR Engineering Inc. Handbook of Public Water Systems 2nd Edition. March 23, 2001. Omaha, NE. John Wiley & Sons Inc. New York, NY and Canada

introduced to water supplies through everyday residential, industrial, agricultural activities, and leaks. Almost all of these compounds have either been proven, or theorized, to have negative health effects.

Contaminant	MCLG (mg/L)	MCL or TT (mg/L)	Potential Health Effects from Ingestion of Contaminated Water	Sources of Contaminant in Drinking Water
Acrylamide	zero	0.05	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment
Alachlor	zero	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Row crop herbicide runoff
Atrazine	0.003	0.003	Cardiovascular/reproductive problems	Row crop herbicide runoff
Benzene	zero	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills
Benzo(a)pyrene (PAHs)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines
Carbofuran	0.04	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa
Carbon tetrachloride	zero	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities
Chlordane	zero	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide
Chlorobenzene	0.1	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories
2,4-D	0.07	0.07	Kidney, liver, or adrenal gland problems	Row crop herbicide runoff
Dalapon	0.2	0.2	Minor kidney changes	Rights of way herbicide runoff
1,2-Dibromo-3-chloropropane (DBCP)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards
o-Dichlorobenzene	0.6	0.6	Liver, kidney, or circulatory system problems	Industrial chemical factory discharge
p-Dichlorobenzene	0.075	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Industrial chemical factory discharge
1,2-Dichloroethane	zero	0.005	Increased risk of cancer	Industrial chemical factory discharge
1,1-Dichloroethylene	0.007	0.007	Liver problems	Industrial chemical factory discharge
cis-1,2-Dichloroethylene	0.07	0.07	Liver problems	Industrial chemical factory discharge
trans-1,2-Dichloroethylene	0.1	0.1	Liver problems	Industrial chemical factory discharge
Dichloromethane	zero	0.005	Liver problems; increased cancer risk	Industrial chemical factory discharge
1,2-Dichloropropane	zero	0.005	Increased risk of cancer	Industrial chemical factory discharge
Di(2-ethylhexyl) adipate	0.4	0.4	Weight loss, liver problems, or possible reproductive difficulties.	Industrial chemical factory discharge
Di(2-ethylhexyl) phthalate	zero	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories
Dinoseb	0.007	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables
Diquat	0.02	0.02	Cataracts	Runoff from herbicide use
Endothall	0.1	0.1	Stomach and intestinal problems	Runoff from herbicide use
Endrin	0.002	0.002	Liver problems	Residue of banned insecticide
Epichlorohydrin	zero	TT9	Increased cancer risk, and over a long period of time, stomach problems	Industrial chemical discharge; an impurity of water treatment chemicals
Ethylbenzene	0.7	0.7	Liver or kidneys problems	Discharge from petroleum refineries
Ethylene dibromide	zero	5E-05	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries
Glyphosate	0.7	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use
Heptachlor	zero	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide
Heptachlor epoxide	zero	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor
Hexachlorobenzene	zero	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories
Hexachlorocyclopentadi				

Contaminant	MCLG (mg/L)	MCL or TT (mg/L)	Potential Health Effects from Ingestion of Contaminated Water	Sources of Contaminant in Drinking Water
Heptachlor	zero	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide
Heptachlor epoxide	zero	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor
Hexachlorobenzene	zero	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories
Hexachlorocyclopentadiene	0.05	0.05	Kidney or stomach problems	Discharge from chemical factories
Lindane	2E-04	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens
Methoxychlor	0.04	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock
Oxamyl (Vydate)	0.2	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes
Polychlorinated biphenyls (PCBs)	zero	0.0005	Problems with skin, thymus gland; immune deficiencies; reproductive/ nervous system ; increased cancer risk	Runoff from landfills; discharge of waste chemicals
Pentachlorophenol	zero	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood preserving factories

Figure 4: Organic drinking water contaminants regulated by the EPA

This chart also shows each chemical's associated Maximum Contaminant Level Goals (MCLG), Maximum Concentration Levels (MCL's take available technology and cost into consideration), potential health effects, and sources of each contaminant.[29].

MTBE

Methyl tert-butyl ether (MTBE) is a volatile, combustible, synthetic liquid resulting from use of isobutylene and methanol. It is produced mainly as a fuel additive in order to raise the oxygen content, replacing lead as the octane enhancer in gasoline in 1979.[30] According to the EPA, it is produced in excess of 200,000 barrels per day (as of 1999) for uses in fuel, laboratory experiments, and medicine.[31] This data is the most recently verifiably recorded and this production level has since decreased in the United States, however there is still significant production and use overseas.

[29] Drinking Water Contaminants. http://www.epa.gov/safewater/contaminants/index.html#9
[30] http://www.epa.gov/mtbe/faq.htm
[31] http://www.epa.gov/mtbe/faq.htm

Aesthetically, MTBE creates both unpleasant odor and taste in drinking water, but more importantly it has been reported that persons exposed to MTBE experience headaches, nausea, dizziness, nasal and esophageal irritation, and confusion. It is currently on the EPA's Contaminate Candidate List, meaning that is planned for regulation but is not yet regulated.[32] There is insufficient data regarding the chronic effects on humans, but multiple animal tests have shown that MTBE is indeed carcinogenic and in some cases causes low birth weight and survival rates.[33]

MTBE dissolves easily in water and when spilled or leaked from storage tanks, seeps into soil polluting area groundwater. According to National Water Quality Assessment, MTBE has been detected in around five percent of ground-water samples across the United States and in 14 percent of urban wells, as MTBE concentrations are highest in urban and industrialized areas.[34] A study by the Environmental Working Group in 2003 found that at least 1,515 public water systems in 28 states serving over 15 million Americans are contaminated with MTBE and the trend is only worsening with time as seen by the figure below.

Year	# of Detections	States with Detections	Systems with Detections
1996	252	11	119
1997	333	9	179
1998	910	15	384
1999	878	14	339
2000	1,042	22	382
2001	1,706	23	665
2002	1,705	22	663

Figure 5: MTBE detections in U.S. drinking water

[32] http://www.epa.gov/mtbe/faq.htm

[33] Methyl t-Butyl Ether (MtBE): Health Information Summary. ARD-EHP-2. NH Dept of Environmental Services. 2007

[34] Hamilton, Moran P and Zogorski, J M. "MTBE and other volatile organic compounds-new findings and the implications on the quality of source waters used for drinking water supplies." US Dept of the Interior. Oct 2001.

Amount Released and Remediation Costs

The cost of remediating MTBE across the country from just public water supplies would be substantial to say the least. Studies in 2005 commissioned by the Association of Metropolitan Water Agencies (AMWA) and the American Water Works Association (AWWA) estimate costs to be at least $33.2 billion, but could feasibly be as high as $85 billion or more.[35] This is a large jump from the AMWA and AWWA'a last 2001 study that put the cost at closer to $29 billion. These estimates do not even include private wells, or the many states that do not require MTBE testing.

Rank	Industrial Sector	Total Environmental Releases (lbs.)	Water Release (lbs.)
1	Petroleum And Coal Products	472,800	54,703
2	Wholesale Trade--Nondurable goods	1,516,307	3,851
3	Chemicals And Allied Products	1,067,809	4,855
4	Transportation Equipment	353,874	1
5	Primary Metal Industries	173,107	
6	Industrial Machinery And Equipment	20,612	
7	Metal Mining	17,627	
8	Stone, Clay, And Glass Products	599	
9	Food And Kindred Products	320	
10	Electric, Gas, And Sanitary Services	176	
		Total Water Release	**63,410**

Figure 6: MTBE environmental release by industry as of 2001[36]

[35] Two Updated Contamination Cost Analyses Pin MTBE Cleanup Costs up to $85 Billion. Water & Wastewater News. June 1, 2005

[36] 2001 Toxics Release Inventory http://www.epa.gov/tri/tridata/tri01/data/index.htm

Carbon Tetrachloride

Carbon tetrachloride is a clear, volatile, aromatic liquid with a wide range of industry and consumer uses such as in propellants, refrigerants, dry cleaning agents, fire extinguishers, nylon production, solvents, soaps, and insecticides. Carbon tetrachloride leaches quickly into soil and dissolves easily in groundwater. The EPA MCLG for carbon tetrachloride is zero, meaning that any exposure to it is considered harmful. Its MCL is set at 5 ppb because when the Safe Drinking Water Act was developed, this was believed to be the lowest level that technology and resources would allow. Even short term exposures can cause liver, kidney, and lung damage, as well as increased risks of cancer.

Amount Released and Remediation Costs

One of the most common ways that Carbon Tetrachloride enters water is through contaminated ground water. This water is most commonly treated using Active or Passive Soil Vapor Extraction. However, this process is extremely costly and to treat an emission stream with a concentration of around 500 ppm costs a facility between $620,000 and $2,000,000 per year.[37] Using packed tower adsorption, aeration basin, or carbon adsorption and not including infrastructure and starting costs, these processes cost respectively up to $0.29/1000 gallons, $0.65/1000 gallons, and $1.34/1000 gallons.[38] These processes also require costly treatment infrastructure and equipment to be installed, as well as regular maintenance.

[37] Cummings, Mark and Roth, Steven R. Passive Soil Vapor Extraction: A Cost Effectiveness Study. Remediation Journal. Volume 6, Issue 3. John Wiley & Sons, Inc. 1996.
[38] Clark,Robert M.; Asce, M.; Eilers, Richard G.; and Goodrich, James A. VOC's in Drinking Water: Cost of Removal. ASCE. Feb 2009.

Rank	Industrial Sector	Total Environmental Releases (lbs.)	Water Release (lbs.)
1	Chemicals And Allied Products	472,800	307
2	Electric, Gas, And Sanitary Services	140,441	13
3	Petroleum And Coal Products	3,253	
4	Stone, Clay, And Glass Products	500	
5	Lumber And Wood Products	41	
6	Electronic & Other Electric Equipment	9	
7	Environmental Quality And Housing	6	
		Total Water Release	**320**

Figure 7: Carbon Tetrachloride environmental release by industry as of 2001[39]

Trichloroethane

Similar in odor to chloroform, trichloroethane is used mainly as a solvent for removing grease from machine parts, textile processing and dyeing, and aerosols. Like many of the other volatile organic contaminants, trichloroethane leaches quickly into soil and dissolves easily in groundwater. The EPA MCLG for carbon tetrachloride is zero, meaning that any exposure to it is considered harmful. Its MCL is set at 5 ppb because when the Safe Drinking Water Act was introduced, this was believed to be the lowest level that technology and resources would allow.[40] Even short term exposure can cause damage to the liver, nervous, and circulatory system.

[39] 2001 Toxics Release Inventory http://www.epa.gov/tri/tridata/tri01/data/index.htm
[40] http://www.epa.gov/safewater/dwh/c-voc/111-tric.html

Amount Released and Remediation Costs

Using packed tower adsorption, aeration basin, or carbon adsorption and not including infrastructure and starting costs, remediating trichloroethane costs respectively up to $0.33/1000 gallons, $2.57/1000 gallons, and $2.61/1000 gallons.

Rank	Industrial Sector	Total Environmental Releases (lbs.)	Water Release (lbs.)
1	Gray Iron Foundries	77,242	1,084
2	Aircraft	73,804	546
3	Manufacturing	73,590	1,018
4	Wood Furniture	53,038	0
5	Fabricated Structural Metal	51,425	0
6	Plating and Polishing	47,799	6,152
7	Turbines and Generators	41,283	40,317
8	Other	394,692	173,286
		Total Water Release	**222403**

Figure 8: Trichloroethane environmental release by industry as of 1993[41]

1,2-Dichloroethane

1,2-Dichloroethane is another colorless, organic contaminant with an odor similar to that of chloroform. It is often used as a solvent to reduce resins and fats. It has also been used in photography, photocopying, cosmetics, drugs, and as a fumigant herbicide for grain and orchard agriculture. Even short term exposure at relatively low levels can cause central nervous system disorders, and adverse lung, kidney, liver circulatory and gastrointestinal effects, as well as cancer in long term exposure situations. The MCLG for 1,2-dichloroethane has been set at zero by the EPA because they believe this is

[41] http://www.epa.gov/safewater/dwh/c-voc/111-tric.html

the only level that would not cause potential health problems.[42] Based on this MCLG, the EPA has set a Maximum Contaminant Level (MCL) of 5 parts per billion (ppb) because they believe, given present technology and resources, this is the lowest level to which water systems can be reasonably required to remove this contaminant should it occur in drinking water. [43]

Amount Released and Remediation Costs

Due to its capabilities of seeping quickly into groundwater and its resistance to microbial and natural degradation, industries must pay top dollar to remove from water withdrawal and discharge. The most common methods to do so are by packed tower adsorption, aeration basin, or carbon adsorption. Not including infrastructure and starting costs, these processes cost respectively up to \$0.29/1000 gallons, \$1.05/1000 gallons, and \$2.98/1000 gallons.[44] Considering that hundreds of billions of gallons of wastewater is created and processed per year, these costs are significant and far reaching.

[42] http://www.epa.gov/safewater/dwh/c-voc/12-dichl.html
[43] http://www.epa.gov/safewater/dwh/c-voc/12-dichl.html
[44] Clark,Robert M.; Asce, M.; Eilers, Richard G.; and Goodrich, James A. VOC's in Drinking Water: Cost of Removal. ASCE. Feb 2009.

Rank	Industrial Sector	Total Environmental Releases (lbs.)	Water Release (lbs.)
1	Chemicals And Allied Products	447,605	4,168
2	Electric, Gas, And Sanitary Services	214,050	111
3	Petroleum And Coal Products	7,796	24
4	Stone, Clay, And Glass Products	632	1
5	Transportation Equipment	248	
6	Wholesale Trade--nondurable Goods	147	
7	Environmental Quality And Housing	6	
		Total Water Release	**4304**

Figure 9: 1,2-Dichloroethane environmental release by industry as of 2001[45]

Dichloromethane

Dichloromethane is another colorless, organic contaminant with an odor similar to that of chloroform. It is used as a solvent and cleaning agent, as well as a herbicidal fumigant for strawberry and grain agriculture, and various substance extraction. Short term exposure can cause damage to blood and the nervous system and long term exposure can cause irreparable liver damage and cancer. The MCLG for 1,2-dichloroethane has been set at zero by the EPA because they believe this is the only level that would not cause potential health problems.[46] Based on this MCLG, the EPA has set a Maximum Contaminant Level (MCL) of 5 parts per billion (ppb) because EPA believes, given present

[45] 2001 Toxics Release Inventory http://www.epa.gov/tri/tridata/tri01/data/index.htm
[46] http://www.epa.gov/safewater/dwh/c-voc/12-dichl.html

technology and resources, this is the lowest level to which water systems can reasonably be required to remove this contaminant should it occur in drinking water. [47]

Amount Released and Remediation Costs

As dichloromethane is chemically similar to dichloroethane, it can often be treated sing many of the same or similar methods. Currently removal cost estimations are not available, but they are assumed to be at least or more than that of dichloroethane. One method often used specifically for dichloromethane is biofiltration. This is generally a costly process with a large necessary infrastructure investment and operating costs.

Rank	Industrial Sector	Total Environmental Releases (lbs.)	Water Release (lbs.)
1	Chemicals And Allied Products	5,423,620	3,444
2	Rubber and Misc. Plastics Products	2,041,723	5
3	Instruments And Related Products	1,030,299	1,300
4	Textile Mill Products	825,714	
5	Transportation Equipment	393,584	
6	Fabricated Metal Products	362,846	
7	Primary Metal Industries	253,514	5
8	Electronic & Other Electric Equipment	169,444	
9	National Security And Intl. Affairs	152,328	
10	Miscellaneous Manufacturing Industries	149,468	
	Other		34
		Total Water Release	**4,788**

Figure 10: Dichloromethane environmental release by industry as of 2001[48]

[47] http://www.epa.gov/safewater/dwh/c-voc/12-dichl.html

Epichlorohydrin

Epichlorohydrin gives water a pungent odor similar to garlic and this organic contaminant is used in the production of glycerin, plastics, and other synthetic polymers, as well as in the paper and pharmaceutical industries, and as an insecticide fumigant. The MCLG for epichlorohydrin has been set at zero by the EPA because they believe this is the only level that would not cause potential health problems.[49] Since there are currently no acceptable means of detecting epichlorohydrin in drinking water, the EPA is requiring water suppliers to use water treatment techniques to control its amount in water. Since epichlorohydrin is often used in drinking water treatment processes, it is necessary to limit its use for this purpose and set in place strict and effective remediation solutions. Short term exposure to it can cause skin irritation and damage to the liver, kidneys, and central nervous system. Long term exposure can cause all of those effects, as well as damage to the stomach, eyes, and blood and even chromosome aberrations and cancer.

Amount Released and Remediation Costs

Unlike many of the other organic contaminants, epichlorohydrin when leached into groundwater can generally be at least partially broken down by natural chemical reactions. Generally epichlorohydrin reduction is performed using an alkali metal sulfite such as sodium sulfite, but it is a costly process and its efficacy has not been fully tested or proven.

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[48] 2001 Toxics Release Inventory http://www.epa.gov/tri/tridata/tri01/data/index.htm
[49] http://www.epa.gov/safewater/dwh/c-voc/12-dichl.html

Rank	Industrial Sector	Total Environmental Releases (lbs.)	Water Release (lbs.)
1	Chemicals And Allied Products	184,215	13,822
2	Electric, Gas, And Sanitary Services	57	
3	Environmental Quality And Housing	2	
		Total Water Release	**13,822**

Figure 11: Epichlorohydrin environmental release by industry as of 2001[50]

Ethylbenzene

A colorless liquid with a gasoline-like odor, ethylebenzene is used almost exclusively to make styrene, which in turn is used to make a variety of synthetic plastics and rubbers. The MCLG ethylebenzene has been set at 0.7 ppm by the EPA because they believe this is the only level that would not cause potential health problems.[51] Based on this MCLG, the EPA has also set a Maximum Contaminant Level (MCL) at 0.7 parts per million (ppm) because EPA believes, given present technology and resources, this is the lowest level to which water systems can reasonably be required to remove this contaminant should it occur in drinking water. [52] Short term exposure to ethylbenzene can result in drowsiness, fatigue, headache and mild eye and respiratory irritation. However, long term exposure can result in permanent damage to the liver, kidneys, central nervous system and eyes.

Amount Released and Remediation Costs

Ethylbenzene has moderate leaching potential and can be partially degraded by natural processes. It can also be removed through a multi-stage biofilter or by using a surfactant-aided

[50] 2001 Toxics Release Inventory http://www.epa.gov/tri/tridata/tri01/data/index.htm
[51] http://www.epa.gov/safewater/dwh/c-voc/ethylben.html
[52] http://www.epa.gov/safewater/dwh/c-voc/ethylben.html

electrokinetic process (SAEK). This can cost anywhere between $5/m^3 to $12/m^3 for soil and between $0.10/gallon and $1.00/gallon of contaminated water.[53]

Rank	Industrial Sector	Total Environmental Releases (lbs.)	Water Release (lbs.)
1	Transportation Equipment	2,461,989	15
2	Chemicals And Allied Products	1,800,403	3,485
3	Lumber and Wood Products	869,239	
4	Petroleum And Coal Products	653,886	5,316
5	Rubber and Misc. Plastics Products	453,019	17
6	Fabricated Metal Products	451,408	
7	Primary Metal Industries	179,492	118
8	Wholesale Trade--Nondurable Goods	102,617	922
9	Furniture And Fixtures	97,622	
10	Electronic & Other Electric Equipment	90,806	
	Other		15
		Total Water Release	**9,888**

Figure 12: : Ethyl Benzene environmental release by industry as of 2001[54]

EPA Regulation

As mentioned at the beginning of this section, there are over 150 drinking water contaminants either proposed, listed, or finalized for government regulation and at least 100 of these are organic compounds. Regulations were first imposed in 1979, when the EPA first established a maximum

[53] http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V74-4D10JVF-1&_user=74021&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000005878&_version=1&_urlVersion=0&_userid=74021&md5=2e5f35d9dcfc372a3f53e0d0a8343faf

[54] 2001 Toxics Release Inventory http://www.epa.gov/tri/tridata/tri01/data/index.htm

concentration level (MCL) of 0.1 mg/L (100 ppb or 100 µg/L) for the total trihalomethane (TTHM), which is defined as the sum of the concentration of trichlomethane or chloroform ($CHCl_3$), tribromomethane or bromoform ($CHBr_3$), bromodichloromethane ($CHBrCl_2$), and bromochloromethane ($CHBrCl_2$).[55]

Disinfectants and Disinfectant By-Product Rule: Stage 1

In 1998, Stage 1 of the Disinfectants and Disinfectant By-Product Rule (D/DBP rule) was established. It was promulgated under a number of amendments to the Safe Water Drinking Act of 1996. The Stage 1 rule reset the maximum contaminant level for TTHM at 80 ppb and set a maximum contaminant level for five haloacetic acids (HAA5) at 60 ppb. Unlike previous MCL for TTHM, Stage I established that all water systems, regardless of source or size, must comply with the D/DBP limits, whereas previously only large systems were required to be compliant. It went into effect for large systems serving over 10,000 people in December 2001 and for small systems serving less than 10,000 in December 2003.[56]

Disinfectants and Disinfectant By-Product Rule: Stage 2

Stage 2 of the Disinfectants and Disinfectant By-Product Rule (D/DBP rule) was initiated on January 4, 2006 and according to the EPA, "is intended to reduce potential cancer and reproductive and developmental health risks from disinfection byproducts (DBPs) in drinking water, which form when disinfectants are used to control microbial pathogens." Every year over 260 million individuals are exposed to disinfection by-products. Stage 2 targets both community and nontransient noncommunity water systems that treat drinking water with a primary or residual disinfectant other than ultraviolet

[55] HDR Engineering Inc. Handbook of Public Water Systems 2nd Edition. March 23, 2001. Omaha, NE. John Wiley & Sons Inc. New York, NY and Canada
[56] Stage 2 Disinfectants and Disinfection Byproduct Rule (Stage 2 DBP rule) http://www.epa.gov/ogwdw/disinfection/stage2/basicinformation.html

light. Compliance monitoring and enforcement will begin between 2012 and 2016 and all systems must be under the established MCL by the end of the first complete monitoring year.[57]

Commercial Water Treatment Products (Consumer Use)

There has been a steady growth in both the Point of Use (POU) and Point of Entry (POE) systems over the last ten years. To clarify, POU systems are installed at a single outlet such as a faucet, whereas POE systems are installed at the point where water enters the whole home. Systems made by companies like PUR and Culligan are generally POU systems whereas those made by companies such as EcoWater and Wellness are installed for the whole house (POE). POU systems have the advantage of lower initial investment, low maintenance costs, simple operation, and often DIY (do it yourself) installation. These factors have given them strategic market advantage over POE systems.[58] However, POE systems, although significantly more costly, are much more effective at removing particulate matter as small as five microns and can provide clean water for the whole house including applications such as the shower and faucets. Both POU and POE systems combined with organic removal technology are useful as a supplemental augmentation to purification done by the municipal system.[59]

[57] Stage 2 Disinfectants and Disinfection Byproduct Rule (Stage 2 DBP rule) http://www.epa.gov/ogwdw/disinfection/stage2/basicinformation.html

[58] Consumer Water Purification & Air Cleaning Systems (US Industry Forecasts for 2012 & 2017) Publication Date: Oct 31, 2008

[59] Leff, Dr. Alan. Projections for 2001…and Beyond. *Water Quality Products* January 2001 Volume: 6 Number: 1. 2009 Scranton Gillette Communications

Brand	Aquasana® Rhino® EQ-300	EcoWater	Life Source®	S.K.W. 2060F	Wellness® MG
Retail Price	$999	$2,899	$3,790	$2,850	$5,950
Replacement Cost	$639.20	$2,890	$3,790	$1,789	$2,950
Capacity	300,000 Gal.	400,000 Gal.	1,000,000 Gal.	225,000 Gal.	400,000 Gal.
Per Month "Use Cost"	$17.75/month	$60.21/month	$31.58/month	$66.26/month	$61.46/month
Removes Chlorine	YES >99%	YES >99%	YES	YES	YES >99%
Removes Particulate	>5 Microns	>10 Microns	>10 Microns	>10 Microns	>5 Microns
UL/NSF Certified Capacity	YES 300,000 Gal.	YES	NO	NO	YES 500,000 Gal.
Requires Electric	NO	YES	YES	NO	NO
Requires Back Flushing	NO	YES	YES	YES	NO

Figure 13: Top Five POE Water Treatment Systems[60]

Brand	Aquasana	Aqua-Pure	Brita	Brita2	Culligan	eSpring	Everpure	GE	Kenmore	PUR
Model Number	AQ-4000	DWS1000	Faucet Filter	Pitcher Filter	SY-2300	100188	H-54	Smart Water GXSV10C	Deluxe 38465	Plus FM-3000
Retail Price	$124.99	$349.95	$34.95	$24.95	$159.99	$577.20	$359.99	$139.99	$149.99	$49.95
Replacement Cartridge Cost & Capacity	$48.00 / 500 Gal.	$79.99 / 625 Gal.	$20.00 / 100 Gal.	$7.70 / 30 Gal.	$50.39 / 500 Gal.	$173.30 / 1320 Gal.	$100.99 / 750 Gal.	$60.00 / 540 Gal.	$49.00 / 500 Gal.	$20.00 / 100 Gal.
Per Gallon "Cost Of Use"	9.6¢ / Gal.	13¢ / Gal.	13¢ / Gal.	25¢ / Gal.	10¢ / Gal	13.1¢ / Gal.	13.5¢ / Gal.	11¢ / Gal	11¢ / Gal	20¢ / Gal.
Removes Chlorine	99%	97%	99%	>75%	97%	>98%	>87%	97%	99%	98%
Removes Lead	>99%	95%	99%	93%	93%	99%	98%	98%	92%	96%
Removes Cysts	>99%	>99%	>99%	NO	99%	>99%	>99%	>99%	NO	>99%
Removes THMs	>99%	92%	NO	NO	95%	>99%	NO	95%	>99%	NO
Removes VOCs	>99%	92%	NO	NO	95%	>99%	NO	99%	95%	NO
Removes Lindane	>99%	>99%	99%	NO	99%	>99%	NO	99%	99%	97%
Removes Alachlor	>98%	98%	99%	NO	98%	99%	NO	98%	95%	NO
Removes Atrazine	>97%	97%	92%	NO	97%	>88%	NO	97%	97%	96%
Removes Benzene	>99%	>99%	96%	NO	99%	>96%	NO	99%	83%	NO
Removes TCE	>99%	>99%	99%	NO	99%	>96%	NO	99%	98%	NO
Removes MTBE	>93%	NO	NO	NO	90%	>96%	NO	NO	NO	NO
Total Cost For 1 Year 1000 gals.	$172.99	$349.95	$214.95	$273.91	$210.38	$750.50	$229.90	$199.99	$198.99	$229.95

Figure 14: Top Ten POU Water Treatment Systems[61]

[60] http://www.waterfiltercomparisons.com/whole_house_filter_comparison.php

The United States Water Market

Water Utility Market

There are approximately fifty-seven thousand community drinking water systems in the United States. These systems provide potable drinking water to over 250 million people, who pay over sixty billion dollars every year.[62] As seen in the figure below, the majority of these systems are municipal, while the secondary majority is investor owned. These systems provide a large market for new and improved treatment techniques.

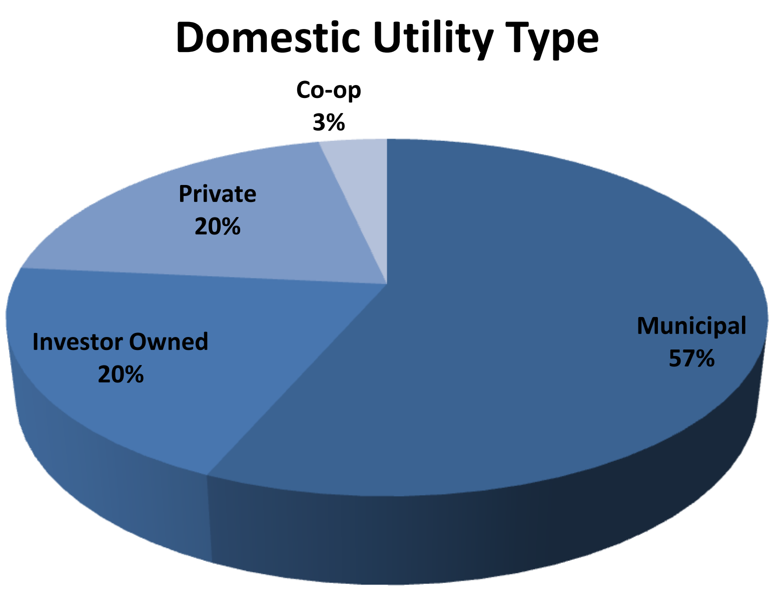

Figure 15: Breakdown of domestic utilities

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[61] http://www.waterfiltercomparisons.com/whole_house_filter_comparison.php
[62] Drinking Water Utilities. QMS Partners

Infrastructure Opportunities

Water infrastructure in developed countries consists of treatment plants, sewer lines, distribution lines, and storage facilities. These systems are vital to each country's way of life. However, these systems are becoming outdated, and as more information comes to light concerning new harmful contaminants, it is being realized that these systems are inadequate in many aspects of treatment. Augmenting these systems is necessary to maintain healthy and potable water.

Municipal

As previously mentioned, the United States municipal water treatment segment accounts for 57 percent of the treatment systems in the United States. According to a survey conducted in 2005, 79 percent of these systems had planned on making major capital investments between the years 2006 and 2009. Analysts projected that at least 60 percent of those companies will actually make those infrastructure and upgrade investments and 49 percent of them will make treatment plant investments.[63] This shows that companies are willing to invest significantly in their treatment systems and demonstrates the large market opportunities for new technology such as Sorption Oxidation.

The Environmental Protection Agency's (EPA) Clean Water State Revolving Fund (SRF)

The EPA's Clean Water Act created the SRF in 1987 to fund a wide range of public water projects from municipal water treatment to environmental protection and pollution control. To date the fifty-one separate funds (one for each state and Puerto Rico) have provided over five billion dollars annually through over 22,700 low-interest loans. This funding provides incentive to water treatment providers to invest in upgrading their systems and research into applying new technologies.

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[63] Drinking Water Utilities. QMS Partners

Under a "revenue growth" scenario there will be total capital spending gaps of $21 billion and $45 billion for clean water and drinking water, respectively, between the years 2000 and 2019.[64] This money is spent between infrastructure maintenance and replacement, meeting growing demand growth, and system improvements. A gap in spending needs such as this is significant and yields annual gaps of $1-2 for clean water and drinking water, leaving a huge demand for cost effective water treatment.

Residential Market

The United States consumer water purification market has traditionally been dominated by POU systems. Conventional filtration media currently accounts for 76 percent of demand, but according to the report, Consumer Water Purification & Air Cleaning Systems (US Industry Forecasts for 2012 & 2017), higher value systems such as Sorption Oxidation, reverse osmosis, and distillation systems are projected to experience high growth rates in the coming years. New technologies such as SOx, combined with new and traditional broad filtration methods, could process wide spectrum of water contaminants very effectively.

Projections

The report, Consumer Water Purification & Air Cleaning Systems (US Industry Forecasts for 2012 & 2017) projects 5.6 percent consumer market annual gains from the current $1.25 billion to $1.5 billion in 2012, based on "increased awareness for the scientific and medical benefits of better quality water," as well as increased scrutiny on public water due to discovery of contaminants recently found to be

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[64] The Clean Water and Drinking Water Infrastructure Gap Analysis. Office of Water. EPA 816-F-02-017. September 2002

harmful and others not previously even known to exist.[65] Another substantial growth segment will be the aftermarket part, filter, and membrane replacement market, with a projected 4.8 percent growth rate through 2012, when it will reach sales of $2.7 billion.[66]

World Market

According to Chemical Week World News, buyers and suppliers both say that, "The $300 billion global water treatment market remains 'resilient' to recessionary pressures."[67] This number is all-inclusive and refers to the total global market including infrastructure, water supply equipment, services, and so forth. Even with the short term financial concerns of the current global economy, municipalities, public water works, and consumers need new water technology to lower operating costs and achieve better water quality.

Demand

The total world product demand for chemical and nonchemical water treatment solutions is currently approximately $33 billion and is projected to increase 6.4 percent every year until 2011, when it is projected to reach $40 billion.[68] This number refers to the entire water treatment demand, but only at the manufacturer level and does not address actual costs for the consumer. The Freedonia Group projects demand for nonchemical treatment products on the global scale to rise 7.4 percent per year to

[65] Leff, Dr. Alan. Projections for 2001…and Beyond. *Water Quality Products* January 2001 Volume: 6 Number: 1. 2009 Scranton Gillette Communications

[66] Consumer Water Purification & Air Cleaning Systems (US Industry Forecasts for 2012 & 2017) Publication Date: Oct 31, 2008

[67] Phillips, Kate and D'Amico, Esther. Chemical and Service Sector Water Treatment Demand to Rise. Chemical Week. November 17, 2008. http://www.chemweek.com/markets/specialty_chemicals/water_treatment/15399.html

[68] World Water Treatment Products: Industry Study with forecasts for 2011 & 2016. Study #2276. The Freedonia Group. January 2008

$25.8 billion in 2011 with a technology breakdown of membranes (43%), demineralization (16%), ozonation (13%), ultraviolet and disinfection (12%). Other products account for another 15 percent. Currently approximately $150 billion are spent on wastewater treatment alone and is expected to grow to $240 billion by 2016.[69] This 60 percent increase is a substantial growth rate and drastically affects the demand for water treatment technology.

Demand in Emerging Industrial Powers

The fastest growth is projected to be in emerging industrial powers such as China, India, Africa, the Middle East, Russia, Latin America, and the Pacific Rim.[70] BWA Water Additives reports 10-15 percent growth rates in the Middle East, North Africa, India, and Russia. China is projected to experience the most dynamic growth rate as it continues to experience drastic industrial growth.[71] It is estimated that approximately 350 million people lack potable drinking water and 70 percent of China's lakes and waterways are polluted.[72] Without intervention, the Chinese government estimates that there will be an annual water shortage of 53 trillion gallons by 2030.[73] Demand for nonchemical water treatment systems will continue to grow faster than chemical treatment methods, but these products are often complimentary. The largest world producers (Veolia, General Electric, and Nalco) account for less than 25 percent of total sales.[74] This allows smaller firms and new products to be able to enter the market, but to compete as well by focusing on narrower product lines.

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[69] QMS Partners. Global Water & Wastewater Infrastructure Demand. 1/13/2009.
[70] Phillips, Kate and D'Amico, Esther. Chemical and Service Sector Water Treatment Demand to Rise. Chemical Week. November 17, 2008.
http://www.chemweek.com/markets/specialty_chemicals/water_treatment/15399.html
[71] Deneen, Michael A. and Cross, Andrew C. The Global Market for Water Treatment Products. Business Economics 2005.
[72] Leung, W. B.C. Firms Clean Up in China: Demand for Waste and Water-Treatment Services Rising. Vancouver Sun, 16 Jan 2006
[73] Gan, A, "Corporate: Asian Environment's Ambitious China Plans. Oct 2005. Lexis Nexis.
[74] Deneen, Michael A. and Cross, Andrew C. The Global Market for Water Treatment Products. Business Economics 2005.

Figure 16: Water usage for domestic purposes by country[75]

Water Filtration World Market Segmentation

In 2007, INSEAD Business School compiled The 2007 Report on Plumbed-In Water Filters: World Market Segmentation by City. This report is very valuable, as there is very little available market data on the water filtration market. It covers the top two thousand cities in over two hundred countries around the world, and ranks them according to market size in terms of latent demand (potential industry earnings), which can be defined as market potential or demand for water filtration technology's core benefits. It is important to consider that latent demand is typically greater than actual sales. Any potential product or service that might be combined with, or directly related to, plumbed in water filters is covered by the study, such as self-contained faucet mounted systems and in-line systems. According to the report, sources used were Euromonitor, Mintel, Thomson Financial Services, the U.S. Industrial Outlook, the World Resources Institute, the Organization for Economic Cooperation and Development,

[75] United Nations Environment Programme. 2002. http://www.unep.org/

various agencies from the United Nations, industry trade associations, the International Monetary Fund, and the World Bank.[76]

Rank	City	Country	US $ million	% Country	% Region	% World	Cumul %
1	New York	United States	193.87	22.75	20.56	4.91	126704.90
2	Paris	France	94.07	70.3	9.99	2.38	126707.29
3	Shanghai	China	73.73	14.32	5.17	1.87	126709.15
4	Los Angeles	United States	70.18	8.23	7.44	1.78	126710.93
5	Chicago	United States	64.51	7.57	6.84	1.63	126712.56
6	Beijing	China	61.44	11.93	4.31	1.55	126714.11
7	Tokyo	Japan	56.09	16.75	3.93	1.42	126715.53
8	Chongqing	China	52.00	10.10	3.65	1.32	126716.85
9	London	United Kingdom	48.33	35.03	5.13	1.22	126718.07
10	Guangzhou	China	47.44	9.21	3.33	1.20	126719.27
11	Chengdu	China	43.66	8.48	3.06	1.10	126720.38
12	Maharashta State	India	41.61	17.25	2.92	1.05	126721.43
13	Tianjin	China	37.77	7.33	2.65	0.96	126722.38
14	Houston	United States	37.55	4.41	3.98	0.95	126723.33
15	Berlin	Germany	37.23	20.32	3.96	0.94	126724.28
16	Bangkok	Thailand	35.09	93.11	2.46	0.89	126725.16
17	Philadelphia	United States	33.29	3.91	3.53	0.84	126726.01
18	Seoul	South Korea	32.49	48.85	2.28	0.82	126726.83
19	Rome	Italy	30.06	25.35	3.19	0.76	126727.59
20	Uttar Pradesh	India	28.57	11.84	2.00	0.72	126728.31
21	Manila	Philippines	26.99	88.46	1.89	0.68	126728.99
22	Harbin	China	24.71	4.80	1.73	0.63	126729.63
23	Nanjing	China	24.60	4.78	1.73	0.62	126730.25
24	Wuhan	China	23.78	2.79	2.52	0.60	126730.87
25	Dallas	United States	23.78	2.79	2.52	0.60	126731.47
26	San Jose	United States	23.50	2.76	2.49	0.59	126732.07
27	San Francisco	United States	23.14	2.71	2.45	0.59	126732.65
28	Jinan	China	22.82	4.43	1.60	0.58	126733.23
29	Yokohama	Japan	22.72	6.79	1.59	0.57	126733.81
30	San Diego	United States	22.51	2.64	2.39	0.57	126734.38

Figure 17: Top 30 cities ranked by water treatment market size

Industrial Water Withdrawal and Discharge

Every day, United States industry alone consumes over 25 billion gallons of water for processing, boiler make-up, condensate, and human consumption, and over 20 billion gallons of that is turned into potentially harmful wastewater.[77] Even more daunting is the amount used by thermoelectric plants.

[76] Parker, Philip M., Ph.D. Eli Lilly Chaired Professor of Business, Innovation and Society. The 2007 Report on Plumbed-In Water Filters: World Market Segmentation by City. INSEAD (Singapore and Fontainebleau, France
[77] Wachinski, Anthony M., Industrial Water Reuse makes Cents. Environmental Protection. October 1, 2004.

These approximately 2,000 plants withdraw over 186 billion gallons of water daily in the US and Canada.[78] More often than not, process water is used once and then discharged to local bodies of water after minimal remediation. These companies spend millions of dollars every year on water and treatment processes. The source water alone in the United States costs on average around $2.06 per 1,000 gallons and can cost up to $2.83 per 1,000 gallons in states such as Arizona.[79] This may not seem like a significant cost, but using the thermoelectric plants as an example, the industry pays about $383.16 million dollars per day for process water.

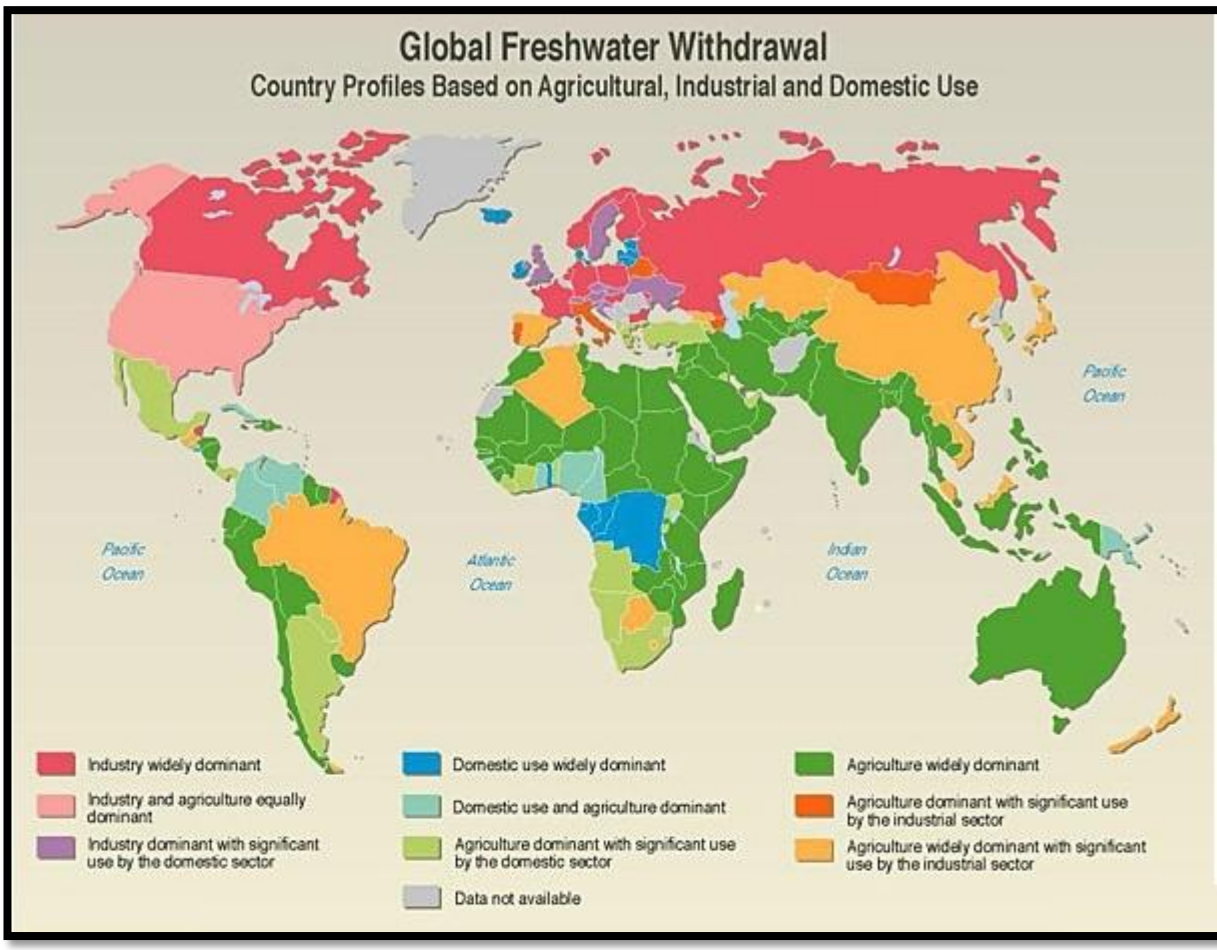

Figure 18: World freshwater withdrawal by dominant usage

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[78] Wachinski, Anthony M., Industrial Water Reuse makes Cents. Environmental Protection. October 1, 2004.
[79] Wachinski, Anthony M., Industrial Water Reuse makes Cents. Environmental Protection. October 1, 2004.

Agriculture

The agricultural sector accounts for 49 percent of total U.S. freshwater usage, while 85-90 percent of all freshwater used in Africa and Asia is used in the agriculture segment, and as of 2000 at least 67 percent of the world freshwater withdrawal.[80] However, water for agricultural applications requires much less treatment than that of the industrial sector and, as mentioned previously, gray and black water can be processed and used for irrigation. Still, the agricultural sector is one of the largest introducers of organic contaminants to water supplies through usage of pesticides, herbicides, and other chemical crop and soil treatments. The water withdrawal usage is projected to increase for the agricultural sector by 1.2 times, domestic by 1.8 times and the industry sector by 1.8 times by the year 2025.[81] This leaves significant market potential for new remediation technologies in all three sectors.

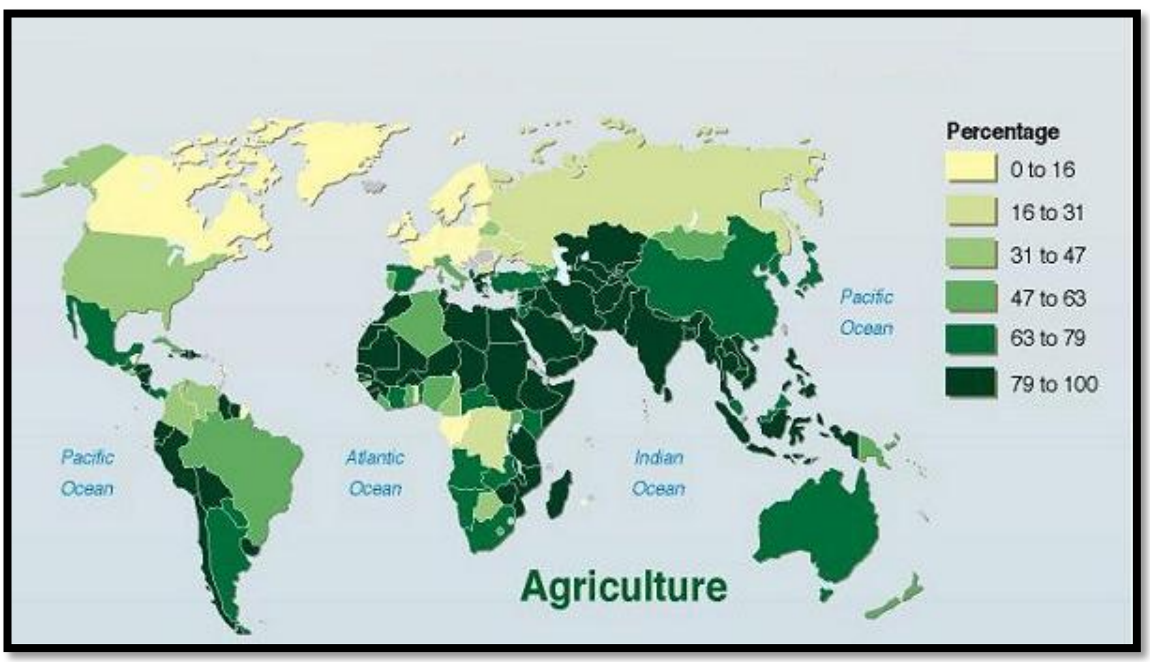


Figure 19: World freshwater withdrawal by country for agricultural use as of 2000[82]

[80] United Nations Environment Programme. 2002. http://www.unep.org/
[81] United Nations Environment Programme. 2002. http://www.unep.org/
[82] United Nations Environment Programme. 2002. http://www.unep.org/

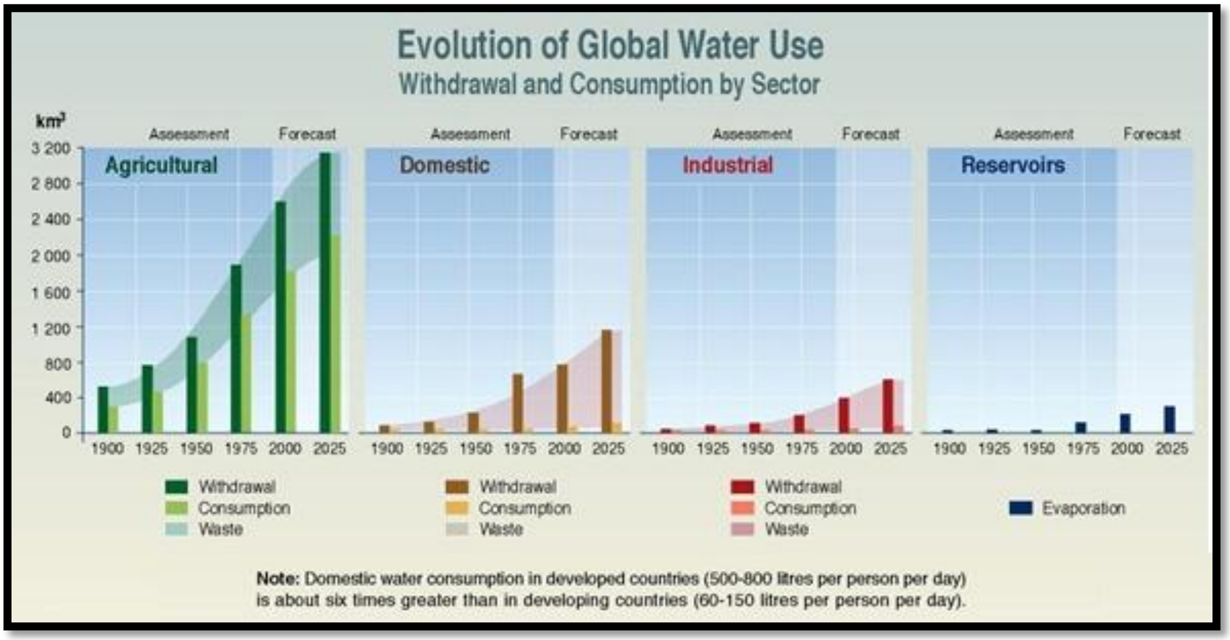


Figure 20: Past and projected water withdrawal by sector[83]

Industry

The industrial sector accounts for 20 percent of global freshwater withdrawals and between 57 and 69 percent is used for hydropower and nuclear generation, between 30 and 40 percent for industrial processes, and between 0.5 – 3 percent for thermal power generation.[84] Industrial plants need to use highly conditioned water in order to prevent problems such as scale, corrosion, carryover, and sludge deposition. If these problems are not prevented or treated they can result in inefficient system function, thermal damage, down-time, increased cleaning time and cost, and reduced product life, or in extreme cases system failure.

[83] United Nations Environment Programme. 2002. http://www.unep.org/
[84] United Nations Environment Programme. 2002. http://www.unep.org/

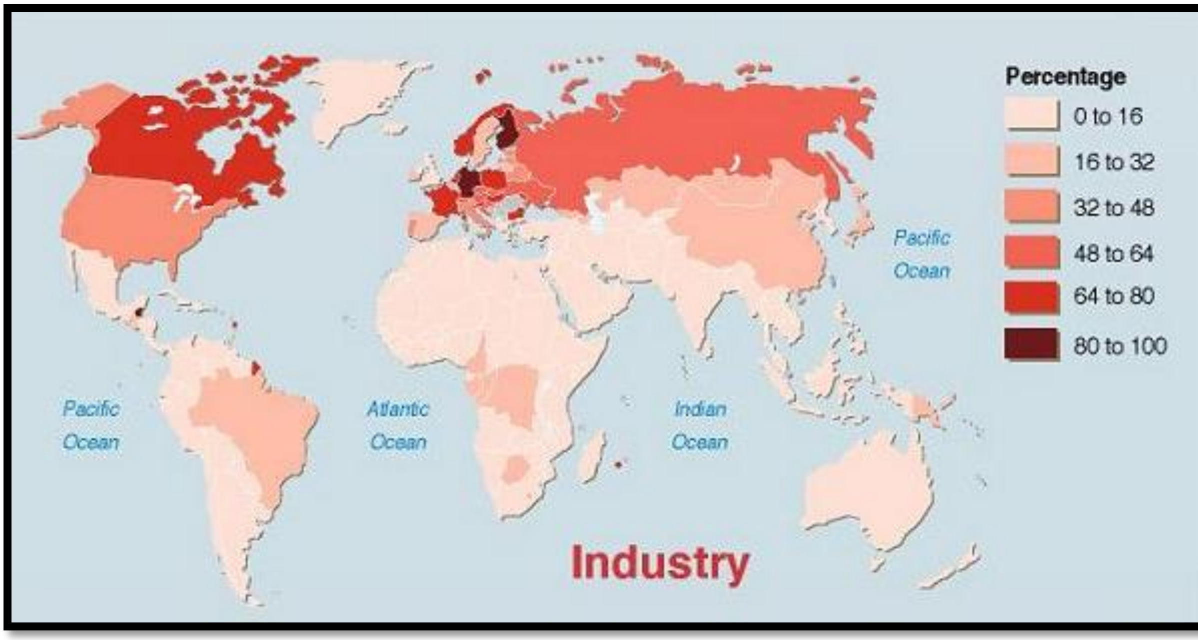


Figure 21: World freshwater withdrawal for industry use by country as of 2000[85]

Treatment and Reuse

Treating and reusing water not only protects the environment, but it also creates savings for the organization using or discharging the water. Discharging wastewater to sewage systems often requires high payment surcharges based on the volume or flow, and contaminants and their associated concentrations. If the organization wishes to discharge wastewater to nearby bodies of water in the U.S. it is required that they purchase a National Pollution Discharge Elimination System (NPDES) permit and satisfy its requirements.[86] Violation of the terms of this permit results in heavy fines and poor publicity. By treating and reusing wastewater, companies can not only circumvent discharge and municipal water purchase fees and surcharges, but can even often avoid the purchase of a NDPES permit.

[85] United Nations Environment Programme. 2002. http://www.unep.org/
[86] Wachinski, Anthony M., Industrial Water Reuse makes Cents. Environmental Protection. October 1, 2004.

Common Remediation Technologies

The major technologies used for water treatment employ one of four options: filtration, ultraviolet, reverse osmosis, or distillation. NSF International currently evaluates these technologies and the applicable standard for each technology is as follows:

Technology	Description of Product
Filtration	(NSF/ANSI 42 & 53) This is the physical process that occurs when liquids, gases, dissolved or suspended matter adhere to the surface of, or in the pores of, an adsorbent medium. Carbon filters use this technology to filter water.
Ultraviolet	(NSF/ANSI 55) This treatment style uses ultraviolet light to disinfect water (Class A systems) or to reduce the amount of heterotrophic bacteria present in the water (Class B systems).
Reverse Osmosis	(NSF/ANSI 58) A process that reverses, by the application of pressure, the flow of water in a natural process of osmosis so that water passes from a more concentrated solution to a more dilute solution through a semi-permeable membrane. Most reverse osmosis systems incorporate pre- and post-filters along with the membrane itself.
Distillation	(NSF/ANSI 62) These systems heat water to the boiling point and then collect the water vapor as it condenses, leaving many of the contaminants behind, particularly the heavy metals. Some contaminants that convert readily into gases, such as volatile organic chemicals, may be carried over with the water vapor.

Figure 22: Commonly used water treatment technologies

Filtration (Activated Carbon)

The most commonly used filtration technology widely used to treat organic contaminants is the use of activated carbon. It uses a derivation of charcoal or coal (carbon) to adsorb waterborne contaminants. It utilizes the porous nature of carbon to provide large adsorbent surface area where contaminants such as organics become trapped. However, activated carbon treatment suffers from many weaknesses and problems. It often has low capacity and is vulnerable to fouling from organic matter in the feed water. One of the biggest problems associated with its use is its disposal or regeneration. Both of these processes are extremely expensive and often harmful to the environment.

Ultraviolet

The ultraviolet disinfection process uses a UV light source encased in a transparent sleeve and mounted so water can pass through a flow chamber beneath or around it. It is effective in disinfecting water of bacteria, protozoa, and some viruses by destroying the reproductive systems of these organisms through DNA/RNA rearrangement. However, this disinfection process is by no means a blanket treatment system and cannot treat sediment, organic, or inorganic contaminants. Also, if used before these contaminants are removed, it loses efficacy in destroying the microbial contaminants such as bacterial and viral organisms, as the UV light is blocked by these contaminants.

Reverse Osmosis (Membrane)

Membrane technologies like reverse osmosis and nanofiltration are alleged to be a cost-effective method of removing a wide range of low molecular weight organic contaminants. Membrane systems are useful treatment methods for producing potable water from surface sources or as supplemental systems for municipal and industrial treatment plants. Companies like DOW Water

Solutions are currently running multiple research studies under real-life conditions to try to determine the rate of improvement for membrane units paired with existing systems.[87]

Distillers

Distillation is another broad range water treatment method. Unlike the others however, distillation uses heat to evaporate the water and condense the vapor to produce treated water. Although distillation generally treats a broader spectrum of contaminants with efficacy than processes such as UV or Reverse Osmosis, it is not effective against some of the more volatile organic contaminants. These contaminants evaporate readily and can be carried with the water vapor into the product water.

Sorption Oxidation (SOx)

The patent pending Sorption Oxidation technology developed at WPI is comprised of two steps: first adsorption and then oxidation. The adsorption process consists of passing the contaminated liquid through the adsorption medium called a zeolite. This zeolite is basically a hydrophobic “molecular sieve,” which separates contaminants from their carrier based on molecular size and does not retain water. Flow speed and efficiency are important to the viability of the system because it needs to be compact and able to process large volumes of fluid in minimal time to meet consumer needs. The inventors have theorized that a pelletized version of zeolite would promote much faster system flow and efficiency than traditional powdered zeolite. These zeolites are readily available and are relatively inexpensive (around $250/kg) and make for a very marketable product.

[87] Tenny, Edward. The Road Ahead for Water & Wastewater. Source: *Water & Wastes Digest* January 2007 Volume: 47 Number: 1. 2009 Scranton Gillette Communications

The oxidation process follows adsorption and is the phase where the now contaminated zeolite is cleaned through exposure to hydrogen peroxide, ultraviolet light, or ozone. This causes a chemical mineralization of the contaminants resulting in the conversion to carbon dioxide that harmlessly dissipates. This cleaning process allows the zeolites to be reused rather than thrown away as are common filters. This is why the SOx technology is such an important, as well as marketable, technology. It can drastically change the negative aspect of chlorination, by reducing disinfection by-products. It also has a long product life-span and leaves a small carbon footprint.

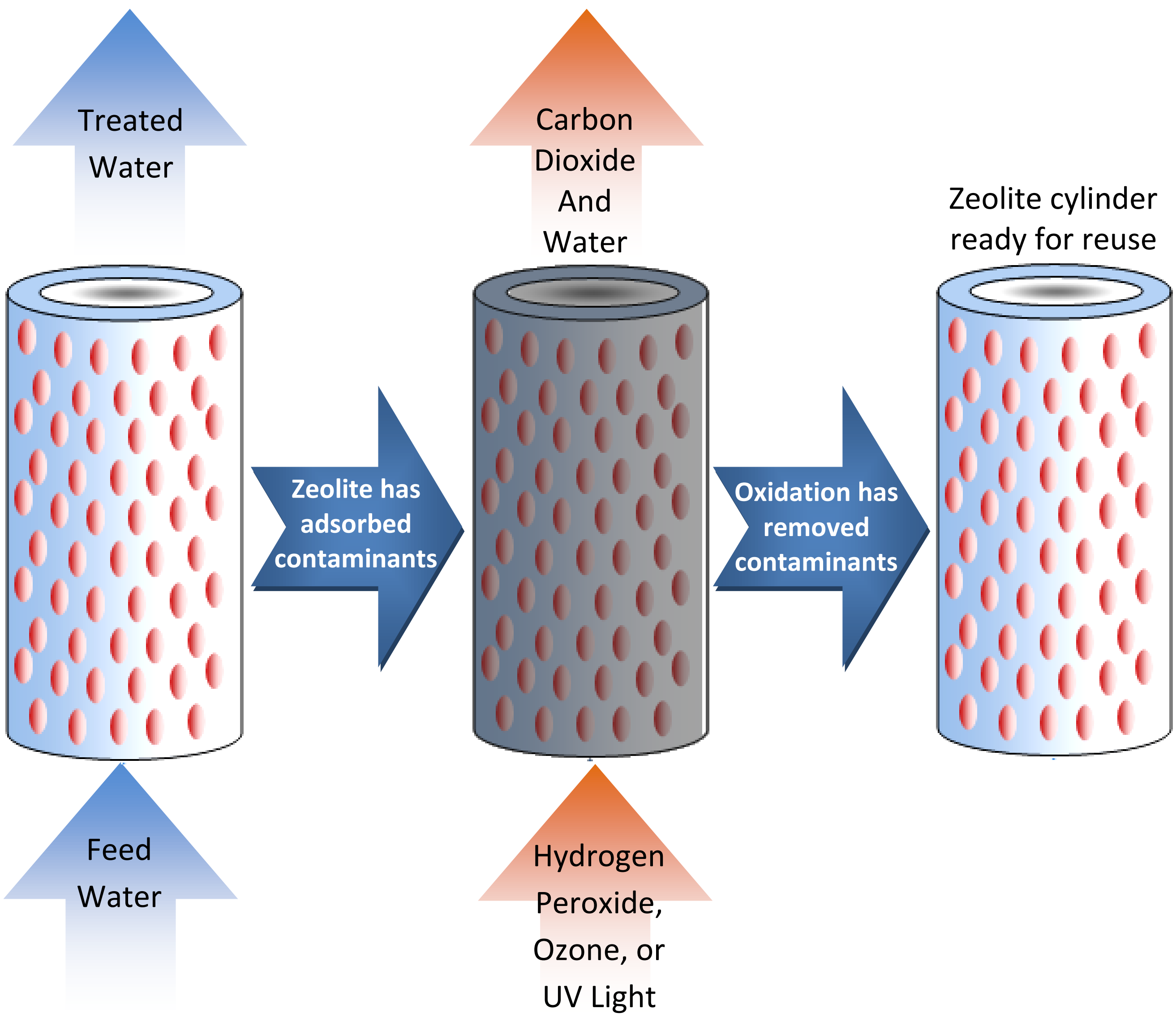


Figure 23: The sorption and oxidation process to remove organic contaminants from water and then from the zeolite

SOx Performance and Testing

The Sorption Oxidation process has few technology rivals. One of these is granular activated carbon, which as previously mentioned is widely used in water treatment. However, research has shown SOx to be far more effective and have a much longer effective usage lifetime. It has been found that the hydrophobic adsorbents used in SOx, such as ZSM-5 and HiSIV3000, have larger uptakes than GAC, especially at very low organics concentrations, and far longer useful adsorbent life. In a 1cm diameter by 12 cm height glass column, with a velocity of 6.62cm/min and a flow rate of 5.2ml/min, ZSM-5 adsorption was able remove 100 percent of MTBE from water for over 890 hours. At that point it was still removing at least 90 percent of MTBE, but considered by the research team to be at an ineffective level and it required regeneration, but can still be reused again at full efficacy after oxidative regeneration.

Sorption Oxidation has been tested and found effective in the removal from water of contaminants such as chlorinated VOC's, MTBE, disinfection by-products, and estrone. Based on research and these results, it is believed that Sorption Oxidation will also be able to remove many other organic contaminants such as carbon tetrachloride, trichloroethane, 1,2-dichlorothane, dichloromethane, epichlorohydrin, ethylbenzene; many of which are on the EPA's list of regulated water contaminants. This process may also be effective in treating water contaminated with pharmaceuticals and endocrine disruptors, now being found at low concentrations in many waters.

Cost to Produce

While Sorption Oxidation is still in the design and research stages, it has been tested extensively, proofs of concept are under way, and a general cost analysis is currently being performed. Thus far it has been estimated that the actual system would cost less than a GAC system of comparable size and application and needs no specialty parts. Important factors to consider in any cost analysis and especially for SOx, are that costs to produce a system such as this vary greatly with application variations, system needs, and size and when mass produced, supply costs greatly decrease.

Adsorption and General System Costs

The SOx system would utilize standardized materials such as glass for the adsorption columns, and standard steel or copper valves and piping for the water transport. The actual adsorbent prices range from ~$17/kg for HiSiv 3000 to $250/kg for high-grade long usage life ZSM-5 made by Exxon Mobil. However, the price has decreased by 37.5 percent in three years. According to a WPI graduate project, ZSM-5 cost $400/kg in 2006. The only other cost is that of the oxidation method which varies by application.

Oxidation/Regeneration Costs

Cost analysis has also been initiated for the chemical oxidation/regeneration step. It is believed that the efficiency of oxidizing contaminates that have been concentrated on the sorbent, is much greater than the efficiency of oxidizing trace contaminants in aqueous solution. This should translate into cost savings over conventional chemical oxidation treatment processes. For a general, preliminary cost estimate, the following information is provided. Hydrogen peroxide can be purchased on the consumer market for less than $0.45/L and even less when bought wholesale from a distributor. Ozone must be generated on-site, but this is a relatively inexpensive process and depending on application size, an ozone generator can cost between $30 for a small in-home version producing 700 mg/hr to $4,000 for a high output generator producing over 12,000 mg/hr. Ultraviolet oxidation would require UV emitting lamps which can be purchased for under $10/ 100w lamp and have a usage lifespan of 500 hours.

Hydrogen peroxide would require the most frequent supply, but is the cheapest oxidation medium and is very effective in zeolite regeneration. Ozone requires a larger capital investment, but is also very effective and can be used with no input other than a power source for long periods of time. UV oxidation requires semi-frequent bulb replacement and special system design, but has mid-range efficacy and maintenance needs. We understand that these are very broad estimates, but considering the reusability and extremely long usage lifespan of the adsorption mediums, our research and experience indicates that SOx will be not only be technically efficient and effective in organic contaminant removal, but also in cost-efficiency and system life span.

Patent Status

The Sorption Oxidation technology's non-provisional patent application was filed internationally on July 11, 2006 under the title of Methods and Devices for the Removal of Organic Contaminants from Water (WO/2007/056717). The applicants are Worcester Polytechnic Institute and the inventors. Something to note is that because parts of the involved research was funded by the National Institutes of Health under an SBIR grant through Triton Systems, the U.S. Government maintains certain rights in the invention. Every patent application must pass an International Search Report (ISR) to establish that it is truly unique. The ISR for SOx was filed in June of 2008 and has no major discrepancies and the patent is expected to be approved shortly. The drawings and diagrams contained in this report are also covered under a provisional patent as of April 2009. The full patent information for the involved technology is as follows:

1) "Remediating MBTE Contamination with Hydrophobic Membranes and Chemical Oxidation" (Thompson et al.), US Prov. Appl. No. 61/150,821, filed 2/9/09.
2) "Simultaneous Reduction/Oxidation Process for Destroying an Organic Solvent" (Bergendahl et al.), PCT/US2008/058673, filed 3/28/08.

3) "Methods and Devices for the Removal of Organic Contaminants from Water", (Bergendahl et al.), PCT/US06/060591, now US Pat. App. No. 12/093,055, filed 11/7/06.

SOx Applications

One of the most marketable aspects of the Sorption Oxidation technology, other than its reusability and efficacy, is its versatility. There are a variety of applications that the author believes SOx will be well suited for and a valuable asset in solving remediation and purification problems. The most prominent of these applications are industrial, municipal, consumer, and military uses. This shows that SOx has excellent potential market positioning because it has a place in all of the major aspects of water treatment.

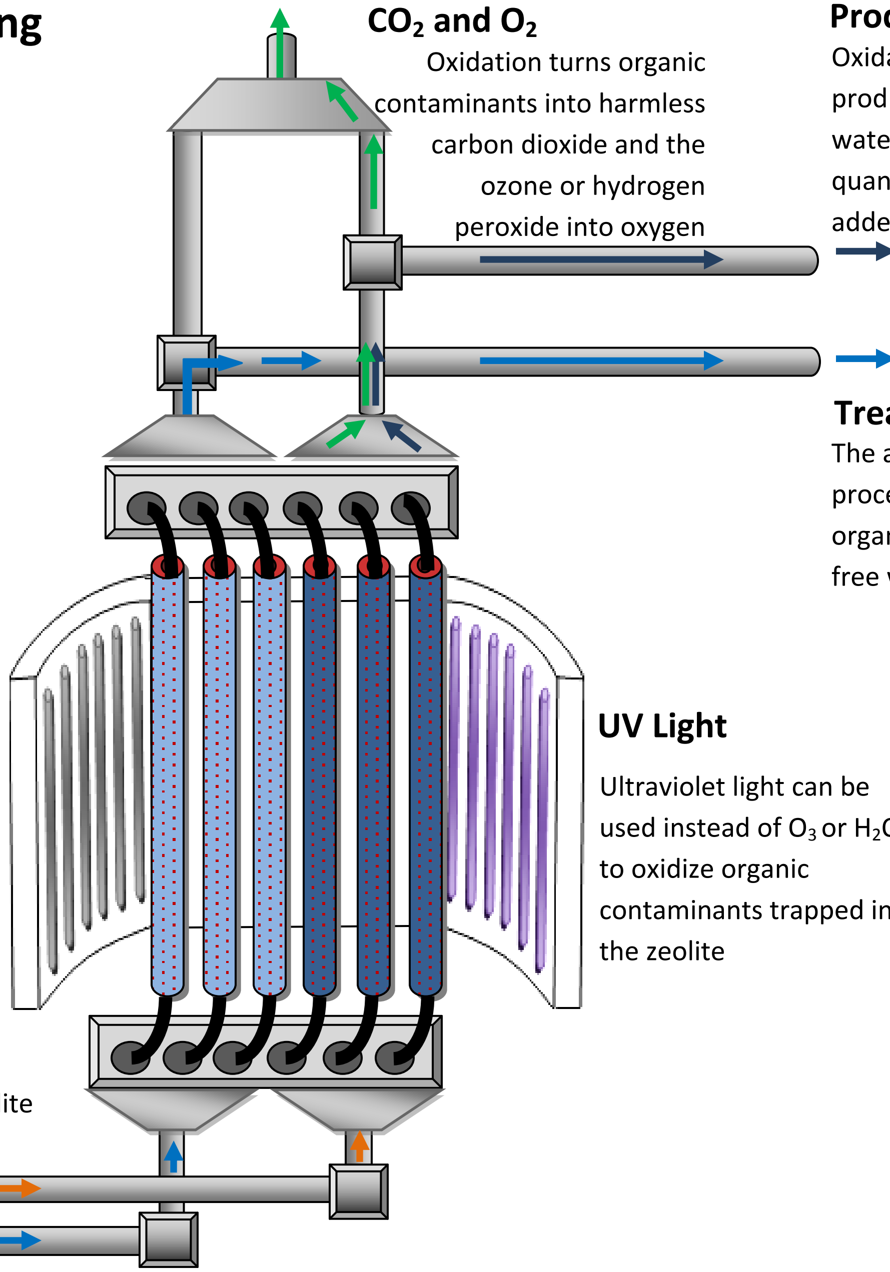
Industrial

As mentioned in the Industrial Demand section, industrial process water often is used and then discharged to local bodies of water after minimal remediation. These companies have to spend millions of dollars every year on water and treatment processes. They also need to use highly conditioned water in order to prevent problems such as scale, corrosion, carryover, and sludge deposition.

Sorption Oxidation would be a highly effective solution to these problems. Due to SOx's reusability, implementing a SOx system in a plant that produces wastewater contaminated with any number of organic contaminants could be very cost effective. Using a large scale system such as the one outlined in the diagrams below that cycles between a number of cylinders in the sorption stage removing contaminants and the rest in oxidation cleaning the zeolite, could allow for continuous effluent treatment with little to no total system down time. These large cylindrical canisters containing zeolite with pore size specific to the targeted contaminant would be used to treat large volumes of water, and when repairs or adjustments are necessary, it would be possible to continue running the system and only disconnect one or two cylinders at a time. The same could be true for feed water coming into a facility.

SOx System Cycling

While the first three zeolite cylinders are being fed with contaminated water and adsorbing organic contaminants, the last three cylinders are being treated with O_3, H_2O_2, or UV light which is oxidizing the organic contaminants from the dirty zeolite and converting it to CO_2. This allows the two mini-processes to run simultaneously and the whole process can be cycled over and over so there is no system downtime and can theoretically be run for extended periods of time with no replacement and little maintenance.



CO_2 and O_2

Oxidation turns organic contaminants into harmless carbon dioxide and the ozone or hydrogen peroxide into oxygen

Product H_2O

Oxidation also produces organic free water in smaller quantities, but can be added to treated H_2O

Treated H_2O

The adsorption process yields organic contaminant free water

UV Light

Ultraviolet light can be used instead of O_3 or H_2O_2 to oxidize organic contaminants trapped in the zeolite

O_3 or H_2O_2

Ozone or Hydrogen Peroxide can be used to clean the zeolite through oxidation

Contaminated H_2O

Contaminated water to be treated is fed through the system

Figure 24: The SOx system general application design*

*This design illustrates the basic template for further prototypes and is the basis for a wide variety of application designs.

Municipal

Municipal treatment would require a slightly different system and infrastructure. This would be a very large system due to the fact that most treatment systems treat and provide millions upon millions of gallons of water per day to the towns or cities it is connected to. Using a large scale, multi-cylinder cycling design similar to that of industry use would be most likely. Municipal water treatment plants seem to prefer to use conventional filtration techniques over modern membrane and other technologies. However, it is expected that as new treatment techniques gain in popularity across the country and around the world, and end users become more aware of the health dangers associated with organic contaminants, there will be a definite demand for a technology that can remediate this problem. This is where Sorption Oxidation would find its niche. Below is a flowchart showing the traditional configuration for municipal water treatment plants, but also including where SOx could be effectively implemented to augment the existing system.

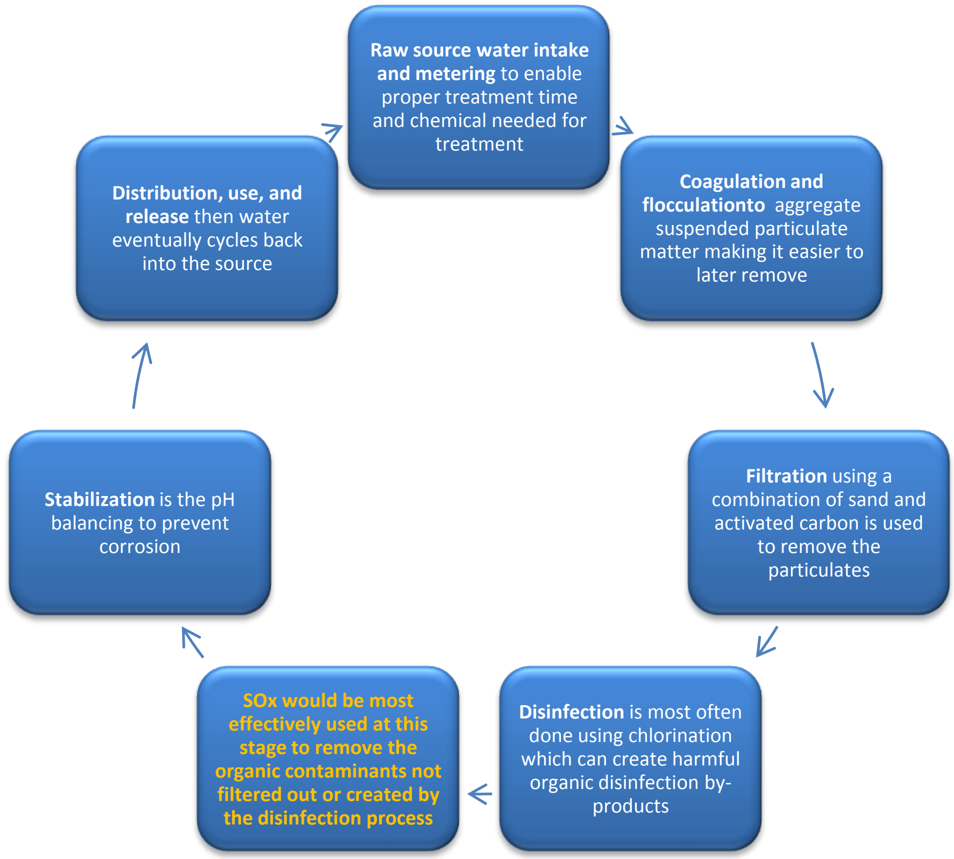


Figure 25: Traditional municipal water treatment system configuration with SOx added

Consumer

A consumer application for Sorption Oxidation would need to be low cost to produce and purchase, and of compact design. In the current economic recession, consumers are less willing to pay high prices for luxury goods and although SOx is necessary to remove harmful organic contaminants from drinking water, these consumers have been living without it for years so consider it a non-necessity.

Design Options

There are two designs that would be applicable for consumer use. The first of which is as an augmentation cartridge that could be added to pitcher purifiers similar to that of Brita or point of use filters that attach right to the faucet. Customers are currently willing to pay anywhere between ten dollars and up for the pitcher purifier, and fifty dollars for the point of use faucet mounted ones. In order to utilize the renewability of the zeolite cartridges, the consumer would also need to have a means of oxidizing the contaminants trapped in the zeolite. This could be achieved through use of a small one-time purchase machine that contains either ultraviolet light emitting lamps, an ozone generator, or hydrogen peroxide canisters. The cartridges could be inserted into the machine and rapidly processed to be used again.

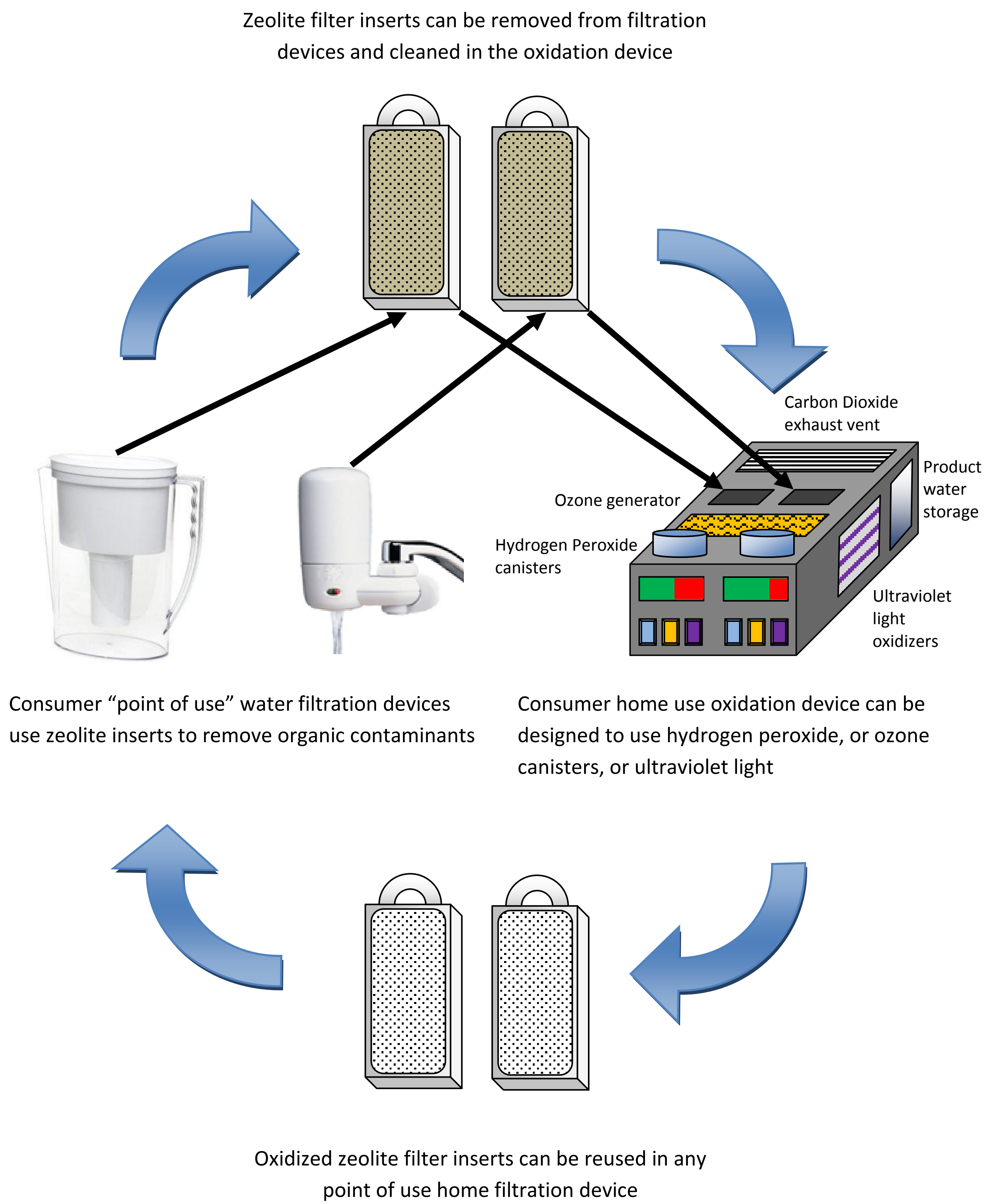


Figure 26: Potential design for in home consumer SOx application

The second design option for consumer use would be a scaled down version of the industrial or municipal version. This would be a significantly higher investment for the consumer, but could produce larger amounts of water much faster and with less maintenance than the cartridge application. This application would also use cylindrical canisters that could cycle between processing water through absorption and the remaining cylinders being cleaned through oxidation with ozone, UV, or hydrogen peroxide.

Oxidation for Home Use

As mentioned, both systems could potentially use any one of three methods for oxidation: ozone, hydrogen peroxide, or ultraviolet light. For consumer use, the most important factors are cost, ease of use, and safety. Upon analysis in the Oxidation section, it has been determined that although all three have been shown effective, one stands out as best suited to home and business use: ultraviolet.

Ozone is effective in oxidizing the trapped organic contaminants, but ozone cannot be stored and sold in canisters, for example. It requires an ozone generator, which proves costly and often cannot produce high enough concentrations and volume of ozone for a SOx system, without using high cost advanced generators. It is also relatively unsafe for use by untrained consumers and according to its MSDS (material safety data sheet) ozone concentrations above 15 percent can explode when coming into contact with organic substances or strong reducing agents. It can also cause respiratory difficulties and eye irritation.[88] Homes need to have user-friendly applications with little danger or room for human error, so ozone is not the most viable option.

The next oxidizing agent, hydrogen peroxide, does not require a generator or at-home production, can be stored in canisters, and is available for under $3/kg when bought in large quantities. However, the major problem with hydrogen peroxide use is that typically hydrogen peroxide available to

[88] http://www.ozoneapplications.com/info/ozone_msds.htm

consumers is between three and five percent, but effective oxidation for SOx requires between ten and fifteen percent concentration. At even this concentration, inhalation of hydrogen peroxide vapors is corrosive and irritating to the respiratory tract and contact with the skin can yield chemical burns. Oxidation using H_2O_2 also yields strong heat of reaction and increases the flammability of many substances that are combustible, organic, and oxidizable.

The author believes that ultraviolet light is currently the most viable oxidation option for consumer applications due to its low cost, safety, and ease of use. Ultraviolet emitting lamps are readily available in the consumer market for under $20/bulb. Ultraviolet light emitting lamps and bulbs provide low health risk to consumers because they are not of high power and only long-term exposure has been proven to cause serious health risks. Consumers would never be exposed to enough UV light from SOx to cause this kind of damage. They are more at risk from the UV light used at tanning salons. These bulbs last for long periods of time and would require no maintenance other than occasional bulb replacement. The only technical consideration would be that there would have to be a very high level of zeolite surface area exposure for UV to effectively oxidize trapped contaminants. One solution for this is the potential design below.

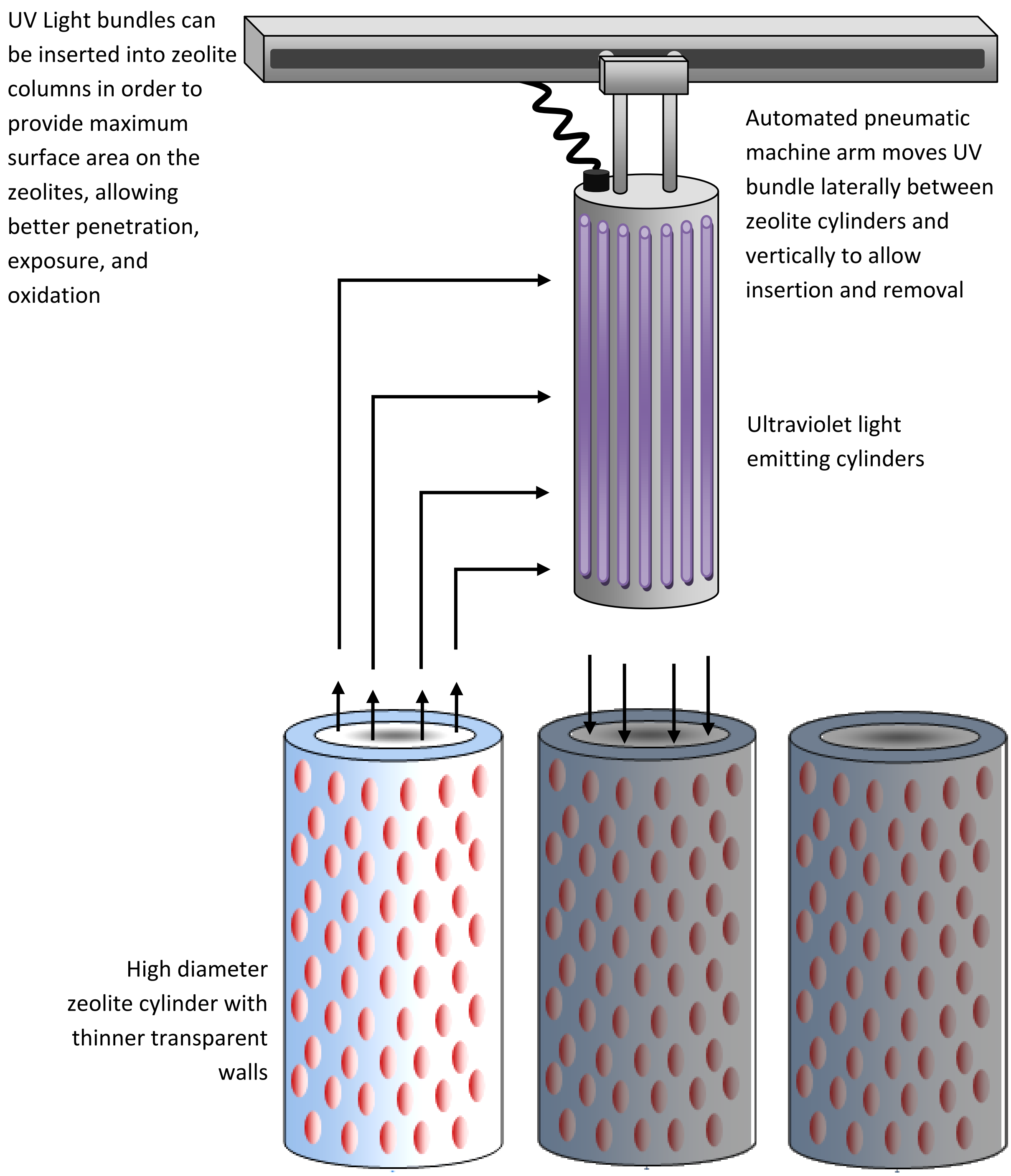


Figure 27: Potential ultraviolet design for potential SOx applications

Military

The United States military is always searching for more efficient and long-lasting solutions for creating potable drinking water for its bases, ships, submarines, and soldiers. Water is the most important consumed material for human life and function and soldiers need to be able to produce potable water wherever they are deployed. The average soldier needs to consume around 3.5 gallons of water per day in order to avoid dehydration.[89] This number does not include water required for vehicles, cooking, washing, and other maintenance processes. Ships and submarines are often at see for long periods of time and are not able to take on additional water. Having a long lasting and self-sufficient system that can create purified water from contaminated or recycled water is of utmost value. This allows for low maintenance; ease of use, and less need for costly water transport and storage.

Alternative Applications

One of Sorption Oxidation's greatest strengths is its versatility and ability to be customized to a wide range of scales and applications to optimize organic contaminant removal and disposal in a cost-efficient and environmentally friendly way. Not only is it applicable in the industrial sector for cleaning process feed water and for removing process byproducts from discharge water, the consumer market for point of use and point of entry water purification, and municipal sector to remediate public drinking supply water, but it also has a number of other possible applications worth mentioning.

[89] Mehney, Paul D. http://www.rdecom.army.mil/rdemagazine/200311/itf_tardec_water.html November 2003

Reuse: Gray Water, Black Water, and Industrial Effluent

As water becomes scarcer and there are increasing imbalances between supply and demand in urbanized areas, ideas such as reusing effluent water have become increasingly common. Gray water is any water that results from home usage except sewage. When recycled, gray water can be used for many home uses including, but not limited to, watering the lawn or flushing the toilet. Some states have restricted gray water use, but as better remediation technology is created and water becomes scarcer, there is an increasing trend to use gray water.

Black water is end-use sewage (i.e., waste water from toilets). Typically end-use wastewater can be used for agriculture and landscape irrigation, groundwater recharge, non-potable reuse (e.g., a car wash), alternative industrial water source (e.g., cooling water) and indirect potable reuse. However, new technology has enabled it to be remediated and reused as drinking water. Countries around the world are turning to this type of reuse to solve environmental and water shortage problems. Los Angeles, California plans to be reusing close to five million gallons of wastewater for drinking water by the year 2019.[90]

[90] U.S. Market for Residential Water Treatment Products. SBI. Rockville, Maryland. July 2008.

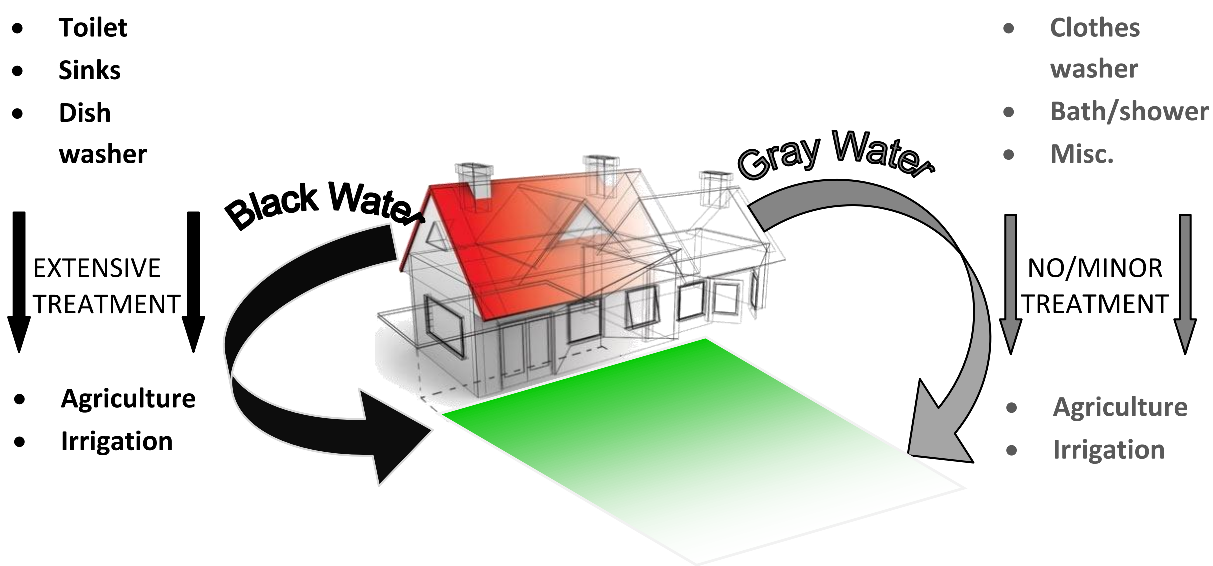


Figure 28: Black water and gray water sources and uses

Unfortunately, there is a lack of infrastructure to support a large changeover to these types of systems. This makes inexpensive modular systems the most feasible systems. Large changeover would also require much more stringent treatment standards as more contaminated feed water would be used. Available systems are very susceptible to irreversible membrane fouling and membrane rejection of undesired organic contaminants.[91] With highly contaminated water such as gray and black water, removal of organic contaminates would be a key factor in remediation success.

The most current available data on federal, wastewater treatment program expenditures is from a 2001 report created by the American Society of Civil Engineers and estimates that between 1973 and 2001 over $71 billion has been spent.[92] Furthermore, the report also states that the 16,000 wastewater system's in the United States still lack more than $12 million of funding for maintenance and

[91] Majamaa, Katariina; Peter, Aerts; & Gomez, Veronica. Ready for Reuse? *Integrating membrane systems to increase water safety, reduce footprint and fouling. Membrane Technology* October 2008 Volume: 7 Number: 2 © 2009 Scranton Gillette Communications

[92] Testimony of the American Society of Civil Engineers on the Proposed Fiscal Budgets for the Environmental Protection Agency, the Federal Emergency Management Agency, and the National Science Foundation. March 21, 2001.

improvement in order to comply with established government regulations for water treatment.[93] The EPA estimated in 2002 that capital funding needs through to 2019 would equal between $331 billion and $450 billion, of which at least ten percent represents steps to comply with the aforementioned Clean Water Act.[94] Considering that these conservative estimates were made over seven years ago, it is safe to state that there is a significant market for technology such as Sorption Oxidation to the federal government and its subsidiaries and contractors alone.

Estrogen Remediation

Estrogen is introduced to drinking water through the use of a number of pharmaceutical and agricultural products. Synthetic estrogen is used in women's oral contraceptives and it is also used to prevent osteoporosis and treat symptoms of menopause in women and even in cases of males with prostate cancer. When these pharmaceuticals are used, they are metabolized by the body and passed through urine into the sewer systems. Another less known source of estrogen is in some brands of shampoo containing what the companies refer to as "placental extract." These are introduced into sewers when people use them in the shower or bathe.

Estrogen is resistant to natural environmental and bacterial degradation, so once they are introduced to a water source, they pervade for long periods of time or until treated. The main effects of estrogen exposure are low fertility, higher probability of miscarriage or stillbirth and can even lower sperm and egg counts.[95] A study conducted by the University of New Brunswick in February of 2008 has shown that estrogen in water is negatively affecting fish populations by harming fertility and causing

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[93] Testimony of the American Society of Civil Engineers on the Proposed Fiscal Budgets for the Environmental Protection Agency, the Federal Emergency Management Agency, and the National Science Foundation. March 21, 2001.

[94] Regulatory Updates for Wastewater Treatment Facility Operators. New York State Department of Environmental Conservation. 2009.

[95] Toxic Exposure Effects. http://www.fertilitycommunity.com/fertility/toxin-exposure-effects-on-fertility.html

hermaphroditism in both fresh and salt water fish and can wipe out whole species if left unchecked.[96] This is a growing concern as more research is published on the subject, but few technologies are capable of remediating it, leaving a market segment for technologies that could do so effectively.

Air/Gas Purification

Although Sorption Oxidation was primarily created for the treatment of water and other liquids, it has been theorized to be able to treat air and other gases as well. Harmful gases such as ammonia, hydrogen sulfide, carbon monoxide, sulfur dioxide, and formaldehyde can be targeted with specific zeolite pore sizes and then removed and oxidized. For industrial uses, SOx could also adsorb carbon dioxide, water vapor, oxygen, and nitrogen.

This capability would allow SOx to be used in some very marketable consumer and industrial applications. A promising one would be in renewable and effective, odor control for bathrooms, pet litter boxes, barns, chicken houses, and other places with odor problems from organic gases. Many odorous gases such as ammonia and methane are often present in and around these areas. A product such as SOx, scaled for size of treatment area, could not only remove those gases, but also turn them into harmless water and carbon dioxide and would rarely or never require a replacement filter. This system could consist of an intake fan and an exhaust fan with a zeolite filtration panel or column in between. For small applications such as home use, the system could have small removable zeolite filter panels, columns, or inserts that can be removed and put in an oxidation, zeolite cleaning machine. For larger applications such as barns or public restrooms, it would be necessary to have the oxidation process contained in the same system, similar to the design for the large SOx water treatment system.

[96] White, Hillary. Study Confirms Estrogen in Water From the Pill Devastating to Fish Populations. February 18, 2008. http://www.lifesitenews.com/ldn/2008/feb/08021805.html

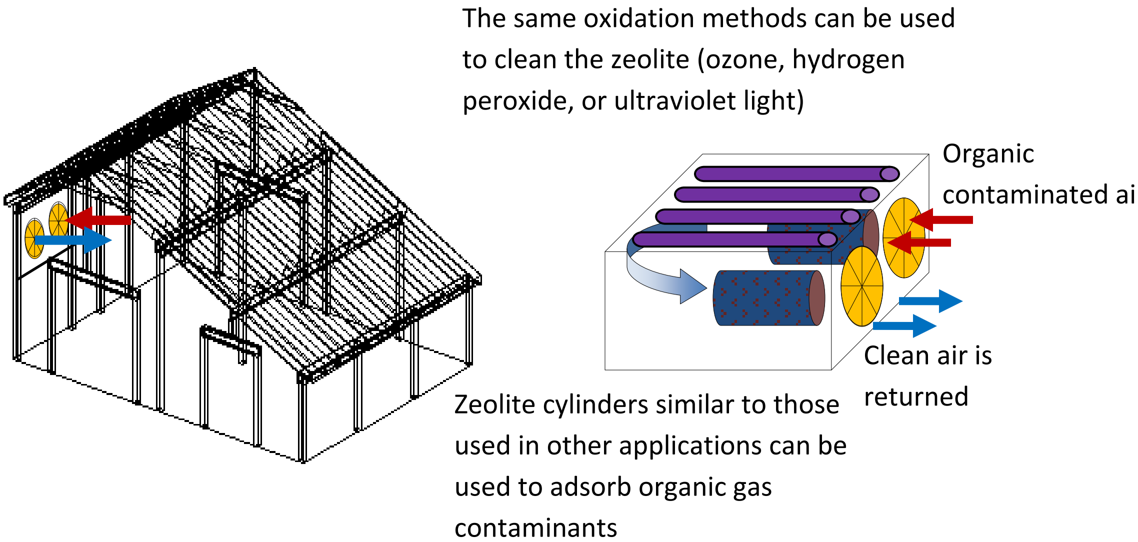

Figure 29: Possible air/gas SOx treatment system

Livestock Drinking Water

As mentioned in the introduction sections, livestock and farm animal health are greatly affected by organic contamination in their drinking and environment water and since many of these animals are raised for human consumption, their health often directly affects that of the humans that consumer them. Livestock often consume three times as much water as they do food.[97] When water is contaminated, this high volume of consumption can quickly lead to detrimental health effects resulting in poor product quality or less product from the livestock, which in turn harms the profit margin for the farmers that raise these animals.

An effective solution to this problem is to implement a medium scale, sorption oxidation and general treatment system at the point of entry for feed water. This type of system would be able to remove harmful disinfection by-products, organic contaminants, bacteria, microorganisms, and other contaminants that cause birth defects, slow growth and small size, disease, poor product quality, and loss of product due to deaths. As mentioned previously, these results of poor water quality directly

[97] Jones, Clay. Ag Notes. 2007.

affect the bottom line profits of the farmers and ranchers. Minimizing production costs is very important to the producers who have little control over the prices paid for their livestock.

Blood Filtration

Even though the Sorption Oxidation technology was conceived as a water remediation solution, all research indicates that SOx could easily be applied as not only a water treatment solution, but a general fluid treatment solution as well. One of these fluids that could provide a promising filtration market would be blood. The 3M Company submitted a report to the United States' Government in 2001 stating that PFOA was found in the blood of ninety-six percent of 598 children tested in twenty-three different states and Washington D.C. [98] Perfluorochemicals such as PFOA have been shown to cause serious health complications, as well as birth defects in babies whose mother's were exposed to PFC's (such as the infants of mothers who worked at the Dupont Teflon Plant in West Virginia.) Once exposed to PFOA, if all exposure is immediately ceased, the human body takes approximately 4.4 years to excrete even half of the mass of PFOA accumulated in the body's organs and tissues.[99] However, with the number of products produced that include PFC's, it is nearly impossible to cease all exposure, and at least fifteen PFC's in human blood.[100]

[98] PFC's: Global Contaminants: PFOA is a pervasive pollutant in human blood, as other PFC's. PFC's: Global Contaminants. 2007-2009. Environmental Working Group.
[99] PFC's: Global Contaminants: PFOA is a pervasive pollutant in human blood, as other PFC's. PFC's: Global Contaminants. 2007-2009. Environmental Working Group.
[100] PFC's: Global Contaminants: PFOA is a pervasive pollutant in human blood, as other PFC's. PFC's: Global Contaminants. 2007-2009. Environmental Working Group.

Year	Groups Found to Have PFC's in Blood	PFC detected
1957	Sweden, 10 individual samples	PFOS
1969-1971	Michigan, 5 individual samples from a breast cancer study	PFOS
1971	Sweden, 10 individual samples	PFOS
1976	U.S., 6 pooled samples from heart disease study	PFOA
1980	U.S., 3 pooled samples from heart disease study	PFOS
1984	Linxian, rural China province, 6 individual samples*	PFOS
1985	U.S., 3 individual samples from heart disease study	PFOS
1994	Shandong, rural China province, 6 individual samples*	PFOS
1995	U.S. children in 23 states plus District of Columbia	PFOS, PFOA, PFHS, PFOSA, PFOSAA, M570, M556
1999	U.S. elderly in Seattle, Wash.	PFOS, PFOA, PFHS, PFOSA, PFOSAA, M570, M556
2000-2002	U.S. blood from commercial and blood bank sources	PFOS, PFOA, PFOSA, PFOSAA, M570, M556, C6, C7, C9, C10, C11, C12, THPFOS, THPFDS

Figure 30: Studies from 1957 to 2002 showing PFC presence in human blood samples[101]

Drinking Water in Developing Nations

Over a quarter of the world's population has no regular access to potable drinking water and eight million die every year from causes associated with contaminated water. At least half of these victims are children.[102] The majority of these people are located in developing and third world countries where fresh water is scarce and there aren't financial resources to treat contaminated water. SOx may be able to offer a cost-effective means to augment current treatment technologies.

As seen in the figure below, this design utilizes gravity and water's natural flow through a declined bed of zeolites to adsorb organic contaminants. The dispersion valves limit water flow to a speed where adsorption is optimized. A quartz glass cover allows maximum Ultraviolet Light to enter and oxidize contaminants that have been adsorbed into the zeolite. This allows for constant flow and

[101] PFC's: Global Contaminants: PFOA is a pervasive pollutant in human blood, as other PFC's. PFC's: Global Contaminants. 2007-2009. Environmental Working Group.
[102] Challenges: Access to Water is a Basic Human Right. Suez Environnement. 2008.

treatment as both processes are run simultaneously. Due to the low flow capacity, this application is not suited for industrial or home use, but does not require an external power source and may be a viable water treatment application for impoverished and developing nations.

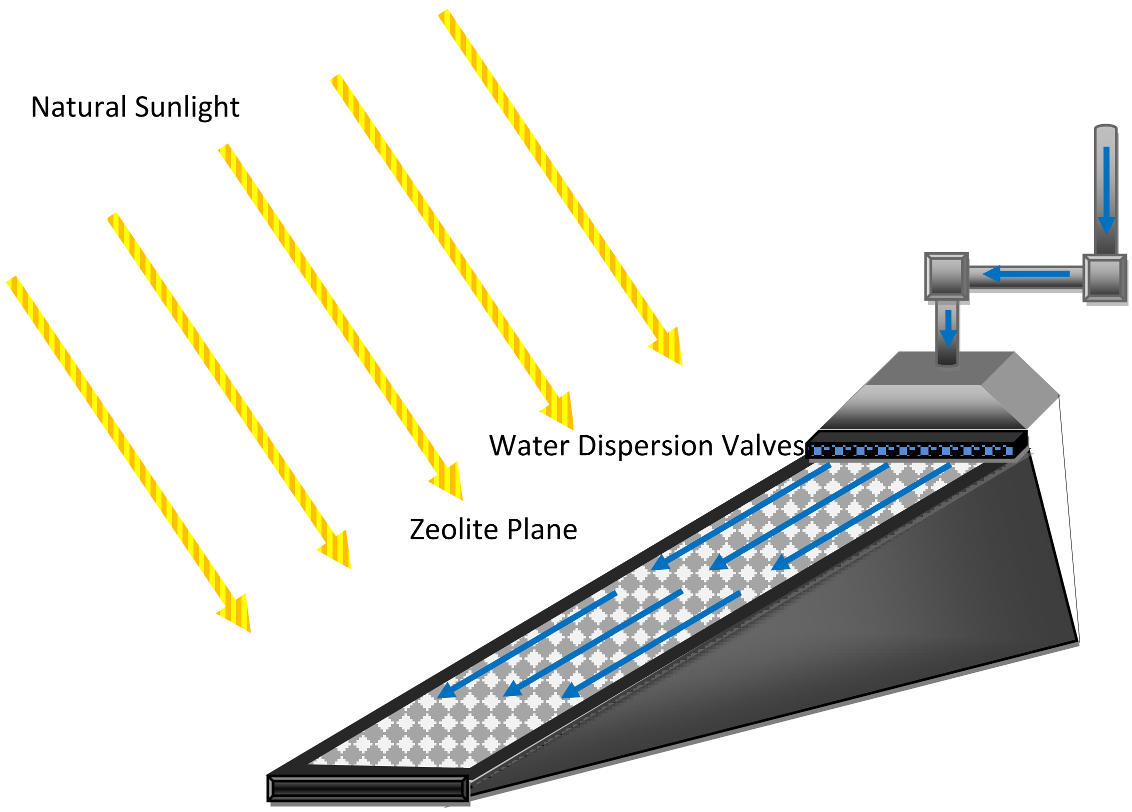

Figure 31: Possible design for the solar SOx device for developing nations

The Zeolite

Many zeolites currently use clay binders and thus are not suitable for water applications. However, zeolites such as the ones used in the SOx system can be bound in other, more durable, binders, so that in itself is not a limiting factor. However, parallel to their water research studies the inventors and their team have an ongoing zeolite synthesis program in which they are evaluating growing zeolites on support surfaces, and growing zeolite aggregates which might be several mm in dimension, thus reducing the pressure drop (or entrainment) problems with powders. That work seeks to improve on a patented process by producing larger zeolite particles. In fact, their first zeolite synthesis publication appeared in 1982 and they have extensive experience in this field.

ZSM-5

One of the most promising zeolites is ZSM-5, developed by Mobil Oil. This zeolite is an aluminosilicate with high silica and low aluminum composition. It was originally designed for use in the petroleum industry for interconversion of hydrocarbons. It utilizes a unique structure comprised of intersecting channels and tunnels as seen in the figure below.[103] ZSM-5 has pores with a width of between 5 and 6 angstroms (1 angstrom is one hundred-millionth of a centimeter.)[104] According to the 2006 WPI graduate project on SOx, ZSM-5 cost about $400/ kg.[105] It is currently available for as low as $250/kg and would be able to be purchased for even less if bought in large quantity. This is a key factor to the success and desirability of SOx, as low cost manufacturing will enable the product to compete in the water treatment market.

Efficacy and usage Lifespan

It has been found that the hydrophobic adsorbents such as ZSM-5 and HiSIV3000 have larger uptakes than GAC and far longer useful adsorbent life. In a 1cm diameter by 12 cm height glass column, with a velocity of 6.62cm/min and a flow rate of 5.2ml/min, ZSM-5 adsorption was able remove 100 percent of MTBE from distilled water for over 890 hours. At that point it was still removing at least 90 percent of MTBE, but was considered by the research team to be operating at an ineffective level and

[103] http://www.3dchem.com/molecules.asp?ID=86#
[104] French, Brent; Khan, Suleman; Paramanantham, Jayapathy. BUS 516 Graduate Qualifying Project. WPI 2006.
[105] French, Brent; Khan, Suleman; Paramanantham, Jayapathy. BUS 516 Graduate Qualifying Project. WPI 2006.

requiring regeneration. Once the zeolites are regenerated through oxidation, they reused again at full efficacy. GAC has been found to only have a fraction of that adsorbent life and efficacy.

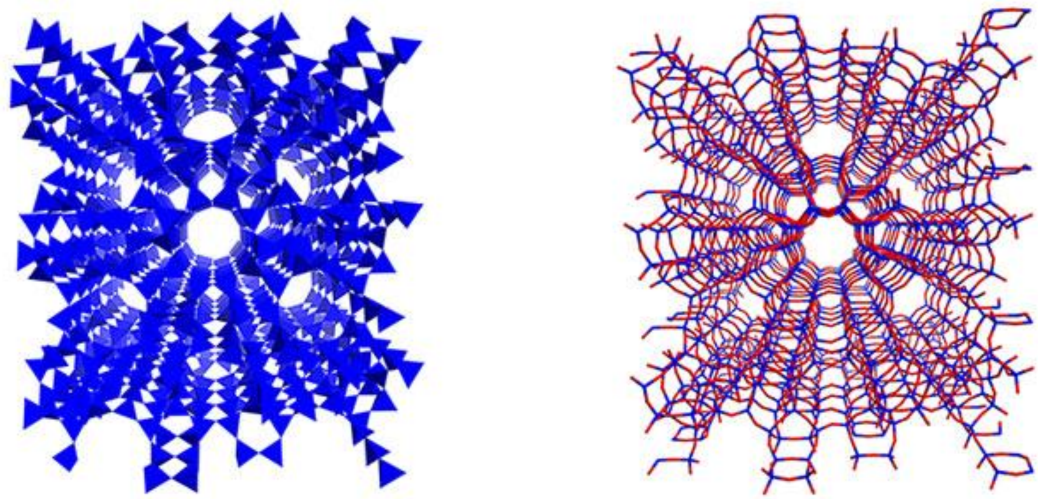

Figure 32: 3-Dimensional model showing channels and tunnels of ZSM-5

The blue fill in first model shows tetrahedral bonds and the open space represents the pores. The second model shows bonding, where red represents oxygen and blue represents silica.[106]

The majority of zeolites use clay binders, yielding them ineffective for water applications, but SOx utilizes other binders in its zeolites. Zeolites such as the ones used in the SOx system can be bound in other, more durable, binders, so that in itself is not a limiting factor. However, parallel to the research team's water research studies, they have an ongoing zeolite synthesis program in which they are evaluating growing zeolites on support surfaces, as well as growing zeolite aggregates which might be several mm in dimension, thus reducing the pressure drop (or entyrainment) problems associated with powdered zeolite. That work seeks to improve on a patented (ExxonMobil) 3-step process by

[106] http://www.3dchem.com/molecules.asp?ID=86#

producing the zeolite particles in a single step. (In fact, the research team's first zeolite synthesis publication appeared in 1982.)

Sorption Oxidation has been tested and found effective in the removal of contaminants such as chlorinated VOC's, MTBE, disinfection by-products, and estrone. Based on research and these results it is believed that Sorption Oxidation will also be able to remediate many if not all other organic contaminants such as carbon tetrachloride, trichloroethane, 1,2-dichlorothane, dichloromethane, epichlorohydrin, ethylbenzene; many of which are on the EPA's list of regulated water contaminants.

Incorporating an Antimicrobial

As mentioned before, Sorption Oxidation on its own can only remediate organic contaminants. However, by coating the zeolite with antimicrobial silver, Sorption Oxidation can destroy a wide range of microbial organisms such as bacteria, fungi, and yeasts and prevent the growth of biofilms. Silver's positively charged ions are naturally toxic to microorganisms, while having a low toxicity to human cells, making it an ideal antimicrobial for use in a water purification product. It has a high affinity for negatively charged groups such as sulfydryl, carboxyl, and phosphate groups. Binding with these groups alters the molecular structure of the organism, preventing growth or, more likely, destroying it.

The Oxidizing Agents

As mentioned earlier, the Sorption Oxidation process requires an oxidizing agent to clean the zeolites once they have adsorbed sufficient organic contaminants. The three candidates that are currently most viable are hydrogen peroxide, ozone, and ultraviolet light, although there are many other oxidizers that may work equally as well or even better. These substances readily transform organic contaminants into water and carbon dioxide.

Hydrogen Peroxide

A very strong oxidizing agent, hydrogen peroxide (H_2O_2) is a highly reactive oxygen species and is naturally produced through oxygen metabolism. It is the fourth strongest known oxidizer, with an oxidation potential of 1.8. (Oxidation potential is the ability of a substance to lose electrons or oxidize a material. The scale is based upon Hydrogen having a rating of 0 volts, and all other chemicals' oxidation potential is measured as a comparison against that standard.) Hydrogen peroxide is widely used in multiple industries such as paper bleaching, metal treatment, disinfection, detergent production, and chemical synthesis. It is available on the consumer market in concentrations of around three percent for disinfection, and up to twelve percent for hair bleaching treatment. The SOx process requires at least ten percent H_2O_2 concentration to be effective. Hydrogen peroxide at this level can be considered dangerous to humans and the environment if not handled properly due to its oxidation potential, corrosiveness, and reactivity.

According to its Material Data Safety Sheet (MSDS), even at this relatively low concentration, inhalation of the vapors is corrosive and irritating to the respiratory tract. Vapor ingestion can cause serious side effects such abdominal pain, vomiting, and diarrhea as well as blistering or tissue destruction, stomach distention, and risk of stomach perforation, convulsions, pulmonary edema, coma, possible cerebral edema, or even death. Contact with the skin can yield chemical burns. Another area of concern when handling or using H_2O_2, is that when it oxidizes, it produces a strong heat of reaction and increases the flammability of many substances that are combustible, organic, or oxidizable. It needs to be stored in a well ventilated area and vented container under 35°C and separated from combustible substances, reducing agents, strong bases, and organics.

Ozone

Ozone, often called trioxygen (O_3) is an allotrope of oxygen, making it much less stable than the oxygen we breathe in air. It is the third strongest oxidizing agent, with an oxidation potential of 2.1. Only fluorine and hydroxyl radical are stronger, but they are more dangerous and difficult to work with and handle. It is naturally present in the Earth's atmosphere and filters damaging ultraviolet light from reaching the surface of Earth, however it is a pollutant when present on Earth's surface. Harmful low level ozone is created by combustion engines in vehicles such as cars, trucks, and trains and results in the creation of smog components. It is used in largest quantities in the preparation if pharmaceuticals, synthetic lubricants, bleaching, and disinfection. Even in relatively low concentrations ozone can cause respiratory complications. Ozone cannot be stored and transported because it decays into diatomic oxygen (O_2), so it must be synthesized on site using one of the following methods:

- Corona Discharge Method: One of the most prevalent methods, corona discharge creates ozone using dry and filtered air and a direct electrical discharge to split the oxygen molecules. The generator electrodes often produce excessive heat, which needs to be dissipated through cooling water, but the corona discharge method is often considered the most sustainable and cost-effective ozone generation method.[107] It produces ozone concentrations of up to 120 ug/ml.[108]
- Ultraviolet Light: UV generation uses a silica-quartz ultraviolet lamp emitting narrow band frequency, with ambient air passing over it to split the oxygen molecules so they can attach to others and create ozone. It is most useful when a slow steady stream of ozone is needed in concentrations around 1 – 3 ug/ml.[109]

[107] http://www.lenntech.com/ozone/ozone-generation.htm
[108] Harrelson, Tom. Ozone Generation Methods. The Story of Ozone. 6th Edition. 8/8/03
[109] Harrelson, Tom. Ozone Generation Methods. The Story of Ozone. 6th Edition. 8/8/03

- Cold Plasma: Cold plasma uses an anode and cathode enclosed in a glass filled with a Noble Gas. High voltage electricity arcs between the glass rods. This results in the formation of a reliable, electrostatic plasma field that creates concentrations up to 70 ug/ml.[110]

According to the Material Data Safety Sheet, ozone concentrations above 15 percent can explode when coming into contact with organic substances or strong reducing agents. It can also cause respiratory difficulties and eye irritation.[111]

Ultraviolet Light

Ultraviolet light is a light wave emitted from a specially designed bulb such as a fluorescent lamp ionizing low-pressure mercury vapor, xenon arc lamp, deuterium arc lamp, metal-halide arc lamp, or tungsten-halogen arc lamp. UV light has a wave length shorter than that of visible light, although it is also contained in sunlight. UV light is the cause of sunburns from prolonged unprotected sun exposure. Visible light's wavelength ranges from 400nm to 700nm, whereas UV light's wavelength ranges from 150nm to 320nm.

It is this short wavelength that gives UV light its oxidative and destructive nature. Photocatalytic oxidation uses ultraviolet or near ultraviolet radiation to remove electrons from the valence band of organic contaminants and destroy them through reaction with molecular oxygen or through reaction with hydroxyl radicals and super-oxide ions.[112] UV light can be hazardous in a number of ways. Long term exposure can cause DNA mutations and complications leading to genetic damage or cancer. Short term exposure to high doses of UV light can cause eye damage or cataracts.[113]

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[110] Harrelson, Tom. Ozone Generation Methods. The Story of Ozone. 6th Edition. 8/8/03

[111] http://www.ozoneapplications.com/info/ozone_msds.htm

[112] Photocatalytic Oxidation of Organic Pollutants Associated with Indoor Air Quality. For Presentation at the Air & Waste Management Association's 91st Annual Meeting & Exhibition, June 14-18, 1998, San Diego, California

[113] Ultraviolet Radiation. http://www.nas.nasa.gov/About/Education/Ozone/radiation.html. May 30, 2001.

Aftermarket Sales

Sorption Oxidation is a very renewable and environmentally safe product. Due to the unique process, the zeolite will rarely or never need to be replaced. This is of high importance in the marketing of this product to consumers as this value proposition is cost-effective. Unlike most home filtration devices, the SOx system would need no replacement filters. This seemingly leaves little aftermarket sales for the SOx company, as no parts or filters are needed. However, because the system needs oxidation materials, the company marketing SOx can sell a number of user-friendly and safe oxidation materials, such as canisters of specific concentration hydrogen peroxide. Hydrogen peroxide sold to consumers in stores such as supermarkets or drug stores is usually only between three and six percent, but effective oxidation requires at least ten percent concentration. The company can also sell ultraviolet emitting diodes or bulbs for SOx systems utilizing UV for oxidation and parts for the ozone generator. These canisters, bulbs, and generator parts create a constant long term supplemental revenue stream for the company on top of actual system sales and is very valuable.

SWOT Analysis

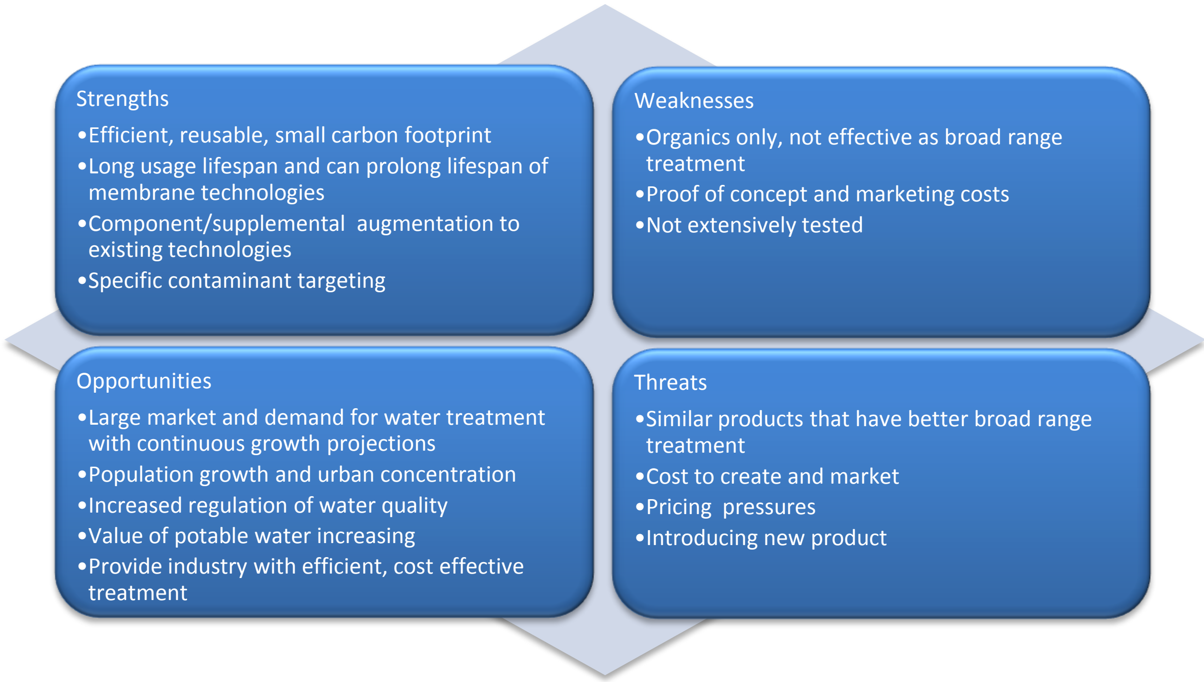

Figure 33: SWOT Analysis

Strengths

Sorption Oxidation is a multi-opportunity technology with a number of promising strengths. One of the most significant advantages to SOx is its long product lifespan and low maintenance requirements. Once installed it will require little to no replacement or upkeep and will function automatically. This is a very considerable value proposition for the consumer. It reduces cost to the end-user because, unlike many conventional water treatment systems, SOx will not require additional filter purchases or labor to replace them and perform maintenance, and it will prevent costly downtime. SOx can be targeted at specific organic contaminants enabling it to be used as a versatile tool to augment existing technology to address specific threats to health.

Weaknesses

Due to its limited efficacy for treatment of broad range contaminants such as pathogens or nonorganic contaminants, SOx is currently confined to the treatment of organics, unless paired with a supplemental treatment system. Another weakness is that it has not yet been established what the best method of production and integration would be and the specific costs associated with such. SOx has also not been thoroughly tested on a wide range of possible targets.

Opportunities

As mentioned in the market and market projection sections, there is a very large and well established market for better water treatment technology and it has shown steady growth. It is also projected to continue significant growth trends through at least the next three years due to factors such as population growth and concentration, urbanization, environmental pollution, and increased awareness and regulation of harmful water contaminants. Another trend lending to opportunity is the increased value of potable water as demand increases and availability decreases. The more consumers pay for drinkable water, the more quality they will expect. Also, when paired with existing broad range water treatment systems, SOx creates a much more attractive product for consumers and industry users because it has been shown to remove harmful contaminants that other systems cannot.

Threats

The water treatment industry has a well established and deeply engrained market. Sorption oxidation will face strong competition from the thousands of already existing companies and products. Many of the products available cannot treat organic disinfection by-products, but there are some that will be able to and it needs to be established that SOx is the superior and most effective and efficient technology. SOx will need to be manufactured, marketed, and distributed with low cost margins in order to be able to compete with products already on the market. Finally, it is important to consider that consumers are reluctant to try new products, so research and study findings must be distributed to show consumers SOx's efficacy and user benefits in order to break through the new product barrier.

Industry Attractiveness Analysis

Figure 34: Five forces industry attractiveness analysis

Competitive Rivalry

- Multiple products – many filtration and purification companies but few have comparable product
- Quality differences – SOx is 100% effective in organics removal
- Switching costs – already made equipment/system investments
- Exit barriers – commitment to suppliers and small workforce (possibly outsourced)
- Industry concentration – low concentration in general water treatment industry, but very high in renewable organics removal
- Fixed costs and value added – relatively low cost to produce and high profit margin
- Industry growth – continuous historical growth and strong industry forecasts
- Intermittent overcapacity – industry does not need large increment capacity changes
- Branding – SOx is not yet branded, whereas existing products have strong brand strength with recognizable brand and products
- Rival's diversity – many of the industry leaders

Barriers to Entry

- Time and cost of entry – at least one year of heavy marketing before seeing profit and low capital investment for consumer applications, but large investment needed for municipal, industrial, and military applications
- Cost advantage – well established industry already has many skilled workers, efficient processes and technology, and cheap inputs
- Brand identity – very important in this industry to have well known and respected branding
- Distribution – online sales, direct sales, and distribution to stores will be necessary

- Proprietary and specialist knowledge – new technology and process concept will require further refinement and development
- Intellectual property protection – patent is still pending, but in final stages

Threat of Substitutes

- Switching costs (cost of change) – low cost for most point of use and stand alone devices, but high cost for point of entry systems and applications for municipal, industry, and military use
- Buyer inclination to substitute – most substitutes already have well established customer base and branding
- Price-performance trade-off of substitutes – substitutes are not reusable and have shorter lifetimes, but can treat wider range of contaminants
- Market availability – substitutes are widely available and accessible with many options
- Cost efficiency – cost to produce is low and renewable nature makes for attractive product

Supplier Power

- Number of suppliers – very large market and high number of suppliers for broad range water treatment, but none have capabilities of SOx
- Supplier size and concentration – large companies act as suppliers for materials needed in the SOx system and there is a low concentration
- Substitute ability – easy to switch suppliers
- Cost of changing – short term or no contract needed so low cost to change
- Impact of inputs on cost – input yields high impact on product cost to produce
- Threat of forward integration – not a concern as suppliers are already well established

Buyer Power

- Bargaining leverage – non-negotiable prices for directly distributed consumer applications, but high volume purchases and large municipal, industrial, and military sales would have to be negotiable
- Buyer volume (order size and number of orders) – low volume direct sales, but larger systems cost far more and consumer application systems can be bulk purchased by ditributor
- Buyer information – consumers are much more environmentally, economically, and medically informed
- Brand identity – will need branding targeted to multiple demographics
- Price sensitivity – geographical and application consideration
- Threat of backward integration – little concern as technology is patented
- Product differentiation – revolutionary technology easily distinguished from other systems
- Incentives – health benefits, renewability, and effectiveness

SOx Marketing Mix

An important factor to consider when deciding to produce, and then market any product, is the promotional mix that one will employ to target specific demographics and markets. In the case of a Sorption Oxidation product, one will need to consider the target customers involved in consumer, industrial, municipal, as well as military water treatment. Each of these will require a slightly different approach, as the needed features and application considerations are different for each of these target markets.

Figure 35: Marketing mix suggested for SOx

Consumer Marketing Mix

Product

The product is the Sorption Oxidation technology as applied for consumer use. Its features are easily integrated sorption inserts to be added to point of use filtration systems to remove organic contaminants and then put in cleaner to oxidize them for reuse. The features of the point of entry system would be similar; except that everything is automated and treated water is provided to entire building. The benefits to the user are one hundred percent organic contaminant removal, leading to better tasting and healthier water with lower chances of causing health problems such as cancer. The zeolite and processes have been extensively tested and material quality will need to be premium. Creating a successful branding or building under an already established brand would be ideal for SOx.

Place

The place objective for the consumer application of SOx is to provide quality, reusable, and user-friendly organic contaminant removal to households and businesses at a competitive price. It is especially important for the consumer models to be widely available through both direct distributions from a website and from companies and distributors that carry home water treatment products, such as home improvement stores or superstores that carry wide variety of goods. Being a new product with features unlike most current products in the market, gaining market exposure through demonstrations, store displays, free trials, and advertisement are imperative to its success.

Price

The price for the point of use systems must be very low in order to appeal to customers who want to try out the technology for the first time, or cannot afford one of the larger and more expensive point of entry models. On the consumer level, these models cannot have very flexible prices, other than discounts/sales, in order to preserve brand strength, but the larger systems must be more flexible according to their size, capacity, and application. Discounts are a valuable resource, especially in the initial marketing phase of a product. They can stimulate interest in a product that a consumer may not be willing to spend full price on. Geographical price considerations are important when marketing a new product nationally and especially internationally. Smaller and more economical systems will be priced to target consumers in remote and low income locations. Larger systems will be priced and marketed to people in high income areas with little access to quality public water.

Promotion

Promotion for the SOx consumer models is very important, as most consumer buying decisions are based on what they have seen or heard about a product, unless they have first-hand experience with it. A method that has been successful for many new products is trial promotion. Many products are made popular primarily by word of mouth through positive experience with a product. An easy to use system such as SOx practically sells itself once this word of mouth influence is combined with actual testing and medical data concerning the dangers of organic contaminants in drinking water. This should be done through multiple media sources such as television, print, radio, online, and in store advertisement. Another key element will be trained sales personnel.   Having these salespeople working on direct, phone, and internet sales can prove invaluable as this sales force will be highly knowledgeable in SOx capabilities and application as well as sales technique. However, because much of the consumer sales will be done online, or through a secondary distributor, it is not necessary to employ a large sales force, but rather to include important information with the actual product and hold training sessions for employees at stores that sell the product so they can sell it effectively.

Demographic	Own a Water Treatment Product		Purchased a Water Treatment Product in Past 12 Months		Total U.S. Households	
	No.	%	No.	%	No.	%
Total	**16,063**	**14.4%**	**2,470**	**2.2%**	**111,914**	**100.0%**
Age (Head of Household)						
18–24	669*	4.2%*	120**	4.8%	6,346	5.7%
25–34	2,542	15.8%	600	24.3%	20,329	18.2%
35–44	3,886	24.2%	438	17.7%	20,953	18.7%
45–54	3,150	19.6%	439	17.8%	22,240	19.9%
55–64	2,915	18.1%	410	16.6%	18,421	16.5%
65–74	1,812	11.3%	312	12.6%	12,849	11.5%
75+	1,089	6.8%	152**	6.1%	10,776	9.6%
Region						
Northeast	3,229	20.1%	496	20.1%	22,898	20.5%
Central	4,413	27.5%	748	30.3%	31,590	28.2%
Southeast	3,731	23.2%	604	24.5%	24,429	21.8%
Southwest	1,688	10.5%	227	9.2%	12,134	10.8%
Pacific	3,002	18.7%	395	16.0%	20,863	18.6%
Gender						
Male	7,381	46.0%	1,049	42.5%	45,869	41.0%
Female	8,682	54.0%	1,421	57.5%	66,045	59.0%
Household Income						
Under $25K	2,601	16.2%	314*	12.7%	26,113	23.3%
$25K–$49K	3,429	21.3%	642	26.0%	27,412	24.5%
$50K–$74K	2,534	15.8%	393	15.9%	19,554	17.5%
$75K–$99K	2,167	13.5%	254	10.3%	13,361	11.9%
$100K–$149K	3,148	19.6%	473	19.1%	14,925	13.3%
$150K+	2,184	13.6%	393	15.9%	10,550	9.4%
Marital Status						
Married	9,116	56.8%	1,209	48.9%	55,602	49.7%
Single (Never Married)	3,390	21.1%	660	26.7%	25,136	22.5%
Divorced/ Separated	1,391	8.7%	**	**	19,164	17.1%
Widowed	1,763	11.0%	420	17.0%	12,013	10.7%
Not Married	6,947	43.2%	1,261	51.1%	56,312	50.3%
Ages of Children						
No Children	10,525	65.5%	1,600	64.8%	72,846	65.1%
Under 6	2,239	13.9%	444	18.0%	13,778	12.3%
6–11	2,184	13.6%	307	12.4%	14,877	13.3%
12–17	2,157	13.4%	278	11.3%	13,478	12.0%

Figure 36: Consumer Demographics for Residential Water Treatment Products (US households in the thousands)[114]

[114] U.S. Market for Residential Water Treatment Products. SBI. Rockville, Maryland. July 2008.

Value of Residence						
Under $100K	2,265	14.1%	206	8.4%	18,703	16.6%
$100K–$199K	3,524	21.9%	493	20.0%	21,380	19.1%
$200K–$299K	2,595	16.2%	447	18.1%	13,998	12.5%
$300K $499K	2,433	15.1%	395	16.0%	13,336	11.9%
$500K–$749K	1,194	7.4%	106*	4.3%	5,476	4.9%
$750K+	700	4.4%	54*	2.2%	4,050	3.6%
Type of Residence						
Own House	11,541	71.8%	1,429	57.9%	67,013	59.9%
Own Condo or Co-Op	732	4.6%	228*	9.2%	4,768	4.3%
Rented House	854	5.3%	262*	10.6%	10,627	9.5%
Rented Apartment	1,763	11.0%	420	17.0%	20,387	18.2%
Own or Rent Mobile Home	643	4.0%	**	**	6,582	5.9%
Rent-Free	588	3.7%	**	**	3,092	2.8%
Education						
Did Not Graduate High School	2,265	14.1%	206	8.3%	18,703	16.7%
High School Grad	3,524	21.9%	493	20.0%	21,380	19.1%
Some College	2,595	16.2%	447	18.1%	13,998	12.5%
College Grad	2,433	15.1%	395	16.0%	13,336	11.9%
Some Grad School	1,194	7.4%	**	**	5,476	4.9%
Grad Degree	700	4.4%	53.9	2.2%	4,050	3.6%
Employment Status						
Full-Time	8,258	51.4%	1,402	56.8%	56,141	50.2%
Part-Time	1,935	12.0%	228	9.2%	12,074	10.8%
Self-Employed	1,108	6.9%	165*	6.7%	7,462	6.7%
Full- or Part-Time College Student	827	5.1%	**	**	5,761	5.1%
Homemaker	1,061	6.6%	200	8.1%	7,872	7.0%
Retired	3,206	20.0%	508	20.6%	23,114	20.7%
Occupation						
Management/Financial Operations	1,541	9.6%	265*	10.7%	8,716	7.8%
Professional/Technical	2,637	16.4%	516	20.9%	17,646	15.8%
Sales	678	4.2%	88*	3.6%	5,673	5.1%
Administrative Support	1,626	10.1%	259*	10.5%	11,707	10.5%
Labor	3,574	22.2%	501	20.3%	23,877	21.3%
Race						
White and Not Hispanic	12,522	78.0%	1,891	76.6%	80,528	72.0%
Hispanic	1,670	10.4%	259	10.5%	12,641	11.3%
Black	907	5.6%	**	**	12,786	11.4%
Asian	620	3.9%	**	**	3,579	3.2%
Other	342*	2.1%	**	**	2,331	2.1%
Size of Household						
1	3,896	24.3%	539*	21.8%	31,099	27.8%
2	6,303	39.2%	1,100	44.5%	41,869	37.4%
3-4	4,728	29.4%	677	27.4%	29,864	26.7%
5 or more	1,136	7.1%	154	6.2%	9,054	8.1%

Figure 37: Consumer Demographics for Residential Water Treatment Products, 2007 (U.S. households in thousands)[115]

[115] U.S. Market for Residential Water Treatment Products. SBI. Rockville, Maryland. July 2008.

Industrial Marketing Mix

As discussed earlier in this report, the design for the industrial application of Sorption Oxidation is different than that for consumers and is targeted at a whole different market. Keeping this in mind, the industrial marketing mix must be different as well.

Product

The product is Sorption Oxidation technology as applied for industrial use. Its features are a low maintenance, high efficiency system that can be easily integrated with large industrial induction or discharge systems to remove organic contaminants and then put in cleaner to oxidize them for reuse. The features of the industrial system would be the same as most of the other applications, with the exception of scalability and less downtime. The system needs to be able to process large volumes of water at high velocity with little system downtime. The benefits to the user are one hundred percent organic contaminant removal leading to cost-effective adherence to industry standards and better processing. The zeolite and processes need to be extensively tested and material quality will be very important to a system such as this. Creating a successful branding or building under an already established brand is not as necessary for the industrial application, but word of mouth and reputation will be.

Place

The place objective for the industrial application of SOx is to provide quality, reusable, and user-friendly organic contaminant removal to large facilities in order to increase the profit margins and minimize downtime in their operations. Industrial models will need to have small scale prototypes to demonstrate operation to customers, and there will need to be project managers and a well trained sales team to coordinate sales and implementation. The most important sale or application will be its first which can be used as proof of concept and effectiveness.

Price

The price for industrial use systems will be very much dependant on the customer's facility's capacity, flow rate, and maintenance needs. These facilities will be willing to pay a higher price if it can be established that SOx will operate effectively over a long period of time and increase their bottom line efficiency and profits. Discounts should not be often used in large scale industrial sales, but negotiations are a common practice. Geographical considerations are important due to the fact that where the system is implemented can affect cost to build and operate.

Promotion

Promotion is important for any product introduction, but for the industrial use system, personal sales and demonstrations combined with reputation and word of mouth are vital. Trade shows and conferences are also a valuable arena to stimulate interest.

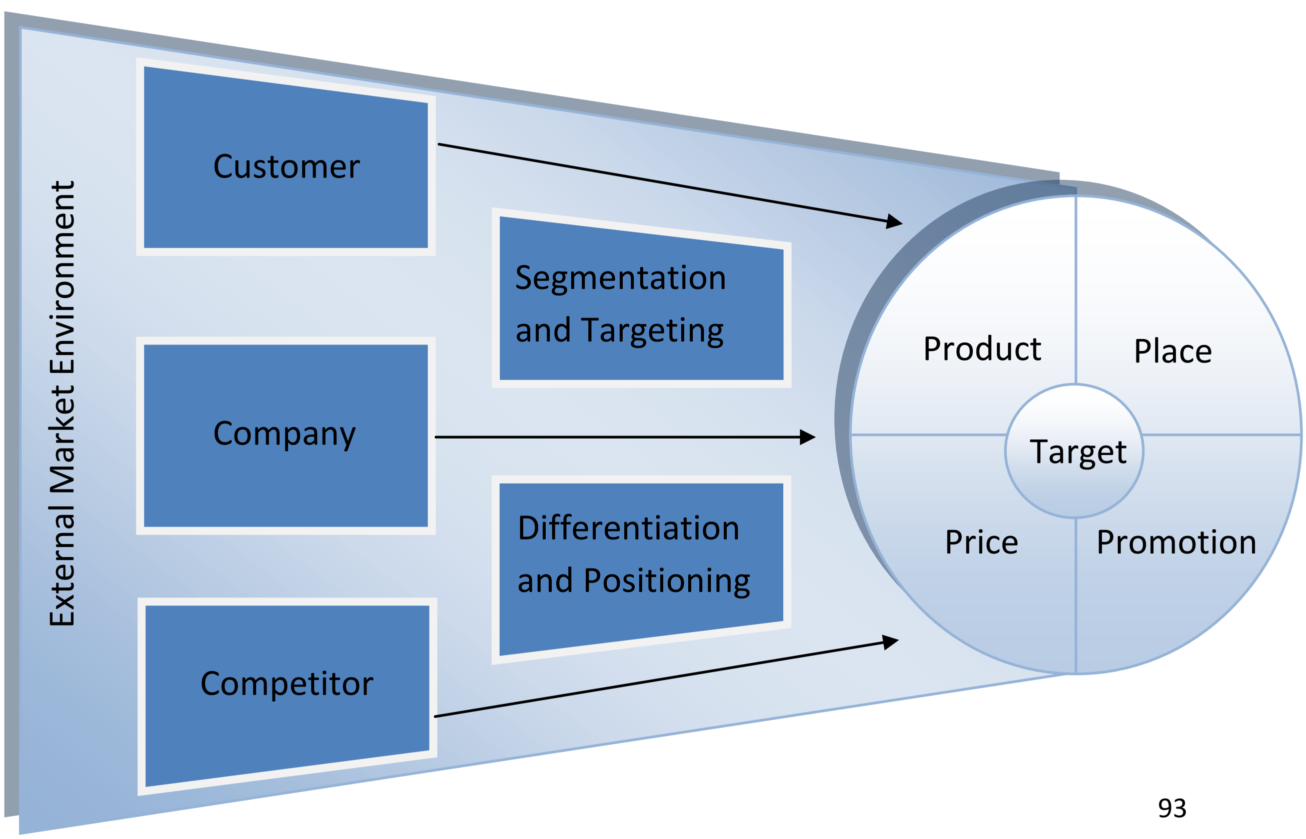

Figure 38: The organization of water treatment market factors and processes

Stage II – Commercialization

Objective

The objective of this stage of the project was to target and contact potential strategic allies or buyers that might be interested in Sorption Oxidation technology. A strategic ally would be valuable to WPI, the inventors, and the actual SOx technology. They must be an organization willing to purchase nonexclusive SOx licensing in part or whole, and possibly fund the research, development, and customization of the technology to meet their company's specific product or solution needs. This option is most desirable because the inventors would like to further explore the many versatile applications that Sorption Oxidation technology could be incorporated into. It is also the belief of the author that due to the current state of the technology, the inventors would be the most experienced, knowledgeable, and qualified persons to bring SOx to a working and viable prototype that would meet commercial design needs. The second purchasing option would be an exclusive purchase of all patent rights, where rights to the technology and development are transferred from WPI and the inventors to the licensees in exchange for monetary compensation.

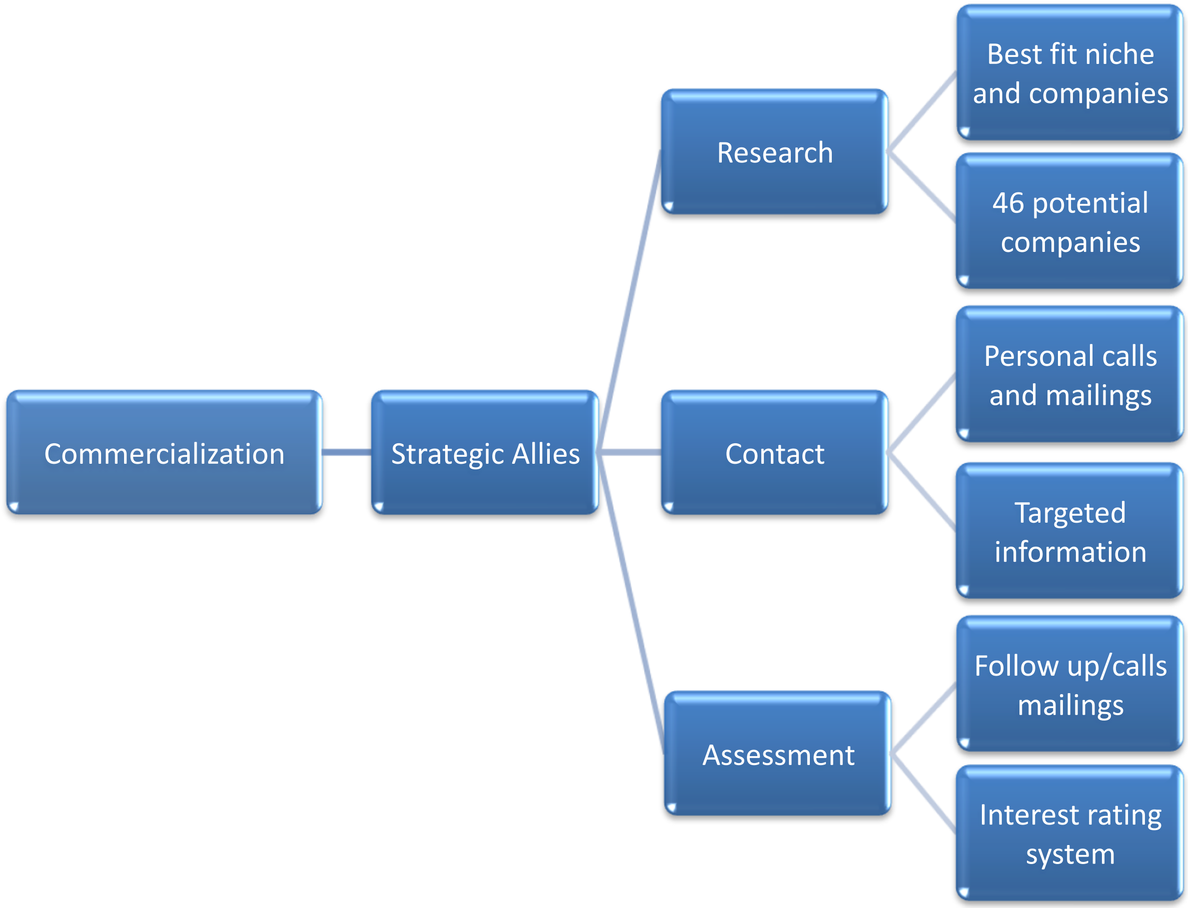

Figure 39: Stage II project scope

Methodology

In order to achieve this objective, a number of successive steps needed to be taken. The first step was the prospecting and qualifying stage, where potential strategic allies were identified and assessed based on their industry, products, methods, size, and company strength. Preapproach consisted of using information collected on potential strategic allies to customize an approach to fit the business plan and product needs of each individual company. Next, the actual approach was made to the potential strategic allies. This step consisted of the initial phone call to confirm that a company is interested in receiving information on Sorption Oxidation. It was also used to obtain or confirm mailing addresses and find a person in the company that would be able to champion the introduction of SOx to the rest of the company. This person was usually in the research and development or new product development department, but included some marketing personnel as well. The presentation and demonstration step consisted of the creation and mailing of informational brochures and cover letters introducing the WPI research team and the Sorption Oxidation technology. Next, the SOx team needed to overcome any objections raised. The majority of these objections were concerns raised by companies concerning viability of SOx and pricing. A FAQ sheet was created to answer more detailed questions, but still did not share proprietary technology information. Once nondisclosure agreements were signed, it became possible to share proprietary information contained in this report to answer further and more specific questions and concerns about the SOx technology. The documents created can be viewed in the attached appendices.

Finalizing Collaborative Efforts with Strategic Allies

Lastly, once the potential strategic allies reach the point of signing an NDA, receive the proprietary report on SOx, and maintain a serious interest in working with the WPI team, the negotiations will be passed on to the WPI Technology Transfer Office, where professionals trained in the actual licensing and legal implications of forging a purchase or contract, will continue negotiations with the company and finalize contractual agreements. The last step in the SOx strategic ally marketing process would be a continuous evaluation and maintenance of the relationship between the strategic ally and the WPI Bioengineering team.

This will be invaluable over the time that the two entities are working together and its goal is to continually evaluate the needs of both parties and fulfillment of their contractual obligations. This can be best done through a number of important practices. The first and perhaps most important practice, is to maintain regular and purposeful communication between the two partners. This can be achieved through regular meetings, telephone calls, and emails. In this case, the strategic ally would be in the "client" role and the WPI research team would be the contractor. This is important to consider because "the customer is always right" and since the strategic ally is essentially paying (funding) the WPI research team to further develop SOx, they will expect the WPI team to produce tangible and measurable results according to deadlines and budget constraints. This however, also places responsibility on the strategic ally to establish detailed and specific goals and objectives. A purposeful mission statement should be agreed upon by both parties, as well as a collaborative strategic plan.

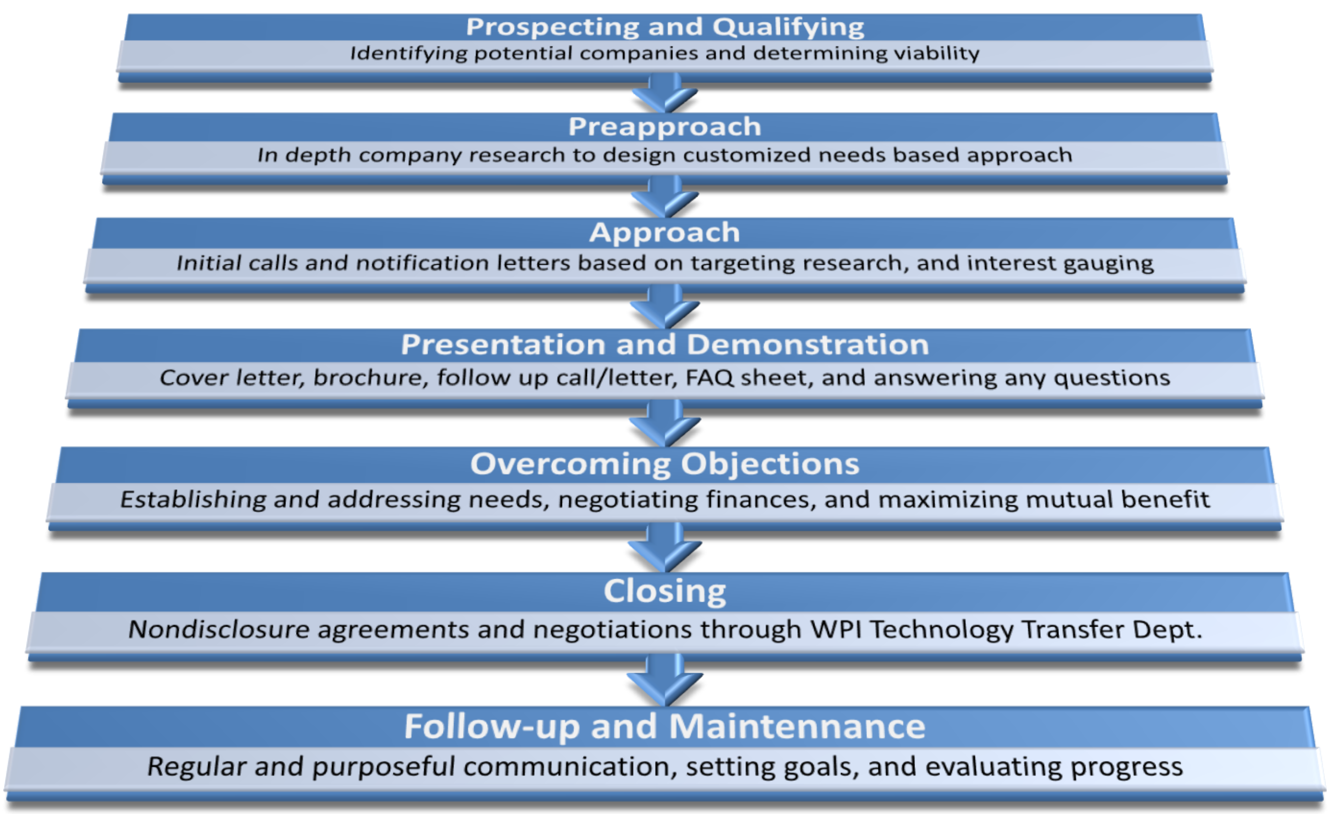

Figure 40: Stage II methods and processes flowchart

Initial Market and Industry Company Research

The first component to this project was the Stage I market and industry research. Once this was completed, it became possible to begin targeting potential strategic ally companies according to their current and future products and technology interests, thus initiating Stage II. A spreadsheet of over fifty companies that fit the profile of a company that might have interest in licensing the Sorption Oxidation process was compiled as seen in the appendices. This spreadsheet includes small firms with sales ranging from the hundreds of thousands of dollars, to large organizations with sales in the hundreds of billions of dollars, and companies with interests ranging from general water and process technologies, to those dealing with targeted filtration and remediation. It outlines the basic important information on each company such as sales, location, contact information, and a brief description of each company and their business.

Marketing and Contact

Once the Stage I market and industry research was completed, it also became both possible and necessary to begin the actual marketing and contact phase of the project. Targeted marketing materials such as the attached cover letters, brochure, and FAQ sheet were created. The purpose of these materials is to summarize Sorption Oxidation capabilities and opportunities and to stimulate initial interest in finding out more information and building a professional relationship with the SOx team.

It was decided that the best way to contact these companies would be to find and personally call the marketing, new product development, or research and development department, or someone in a similar capacity that could be a supporter and spokesman for the SOx technology. The purpose of the call would be to introduce SOx, as well as confirm the address and identity of the best person to send the brochure to and inform them that they would be receiving it shortly. A personalized cover letter was also written and sent to thank them for their time and interest and remind them of the purpose and subject of the mailing. A total of thirty-seven companies received physical mailings or digital ones if preferred, as well as follow up letters.

Gauging and Recording Interest

Another spreadsheet was constructed in order to track both contact companies and record their interest. The first round of calling allowed for elimination of thirteen of the original companies based on lack of interest or poor fit for the project, yielding interest ratings of "0". Eighteen companies were initially given ratings of "1" meaning that they had minimal interest and would require further contact. Companies with general or potential interest expressed by contact with someone in the research and development or new product development department, were given a rating of "2." There were eight of these companies. Lastly, there were sixteen companies deemed to have an interest rating of "3." These companies had a definite and promising interest in the technology, and are currently the focus of further contact, although the goal is to bring the companies on lower levels up to the third tier as well, through further contact and follow up. Once secondary contact with a company was initiated, they became a "4," once they signed an NDA and received a full report they were considered a "5," and a "6" was a company in the negotiation stage and passed on to the WPI Technology Transfer Office.

Follow-up

Once the cover letter and brochure were sent, a follow-up call was made, and a follow up letter was sent to the thirty-seven companies in order to remind companies to contact the SOx team, gauge further interest in the technology, and provide contact information and further information on proceeding with negotiations if the parties were interested. The follow up letter also sought to make sure that potential strategic allies actually received the first informational packets. A general nondisclosure agreement was given to companies that wished to obtain further proprietary information on Sorption Oxidation and its market and industry research. Once this agreement was signed it became possible to safely share information such as that of this report with them.

Results

One of the significant contributions that this project has provided to the WPI Technology Transfer Office and the WPI Bioengineering Institute Center for Water Research is the large volume of reusable and distributable deliverables, including the exhaustive industry and market report contained in this paper. Some of the other deliverables resulting from this project are the professional, informational brochures, multiple cover letters, and a detailed and specific FAQ sheet as seen in the subsequent appendices. The potential, system application designs detailing possible and plausible uses for the SOx technology also provide a valuable resource these teams.

As a direct result of this project, there are currently two companies interested in becoming strategic allies of the WPI Bioengineering Institute Center for Water Research. This is a very significant outcome considering the broad and competitive industry and how difficult introducing a new technology without even a proof of design prototype can be. Increasing consumer demand and industry growth have created a highly competitive market, so gaining these potential strategic allies represents an important step towards the further development and commercialization of the Sorption Oxidation technology.

The two companies are U.S. Water Services and Calgon Corporation. U.S. Water Services is one of the fastest growing water treatment companies in the U.S. and concentrates on capital equipment, support services, repair and cleaning, and custom chemical production and Calgon Corporation is a leading producer of activated carbon and broad spectrum water treatment systems. These were the first companies expressing serious interest, but due to the short time span of this project, it is expected that further companies will respond to the marketing information as time progresses. These future, potential strategic allies will be forwarded to the WPI Technology Transfer Office and the inventors.

Conclusions and Recommendations

After in-depth product, cost, industry, and market analyses, it has been concluded that there are broad market opportunities for SOx in the domestic and international organic contaminant treatment markets. There are few products that can address organic contamination effectively and none of them are as renewable, environmentally friendly, and cost-effective as Sorption Oxidation. With further research and customization, SOx can be effectively marketed and applied to a wide range of applications and sectors.

It is recommended that the inventors and WPI Bioengineering Institute Center for Water Research work to further develop SOx by creating proofs of concept. This is vital in the continuation of the commercialization process, as it is very difficult to market a technology that does not have a tangible example of operation, efficiency, and success. It would also be valuable to continue testing SOx in various technical applications with multiple organic contaminants to establish its versatility and effectiveness.

With the assistance of the WPI Technology Transfer Department, the WPI Bioengineering Institute Center for Water Research should also continue to pursue further negotiations with potential strategic allies, such as Calgon and U.S. Water Services. These negotiations are essential to the funding of further technology development. It is also recommended that they expand their efforts to international markets in emerging industrial powers such as China, India, Africa, the Middle East, Russia, Latin America, and the Pacific Rim, which provide a growing market for technologies such as Sorption Oxidation.

Acknowledgements

The author would like to extend special thanks to Dr. McRae Banks, Dr. John Bergendahl, Dr. Robert Thompson, and Dr. Michael Manning. This project would not have been possible without all of your continual support, advisement, and insight. Others deserving of special recognition and appreciation are Marge Gribouski, Marcia Kwederis, and Colleen Burton for their assistance throughout the duration of the project and report.

Appendices

List of Potential Strategic Allies with sales, phone numbers, addresses, and brief description of the company.

Company	Sales (million)	Location	Website	Phone
Danfoss Water and Wastewater	0.1	Oviedo, FL 32765	http://www.danfoss.com/North_America/BusinessAreas/Water+and+Waste+Water/	407-977-7888
Argonide Corporation	0.60	Sanford, FL 32771-9406		407-322-2500
Solutions-Ies, Inc	2.50	Raleigh, NC 27607-5242		919-873-1060
Zero Technologies, Llc	2.90	Bensalem, PA 19020		215-244-0823
The DrinkMore Water Store	3.10	Gaithersburg, MD 20879-4776	http://www.drinkmorewater.com	301-417-9333
Terra Systems Inc	4.00	Hudson, MA 01749-3047		978-568-0351
Ozocan Corporation	5.70	Scarborough, ON M1H 3A6 Canada	http://www.ozocan.com	416-439-7860

LifeSource Water Systems, Inc	6.60	Pasadena, CA 91105	http://www.lifesourcewater.com	626-792-9996
Hanna Instruments	11.8	Woonsocket, RI 02895	http://www.hannainst.com/	401-765-7500
Campbell Manufacturing, Inc.	12.10	Bechtelsville, PA 19505-0207	http://www.campbellmfg.com	610-367-2107
Elster AMCO Water, Inc.	19.40	Ocala, FL 34474-9374	http://www.elsteramcowater.com/	352-732-4670
F.B. Leopold Company, Inc.	29.30	Zelienople, PA 16063 United	http://www.fbleopold.com	724-452-6300
Hydranautics	43.20	Oceanside, CA 92054 United	http://www.hydranautics.com	760-901-2500
Graver Technologies, Inc.	44.00	Glasgow, DE 19702	http://www.gravertech.net	302-731-1700
Endress + Hauser Flowtec	51	Greenwood, IN 46143	http://www.endress.com/	317-535-1345
Trojan Technologies Inc.	56.40	London, ON N5V 4T7 Canada	http://www.trojanuv.com	519-457-3400
EcoWater Sytems LLC	58.80	Woodbury, MN 55125-2913	http://www.ecowater.com	651-739-5330

AWTP, LLC (Rainsoft)	64.10	Elk Grove Village, IL 60007	http://www.rainsoft.com	847-437-9400
Emerson Process Management Power & Water Solutions, Inc	64.6	Pittsburgh, PA 15238	http://www.emersonprocess.com/home/	412-963-4000
Peerless Mfg. Co.	75.10	Dallas, TX 75254 United	http://www.peerlessmfg.com	214-357-6181
Glacier Water Services, Inc.	90.40	Vista, CA 92081	http://www.glacierwater.com	760-560-1111
Hach Company	118.1	Loveland, CO 80538	http://www.hach.com/	970-669-3050
Aquaterra Corporation Ltd.	166.00	Mississauga, ON L4Z 3C9, Canada	http://www.aquaterracorporation.com	905-795-6500
Cantel Medical Corp.	249.40	Little Falls, NJ 07424	http://www.cantelmedical.com	973-890-7220
CUNO Inc.	274.5	Meriden, CT 06450	http://www.cuno.com	203-237-5541
Calgon Carbon Corporation	351.1	Pittsburgh, PA 15205	http://www.calgoncarbon.com	412-787-6700
NATCO group, Inc.	570.1	Houston, TX 77041	http://www.natcogroup.com	713-849-7500

GE Water and Process Technologies	572.70	Trevose, PA 19053-6783 United	http://www.gewater.com	215-355-3300
Siemens Water Technologies	724.80	Warrendale, PA 15086	http://www.industry.siemens.com/Water	724-772-0044
IDEX Corporation	1,358.60	Northbrook, IL 60062	http://www.idexcorp.com	847-498-7070
Millipore Corporation	1,531.60	Billerica, MA 01821 United	http://www.millipore.com	978-715-4321
Gardner Denver, Inc.	1,868.80	Quincy, IL 62305	http://www.gardnerdenver.com	217-222-5400
ITT Fluid Technology	1,900.00	Upper Saddle River, NJ 07458	http://www.ittfluidbusiness.com	201-760-9800
AMETEK, Inc.	2,136.90	Paoli, PA 19301	http://www.ametek.com	610-647-2121
Axel Johnson	2,147.50	Stamford, CT 06901-3530	http://www.axeljohnson.com	203-326-5200
Pall Corporation	2,571.60	East Hills, NY 11548-1289	http://www.pall.com	516-484-5400
Pall Corporation	2,571.60	East Hills, NY 11548	http://www.pall.com	516-484-5400

Crane Company	2,619.20	Stamford, CT 06902	http://www.craneco.com	203-363-7300
Black & Veatch Holding Company	3,200.00	Kansas City, MO 64114	http://www.bv.com	913-458-2000
Flowserve Corporation	3,762.70	Irving, TX 75039	http://www.flowserve.com	972-443-6500
NALCO Holding Company	3,912.50	Naperville, IL 60563	http://www.nalco.com	630-305-1000
Rohm and Haas Company	8,897	Philadelphia, PA 19106-2399	http://www.rohmhaas.com	215-592-3000
Danaher Corporation	11,025.90	Washington, DC 20006	http://www.danaher.com	202-828-0850
3M Company	24,462.00	St. Paul, MN 55144	http://www.mmm.com	651-733-1110
Coca-Cola Company	28,857.00	Atlanta, GA 30313-2499	http://www.coca-cola.com	404-676-2121
PepsiCo, Inc.	39,474.00	Purchase, NY 10577-1444	http://www.pepsico.com	914-253-2000
Veolia Environnement SA	48,058.10	Paris France	http://www.veoliaenvironnement.com	33-1-7175-0000
The Dow Chemical Company	53,513.00	Midland, MI 48674	http://www.dow.com/liquidseps/	989-636-1000

Proctor and Gamble Company (PUR)	83,503.00	Cincinnati, OH 45202	http://www.pg.com	513-983-1100
ConocoPhillips	194,495	Houston, TX 77079	http://www.conocophillips.com	281-293-1000
BRITA GmbH		Oakland, CA 94612	http://www.brita.com	510-271-7000
Culligan International Company		Rosemont, IL 60018	http://www.culligan.com	847-430-2800
Ionics, Incorporated		Watertown, MA 02472-2882		617-926-2500
PUR (under proctor and gamble)			http://www.purwater.com/#/products	
Sandia National Laboratories		Albuquerque, NM 87123	http://www.sandia.gov	505-845-0011
U.S. Pure Water Corp.		Greenbrae, CA 94904	http://www.uspurewater.com	415-883-9900
U.S. Water Purification, Inc.		Colorado Springs, Colorado 80907	http://www.uswaterpurification.com/	719-475-8075
U.S. Water Services		Cambridge, MN 55008	http://www.uswaterservices.com	866-663-7632

Company	Description
3M Company (Aqua-pure)	Owns Aqua-pure. The company has six operating segments: display and graphics (specialty film, traffic control materials); health care (dental and medical supplies, and health IT); safety, security, and protection (commercial care, occupational health and safety products); electro and communications (connecting, splicing, and insulating products); industrial and transportation (specialty materials, tapes, and adhesives); and consumer and office. Well-known brands include Scotchgard fabric protectors, Post-it Notes, Scotch-Brite scouring products, and Scotch tapes. Sales outside the US account for about two-thirds of 3M's sales.
AMETEK, Inc.	Monitoring equipment and electric motors. The company's Electronic Instruments Group (56% of sales) makes monitoring, calibration, and display devices for the aerospace, heavy equipment, power generation, and other industrial markets. AMETEK's Electromechanical Group (44% of sales) makes air-moving electric motors for vacuum cleaners and other floor-care equipment, and brushless air-moving motors for the aerospace, mass transit, medical, and computer markets. The group also makes specialty metals for the telecommunications, electronics, consumer, and automotive industries. AMETEK gets about half of its sales in the US.
Aquaterra Corporation Ltd.	Operating under the Canadian Springs and Labrador Source brands, Aquaterra delivers 18.5-litre returnable and small format bottled water to more than 175,000 customers in Canada through retail, office, and home delivery channels. The company also provides services such as water cooler rental, sales and cleaning, and point of use water filtration systems.
Argonide Corporation	Mercury removal sorbent patent: A sorbent composition comprising a vanadium compound and a TiO.sub.2 support material is disclosed. Methods of making and using the composition to remove heavy metals or heavy metal containing compounds from a fluid stream are also provided. Such methods are particularly useful in the removal of mercury and mercury compounds from flue gas streams produced from the combustion of hydrocarbon-containing materials such as coal and petroleum fuels.
AWTP, LLC (Rainsoft)	AWTP wants to clear up the water in your home or office. Through its RainSoft division, the company makes residential and commercial water treatment equipment. Products include whole-house water conditioning systems, drinking water systems, and filters designed to remove particular contaminants that detract from water's taste and odor. RainSoft's products are distributed through a network of more than 300 independent dealers in the US and in 24 countries in Asia, Europe, and the Middle East. Clients have included Allstate , Dow Chemical, Ford Motor, Holiday Inn, and Underwriters Laboratories.

Axel Johnson	Axel Johnson Inc. owns and operates North American businesses like Kinetico (over $24 million) on behalf of the dynasty. The investment firm focuses on the energy distribution, materials handling, and water industries. Its investments include Sprague Energy, Parkson Corp., and Kinetico Incorporated. The average length of ownership span is about 20 years. Axel Johnson Inc., Axel Johnson AB, and AXFast BV are all affiliated with the Axel Johnson Group but are legally and financially independent. Established in 1873, the Johnson family of companies is in its fourth generation of family ownership.
Black & Veatch Holding Company	The international group is one of the largest private companies in the US. Targeting infrastructure development for the energy, water, services, and telecommunications markets, the group engages in all phases of building projects, including design and engineering, financing and procurement, and construction. Among its services are environmental consulting, operations and maintenance, security design and consulting, management consulting, and IT services. Projects include coal, nuclear, and combustion turbine plants; drinking water and coastal water operations; and wireless and broadband installation.
BRITA GmbH	The firm is the world leader in household water filters, producing pour-through pitcher filters, tap filters, and squeeze-bottle filters. The company's products are sold by mass merchants, home improvement stores, supermarkets, specialty stores, and at warehouse clubs. Cleaning products company Clorox owns the North American distribution rights to BRITA products.
Calgon Carbon Corporation	Calgon Carbon makes activated carbons and purification systems and offers purification, separation, and concentration services to the industrial process and environmental markets. The company provides activated, impregnated, and acid-washed carbons (about 130 million pounds annually) for use in applications such as food processing, wastewater treatment, and emissions control. Calgon Carbon also sells equipment that uses activated carbon and ion exchange resins for the purification of products in the chemical, food, and pharmaceutical industries. The company's consumer products include charcoal and carbon cloth.
Campbell Manufacturing, Inc.	The company makes faucets, fittings, gauges, and other items for water filtration and purification systems. It also makes parts for sump pumps and sewage and effluent treatment systems. Campbell Manufacturing's Monoflex division manufactures products for irrigation, dewatering, and environmental groundwater monitoring.
Cantel Medical Corp.	Firm sells infection prevention and control products to hospitals, dentists, drugmakers, researchers, and others in the health care market. Its offerings include medical device reprocessing systems and disinfectants for dialyzers and endoscopes, water purification equipment, masks and bibs used in dental offices, specialty packaging of biological and pharmaceutical products, and therapeutic filtration systems. Its principal subsidiary Minntech makes dialyzer reprocessing equipment, fluid filtration systems, and the Medivators line of endoscope reprocessing products.

Coca-Cola Company	The Coca-Cola Company owns four of the top five soft-drink brands (Coca-Cola, Diet Coke, Fanta, and Sprite). Its other brands include Barq's, Minute Maid, POWERade, and Dasani water. In North America, it sells Groupe Danone's Evian. Coca-Cola sells brands from Dr Pepper Snapple Group (Crush, Dr Pepper, and Schweppes) outside Australia, Europe, and North America. The firm makes or licenses more than 400 drink products in more than 200 nations. Although it does no bottling itself, Coke owns 35% of Coca-Cola Enterprises (the #1 Coke bottler in the world); 32% of Mexico's bottler Coca-Cola FEMSA; and 23% of European bottler Coca-Cola Hellenic Bottling.
ConocoPhillips	Formed by the merger of Conoco and Phillips Petroleum, ConocoPhillips is the #3 integrated oil and gas company in the US, behind Exxon Mobil and Chevron, and consolidated that position by buying Burlington Resources (for a reported $35 billion). The company explores for oil and gas in more than 30 countries and has estimated proved reserves of 11.2 billion barrels of oil equivalent, excluding its Syncrude (Canadian oil sands) assets. It has a refining capacity of more than 2.7 million barrels per day and sells petroleum at 8,750 retail outlets in the US under the 76, Conoco, and Phillips 66 brands. Other operations include chemicals, gas gathering, fuels technology, and power generation.
Culligan International Company	Culligan produces filters for tap water, household water softeners, microfiltration products, desalination systems, and portable deionization services for commercial and industrial users. The franchised "Culligan Man" noted in the advertising phrase delivers bottled water and water systems to consumers and businesses throughout the US and in more than 90 other countries. Besides Culligan, the company's brand names include Everpure, Elga, and Bruner. Buyout firm Clayton, Dubilier & Rice acquired the company for $610 million in 2004.
CUNO Inc.	The company, a unit of 3M, makes a full line of filtration products for the health care, fluid-processing, and potable-water markets. Its filters remove contaminants as small as molecules and as large as sand particles from liquids and gases. They are used to purify drugs, paints and resins, oil and gas, and home drinking water. Under its Scientific Application Support banner, CUNO assigns its own scientists to work with customers when creating new products. The company operates offices worldwide and eight manufacturing plants in Australia, Brazil, Europe, Japan, and the US and has sales offices worldwide. CUNO was acquired by 3M in 2005.
Danaher Corporation	Uses UV for water treatment. Its Professional Instrumentation group produces environmental and electronic testing technology. The Industrial Technologies unit makes motion control equipment and devices that read bar codes, and the Medical Technologies division makes dental products and medical instrumentation devices. Danaher's Tools and Components segment includes hand tools, automotive specialty tools, and accessories under brand names like Sears' Craftsman. Brothers Steven Rales (chairman) and Mitchell Rales (a director) together own approximately 20% of the company.

Danfoss Water and Wastewater	Danfoss has supplied innovative products to the water industry worldwide. Products are sold by a network of subsidiaries and distributors. These companies provide on-time deliveries from convenient local stocks. More important, however, is their total commitment to customer satisfaction. Danfoss Water and Wastewater, headquartered in Milwaukee, WI, sells and supports various products, including adjustable frequency drives, soft starters, and other components to improve water systems.
EcoWater Sytems LLC	The company manufactures commercial and residential water treatment systems. It sells its products through a network of more than 1,400 dealers, wholesalers, and private-label retailers. Those products include water refiners, conditioners, and purifiers. Founded in 1925, EcoWater Systems is a member of the Marmon Group but, like that company's other subsidiaries, maintains its own management. In addition to its US operations in Minnesota and Mississippi, the company operates subsidiaries in Australia, Belgium, Canada, China, France, Poland, and the UK.
Elster AMCO Water, Inc.	Elster AMCO Water is part of Elster, the world's largest metering and smart metering system solution company. Elster AMCO Water is an industry leader in the development and implementation of innovative metering and system solutions and is committed to delivering superior customer service, quality products, solutions and services to the water utility industry.
Emerson Process Management Power & Water Solutions, Inc	Emerson Process Management offers the industry's broadest array of process-automation products. Our technology know-how and application experience enable us to develop measurement and analytical instruments, final-control devices, and systems and software that deliver the proven performance and reliability our customers expect. And our open, standards-based PlantWeb architecture unleashes the power of intelligent field devices, systems, and software to deliver better process, plant, and business results.
Endress + Hauser Flowtec	Broad array of services and technologies in various industries offer multiple revenue sources.
F.B. Leopold Company, Inc.	F.B. Leopold develops and manufactures water and wastewater clarification, purification, and sludge collection equipment and backwash recovery systems.
Flowserve Corporation	The company makes pumps, valves, and mechanical seals. The acquisition of Ingersoll-Dresser Pumps (IDP) from Ingersoll-Rand made Flowserve the world's largest provider of pumps for the chemical, petroleum, and power industries. It provides its products and services to more than 10,000 customers around the globe. Flowserve's flow solutions division offers mechanical seals, sealing systems, and repair services to OEMs that make pumps, compressors, and mixers. Its flow control division makes valves, actuators, and related equipment that control the flow of liquids and gases.

Gardner Denver, Inc.	The company makes a variety of compressors, such as reciprocating, rotary screw, and sliding vane compressors, as well as positive displacement and centrifugal blowers. Manufacturing plants and industrial facilities use the compressors to produce durable goods, process petroleum and pharmaceuticals, and to treat wastewater. Compressed air products are its principal product. Gardner Denver also makes well-servicing pumps for oil and natural gas companies, and it is adding new lines, such as water-jetting products. More than half of the company's sales comes from outside the US.
GE Water and Process Tech	A unit of GE's Infrastructure division, GE Water combines the forces of GE Betz, GE Osmonics, and GE Glegg. Besides making water treatment chemicals (Betz), the business unit also manufactures pumps, filters, and fluid controls that help purify water, work against corrosion, and prepare waste water for disposal.
Glacier Water Services, Inc.	The company operates more than 16,000 self-service vending machines that dispense filtered drinking water, maing it a leading brand in vended water. Its machines are in 43 US states and Canada. The machines are connected to municipal water sources and are designed to reduce impurities in the water through processes such as micron filtration, reverse osmosis, carbon absorption, and ultraviolet disinfection. Glacier Water's machines are placed outside supermarkets and other stores; it uses indoor models in colder climates.
Graver Technologies, Inc.	Graver Technologies makes filtration and separation products to eliminate impurities from water and air. The company's offerings include adsorbents, industrial air and gas filters, ion exchange resins, liquid filter cartridges, and stainless steel filter membranes. Graver Technologies' products are used primarily in manufacturing processes. The company's customers include operators of power plants and companies in the chemical, food and beverage, and pharmaceutical industries, along with makers of compressors, pumps, and turbines. Graver Technologies is a unit of the diversified Marmon Group of manufacturing companies.
Hach Company	Drinking water treatment and diagnostic products. Strong brand presence and brand perception in the marketplace. Perceived as having “bestin-class” customer service offerings. Breadth of applications and technologies within water treatment offer multiple revenue sources and significant opportunities for cross-marketing.
Hanna Instruments	world leading manufacturer of analytical instrumentation, HANNA offers over 3000 products to its customers.
Hydranautics	Hydranautics is a manufacturer of water purification equipment. The company's products use a process called membrane separation to purify water for such purposes as seawater desalination, surface water treatment, and agricultural irrigation.

IDEX Corporation	The company is a leading manufacturer of pump products, dispensing equipment, and other engineered products. Its fluid and metering segment includes industrial pumps, injectors, compressors, and flow meters that move chemicals, fuels, and similar fluids. Its health and science segment consists of low-flow pumps and equipment for analytical and clinical applications. The company's dispensing equipment includes gear for dispensing, metering, and mixing dyes, inks, and paints. IDEX's fire and safety/diversified products segment manufactures banding and clamping equipment, fire-fighting pumps, and rescue tools, including the Jaws of Life.
Ionics, Incorporated	Ionics made water-treatment and water-purification systems for consumer, industrial, municipal, and utility applications. Municipal and commercial offerings included desalination systems that turn brackish water into potable water and systems that purify normal water for semiconductor manufacturing or drug production. Consumer products included a variety of home water-filtering systems. To ensure that water met drinking, industrial, or environmental standards, Ionics' instrument group also made measuring devices used by industrial, governmental, and pharmaceutical customers. GE Infrastructure acquired Ionics in 2005.
ITT Fluid Technology	The ITT Industries subsidiary is made up of more than 20 companies that produce a variety of pumps, mixers, and valves used in the biopharmaceutical, building trades, industrial process, wastewater, and water industries. Group companies include Flygt, Goulds Pumps, Lowara, and Hoffman Specialty. ITT Fluid Technology, which does business in more than 130 countries worldwide, also manufactures boiler controls, heat exchangers, and related products under the brand names ITT Standard and McDonnell & Miller.
LifeSource Water Systems, Inc	The water treament product company manufactures and distributes water filtration equipment to residential, commercial, and industrial customers. LifeSource Water Systems' system uses an activated carbon filter rather than salts or chemicals. Its Beotron branded systems are tested and certified and have earned the Gold Seal issued by the Water Quality Association.
Millipore Corporation	Millipore is a leader in membrane separation technology, which is used for fluid analysis, identification, and purification. The company's membranes filter particulate, molecular, bacterial, or viral entities from fluids and are also used to concentrate such material for further processing. Customers in the pharmaceutical and biotechnology industries use the products for sterilizing (including virus reduction and sterility testing of antibiotics and protein solutions), cell harvesting, and isolating compounds from complex mixtures. The beverage industry uses Millipore's filters to remove bacteria and yeast from wine, beer, juice, and water.

NALCO Holding Company	Dirty water? Wastewater? Process-stream water? Nalco treats them all. The company is the world's largest maker of chemicals used in water treatment and for industrial processes (in front of #2 GE Water and Process Technologies). Nalco's Energy Services segment is also #1 worldwide, ahead of Baker Petrolite; it provides fuel additives, oilfield chemicals, and flow assurance services to energy companies. The company's chemicals help clarify water, conserve energy, prevent pollution, separate liquids from solids, and prevent corrosion in cooling systems and boilers. Its top-ranked Industrial and Institutional Services segment has a 20% market share, and Nalco's pulp and paper unit is #3 behind Ashland and Ciba.
NATCO group, Inc.	Operating in three segments -- automation and controls, gas technologies, and oil and water technologies -- NATCO's products include dehydration and desalting units, heaters to prevent solids from forming in gas, gas conditioning equipment, water filtration systems, and production equipment control systems. The company's products are used in oil and gas fields throughout the world, and it has sales offices in Canada, Japan, Malaysia, the UK, the US, and other countries.
Ozocan Corporation	Ozocan (formerly Hankin Water Technologies) provides water-purification equipment for aquaculture, commercial aquariums, drinking-water treatment, industrial-waste treatment, and other uses
Pall Corporation	The company makes filtration and separation systems designed to remove solid, liquid, and gaseous contaminants from a variety of materials. Pall's industrial business segment makes filtration products for general industrial applications, including water purification, as well as for use in the aerospace and microelectronics industries. Products of Pall's life sciences segment are used to help develop and manufacture drugs and for medical functions such as removing white blood cells from blood. Most of Pall's sales are made outside the US.
Peerless Mfg. Co.	Peerless is without peer when it comes to putting products in pipes for purposes of removing contaminants. The company's separation filtration systems are used to remove solid and liquid contaminants from natural gas and to remove saltwater aerosols from the air intakes of marine gas turbine and diesel engines. Customers include natural gas producers and shipbuilders. Products of the company's other business segment, environmental systems, include selective catalytic reduction (SCR) systems, which are used to convert nitrogen oxide produced by the burning of fossil fuels into nitrogen and water vapor. SCR systems are sold to power producers, construction companies, and refineries.
PepsiCo, Inc	Its soft drinks include Pepsi, Mountain Dew, and Slice. Cola is not the company's only beverage: Pepsi sells Tropicana orange juice brands, Gatorade sports drink, and Aquafina water.

Proctor and Gamble Company (PUR)	Owns PUR. http://www.purwater.com/#/healthy%20water,%20healthy%20you The world's #1 maker of household products courts market share and billion-dollar names. It's divided into three global units: health and well being, beauty, and household care. The company also makes pet food and water filters and produces soap operas. Some 25 of P&G's brands are billion-dollar sellers, including Fusion, Always/Whisper, Braun, Bounty, Charmin, Crest, Downy/Lenor, Gillette, Iams, Olay, Pampers, Pantene, Pringles, Tide, and Wella, among others. P&G shed its coffee brands in late 2008. Being the acquisitive type, with Clairol and Wella as notable conquests, P&G's biggest buy in company history was Gillette in late 2005.
Rohm and Haas Company	Has patent for removing halogenated organic materials and arsenic. The company's divides its operations among six units, the largest of which is the paints and coatings materials group, which makes additives and binders used by paint makers. There's also the packaging and building materials group and the primary materials division, which makes on acrylates. (Those businesses operate within the Specialty Materials segment.) The electronic materials segment makes photoresists and materials for printed wiring boards. Rohm and Haas' salt group markets salt for road ice control, table salt, and water softening, and the performance materials unit makes plastics additives and antimicrobials.
Sandia National Laboratories	Sandia National Laboratories performs research and development primarily related to national security and defense. Its focus is nuclear weapons systems research, but Sandia also performs nonproliferation assessments, infrastructure assurance, and other research and development on such topics as energy and environmental technologies and economic competitiveness. Sandia's recent duties have expanded to combat terrorism, aid homeland security, and support US military in Afghanistan and Iraq. A part of the US Department of Energy, Sandia is operated by Lockheed Martin.
Siemens Water Technologies	Leading producer of water- and wastewater-treatment equipment worldwide. Through its Water and Wastewater Systems and Water Services and Products groups, Siemens Water Technologies provides services to municipal, industrial, and institutional clients. It has more than 200,000 installations on several continents and a portfolio of more than 900 water treatment products and technologies. The company is a division within Siemens Industrial Solutions and Services group.
Solutions-Ies, Inc	Has patented a method for remediating aquifers and groundwater contaminated, for example by toxic halogenated organic compounds, certain inorganic compounds, and oxidized heavy metals and radionuclides, using the introduction of an innocuous oil, preferably an edible, food grade oil such as soybean oil, formulated into a microemulsion preferably by mixing with a natural food-grade emulsifier (such as lecithin) and water.

Terra Systems Inc	Has patented a method for remediating aquifers and groundwater contaminated, for example by toxic halogenated organic compounds, certain inorganic compounds, and oxidized heavy metals and radionuclides, using the introduction of an innocuous oil, preferably an edible, food grade oil such as soybean oil, formulated into a microemulsion preferably by mixing with a natural food-grade emulsifier (such as lecithin) and water.
The Dow Chemical Company	**(TSI)** offers feasibility and field remediation services to solve a wide variety of industrial groundwater and soil contamination problems.
The DrinkMore Water Store	DrinkMore Water filters and purifies, delivers, and retails drinking water and accessories to thirsty customers in their homes or at the officed in the greater Washington D.C. area. The company's filtered water, produced at its bottling facility in Gaithersburg, Maryland, is also available at a number of retail outlets in Maryland and Virginia. DrinkMore Water rents hot and cold water coolers and dispensers. In addition to water and its accoutrements, the company also offers Green Mountain Coffee, Keurig single-cup coffee brewers, and lemon and grape juice.
Trojan Technologies Inc.	Ultraviolet (UV) lighting systems for disinfecting wastewater and treating contaminated soil and groundwater. Trojan's wastewater treatment systems are used in about 4,000 municipalities in 50-plus countries
U.S. Pure Water Corp.	Full spectrum water treatment service and sales company provides an ecological & economical alternative to bottled and tap water, by providing drinking water equipment which treats water at the point of use (i.e. your kitchen sink, your break room at work, or the grocery store where you shop), rather than at a treatment plant hundreds of miles away.
U.S. Water Purification, Inc	The company designs and manufactures water purification systems for many applications including: Agricultural - Boiler Feed - Bottling - Drinking - Electronics - Pharmaceutical - Refining and more. US Water Purification, Inc. specializes in the technologies of: Filtration, Ultrafiltration, Reverse Osmosis, Ultraviolet Light, Ion Exchange, Electrodeionization, Ozonation, Chlorination, Advanced Oxidation, Degasification and various chemical treatments.
U.S. Water Services	One of the nation's leading water treatment providers, U.S. Water Services is the largest independently owned water treatment/service company in Minnesota, and the fastest growing water treatment company in the country. Focus on capital equipment, support services, repair and cleaning services, custom chemical production.
Veolia Environnement SA	Veolia Environnement holds water -- as well as waste management, energy, and transportation -- operations. The company's Veolia Eau unit, which provides water and wastewater services to 132 million people, is the world's largest water company, ahead of SUEZ Environnement. Veolia Environmental Services, one of the world's leading waste management companies, serves more than 50 million people a year.

Zero Technologies, Llc	Patented an apparatus designed so that no water pressure need be applied to force the water through the apparatus, as gravity pulls the water down through the filtering layers. Water may also be force fed through the treatment apparatus; when the water is force fed, the housing portions need not be vertically stacked, but may be configured in any suitable arrangement. The treatment sections are distributed through the various housing portions in logical groups to perform various kinds of filtering. The housing portions are detachable and sealably stackable in multiple configurations, thus passing water through more or fewer treatment layers, depending on the quality of the incoming water.

Company	Website	Phone	Contact	Interest Level	Received Info
Danfoss Water and Wastewater	http://www.danfoss.com/North_America/BusinessAreas/Water+and+Waste+Water/	407-977-7888		0	
Elster AMCO Water, Inc.	http://www.elsteramcowater.com/	352-732-4670		0	
Emerson Process Management Power & Water Solutions, Inc	http://www.emersonprocess.com/home/	412-963-4000		0	
Endress + Hauser Flowtec	http://www.endress.com/	317-535-1345		0	
Flowserve Corporation	http://www.flowserve.com	972-443-6500		0	
Gardner Denver, Inc.	http://www.gardnerdenver.com	217-222-5400		0	
Hanna Instruments	http://www.hannainst.com/	401-765-7500		0	

IDEX Corporation	http://www.idexcorp.com	847-498-7070		0	
ITT Fluid Technology	http://www.ittfluidbusiness.com	201-760-9800		0	
PepsiCo, Inc.	http://www.pepsico.com	914-253-2000		0	
Terra Systems Inc	http://www.terrasystems.net/	302-798-9553		0	
U.S. Pure Water Corp.	http://www.uspurewater.com	415-883-9900		0	
Aquaterra Corporation Ltd.	http://www.aquaterracorporation.com	905-795-6500	waiting for callback	1	X
Argonide Corporation		407-322-2500	waiting for callback	1	X
AWTP, LLC (Rainsoft)	http://www.rainsoft.com	847-437-9400	waiting for callback	1	X
Axel Johnson	http://www.axeljohnson.com	203-326-5200	waiting for callback	1	X
Campbell Manufacturing, Inc.	http://www.campbellmfg.com	610-367-2107	waiting for callback	1	X
Cantel Medical Corp.	http://www.cantelmedical.com	763-553-3300	Mike Peterson	1	X
Culligan International Company	http://www.culligan.com	847-430-2800	Steve Reef	1	X
Danaher Corporation	http://www.danaher.com	202-828-0850	see below	1	X

Ionics, Incorporated		617-926-2500	now part of GE Water	1	X
Millipore Corporation	http://www.millipore.com	978-715-4321	Tim Derlinga 6175136411	1	X
NALCO Holding Company	http://www.nalco.com	630-305-1000	Christine tocars ext 1920	1	X
Pall Corporation	http://www.pall.com	516-484-5400	ext 9309	1	X
Peerless Mfg. Co.	http://www.peerlessmfg.com	214-357-6181	waiting for callback	1	X
Rohm and Haas Company	http://www.rohmhaas.com	215-592-3000	waiting for callback	1	X
Solutions-Ies, Inc		919-873-1060	Joe Star	1	X
The DrinkMore Water Store	http://www.drinkmorewater.com	301-417-9333	waiting for callback	1	X
U.S. Water Purification, Inc.	http://www.uswaterpurification.com/	719-475-8075	waiting for callback	1	X
U.S. Water Services	http://www.uswaterservices.com	866-663-7632	Duane ext 108	1	X
3M Company	http://www.mmm.com/suppliers	651-733-1110	fill out forms	2	X
AMETEK, Inc.	http://www.ametek.com	610-647-2121	find specific divisions	2	X
BRITA GmbH	http://www.brita.com	510-271-7000	use website	2	X

Coca-Cola Company	http://www.coca-cola.com	404-676-2121	Industry and Consumer Affairs	2	X
GE Water and Process Technologies	http://www.gewater.com	215-355-3300	Use OMLP contact	2	X
PUR (under proctor and gamble)	http://www.purwater.com/#/products	800-787-5463	use website	2	X
The Dow Chemical Company	http://www.dow.com/liquidseps/	989-636-1000	ebusiness and then contact us	2	X
Veolia Environnement SA	http://www.veoliaenvironnement.com	33-1-7175-0000	use website	2	X
NATCO group, Inc.	http://www.natcogroup.com	713-849-7500	Judy Bollison Marketing	3	X
Sandia	http://www.sandia.gov	505-845-0011…284-4743	Ann Riley 505-284-9550 ajriley@sandia.gov	3	X
Siemens Water Technologies	http://www.industry.siemens.com/Water	724-772-0044	information.water@siemens.com	3	X
Black & Veatch Holding Co. (water dept)	http://www.bv.com	913-458-2000	Mark Bushhouse bushousemd@bv.com	3	X
Calgon Carbon Corporation	http://www.calgoncarbon.com	412-787-6700	Nick Pollack	3	X
ConocoPhillips	http://www.conocophillips.com	281-293-1000	mail	3	X

CUNO Inc.	http://www.cuno.com	203-237-5541	John Pulek Director RD for Industrial	3	X
EcoWater Sytems LLC	http://www.ecowater.com	651-739-5330	Jeff Vermullen	3	
F.B. Leopold Company, Inc.	http://www.fbleopold.com	724-452-6300	Robert Wiley R+D	3	X
Glacier Water Services, Inc.	http://www.glacierwater.com	760-560-1111	Kris Anderson	3	X
Hach Company	http://www.hach.com/	970-669-3050	Kathy Simpson RD Admin	3	X
Hydranautics	http://www.hydranautics.com	760-901-2500	Ben Weaver Appllications Engineer	3	X
LifeSource Water Systems, Inc	http://www.lifesourcewater.com	626-792-9996	Sherie Harris	3	X
Ozocan Corporation	http://www.ozocan.com	416-439-7860	ronaldl@ozocan.com	3	X
Trojan Technologies Inc.	http://www.trojanuv.com	519-457-3400	Dr Gordon Knight Research Operations manager	3	X
Zero Technologies, Llc		215-244-0823	Tony Wirtel Senior Development Engineer	3	X
Proctor and Gamble Company (PUR)	http://www.pg.com	513-983-1100		na	X

Graver Technologies, Inc.	http://www.gravertech.net	302-731-1700	X

Sorption Oxidation Strategic Ally Informational Brochure

Your Company and SOx

We are looking for strategic allies, who would like to fund further research into further developing SOx technology to specifically fit your company's product needs, or a company looking to purchase the licensing outright. The research and development team under Doctors Bergendahl and Thompson is highly experienced and knowledgeable and will be able to create customized SOX treatment solutions for your company.

Interested?

If your company is interested in finding out more information regarding this revolutionary technology, please contact Jonathan Bahlatzis of Worcester Polytechnic Institute using the contact information on the back of this pamphlet. A full report on the technology and its market viability, as well as proprietary information can be made available to you by request after the signing of a mutually acceptable Nondisclosure Agreement. Thank you for your time and interest in SOx and we look forward to further contact with you.

Sorption Oxidation

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Sorption Oxidation

Cost-effective Organic Contaminant Removal

S O X

Patent Pending Water Treatment Technology

Sorption Oxidation

The $300 billion international water treatment industry is steadily growing in size due to pollution and climate changes, population growth and concentration, and urbanization and industrialization. There is an increasing demand for potable and industry-usable water, as well as increasing standards for both water quality in withdrawal and discharge. The patent pending Sorption Oxidation (SOx) process developed by Dr. John Bergendahl and Dr. Robert Thompson of Worcester Polytechnic Institute is an effective treatment technique for the removal of a myriad of organic contaminants in both consumer and industry water treatment applications.

Strengths

- Efficient, reusable, small carbon footprint
- Long usage lifespan and can prolong lifespan of membrane technologies
- Component/supplemental augmentation to existing technologies
- Specific contaminant targeting

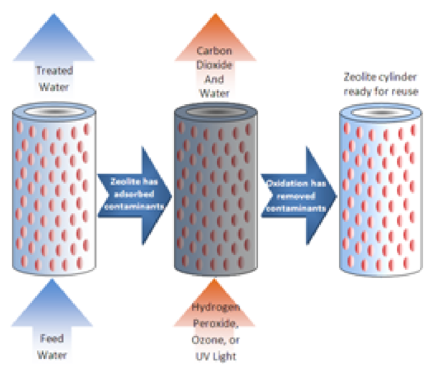
Opportunities

- Large market demand for water treatment with continuous growth projections
- Population growth and urban concentration
- Increased regulation of water quality
- Value of potable water increasing
- Provide industry with efficient, cost effective treatment

The Technology

The patent pending SOx technology developed at WPI is comprised of two steps: first adsorption and then oxidation. The adsorption process consists of passing the contaminated liquid through the adsorption medium called a zeolite. This zeolite is basically a "molecular sieve," which separates contaminants from their carrier based on molecular size. These reusable zeolites are readily available and are relatively inexpensive (around $250/kg) and make for a very marketable product.

The oxidation process follows adsorption and is the phase where the now contaminated zeolite is cleaned of contaminants through exposure to hydrogen peroxide, ultraviolet light, or ozone. This causes a chemical mineralization of the contaminants resulting in the conversion to carbon dioxide and water. This cleaning process allows the zeolites to be reused rather than thrown away as common filters are. This is why the SOx technology is such an important, as well as marketable technology. It can drastically change the negative aspect of chlorination, by reducing disinfection by-products and can remove both synthetic and volatile organics. It also has a long product life-span and leaves a small carbon footprint.



Organic Contaminants

It is currently estimated that over 5,000 new organic compounds are brought into market every year. Over 150 of these water contaminants are proposed, listed, or finalized for government regulation and at least 100 of these are organic. When humans are exposed to many of these organics, potential health effects can include problems with cardiovascular, reproductive, digestive, and nervous systems, as well as eyes, liver, kidneys, blood, adrenal glands, and an increased risk of cancer. Sox can remove these contaminants with utmost efficacy.

Traditional Remediation Costs

Sorption oxidation will save your company money. The removal of organic contaminants is a vast and ever growing market. According to the Association of Metropolitan Water Agencies and the American Water Works Association, the cost to remediate Methyl t-Butyl Ether (MTBE) alone at over $33 billion per year, but could feasibly be as high as $85 billion in the US alone. MTBE is only one of the many organic contaminants that SOx can effectively remediate.

Every day, US industry withdraws over 25 billion gallons of water for processing, boiler make-up, condensate, and human consumption and over 20 billion gallons of that is turned into potentially harmful wastewater. Source water alone in the United States costs on average around $2.06/1,000 gal and can cost up to $2.83/ 1,000 gal in states such as Arizona. This may not seem like a significant cost, but using the thermoelectric plants as an example, the industry pays about $383.16 million/per day for process water.

Sorption Oxidation will not only cut industry water costs, but is also marketable to the increasingly environmentally conscious consumer market. It provides a user-friendly and cost-efficient method to remove potentially harmful contaminants and due to its reusability, zeolite, is ecologically friendly as well.

Cover letter for strategic allies

Jonathan Bahlatzis
WPI Box #246
100 Institute Rd.
Worcester, MA 01609
March 16, 2009

[**Recipient Name**]
[**Title**]
[**Company Name**]
[**Street Address**]
[**City, ST ZIP Code**]

Dear[**Recipient Name**]:

Thank you for taking the time to speak with me regarding the opportunity to find out more about the patent pending Sorption Oxidation technology invented by Dr. John Bergendahl and Dr. Robert Thompson. I enjoyed speaking with you on the phone, and I appreciate your interest in this revolutionary technology.

As promised, I've enclosed the general information pamphlet on the Sorption Oxidation technology. If this is something your company would be interested in developing further with the research team at Worcester Polytechnic Institute, or purchasing the licensing outright please feel free to contact me by email or phone.

I would welcome the opportunity to further discuss the technology with you. If you would like to learn more about the proprietary system information we can easily negotiate a mutually acceptable nondisclosure agreement. I look forward to further contact with you and your company.

Sincerely,

Jonathan Bahlatzis
Management Engineering and Chemical Engineering
Worcester Polytechnic Institute 2009
Email: jon@wpi.edu

FAQ Sheet

Sorption Oxidation Commercialization

A Major Qualifying Report Submitted to the Faculty of Worcester Polytechnic Institute

Submitted by: Submitted by:
Jonathan Bahlatzis
Management Engineering and Chemical Engineering
jon@wpi.edu

WPI Bioengineering Institute Center for Water Research
Dr. John A. Bergendahl
jberg@wpi.edu
Dr. Robert W. Thompson
rwt@wpi.edu

WPI Technology Transfer Department
techtransfer@wpi.edu

Submitted for:
Potential Strategic Allies

4/30/2009

1. Has Sorption Oxidation been compared to the performance of activated carbon?

Yes, the SOx process has been compared to activated carbon. It has been found that hydrophobic adsorbents such as ZSM-5 and HiSIV3000 have larger uptakes than GAC, especially at very low organics concentrations, and far longer useful adsorbent life. In a 1cm diameter by 12 cm height glass column, with a velocity of 6.62cm/min and a flow rate of 5.2ml/min, ZSM-5 adsorption was able remove 100 percent of MTBE from water for over 890 hours. At that point it was still removing at least 90 percent of MTBE, but considered by the research team to be at an ineffective level and it required regeneration, but can still be reused again at full efficacy after oxidative regeneration.

2. What compounds have been tested using Sorption Oxidation?

Sorption Oxidation has been tested and found effective in the removal from water of contaminants such as chlorinated VOC's, MTBE, disinfection by-products, and estrone. Based on research and these results it is believed that Sorption Oxidation will also be able to remove many other organic contaminants such as carbon tetrachloride, trichloroethane, 1,2-dichlorothane, dichloromethane, epichlorohydrin, ethylbenzene; many of which are on the EPA's list of regulated water contaminants. This process may also be effective in treating water contaminated with pharmaceuticals and endocrine disruptors, now being found at low concentrations in many waters.

3. Has Sorption Oxidation been compared to other water treatment technologies such as UV Oxidation or membranes?

The WPI Water Research team has been working with membrane water treatment technologies, which have yielded promising, but proprietary results that are in the initial stages of intellectual property protection. Our team has also been working with other forms of aqueous chemical oxidation processes, such as UV/hydrogen peroxide oxidation, ozone oxidation, and activated persulfate oxidation. UV Oxidation is also currently used as a disinfection technique and may be used in conjunction with SOx, in which it has been applied to regenerate our adsorbents.

4. What cost analysis data is available?

While the details are contained in the proprietary final report, a general cost analysis is currently being performed. Thus far it has been estimated that the actual system would cost less than a GAC system of comparable size and application and needs no specialty parts. The actual adsorbent prices range from ~$17/kg for HiSiv 3000 to $250/kg for high-grade long usage life ZSM-5 made by Exxon Mobil. However, the price has decreased by 37.5 percent in three years. According to a WPI graduate project, ZSM-5 cost $400/kg in 2006. The only other cost is that of the oxidation method which varies by application.

Our team has started cost analysis for the chemical oxidation/regeneration step. It is believed that the efficiency of oxidizing contaminates that have been concentrated on the sorbent is much greater than the efficiency of oxidizing trace contaminants in aqueous solution. This should translate into cost savings over conventional chemical oxidation treatment processes. For a general, preliminary cost estimate, the following information is provided. Hydrogen peroxide can be purchased on the consumer market for less than $0.45/L and even less when bought wholesale from a distributor. Ozone must be generated on-site, but this is a relatively inexpensive process and depending on application size, an ozone generator can cost between $30 for a small in-home version producing 700 mg/hr to $4,000 for a high output generator producing over 12,000 mg/hr. Ultraviolet oxidation would require UV emitting lamps which can be purchased for under $10/ 100w lamp and have a usage lifespan of 500 hours.

Hydrogen peroxide would require the most frequent supply, but is the cheapest oxidation medium and is very effective in zeolite regeneration. Ozone requires a larger capital investment, but is also very effective and can be used with no input other than a power source for long periods of time. UV oxidation requires semi-frequent bulb replacement and special system design, but has mid-range efficacy and maintenance needs. We understand that these are very broad estimates, but considering the reusability and extremely long usage lifespan of the adsorption mediums, our research and experience indicates that SOx will be not only be technically efficient and effective in organic contaminant removal, but also in cost-efficiency and system life span.

5. Most zeolites use clay binders and thus are not suitable for water applications. Is this true for Sorption Oxidation?

Zeolites such as the ones used in the SOx system can be bound in other, more durable, binders, so that in itself is not a limiting factor. However, parallel to our water research studies we have an ongoing zeolite synthesis program in which we are evaluating growing zeolites on support surfaces, and growing zeolite aggregates which might be several mm in dimension, thus reducing the pressure drop (or entrainment) problems with powders. That work seeks to improve on a patented process by producing the larger zeolite particles . (In fact, our first zeolite synthesis publication appeared in 1982 and we have extensive experience in this field.)

6. What patents are involved in the Sorption Oxidation process?

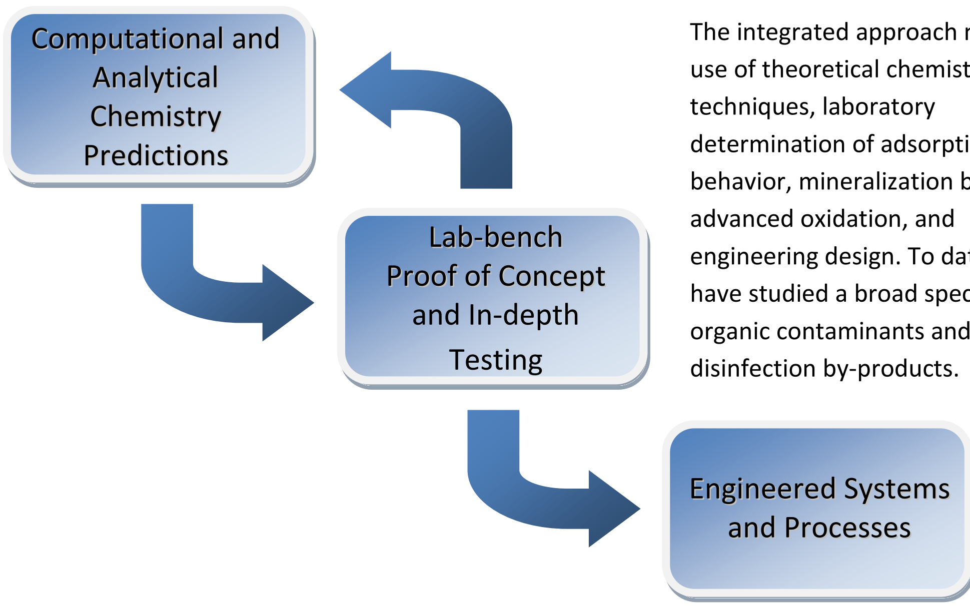
The patent information for the involved technology is as follows:

1) "Remediating MBTE Contamination with Hydrophobic Membranes and Chemical Oxidation" (Thompson et al.), US Prov. Appl. No. 61/150,821, filed 2/9/09.
2) "Simultaneous Reduction/Oxidation Process for Destroying an Organic Solvent" (Bergendahl et al.), PCT/US2008/058673, filed 3/28/08.
3) "Methods and Devices for the Removal of Organic Contaminants from Water", (Bergendahl et al.),PCT/US06/060591, now US Pat. App. No. 12/093,055, filed 11/7/06.

7. Who is currently working on this technology?

The WPI Bioengineering Institute Center for Water Research believes in an integrated approach to organic contaminant remediation. This group is comprised of Prof. John A. Bergendahl,[116] Prof. Nikolas Kazantzis,[117] Prof. Robert W. Thompson,[118] Prof. Ayşe Erdem-Şenatalar,[119] Dr. Arjan Giaya,[120] and Prof. James F. Hauri.[121] They are currently focusing their efforts on the numerous organic compounds that have been found in US and world water supplies in varying concentrations. Among these are pesticides, insecticides, pharmaceuticals, antibiotics, personal care products, solvents and organic additives, disinfection by-products, and natural compounds such as hormones. Many of these have been proven to detract from water taste, appearance, and odor quality and are toxic, carcinogenic, or cause other various negative health issues even in very low concentrations.

The BioEngineering Center for Water Research at WPI uses an effective integrated approach to address, understand, and solve water remediation problems involving these harmful organic compounds. This unique approach, illustrated in the figure below, takes advantage of the team's broad range of experience and expertise in computational chemistry techniques to understand molecular interactions between organic compounds and potential adsorbents, predict adsorption affinities, and modify adsorbent structures to enhance separations. Theoretical predictions are then tested in our laboratories by adsorption experiments coupled with advanced analytical techniques. Activated carbons, molecular sieve zeolites, and other hydrophobic adsorbents are tested and compared. Advanced oxidation techniques are used to destroy the organics in the adsorbent pores, thus regenerating the adsorbent medium.



The integrated approach makes use of theoretical chemistry techniques, laboratory determination of adsorption behavior, mineralization by advanced oxidation, and engineering design. To date we have studied a broad spectrum of organic contaminants and disinfection by-products.

[116] Worcester Polytechnic Institute, Department of Civil &Environmental Engineering, Worcester, Massachusetts
[117] Worcester Polytechnic Institute, Department of Chemical Engineering, Worcester, Massachusetts
[118] Worcester Polytechnic Institute, Department of Chemical Engineering, Worcester, Massachusetts
[119] Istanbul Technical University, Department of Chemical Engineering, Istanbul, Turkey
[120] Triton Systems, Inc, Chelmsford, Massachusetts
[121] Assumption College, Department of Chemistry, Worcester, Massachusetts

7. What can your company do?

The BioEngineering Center for Water Research at WPI is looking to find a strategic ally to build a partnership with the research team in order to further develop the technology and develop customized remediation solutions for a myriad of applications. Your company can fund this research and reap the benefits of a highly qualified and experienced team of research and engineering professionals, or even purchase the licensing outright. Please do not hesitate to contact us with any further questions or concerns that you may have. We look forward to hearing from you and thank you for your interest in Sorption Oxidation.

Follow up Letter

Jonathan Bahlatzis
WPI Box #246
100 Institute Rd.
Worcester, MA 01609
jon@wpi.edu
April 7, 2009

[**Recipient Name**]
[**Title**]
[**Company Name**]
[**Street Address**]
[**City, ST ZIP Code**]

Dear[**Recipient Name**]:

I hope that you received the informational brochure that was sent to you last week discussing the basic premises of the patent-pending Sorption Oxidation process. If for some reason you did not receive it, or would like another, feel free to contact me and I will be sure to send another promptly.

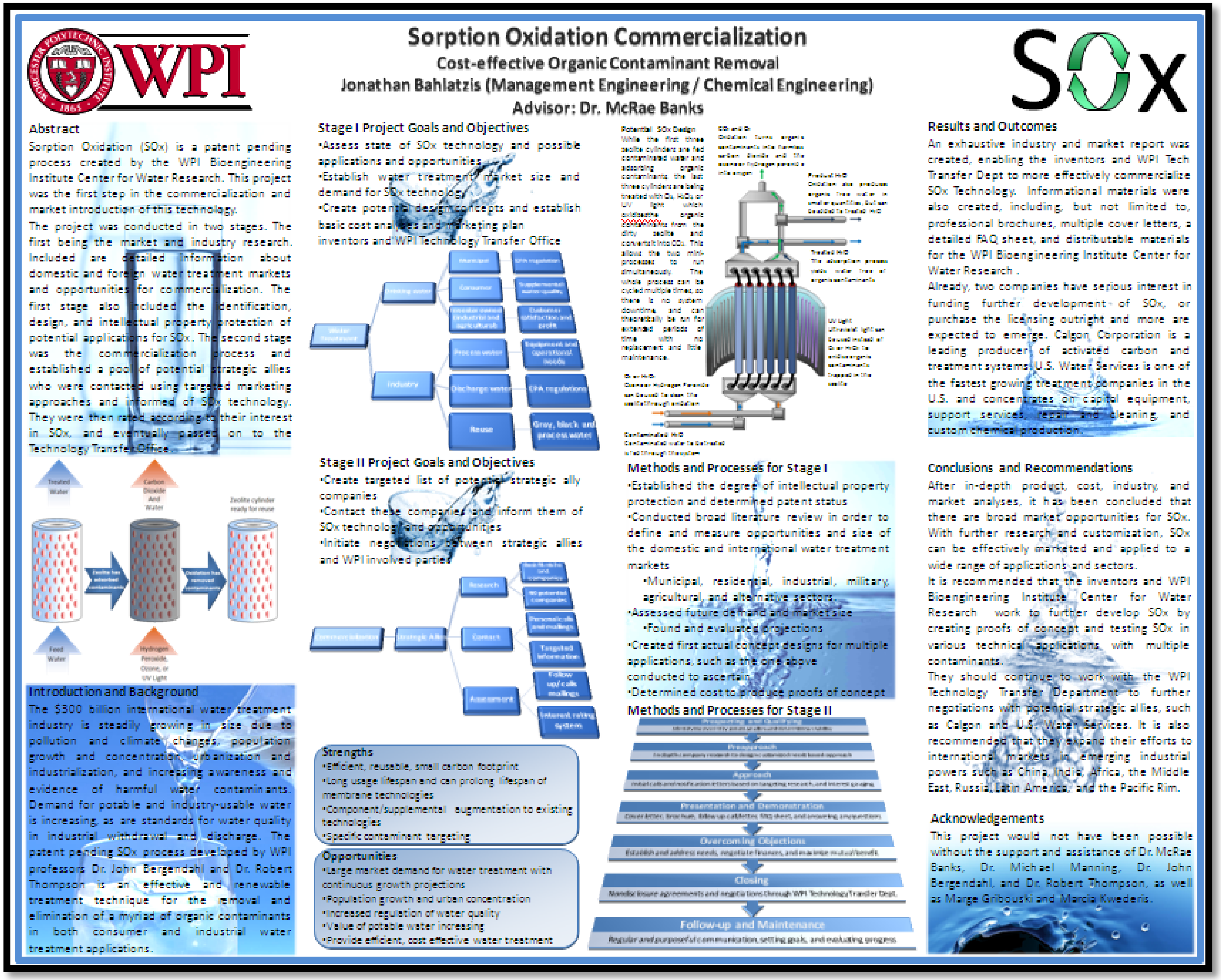
As I mentioned in the brochure and cover letter, we are seeking to build a working relationship with your company. If you are interested in learning more about the Sorption Oxidation technology, please contact me by email or phone. Our Technology Transfer Director, Dr. Michael Manning, and the research team led by Drs. Bergendahl and Thompson, would welcome the opportunity to further discuss the technology with you and provide you with information regarding how it may be beneficial for your company.

An in-depth market and industry report, also including more detailed information about the process and technology is also available. Through Dr. Manning we can easily negotiate a mutually acceptable nondisclosure agreement so we can share proprietary information such as this with you and your company. I look forward to further contact with you and your company.

Sincerely,

Jonathan Bahlatzis
Management Engineering and Chemical Engineering
Worcester Polytechnic Institute 2009
jon@wpi.edu

SOx Commercialization Poster



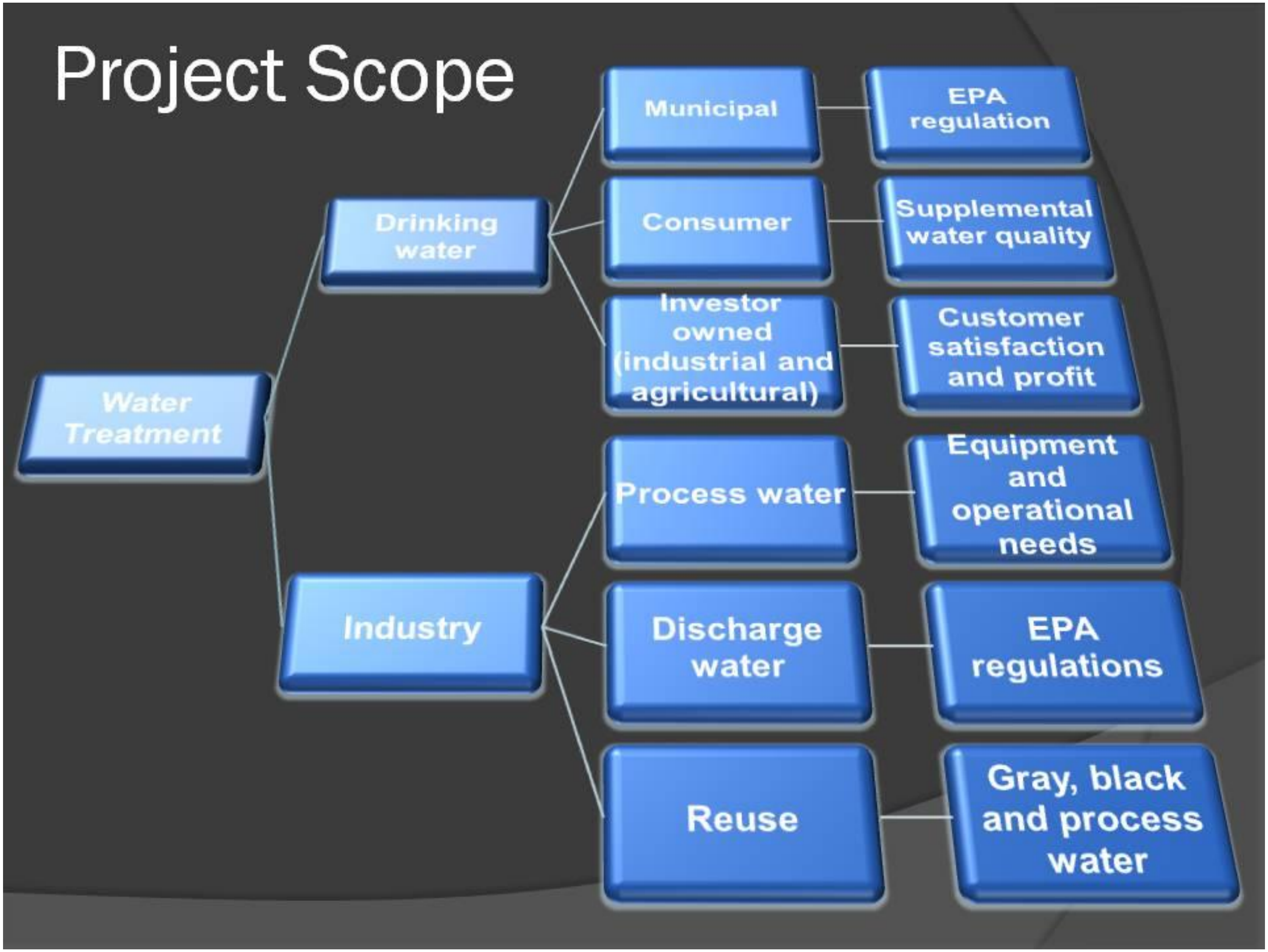

WPI
WORCESTER POLYTECHNIC INSTITUTE 1865
SOx
SORPTION OXIDATION COMMERCIALIZATION
Cost-effective Organic Contaminant Removal
Jonathan Bahlatzis
Management Engineering / Chemical Engineering
Worcester Polytechnic Institute
Major Qualifying Project
Primary Advisor: Dr. McRae Banks
Secondary Advisors: Dr. John Bergendahl and Dr. Robert Thompson
April 23, 2009

Stage I – Market and Industry Research

- Stage I Objectives
- Project Scope
- Water and Its Future
- Organic Contaminants
- Water Treatment Markets
- Sorption Oxidation
- SOx Applications
- SWOT Analysis
- Market Profitability
- Marketing Mix

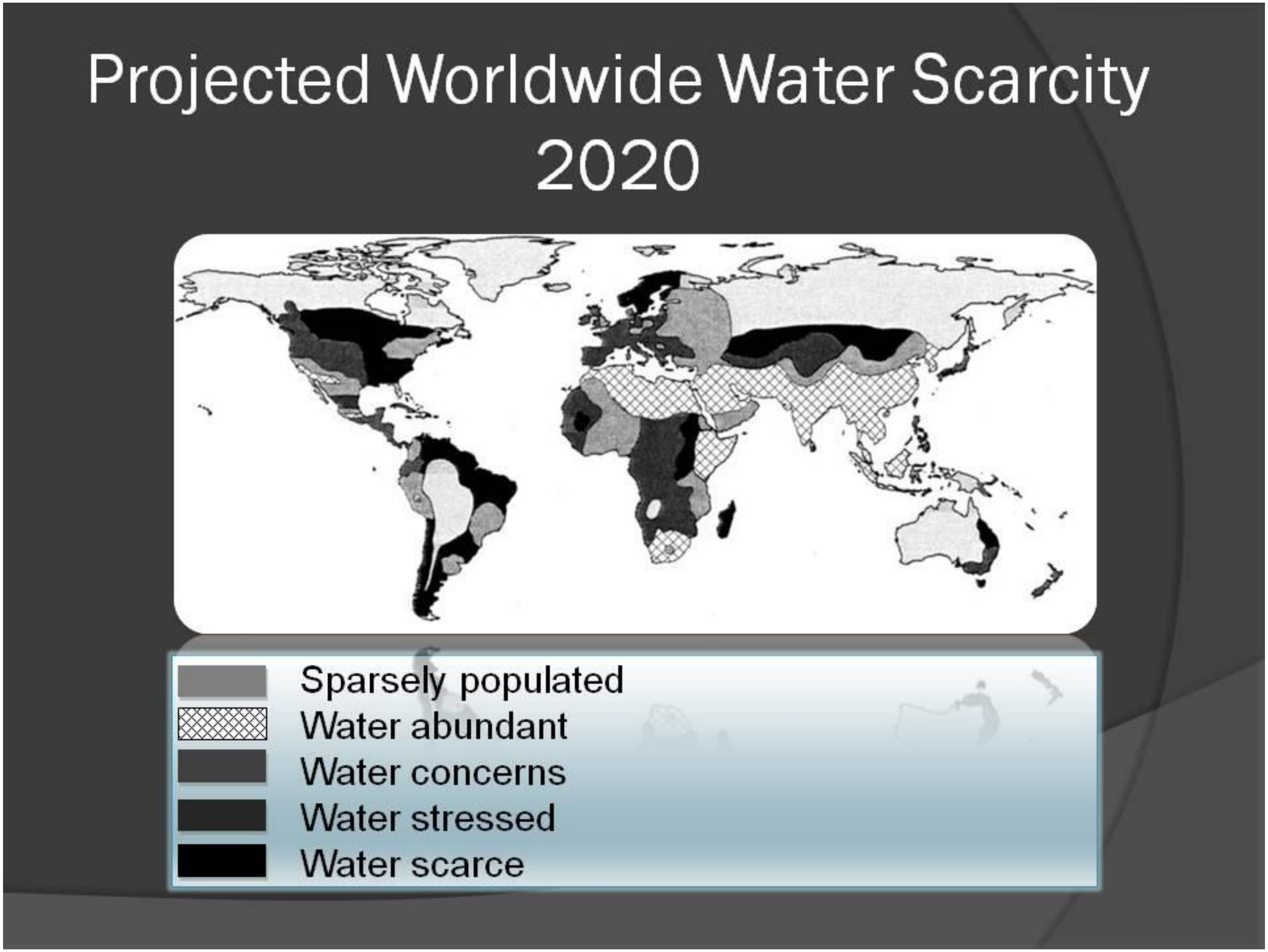
Stage I Project Objectives

- Assess state of SOx technology and possible applications and opportunities
- Establish water treatment market size and demand for SOx technology
- Create potential design concepts
- Establish basic cost analyses and marketing plan for the inventors and WPI Technology Transfer Office


Project Scope
Water Treatment
Drinking water
Industry
Municipal
Consumer
Investor owned (industrial and agricultural)
Process water
Discharge water
Reuse
EPA regulation
Supplemental water quality
Customer satisfaction and profit
Equipment and operational needs
EPA regulations
Gray, black and process water

Water and Its Future

- Purification, remediation, and transportation growth
- Water as a valuable resource
  - Population growth and relocation to concentrated areas
    - 7 billion to 10 billion within 50 years
  - Limited resource
    - Most common substance in the world
    - Only 3% freshwater and only 1% can be used for consumption
  - Newly protected environmental areas
  - Displacement of normal water patterns
  - Cycles from climate and weather changes


Projected Worldwide Water Scarcity
2020
Sparsely populated
Water abundant
Water concerns
Water stressed
Water scarce

"Water in the United States has been both undervalued and underpriced, but with a shrinking supply or fresh water, the need for infrastructure repair, increasing standards and regulation needing new, and more expensive treatment, one should expect the cost to steadily rise."

-Edward Tenny, Senior Vice President of HDR Engineering Inc.

- More expensive water
- People become accustomed
- Demand for better, purer product

Organic Contaminants

- **Over 5,000 new organic compounds every year**
- **Over 150 drinking water contaminants proposed, listed, or finalized for government regulation**
  - At least 100 of are organic compounds
- **Potential health effects can include problems with:**
  - Cardiovascular system
  - Reproductive organs
  - Digestive system
  - Nervous system
  - Eyes
  - Liver
  - Kidneys
  - Blood
  - Adrenal glands
- **Increased risk of cancer**
  - 93 percent higher cancer rate in people drinking chlorinated water
  - Disinfection byproducts (Trihalomethanes)

Water Treatment Markets

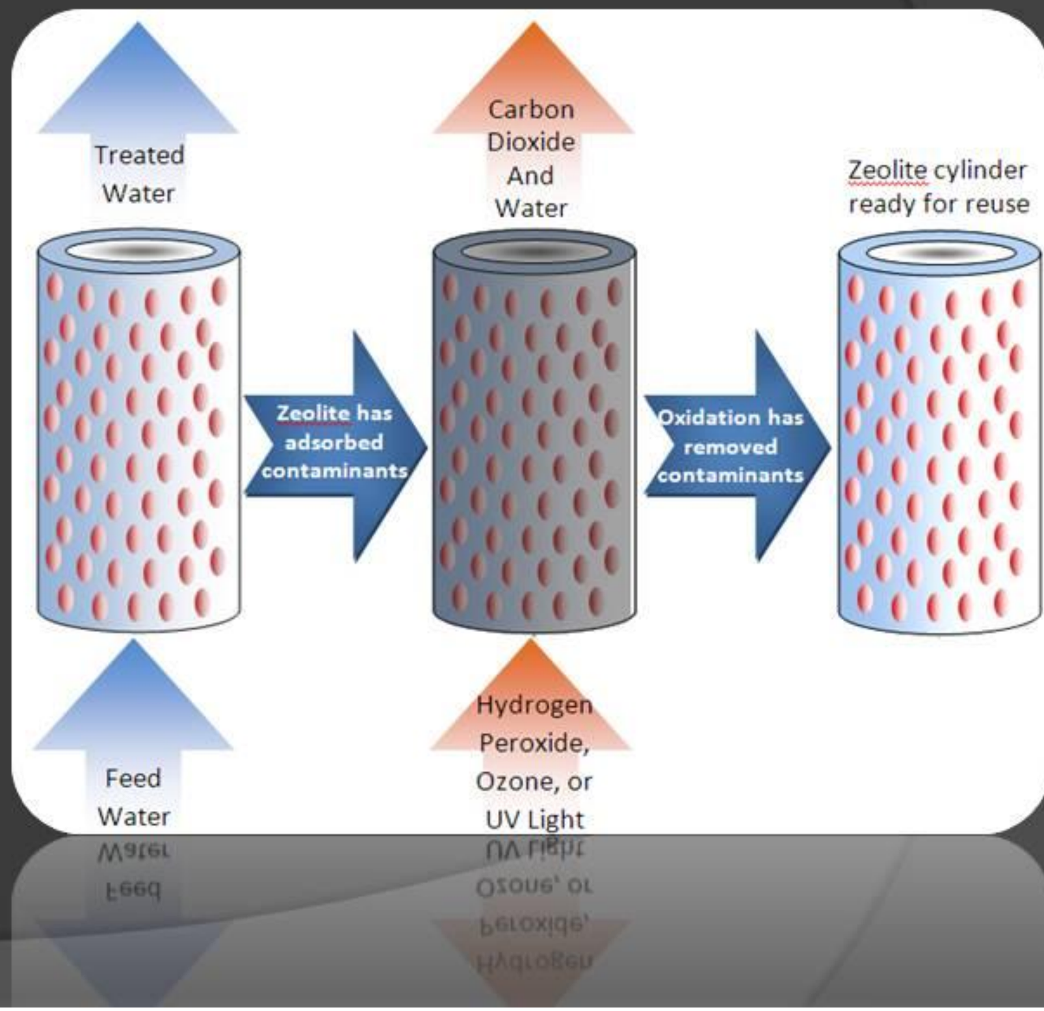
- **Municipal**
  - 57% of the systems in the U.S.
  - 79% plan capital improvements
  - Needs of over $21 billion
- **Consumer / Residental**
  - Projected 5.6% annual system market gains
  - Projected 4.8% growth for aftermarket sales
- **Industrial**
  - 20 percent of global freshwater withdrawals
  - U.S. consumes over 25 billion gallons/day
    - Processing, boiler make-up, condensate, and consumption
    - 20 billion gallons turned into potentially harmful wastewater
  - Source water costs on average $2.06/1,000 gallons
    - Thermoelectric plants pay about $383.16 million/day
- **Agricultural**
  - 49% of total U.S. freshwater usage
  - 85-90% of freshwater used in Africa and
  - 67% of world freshwater withdrawal

World Market

- $300 billion total
  - Resilient to economic recession
  - $33 billion chemical and nonchemical treatment will increase 6.4% annually until 2011 (reaching $40 billion)
- Emerging industrial powers – China, India, Africa, the Middle East, Russia, Latin America, and the Pacific Rim
  - Estimated 350 million people lack potable drinking water and 70 percent of the China's lakes and waterways are polluted
  - Annual water shortage of 53 trillion gallons by 2030

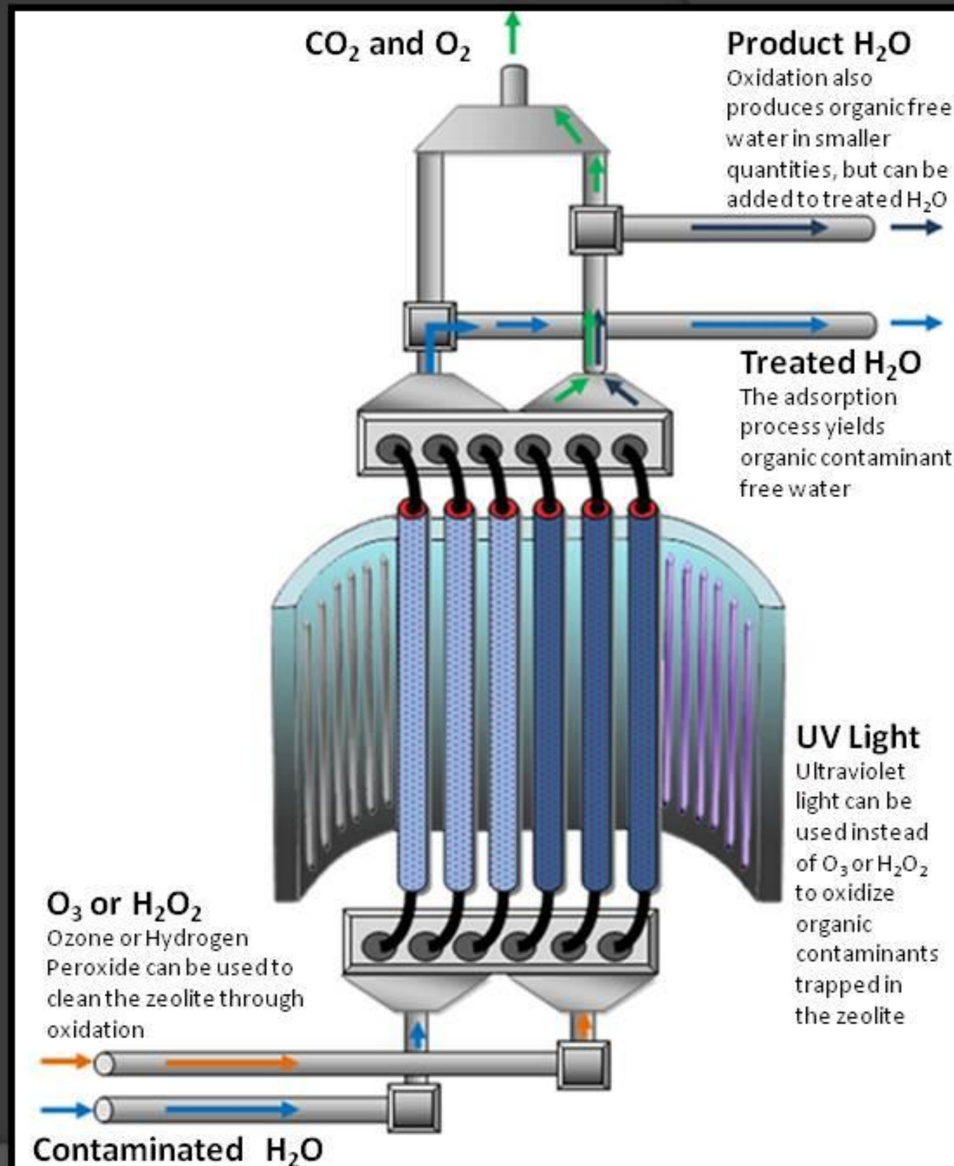
The Sorption Oxidation Process

- The zeolite
  - Hydrophobic
  - Readily available
  - Cheaper every year
  - Reusable
- Zeolites such as ZSM-5 and HiSIV3000, have larger uptakes than GAC
  - Far longer useful adsorbent life
  - ZSM-5 adsorption was able remove 100 percent of MTBE from water for over 890 hours



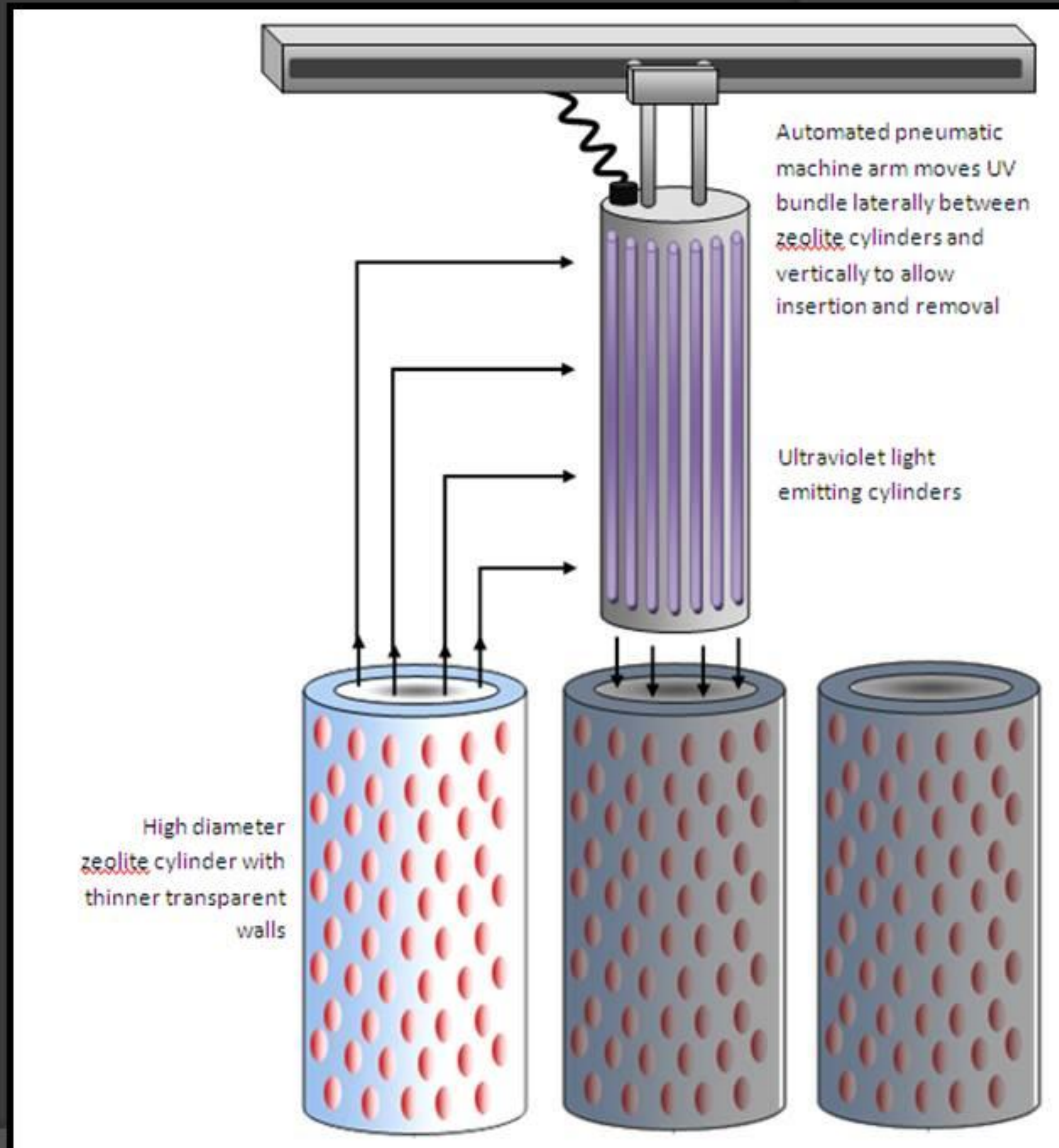
S0x System

- First three zeolite cylinders fed contaminated water
  - adsorb organic contaminants
- Last three cylinders treated with O_3, H_2O_2, or UV
  - Conversion to CO_2
- Simultaneous mini-processes
- Whole process can be cycled
  - No system downtime



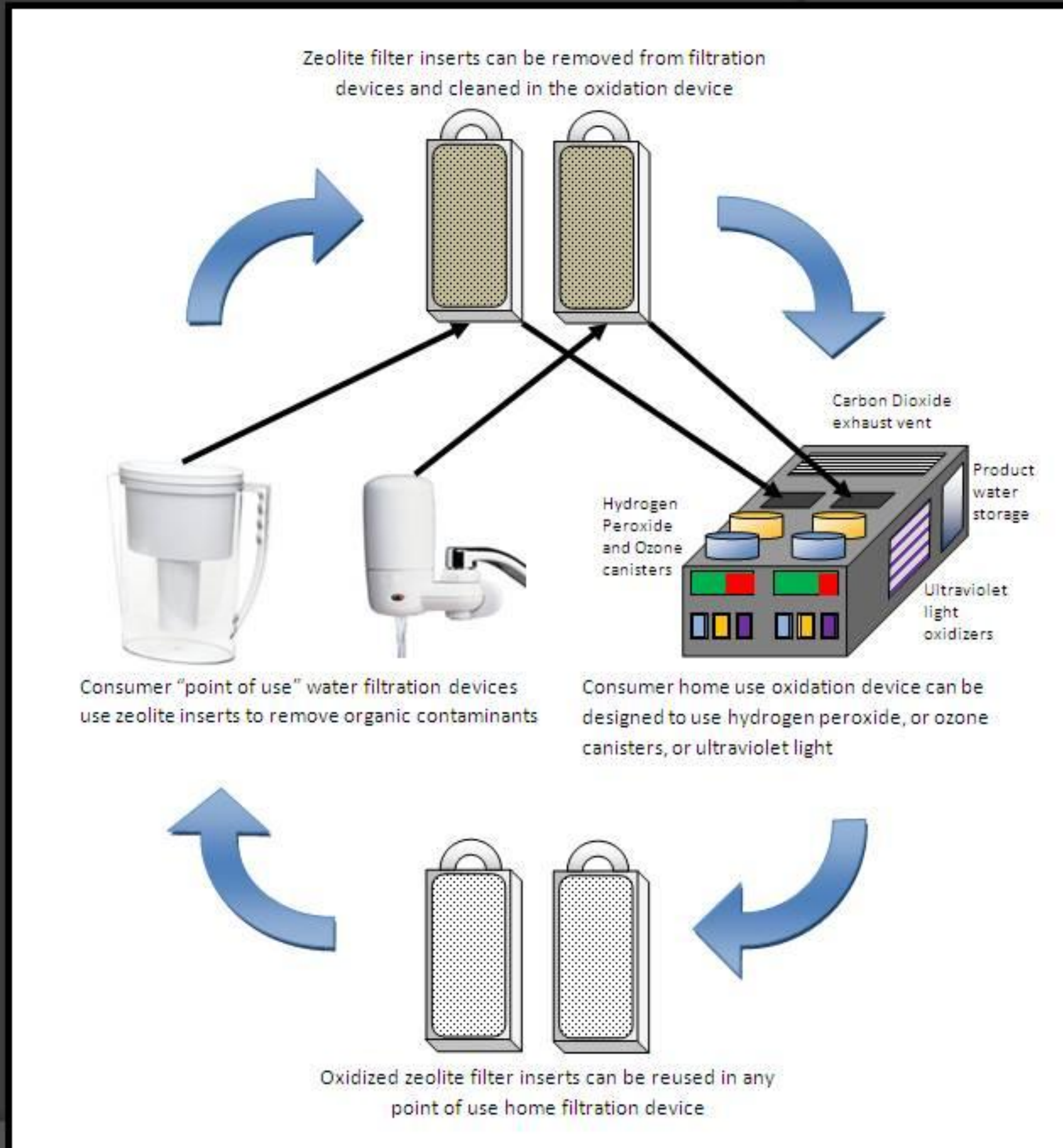
Alternative Design (UV)

- Maximize zeolite surface area exposure
- Able to cycle
- Little downtime
- Need replacement lamps



Alternative Design (Consumer Point of Use)

- Complimentary product
- Foolproof
- Broad range treatment



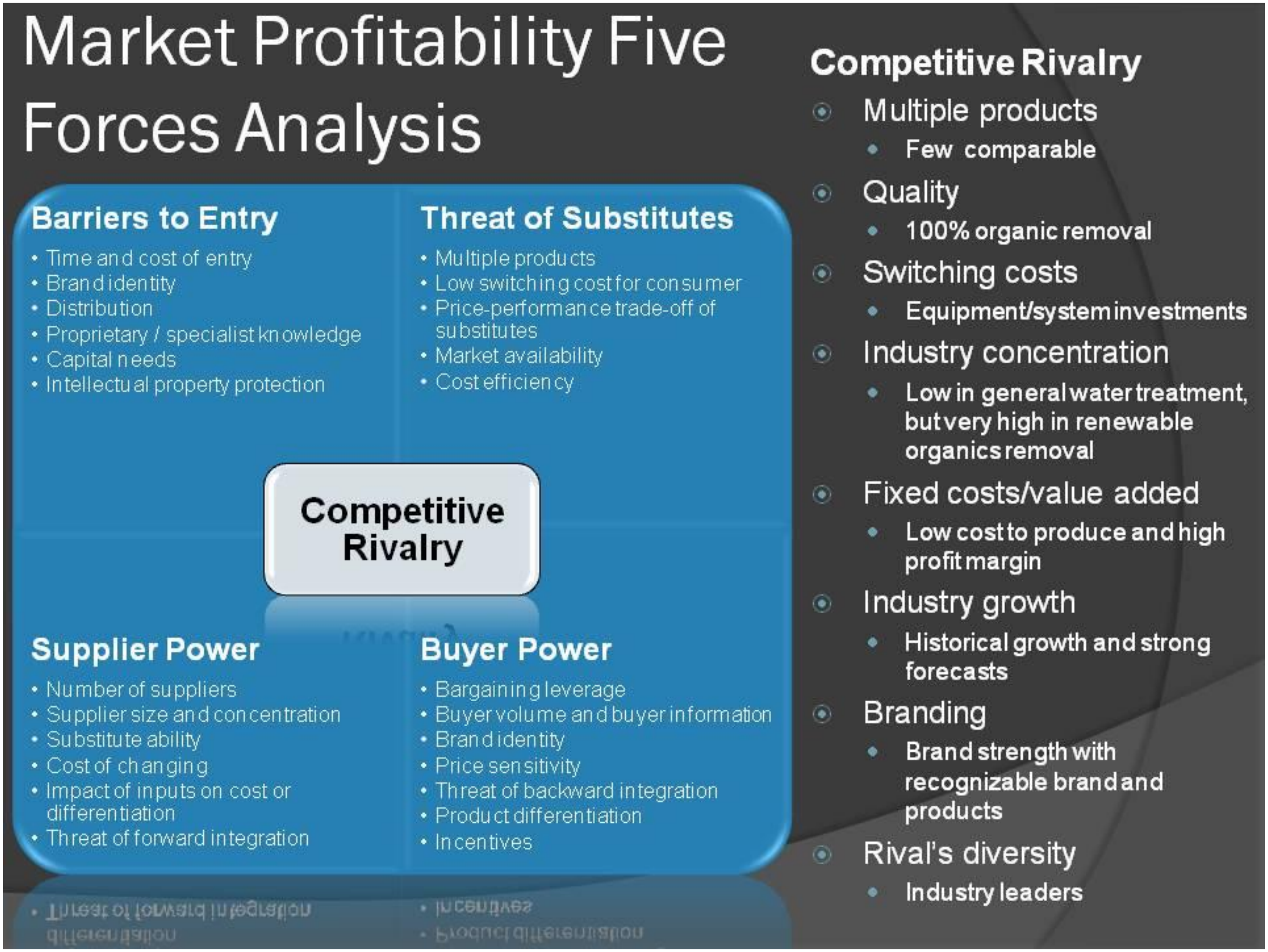
SWOT Analysis

Strengths
- Efficient, reusable, small carbon footprint
- Long usage lifespan and can prolong lifespan of membrane technologies
- Component/supplemental augmentation to existing technologies
- Specific contaminant targeting

Weaknesses
- Organics only, not effective as broad range treatment
- Proof of concept
- Marketing costs
- Not extensively tested

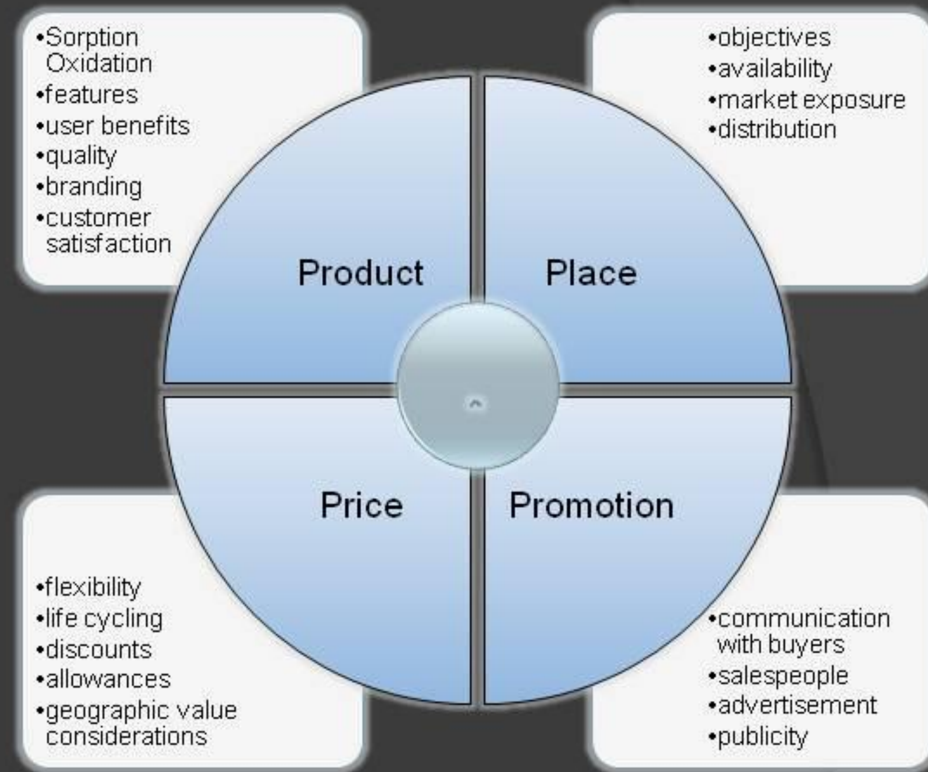
Opportunities
- Large market demand for water treatment with continuous growth projections
- Population growth and urban concentration
- Increased regulation of water quality
- Value of potable water increasing
- Provide efficient, cost effective treatment

Threats
- Similar products that have better broad range treatment
- Cost to create and market
- Pricing pressures
- Introducing new product


Market Profitability Five Forces Analysis
Barriers to Entry
• Time and cost of entry
• Brand identity
• Distribution
• Proprietary / specialist knowledge
• Capital needs
• Intellectual property protection
Threat of Substitutes
• Multiple products
• Low switching cost for consumer
• Price-performance trade-off of substitutes
• Market availability
• Cost efficiency
Competitive Rivalry
Supplier Power
• Number of suppliers
• Supplier size and concentration
• Substitute ability
• Cost of changing
• Impact of inputs on cost or differentiation
• Threat of forward integration
Buyer Power
• Bargaining leverage
• Buyer volume and buyer information
• Brand identity
• Price sensitivity
• Threat of backward integration
• Product differentiation
• Incentives
Competitive Rivalry
Multiple products
Few comparable
Quality
100% organic removal
Switching costs
Equipment/system investments
Industry concentration
Low in general water treatment, but very high in renewable organics removal
Fixed costs/value added
Low cost to produce and high profit margin
Industry growth
Historical growth and strong forecasts
Branding
Brand strength with recognizable brand and products
Rival's diversity
Industry leaders

Marketing Mix

- Product
  - Ease of use
  - Long life
  - 100% contaminant removal
- Place
  - Quality, reusable, user-friendly water treatment solutions
  - Competitive price and brand
- Price
  - Varying by system size and application
  - Target markets
- Promotion
  - Informational packets
  - Direct calls and mailings
  - Journal articles
  - Word of mouth

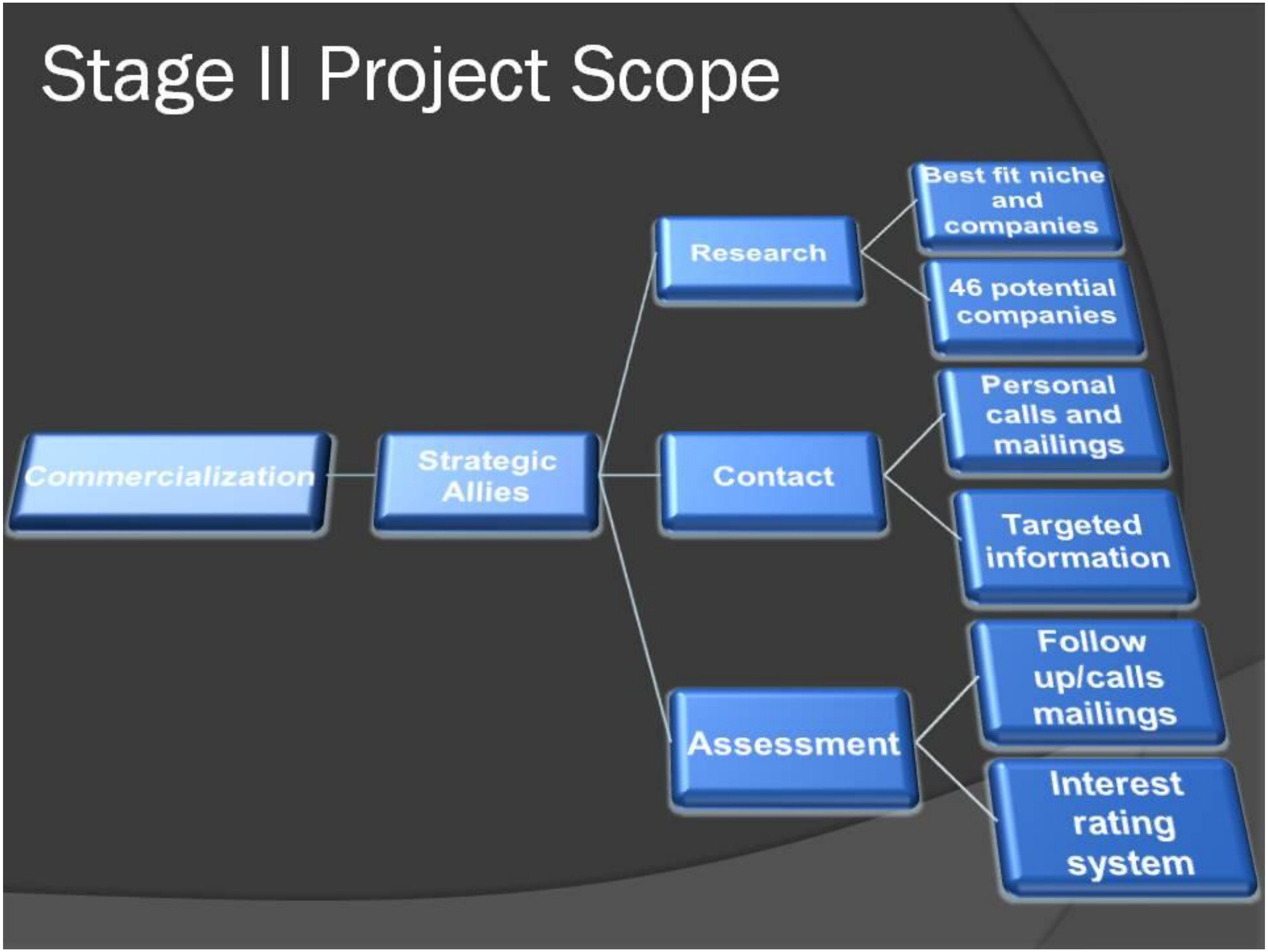


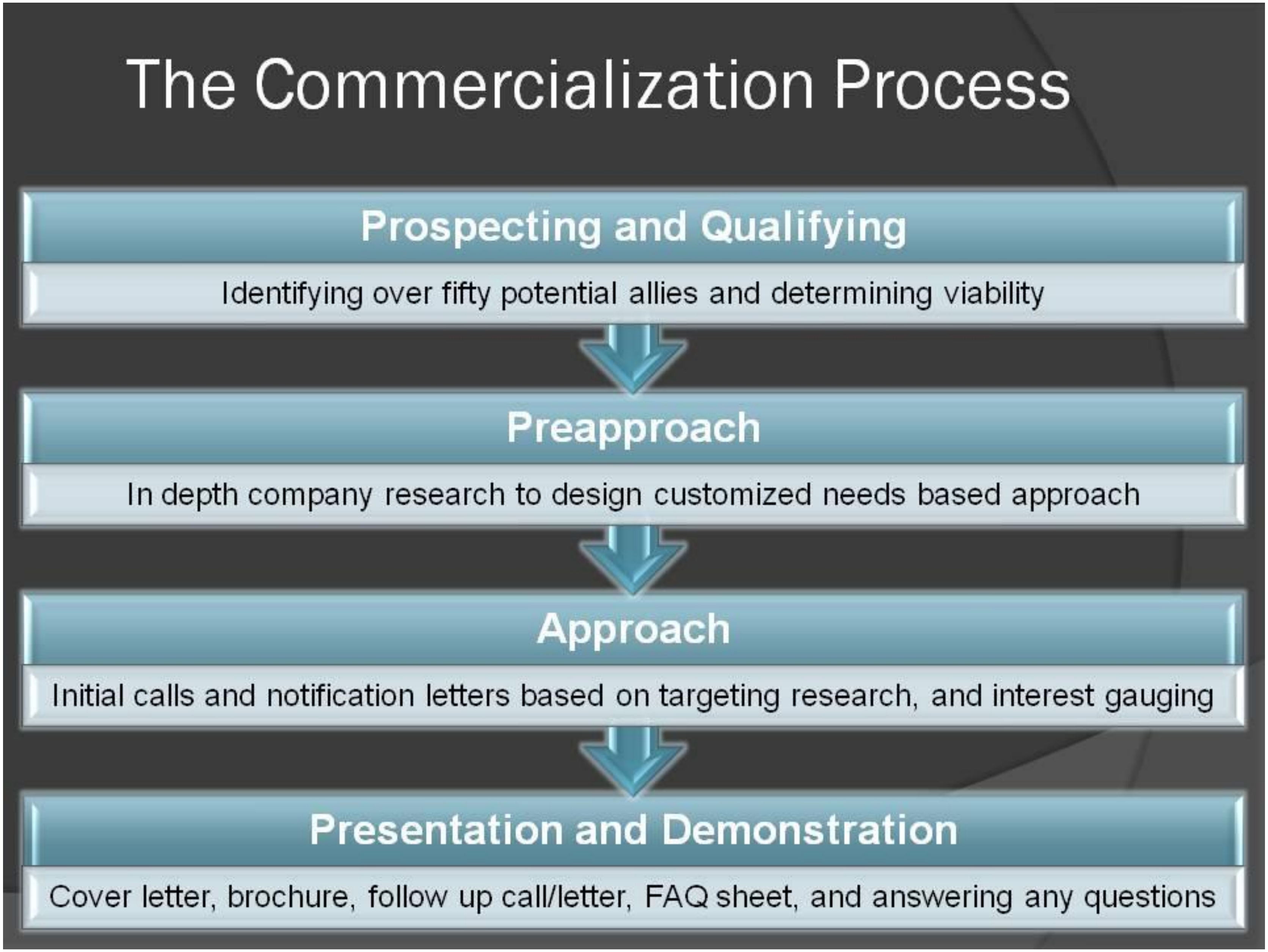
Stage II - Commercialization

- Stage II Objectives
- Stage II Scope
- The Commercialization Process
- Potential Strategic Allies
- Marketing and Contact
- Gauging and Recording Interest
- Concluding the Commercialization Process
- Results and Conclusions
- Recommendations

Stage II Project Objectives

- Create targeted list of potential strategic ally companies
- Contact these companies and inform them of SOx technology and opportunities
- Initiate negotiations between strategic allies and WPI involved parties


Stage II Project Scope
Commercialization
Strategic Allies
Research
Contact
Assessment
Best fit niche and companies
46 potential companies
Personal calls and mailings
Targeted information
Follow up/calls mailings
Interest rating system


The Commercialization Process
Prospecting and Qualifying
Identifying over fifty potential allies and determining viability
Preapproach
In depth company research to design customized needs based approach
Approach
Initial calls and notification letters based on targeting research, and interest gauging
Presentation and Demonstration
Cover letter, brochure, follow up call/letter, FAQ sheet, and answering any questions

Potential Strategic Allies

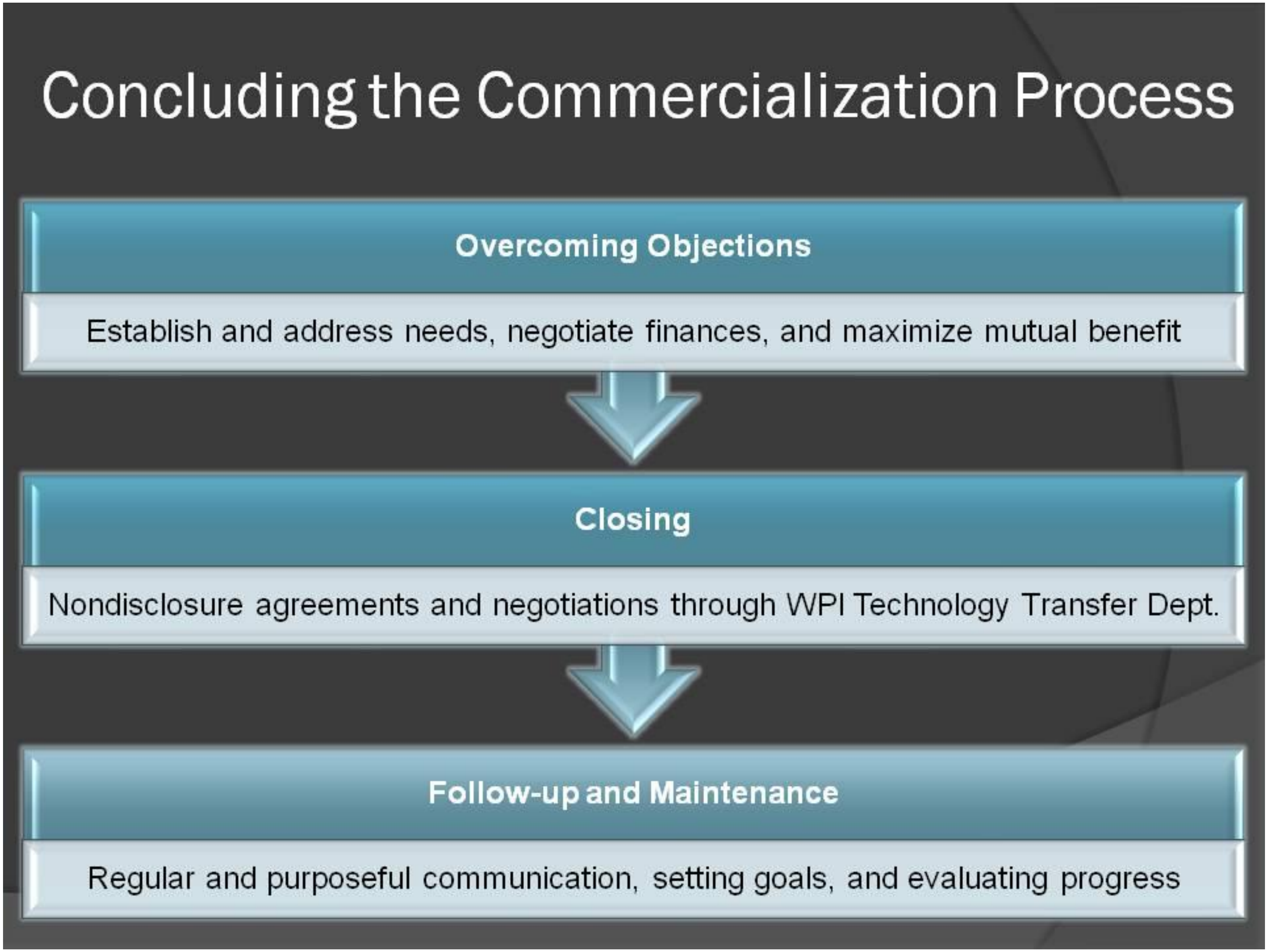
- Spreadsheet including 56 water treatment companies
  - Sales ranging from hundreds of thousands of dollars to hundreds of billions
  - Location, contact info., and brief business descriptions

3M Company
AMETEK, Inc.
Aquaterra Corporation Ltd.
Argonide Corporation
AWTP, LLC (Rainsoft)
Axel Johnson
Black & Veatch Holding Co.
BRITA GmbH
Calgon Carbon Corporation
Campbell Manufacturing
Cantel Medical Corp.
Coca-Cola Company
ConocoPhillips
Culligan International Company
CUNO Inc.
Danaher Corporation
Danfoss Water and Wastewater
EcoWater Sytems LLC
Elster AMCO Water
Emerson Process Management Power & Water Solutions, Inc
Endress + Hauser Flowtec
F.B. Leopold Company
Flowserve Corporation
Gardner Denver
GE Water and Process Technologies
Glacier Water Services
Graver Technologies

Hach Company
Hanna Instruments
Hydranautics
IDEX Corporation
Ionics, Incorporated
ITT Fluid Technology
LifeSource Water Systems
Millipore Corporation
NALCO Holding Company
NATCO Group
Ozocan Corporation
Pall Corporation
Peerless Mfg. Co.
PepsiCo
PUR (under Proctor and Gamble)
Rohm and Haas Company
Sandia
Siemens Water Technologies
Solutions-Ies
Terra Systems
The Dow Chemical Company
The DrinkMore Water Store
Trojan Technologies
U.S. Pure Water Corp.
U.S. Water Purification
U.S. Water Services
Veolia Environnement SA
Zero Technologies, Llc

Gauging and Recording Interest

- 0 – lack of interest or poor business fit
  - 13 companies eliminated
- 1 – minimal interest and requires further contact
  - 18 companies
- 2 – general interest expressed by company development department
  - 8 companies
- 3 – definite and promising interest and the focus of further contact
  - 16 companies
- 4 – secondary contact and further information
  - 2 companies
- 5 – Nondisclosure Agreement (NDA)
- 6 – negotiations passed on to the WPI Technology Transfer Office



Concluding the Commercialization Process
Overcoming Objections
Establish and address needs, negotiate finances, and maximize mutual benefit
Closing
Nondisclosure agreements and negotiations through WPI Technology Transfer Dept.
Follow-up and Maintenance
Regular and purposeful communication, setting goals, and evaluating progress

Results and Conclusions

- Exhaustive industry and market report
  - More effective commercialization of SOx Technology
- Distributable materials for WPI Bioengineering Institute Center for Water Research
  - Professional brochures
  - Multiple cover letters
  - Detailed FAQ sheet
  - Patented system designs
- Two companies with serious interest
  - Further funding for development of SOx
  - Outright licensing purchase,
  - Calgon Corporation
    - Leading producer of activated carbon and treatment systems
  - U.S. Water Services
    - One of the fastest growing treatment companies in the U.S.
    - Concentrates on capital equipment, support services, repair and cleaning, and custom chemical production.

Recommendations

- Further research and product customization
  - Wide range of applications and sectors
  - Alternative applications – air/gas purification, estrogen remediation, low cost solar system, military needs, blood filtration, wastewater
- Proofs of concept
  - Different zeolite and oxidizer combinations
- Testing in various technical applications with multiple contaminants
- Work with the WPI Technology Transfer Department to further negotiations with potential strategic allies
  - Expand efforts to international markets in emerging industrial powers such as China, India, Africa, the Middle East, Russia, Latin America, and the Pacific Rim