ANALYSIS OF AMMONIA REMOVAL FROM WASTEWATER MARKET: FEASIBILITY OF SALTWORKS INTRODUCING NEW TECHNOLOGY

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Abstract

This paper presents an analysis of the market for removing ammonia from wastewater to assess its attractiveness and confirm the feasibility of Saltworks developing and launching its promising new ammonia removal technology. After an introduction, the paper qualitatively analyses the opportunity for Saltworks to enter the ammonia removal market using a SWOT analysis. The author's personal experiences, Saltworks documentation, and interviews with Saltworks staff provide insight into the company's strategies and capabilities. Current ammonia removal technologies are then reviewed. Next, Saltworks' primary competitors in the ammonia removal market are examined using Porter's Five Forces framework. The paper concludes with an exploration of the primary sources of ammonia pollution in wastewater using EPA and Environment Canada census data. From the analysis, it is concluded that this market overall is attractive to Saltworks. There is increasing demand for technological solutions for the removal of ammonia from wastewater. The innovative solution that Saltworks offers, although new to the market, promises to solve many of the problems besetting existing technologies. Saltworks' technology has significant technical advantages that will allow it to enter the more profitable and less competitive segments of this market. Several segments are particularly attractive due to higher customer willingness to pay and the barriers to entry for most other competitors. Saltworks could capture the greatest value by targeting those segments faced with high ammonia concentrations. They include landfill leachate, coal exhaust scrubbers, and concentrated animal feeding operations. This paper recommends that Saltworks target the most technologically challenging markets, where its technology has a technical advantage over competitors, to find early adopters to purchase initial installations. After establishing itself in the industry, Saltworks can lower prices and enter lower value market segments to continue growing.

Keywords: market analysis; competitive analysis; ammonia; wastewater; wastewater treatment; Saltworks; biological nitrification

Executive Summary

Ammonia is a toxic pollutant increasingly found in common urban and industrial wastewaters and unprotected surface waters. Ammonia pollution can result in massive marine die offs and cause long-term negative side effects in fish. The EPA has recently established regulations governing ammonia pollution in wastewater for the first time. This has resulted in a dramatic increase in demand for ammonia removal technologies, as many wastewater treatment plants cannot treat ammonia wastewater sufficiently to meet regulations. Demand for alternative ammonia removal technology is growing; conventional technologies are not satisfactory to many customers. Saltworks has invented a new ammonia-removal-from-wastewater system that is superior to current technology to solve one of industries most difficult wastewater challenges. This paper provides a market analysis to assess the attractiveness of the ammonia removal market, and confirms the feasibility of Saltworks entering the market with its new technology.

Ammonia is a clear gas with a distinctive pungent odour, commonly used in window cleaners. It is a natural component of the global nitrogen cycle and a widely produced industrial chemical. Ammonia is extremely toxic to aquatic life in small concentrations and causes long-term damage to fish and marine environments in very low concentrations. Additionally, excess ammonia in surface waters causes algae blooms. When the alga exhausts the excess ammonia from the surrounding waters, it begins to die and decompose. This deoxygenates surrounding waters, and suffocates marine life.

Ammonia pollution in North American sewers and natural waterways is extremely common. Industry discharges and fertilizer run off release ammonia into sewers and streams, overloading wastewater treatment plants and causing fish deaths in uncontrolled surface waters, such as rivers and lakes. Canada currently has no regulations governing the concentrations of ammonia pollution and the US has only recently implemented regulations for ammonia in wastewater. The new regulations have significantly increased demand for ammonia removal technologies from the many small and medium businesses that now require water treatment systems to meet regulated concentrations. Current ammonia removal technologies are not satisfactory to many industrial customers due to significant tradeoffs and technical limitations. Therefore, industry seeks new technology that surpasses the limitations of conventional ammonia

removal methods. Saltworks has developed a prototype ammonia device that out performs current technology and has fewer negative tradeoffs.

Saltworks has built its ammonia removal device around its existing ElectroChem technology platform. ElectroChem uses Saltworks' ammonia tuned ion exchange membranes to separate and destroy ammonia, requiring only electricity and producing no waste products. Saltworks' ammonia technology overcomes several disadvantages of conventional ammonia removal technologies. It is small and compact, temperature insensitive, and starts working immediately. Ammonia removal rates scale with power applied: increase power to increase removal rates. The key advantages provided by Saltworks ammonia removal system are that it 1) reduces capital and operating costs by requiring a smaller plant footprint, 2) requires no consumable chemicals, and 3) produces no waste product. Saltworks' ammonia technology is an extremely promising solution to industry's ammonia wastewater challenges.

This paper provides a market analysis of the ammonia removal from wastewater market to identify the most attractive market segments to target. The paper further analyses the advantages and disadvantages of conventional technology and describes Saltworks primary competitors in this market. This paper seeks to prove the feasibility of Saltworks successfully developing and marketing its new technology.

This paper has found that the ammonia removal market is, in general, very attractive to Saltworks. A Porter's Five-Forces analysis revealed that Saltworks has created several barriers to prevent entry by competitors including IP protection, an extensive customer list, and an operational process geared to deliver innovative solutions in response to industry demands. A sixth force, government regulations, is applying pressure to the market by introducing new pollution regulations, driving rapid growth within the US.

The most attractive market segments are those with the highest concentrations of ammonia, as willingness to pay is highest and competition is the lowest. Current ammonia removal technologies have several technical disadvantages such as process sensitivity to temperature, the requirement for significant space, and waste product production, which requires disposal. Thus, we can conclude that Saltworks' ammonia removal system has strong potential in the ammonia removal from wastewater market. The paper finishes with an implementation plan for Saltworks to enter the ammonia removal market.

I dedicate this paper to my amazing wife, Karen.

Your love and patience gave me the courage and strength to succeed.

Without you, I would never have made it.

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Glossary

Algae Bloom	A large and sudden increase in algae populations in surface water, due to excessive nutrient levels.
Ammonification	Ammonification is the natural process of bacteria converting organic nitrogen into ammonia.
Anion	A negatively charged ion
AOR	Advanced oil recovery is the collection of technologies that improves the total yield possible from oil fields.
Bitumen	A black, semisolid, form of petroleum most commonly found in oil sands: it is also a primary component of asphalt.
CAFO	CAFO is an abbreviation for concentrated animal feeding operations, also known as industrial farms.
Cation	A positively charged ion
EC	Environment Canada
ElectroChem	Proprietary ion exchange membrane based technology developed by Saltworks.
EPC	Engineering, Procurement, and Construction.
Euphoric Zone	The upper light filled layer of surface water that supports microorganisms.
Eutrophication	A condition that occurs when marine environments contain excessive nutrients, often leads to rapid increases in microorganism populations.
FGD	Abbreviation of flue gas desulphurization, a collection of technologies used to remove the sulphur dioxide from hydrocarbon exhaust stacks.

GPM	Gallons per minute.
Hydraulic Fracturing	Also known as, “fracking” it is an oil extraction process that uses high-pressure water to fracture subterranean rocks to improve the recovery from highly viscous oil fields.
Hydrophobic	Hydrophobic is a property of a material surface that uses microscopic structures to enable a surface to repulse water
N_2	Nitrogen gas is a clear, colorless, inert gas that forms 78% of the Earths atmosphere
NH_3	Ammonia is a toxic clear gas with a distinctive pungent odour.
NH_4	Ammonium is a positive ion of ammonia that is less toxic to aquatic life than ammonia.
NPRI	Acronym for National Pollutant Release Inventory, a Canadian government institute that tracks human induced pollution
Overburden	The top layer of waste earth removed to gain access to underground minerals.
Paydirt	Earth rich in valuable minerals that is excavated and processed to recover the minerals.
Phytoplankton	They are microscopic organisms that occupy the upper sunlight layers of the oceans and form the backbone of the ocean food web.
PRC	Peoples Republic of China.
SaltMaker	A proprietary evaporative crystallization technology developed by Saltworks that achieves true zero liquid discharge.

1: Introduction

High levels of ammonia and other nutrients in surface waters are pollutants that destroy marine ecosystems and kill aquatic life. Controlling these types of pollution is one of the world's greatest water quality challenges.[1] Tightening regulations are forcing companies to seek solutions to manage ammonia pollution.[2] However, existing methods of ammonia removal are unsatisfactory due to their significant technical limitations and tradeoffs. This mismatch between industry's needs and existing technology presents an opportunity to develop and implement new technologies. Saltworks Technologies, a world leader in innovative wastewater technologies, has developed a potential solution. Founded in 2008 in Vancouver, BC, the company has developed the prototype of an ammonia removal process, based on its existing ElectroChem membrane technology. This paper analyses the North American wastewater treatment market, as it applies to removing ammonia from wastewater, to assess the opportunities for Saltworks to implement its novel ammonia removal technology.

To implement its new technology, Saltworks needs to verify the business case for continued development by surveying the competitive landscape and identifying the most attractive segments to target. This paper analyses Saltworks' capabilities, the potential ammonia removal markets, current ammonia removal technologies available, and the incumbents in this space, to inform the business case for implementing Saltworks' ammonia removal technology. With this analysis, Saltworks will be better prepared to implement its novel ammonia removal system.

1.1 What is Ammonia?

Ammonia is a clear, colourless gas consisting of one nitrogen atom and three hydrogen atoms. As an important step in the global nitrogen cycle, ammonia is a vital source of nitrogen, an important nutrient for plants and microorganisms. The largest natural sources of ammonia are bacterial decomposition and animal excrement. Ammonia is also one of the most commonly produced chemicals in the world. It is present or used in the manufacture of many products,

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[1] University of York. http://www.essentialchemicalindustry.org/chemicals/ammonia.html
[2] EPA. http://water.epa.gov/polwaste/npdes/stormwater/EPA-Multi-Sector-General-Permit-MSGP.cfm

including household cleaning chemicals, such as window cleaners and oven cleaners, in fertilizers, refrigerants, and explosives. It is also an important feedstock for other chemicals and plastics.

Global production of ammonia is approximately 144 million tons every year, making ammonia the second most produced chemical in the world, after sulphuric acid.[3] Most commercial ammonia is produced from petroleum feed stocks via the Haber – Bosch process, invented in the early 1900s by Fritz Haber, the chemist who developed the process in the laboratory and Carl Bosch, the engineer who developed an economical, large scale process. The greatest producers of ammonia are in countries with access to cheap petroleum gas (usually natural gas). As of 2011, China and Russia accounted for 40% of global production.[4]

The fertilizer industry uses approximately 85% of the ammonia produced worldwide. It is also used in the production of explosives and amide plastics, and as a chemical digester in pulp mills. These industries are also some of the largest sources of ammonia pollution. Municipal water treatment plants are the single largest source of ammonia pollution with agriculture, mining, and industry being the next largest sources.[5] This means that most ammonia pollution is controllable at the points of origin.

Although ammonia is a vital resource in modern industry, it is also a toxic pollutant. In fact, ammonia is one of the most common pollutants in the world's waters and a serious threat to aquatic environments. In sufficient concentrations, ammonia is toxic to aquatic life and to humans. At less than fatal concentrations, ammonia pollution in surface waters can still damage aquatic environments and cause long-term damage to marine life. As a nutrient, ammonia causes eutrophication, excessive enrichment of an environment that causes microorganisms to flourish. If unchecked by, for instance, the scarcity of other normal nutrients, masses of microorganisms grow to form vast algae blooms. The algae blooms begin to die once the excess nutrients are consumed, leading to mass decay as the algae begin to die simultaneously. The decaying biomass quickly deoxygenates the water and suffocates all aquatic life in the surrounding area.

Ammonia pollution represents significant cost and operational risk for industry. Companies producing wastewater with high levels of ammonia have to be prepared to treat the wastewater appropriately to prevent damage to the environment. Public consent to operate and

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[3] USGS. http://minerals.usgs.gov/minerals/pubs/commodity/nitrogen/mcs-2015-nitro.pdf

[4] University of York. http://www.essentialchemicalindustry.org/chemicals/ammonia.html

[5] Environment Canada. http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1

popular opinion can quickly turn if the public perceive that a company is not taking a sufficiently responsible approach in this respect. Increasing regulations are also forcing companies to treat the ammonia in their wastewater before they discharge it. Therefore, industry must invest in expensive water treatment systems or pay the consequences of fines, negative publicity, and even a shutdown of operations. Industry now seeks new technologies to reduce the costs of ammonia treatment. This represents a major opportunity for Saltworks.

1.1.1 Marine Nitrogen Cycle

Ammonia is a natural step in the marine nitrogen cycle, one of the most important bio chemical systems in the oceans. Nitrogen is a limiting nutrient for microorganisms in water. The presence or absence of nitrogen, often in the form of ammonia, drives plant and microorganism growth (Walker, 2014). It exists as a parallel and interrelated biochemical system to the land based nitrogen cycle. Therefore, understanding the marine nitrogen cycle and the effects of human induced pollution on the environment are critical to maintaining a balanced marine ecosystem.

Aquatic ammonia originates from many natural and human induced sources. The bacteria consuming dead biological material on the sea floor generate the majority of naturally occurring ammonia. The excretions from the gills of fish are another natural source of aquatic ammonia (Ip, Chew, 2010). Human induced sources of ammonia pollution include mine tailing ponds, fertilizer runoff, industrial discharge, wastewater plant discharge, and domestic animal manure.

Nitrogen has many forms and phases throughout its cycle. Figure 1 illustrates the complete marine nitrogen cycle. In its simplest form, nitrogen enters the marine system from precipitation, N_2 from the atmosphere, rainwater runoff from land, and oceanic mixing. Bacteria floating in the light filled euphotic zone absorb sunlight and consume the dissolved nitrogen to produce ‘fixed’ nitrogen, nitrogen that has been processed into ammonia and urea. Most organisms cannot absorb N_2 directly and can only intake nitrogen in a ‘fixed’ form (Anderson, Glibert, and Burkholder, 2002). Next, phytoplanktons consume the fixed nitrogen and multiply to provide food for large creatures. Phytoplanktons form the backbone of the marine food web (Capone, Carpenter, and Bronk, 2008). Nitrogen leaves the euphoric zone when larger marine organisms, such as krill, eat the phytoplankton, or when the phytoplankton die and sink to the bottom of the ocean. The dead phytoplankton that sinks to the bottom of the ocean decomposes. The nitrogen locked in the dead phytoplankton is released by bacterial action into N_2, a process known as de-nitrification. The N_2 released is eventually off-gassed from the water (Brandes, Devol, and Deutsch, 2007). The biological nitrification method of ammonia removal emulates this approach by utilizing bacteria to consume the fixed nitrogen and oxygen and excrete N_2, which off-gasses from large concrete tanks.

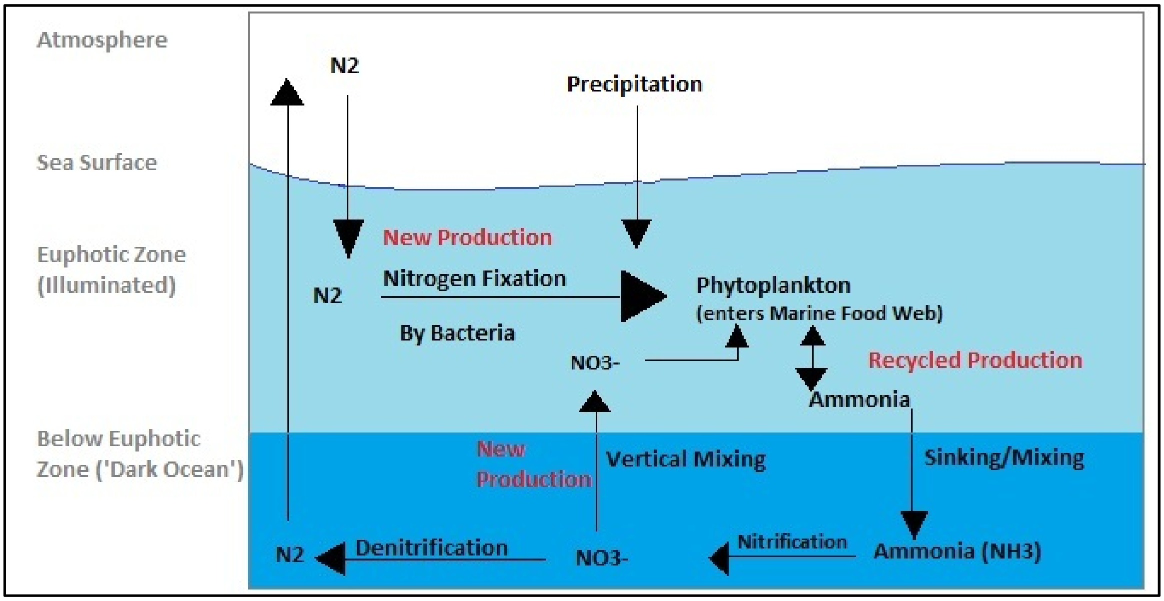

Figure 1: Marine Nitrogen Cycle

Source: Trea Chang, 2011, used under CC BY-SA 3.0[6]

A low level of ammonia in surface water is necessary for microorganisms to grow and form the backbone of the marine food web. However, human induced ammonia pollution has raised the levels of nutrients, such as ammonia, to dangerously high levels. As described above, such high levels of ammonia cause the microorganism populations to explode uncontrollably, creating algae blooms. Algae blooms exist as long as they can consume nutrients and grow. In sufficient concentrations, algae turn the water opaque and give it a green, red, or brown colouring depending on the species of microorganism. The algae begin to die and decay simultaneously after exhausting all the available nutrients in the surrounding area. This decaying biomass deoxygenates the surrounding waters, leading to the loss of fish and other marine life. Few examples of the acute effects of human induced water pollution are more dramatic than algae blooms and the resulting fish deaths.

[6] Wikimedia Foundation. https://commons.wikimedia.org/wiki/File:Marine_Nitrogen_Cycle.jpg

1.1.2 Ammonia Toxicity, Temperature, and pH.

Measuring the toxicity of aqueous ammonia is challenging due to the differing nature of the two common forms of ammonia when dissolved in water. NH_3 is the toxic, un-ionized, form of ammonia that occurs in high pH water (dissolved gas in water). NH_4 is the less toxic, ionized form of ammonia that forms in lower pH waters (ion in water). The concentration of each form of ammonia depends on the temperature and pH of the water at any given moment. Figure 2 illustrates the relationship between water temperature, ammonia concentrations, and pH value. The toxicity of wastewater depends on the concentration of the toxic NH_3. However, the concentration of NH_3 can vary at any given moment depending on the water conditions.

This can be a challenge for regulators, as well as companies whose manufacturing operations result in wastewater with measureable ammonia levels. This is resolved by measuring the total ammonia content (TAN) of the water. TAN is the sum total of both forms of ammonia. Once TAN is measured, the concentrations of NH_3 can be calculated. Wastewater can become toxic depending upon the time of day and the season. Companies must be vigilant to prevent discharging excessive amounts of NH_3 in their wastewater to avoid penalties.

To determine the toxicity of water due to ammonia, we must calculate the concentration of the un-ionized form of ammonia. While the ratio of NH_3 to NH_4 depends upon the water temperature and the pH value, the later has the greater effect.[7] For example, at 20°C and at a pH of 8.4 over 90% of the TAN is NH_4, the less toxic, ionized form of ammonia. If the pH were to change from 8.4 to 10, only 20% of the TAN would be NH_4. The toxicity of ammonia to aquatic life depends largely upon concentration of un-ionized ammonia and duration of exposure. Actual toxicity depends upon the organism; tolerance to ammonia varies greatly from species to species.

[7] Kentucky State University. http://www2.ca.uky.edu/wkrec/pHAmmonia.PDF

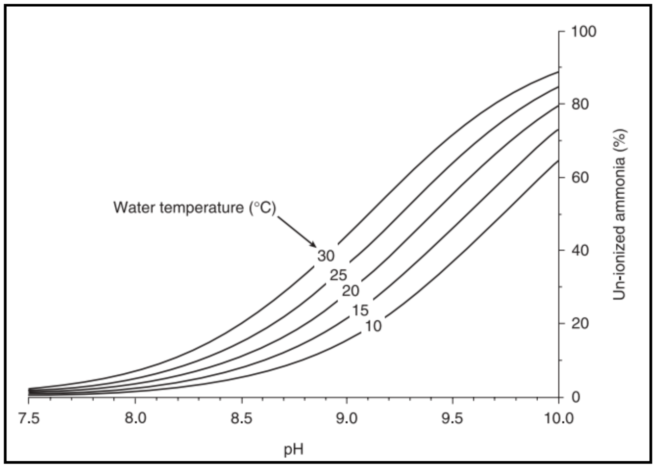

Figure 2: Relationship between NH3 Concentrations, pH, and Temperature

Source: John A. Hargreaves and Craig S. Tucker, 2014, used with permission[8]

1.1.3 North American Ammonia Discharge Regulations

North American regulations governing ammonia pollution are unable to fully protect the marine environment. Although current regulations and guidelines are still too weak to prevent chronic damage to marine life and eutrophication, there are signs of change. The US has recently broadened and strengthened its wastewater discharge regulations. The US Environmental Protection Agency (EPA) has set limits of ammonia discharge into municipal sewer systems to 4.9 mg/L TAN average per month and 10 mg/L TAN daily maximum of ammonia dissolved in water.[9] Companies in the US are now scrambling to install water treatment systems to meet these new regulations, creating strong market demand for ammonia treatment technology. The US is a North American leader in environmental policy in this area and the precedent it has set with its tough new regulations will encourage other nations to also set discharge limits.

Canada has no regulations governing ammonia pollution. Environment Canada (EC) does publish water quality guidelines that recommend that the concentration of ammonia discharges into surface waters should not exceed the acute toxicity level of ammonia for marine life. The recommended limit to long term, chronic concentration of unionized ammonia is no greater than 0.019 mg/L[10]. The long-term guidelines are set to avoid long-term damage to fish gills,

[8] Southern Regional Aquaculture Centre. http://www2.ca.uky.edu/wkrec/ManagingAmmonia.pdf

[9] EPA. http://water.epa.gov/polwaste/npdes/stormwater/upload/msgp2015_part8.pdf

[10] Environment Canada. http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=B7CE1A5E-1&offset=1&toc=show#s4

reproductive capability, and fish fry growth rate. The guidelines mean that dischargers of ammonia have to calculate the toxicity of their waters, based on water temperature, ammonia concentration, and pH value.

Health Canada (HC) regulates the concentrations of contaminants in drinking water, but as it does not treat ammonia as one of those contaminants, it does not regulate the concentrations of ammonia.[11] Ingesting ammonia is not as toxic as inhalation or dermal exposure. Humans naturally produce ammonia; the body can metabolize and excrete ammonia. Therefore, HC has found no reason to limit the concentrations of ammonia in drinking water.[12]

Due to the recent adjustments of ammonia discharge limitations by the EPA, the US has tighter ammonia discharge limitations than the rest of North America. That means that dischargers of ammonia will have to comply with stricter regulations in the US than they would elsewhere. Canada has not updated its ammonia discharge guidelines since 1999, nor has it created regulations governing ammonia discharges.[13] This would seem to indicate that growth in the ammonia removal market would more likely arise in the US than in Canada. Indeed, US firms are now increasing ammonia removal capacity to meet the recently tightened regulations.

1.2 Saltworks

SFU alumni Ben Sparrow and Joshua Zoshi founded Saltworks Technologies in 2008, initially around a novel method of desalinating water. Saltworks has since moved on from this initial technology and invented new water treatment technologies. Working in tandem with industry to solve some of the biggest water problems, Saltworks now advances the commercialization of its two core technology platforms: ElectroChem and SaltMaker. The Electrochem system uses specialized membranes to separate ions from water streams. ElectroChems first application was a pilot program for Teck Resources Limited. The SaltMaker plant concentrates and separates wastewater to produce a stream of distilled water and a solid waste stream. Saltworks piloted the first SaltMaker in Australia with Origin energy. Saltworks continues to innovate within its two technology platforms as well as develop new technologies.

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[11] Health Canada. http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/sum_guide-res_recom/index-eng.php#t2

[12] Health Canada. http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/ammonia-ammoni/index-eng.php#a10.0

[13] Environment Canada. http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=B7CE1A5E-1&offset=1&toc=show#s4

Saltworks R&D efforts has resulted in inventing a new technology to remove ammonia from wastewater. The ammonia removal invention stems from Saltwork's flexible ElectroChem technology platform. Saltworks has successfully developed a prototype ElectroChem system that selectively removes ammonia. The system removes ammonia from wastewater and can convert it into multiple products. Saltworks believes that the ammonia removal market has much potential. Prior to investing in piloting and marketing the new system, Saltworks requires market data to inform the business case and technology commercialization direction. The following section examines the business case for developing and implementing Saltworks' ammonia removal technology.

1.3 Business Case for Ammonia Removal

The largest sources of ammonia wastewater pollution are also the largest sources of wastewater, such as wastewater treatment plants (WWTP), landfills, mines, agriculture, and animal rearing operations. As regulations tighten, these entities are required to invest in solutions to lower the ammonia content in their wastewater, in compliance with regulations. The Association of Civil Engineers gave US wastewater infrastructure a D grade, citing deteriorating infrastructure and insufficient funding as the main reasons for the poor grade. The US spent an estimated $93 billion in 2008 on wastewater and drinking water infrastructure. To meet new regulations, maintain existing infrastructure and to meet growing demand, forecasted at 5% annually, at least $300 billion in investments is required over the next 20 years. [14,15]

The water treatment industry represents a low risk opportunity for Saltworks in its growth and innovation plans. A survey organized by Water World Magazine on the industry's spending on water treatment revealed that in 2010, on average, each company spent $600,000 on water treatment and sewage disposal surcharges, based on average outfall of 760,000 gallons per day.[16] Additionally, most respondents believed that the cost of water treatment was going to increase in coming years. Wastewater treatment, like other utilities, is a non-cyclical and recession-proof industry. Water treatment plants represent safe investments in a vital and growing industry that is ripe for innovation.

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[14] Water World. http://www.waterworld.com/articles/wwi/print/volume-24/issue-6/regulars/perspective/water-market-continues.html

[15] ASCE. http://www.infrastructurereportcard.org/a/#p/wastewater/investment-and-funding

[16] Water World. http://www.waterworld.com/articles/iww/print/volume-11/issue-1/feature-editorial/survey-examines-wastewater-treatment-costs.html

Although there are several technologies and processes available to remove ammonia from wastewater, there is no one universally accepted solution. The most common ammonia removal methods have significant tradeoffs and technical disadvantages. Biological nitrification and related technologies are the most commonly used methods. Secondary methods of ammonia removal include air stripping, membranes, and ion exchange media for select applications. The lack of a dominant technology provides an opportunity for Saltworks to disrupt the market. This would be a opportunity for the company to add to its growing reputation for solving tough water processing challenges.

Saltworks' novel ammonia system has several critical advantages that include compact size, robust materials of construction, and the ability to completely destroy the removed ammonia. The primary disadvantage of the system is its high electrical power consumption. However, Saltworks is working to optimise and minimize the system's power consumption on its prototype unit. At present power consumption levels, Saltworks' technology still represents lower costs than the input chemical and operations costs of other processes on the market. The Saltworks technology presents the company with an opportunity to disrupt the market and potentially to become an industry standard.

According to one survey of industry, ammonia costs on average $0.94/lb to dispose of through municipal sewer systems.[17] The Saltworks ammonia system can remove 1 lb of ammonia using $0.26 worth of electricity[18]; assuming an electricity price of $0.066/kWh, the average price for US industrial users as of May 2015.[19] Therefore, Saltworks' ammonia process could offer operational savings of up to 72% over the average cost of ammonia disposal through municipal sewer systems. The same study also discovered that most respondents would have moderate to high interest in an ammonia removal technology that could reduce operating costs by at least 40%. The prototype ammonia removal system developed by Saltworks offers the advantages of compact size, total destruction of ammonia, no consumable chemicals, and lower operating costs over traditional removal methods. The aim of this report is to lay out the business case for Saltworks to develop their prototype into a commercially available ammonia removal system.

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[18] Saltworks Technologies. Data extrapolated from initial prototype test results.

[19] US Energy Information System. http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a

2: Internal Analysis of Saltworks

This chapter analyses Saltworks' internal processes and capabilities as they relate to developing and implementing their innovative ammonia removal technology. First, we introduce Saltworks and summarize the company's history, technology platforms, organizational structure, and facilities. Next, we analyse its key strategies including growth, marketing, and production scale up strategies. Continuing the analysis, we examine Saltworks' competitive advantages by reviewing the strengths, weaknesses, opportunities, and threats it faces. We conclude the chapter with an analysis of the feasibility of Saltworks entering the ammonia removal market and implementation plan.

2.1 Introduction to Saltworks

Saltworks Technologies is a Canadian manufacturer of novel desalination and wastewater treatment capabilities. Headquartered in Vancouver BC, Saltworks specializes in treating the world's most challenging wastewaters and brines.[20] Having developing two revolutionary water treatment technologies, ElectroChem and SaltMaker, Saltworks continues to explore new applications. The company's list of international customers includes NASA, Origin Energy, Natural Resources Canada, and Waste Management USA. Saltworks' major industrial shareholders include Teck Resources, BP and ConocoPhillips. Saltworks works closely with industry to develop and deliver effective water treatment solutions for industry.

2.1.1 Company History

Founded in 2008 by SFU alumni Benjamin Sparrow and Joshua Zoshi, Saltworks incorporated shortly before Sparrow and Zoshi won the first place prize in the 2008 BC New Ventures Awards for Thermo-Ionic, a breakthrough desalination technology invented by Sparrow. Thermo-Ionic is a membrane-based desalination technology that harnesses the gradient between separate water streams with high and low salt concentrations to desalinate a third stream. This approach to desalination does not require high pressure, large amounts of electricity or

[20] Saltworks. https://www.linkedin.com/company/saltworks-technologies-inc-

additional chemicals. The majority of the energy that drives the process comes from the sun, which evaporates water from a solar spray pond, concentrating the salt water and providing the high concentration stream that Thermo-Ionic requires.[21] Capable of low cost desalination of high concentration seawaters, Thermo-Ionic is a game changing innovation. Within a year of introducing Thermo-Ionic, Saltworks moved into a larger, oceanfront, facility to produce its proprietary membranes and develop its technology.

Initially focused on desalination for the potable water market, Saltworks soon turned to industrial water treatment plants in recognition of greater customer demand and higher willingness to pay for industrial wastewater disposal. The oil, gas and mining industries often produce high salt concentration wastewaters at widely varying pH that require treatment before reuse or disposal. In response, Saltworks invented new, hydrocarbon tolerant membranes and, based on Thermo-Ionic technology, developed a new technology platform. ElectroChem is a flexible, membrane-based technology that configures to different water chemistries for a variety of water treatment applications including RO brine concentrating, acid recycling and advanced oil recover (AOR) produced water desalting. Similar to Thermo-Ionic, ElectroChem has a small footprint and does not require expensive materials in its construction or high pressure pumps in its operation. These are desirable features to potential oil and gas customers. However, since the decline of oil prices in 2014, the oil and gas majors have reduced their overall capital investment, which has reduced the demand for Saltworks plants. Saltworks has responded by diversifying again to a new market segment: landfill leachate.

Saltworks contracted with a major North American waste disposal company to build a SaltMaker to treat landfill leachate. The SaltMaker is Saltwork's second technology line that evaporates wastewater in stages to concentrate pollutants and recover freshwater. Leachate is the product of rainwater percolating through buried landfill material. Containing salts, acids, heavy metals, and dissolved organic material, landfill leachate is toxic and expensive to dispose of. In 2014, Saltworks contracted to build a 100 m^3 per day SaltMaker to treat leachate at a landfill in Mississippi. The SaltMaker will deliver significant cost reductions to the disposal of landfill leachate at the site. It is expected to reduce the number of tanker trucks removing leachate from the landfill from three trucks a day to one a week, representing more than twenty times reduction in leachate volume. The landfill leachate SaltMaker begins commissioning trials in mid 2015.

[21] WateReuse. https://www.watereuse.org/sites/default/files/u3/MM%20SW_EV_WateReuse_2011-Presentation%20-%20RB.pdf

Saltworks has a proven record of developing new technologies in response to market pressures and opportunities. Saltworks currently produces two patented technology platforms: ElectroChem and SaltMaker. The next two sections describe these two platforms in detail.

2.1.2 ElectroChem

Saltworks main product offering for the oil, gas, mining, and desalination markets is ElectroChem, the successor to Saltworks' initial technology, Thermo-Ionic.[22] ElectroChem is a membrane-based technology for targeted ion removal. It utilizes Saltworks' patented ion exchange membranes, packaged into stacks. Each stack consists of multiple layers of membranes and spacers to create internal compartments for water to flow and contact the membrane. In this system, ions are present as electrically charged particles suspended in water, inside the stacks.[23]

The stacks utilize two kinds of membranes: cation exchange membranes and anion exchange membranes. Each kind of membrane permits the passage of either positive or negative charged ions. Stacks consist of membranes arranged in alternative layers to direct the flow of positive ions in one direction and negative ions in the other direction, as shown in figure 3.

Voltage applied to the stack electrodes drives the flow of ions from one water stream to another, through the membranes. The receiving water stream increases in concentration as ion enter the stream. The water stream donating ions becomes free of the selected ion. Mobile shipping containers house ElectroChem stacks, supporting equipment and an advanced control system that automatically operates the plant to ensure longevity and the optimal operating parameters.

[22] Saltworks Technologies. http://www.saltworkstech.com/electrochem-produced-water-desalter/
[23] Saltworks Technologies. http://www.saltworkstech.com/ionflux-ion-exchange-membrane/

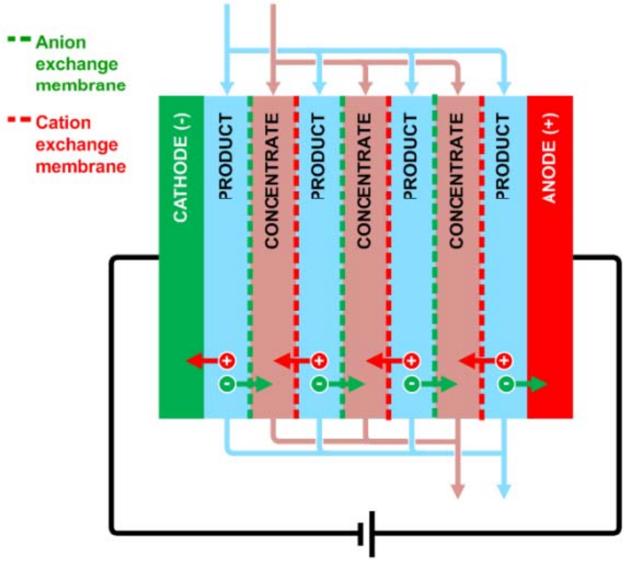

Figure 3: ElectroChem Stack Basic Operation

Source: Saltworks, 2015, used with permission[24]

Using one of Saltworks' patented ion exchange membranes, Saltworks can configure ElectroChem systems for each application. For instance, working closely with its oil and gas industry investors and customers, Saltworks developed the ElectroChem Produced Water Desalter. This ElectroChem stack is capable of desalinating the wastewater stream produced by steam assisted gravity drainage (SAGD) oil recovery.[25] Water produced by the SAGD process is the result of injecting steam into bitumen deposits below the ground to heat the bitumen and allow it to flow to the surface via a collection pipe. The recovered liquid contains bitumen, water, sand and drilling chemicals added to reduce friction and inhibit biological growth and corrosion. After extracting the bitumen, the remaining fluid is stored in a holding pond. These ponds are expensive to maintain and present an environmental and regulatory risk for operators. Saltworks developed a prototype ElectroChem stack built with specialized membranes that could tolerate exposure to the hydrocarbons in SAGD produced water. The prototype was tested in a bench-top device at Saltworks' R&D facility. Upon success of the bench top unit, Saltworks dispatched pilot plants to customer sites across North America for further testing. The ElectroChem system cleans process water of salts and other ion, which regenerates the drilling chemicals in the wastewater. Regenerating drilling chemicals allows wastewater to be re-injected into wells, reducing overall water and chemical consumption.

[24] Saltworks Technologies. http://www.saltworkstech.com/electrochem-wastewater-desalter/

[25] Saltworks Technologies. http://www.saltworkstech.com/wp-content/uploads/2015/03/Saltworks_ElectroChem_Product_Sheet_EN.pdf

Acid regeneration is another application uniquely suited to treatment by ElectroChem. Acid is utilised in several industrial processes including anodizing and brightening, steel pickling, and battery production and recycling. Most acid wastewater is discharged and replaced once exhausted but it is possible to regenerate acid wastewater, at a fraction of the cost of disposal and replacement. The ElectroChem Acid Regen system utilizes Saltworks' pH tolerant membranes to regenerate wastewater by stripping the acid from the acid wastewater stream and transferring it to into a purified freshwater stream. The freshwater stream containing the regenerated acid can then be concentrated and reused. Regenerating acid in this way saves the considerable expense associated with disposing of waste acid and procuring new acid. ElectroChem can reach recovery rates of as high as 95%.[26] The ElectroChem process also reduces the safety hazards associated with acid handling and transport, further reducing costs and risk.

2.1.3 SaltMaker

Saltworks' second technology is a modular evaporative crystallizer technology that can process virtually any industrial water to produce a distillate and a stream of highly concentrated waste material. The SaltMaker is a multi-effect, humidification- dehumidification process that reduces the volume of wastewater by heating, then evaporating wastewater in an enclosed chamber to create a stream of low temperature, humidified air. The humidified air then condenses on heat exchangers and the condensate is collected. The SaltMaker system can inject the condensate back into the customer's process for reuse or disposal in sanitary sewers. The SaltMaker process is comprised of multiple insulated modules, sealed against one another, to conserve thermal energy and contain the wastewater, which is often hazardous.

SaltMaker is an energy efficient process that uses low-grade waste heat and recaptures heat rejected by the condensed water in each effect to heat the water used in subsequent effects. Multiple effects increase plant efficiency by heating the water once then utilizing it many times to produce distillate. Water cycles through the plant in a closed loop with freshwater removed in each effect, allowing salts and minerals to concentrate in the system. Depending on the water chemistry, SaltMakers can produce a stream of solid material or discharge highly concentrated brine.

The SaltMaker excels at concentrating highly saline brines that easily crystallize during treatment and plug normal process equipment such as heat exchangers and pipe works. Saltworks

[26] Saltworks Technologies. http://www.saltworkstech.com/wp-content/uploads/2015/02/Saltworks_Case-Study_Acid-Recovery_EN.pdf

sold the first full sized SaltMaker for a steel dust recycler in Mexico. The steel dust recycler used a wet chemical process to create zinc salts for use in agriculture, feedlots, and aluminium smelting. The SaltMaker was able to recycle the wastewater, producing distilled water for reuse and a stream of solid salt. The removed salt is dried and sold at a premium due to the large crystal size.

The SaltMaker system offers lower operating costs and higher reliability compared to other crystallizers or evaporators due to its advanced design that includes automated self-cleaning capabilities and a crystallized solids management system. Constructed from robust, non-metallic modules the SaltMaker easily expands to meet a customer's growing capacity needs. Packaged into a series of ISO shipping containers the SaltMaker has a short production lead-time and rapid site assembly.

2.1.4 Organizational Structure

Saltworks' team of approximately fifty includes engineers, technicians, chemists and trades people located in three separate facilities in Vancouver, BC. Chief Engineer and CEO Ben Sparrow leads operations and engineering while President, Joshua Zoshi, heads administration, HR, and finance. The Saltworks team works to design, build, and deliver advanced water treatment systems. Projects and operations are organized internally through a soft functional matrix where project managers work with staff and resources from functional departments to design, procure, build, and install plants at client sites. Mechanical, chemical and electrical engineers first design the plants using 3D and 2D modelling software. The supply chain executes purchase orders for raw materials and finished components specified by engineering. The production department process the raw materials into components and combine them with purchased equipment to build the plants. Utilizing project managers supported by functional staff allows Saltworks to very quickly test and develop new solutions in reaction to market pressures and opportunities, sometimes within just a few weeks.

2.1.5 Facilities

Saltworks' headquarters is a waterfront facility with fully permitted access to seawater for testing and commissioning desalination plants. The headquarters also houses Saltworks' R&D facilities that comprise engineering offices and chemistry labs as well as test facilities for developing new water treatment solutions and demonstrating the technology to customers.

Saltworks manufactures its advanced membranes used in the ElectroChem technology in a separate, clean room, production facility. Saltworks has developed custom roll-to-roll membrane production equipment to produce its specialized membranes for use in ElectroChem plants as well as for resale to external firms that specialize in packaging membranes into stacks and treatment plants.

Manufacturing, inventory, and final assembly take place at another waterfront facility. Saltworks manufactures its plant modules in its factory then assembles them in a secure outdoor space for commission and tuning before shipping to a customer's site. Saltworks maintains a production staff of skilled technicians and trades people, and utilizes modern CNC equipment to manufacture many of its own components in-house. As Saltworks grows to meet increased customer demand, it is planning to move its SaltMaker production facilities and warehouse to a much larger facility in late 2015. The larger facility and an increase in production staff will increase production rates and improve efficiency to reduce lead-times and to lower costs. The strategic decision to increase production is in line with the company's long-term growth strategy.

2.2 Analysis of Saltworks Strategy

This section reviews the key strategies that guide Saltworks' activities, including growth strategy, marketing strategy and production scale-up strategy.

2.2.1 Growth Strategy

Saltworks' strategy for growth is to focus on commercializing its technologies by finding new market applications and engaging with key customers to develop solutions tailored for industry. Saltworks is growing several parts of its operations at once, including marketing, production, HR, and IT systems. Marketing approaches are increasing the company's website relevance and web traffic to attract more potential customers. Saltworks has invested in new production facilities and is managing its supply chain more closely to reduce lead-times and costs. Production and technical staff numbers are growing to meet increased demand. Saltworks is also implementing an enterprise resource program (ERP) to better control the flow of its resources, assets and work scheduling. These improvements are intended to ensure that initial customer site implementations are successful in winning new orders, earning customer referrals and allowing Saltworks to meet the increasing demand.

Saltworks leverages the experience its staff gain in working with these initial customers to meet the needs of the rest of market. The company seeks innovators in each industry, those who are willing to try new solutions to address old problems. Working closely with these critical first adopters teaches Saltworks a great deal about the industry and the water challenges it faces. Saltworks will continue to grow by seeking out and developing new market segments that have water treatment issues compatible with Saltworks' technologies. Seeking out new applications for its water treatment technologies will increase the company's experience in solving water treatment issues and increase the scope of potential solutions for the next market segment.

2.2.2 Marketing Strategy

Saltworks' business development team engages with markets in four ways: through the company website, by maintaining a presence at relevant industry events, by actively engaging key customers in target market segments and through customer referrals. The combination of passive and active marketing allows Saltworks to efficiently pursue high value customers as well as to remain receptive to opportunities arising from the website, tradeshows or referrals.

Developed to attract and inform customers, the Saltworks website features case studies and white papers on common water treatment issues that are intended to educate customers about the company's capabilities.[27] The case studies describe water treatment challenges that Saltworks has successfully resolved. The goal is to entice potential customers to contact Saltworks in order to explore their own similar water treatment issues. The Saltworks website also achieves a high Google ranking for keywords associated with specific water treatment issues, to better attract customers carrying out online searches for water treatment solutions. A portion of the website has been translated into Mandarin in order to attract potential customers from China.[28] Website analytics provide Saltworks with important information about site visitors, such as their geographic location and what content they viewed; this data informs the company's active search for new market segments. The Saltworks website promises not only to yield new customer leads but also to act as a window into the water treatment world, providing insight into new applications, new water treatment challenges, and new strategic opportunities. Since upgrading its website, Saltworks has seen a substantial increase in customer engagement and inquiries that have led to new pilot and bench top tests; these may translate into full-scale plants.

Saltworks regularly attends and presents at wastewater industry events and environmental technology conferences to advertise its capabilities and to engage with potential customers. Saltworks has presented its technologies at industry events including the 2009 International

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[27] Saltworks Technologies. http://www.saltworkstech.com/case-studies/
[28] Saltworks Technologies. http://www.saltworkstech.com/cn/

Desalination Association (IDA) world congress in Dubai[29], the 2010 GLOBE conference in Vancouver BC[30] and the 2010 Governors Climate Summit in California.[31] Such tradeshows and conferences provide an opportunity to reinforce relationships with existing contacts and build new ones with potential customers. Tradeshows also allow Saltworks to monitor its competitors. Typically, customers investigate multiple technologies to address their water treatment issue, so Saltworks often competes next to other pilot programs at customer sites. Tradeshows were initially useful to advertise, gain legitimacy, and engage with industry to learn about their challenges and ideal solutions. As Saltworks grows and becomes more established, tradeshows will become less valuable as a venue to advertise and more valuable as a way to monitor industry trends, keep an eye on competitors, and meet potential new clients. Relationships established at tradeshows often become the starting point for more active marketing efforts.

Actively seeking the key initial customers in new market segments is an important part of Saltworks' marketing and growth strategies. The company's marketing efforts are aimed at transforming potential customers into key early adopters and a source of referrals. Target markets are analysed based on several metrics including size and value of market, composition of the market segment and chemical compatibility with Saltworks technology. After engaging potential early adopters, Saltworks will often offer a free bench top study using actual customer water to entice into further dialogue about their water treatment issues. Upon conclusion of the bench-top tests, Saltworks sends a presentation to the customer. Based on the results, the customer is encouraged to advance to a low risk, small-scale mobile pilot dispatched to a customer's site. Pilot tests often run for two months, with the customer encouraged to interact with and learn about the technology, and teach Saltworks about the technical challenges associated with their wastewaters. When the pilot program concludes, Saltworks can develop a full size solution, customized to match a customer's specific wastewater needs.

The Saltworks process of engaging customers through the stages of education and desktop studies, bench top tests, site pilots, and finally, full-scale plants is repeated each time the company engages with a new major customer, market segment or industry.[32] The approach has resulted in successfully finding key initial customers for ElectroChem and SaltMaker technologies. This incremental method is attractive to potential customers for several reasons.

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[29] Saltworks Technologies. http://www.saltworkstech.com/saltworks-desalination-world-congress/

[30] Saltworks Technologies. http://www.saltworkstech.com/saltworks-globe-bc-innovation/

[31] Saltworks Technologies. http://www.saltworkstech.com/saltworks-desalination-technology-california-climate-summit/

[32] Saltworks Technologies. http://www.saltworkstech.com/our-approach/

Customers seeking solutions to their water treatment problems will rarely refuse a free, low risk analysis of their own water. The lure of free, personalized information is powerful for any company facing challenges. The Saltworks approach significantly reduces risks for those wanting to implement new water treatment technologies but not expose themselves to the risks inherent in implementing an unproven technology. As a result, customers learn a great deal about their water chemistry from the bench top and pilot tests and often then want to know more and explore further tests with Saltworks. This becomes a low risk and value-adding process for everyone involved.

Saltworks as a company has passed the site pilot stage for its two core technologies and the first commercial plants are now dispatching. As Saltworks develops new water treatment technologies, the process will begin again with the new market segment and new customers. This iterative customer engagement process ensures that focusing on customers' needs, the ability to innovate, and the power to grow is a part the company's DNA.

2.2.3 Production Scale up Strategy

Saltworks currently produces one to two full sized SaltMakers at its ocean front production facility per year. To meet the expected demand of SaltMaker in the landfill leachate industry, Saltworks is increasing production to four to six full sized SaltMakers per year in 2016 and ten to twelve plants in 2017. To handle the rapid growth, Saltworks is expanding in several areas at once. In late 2015, SaltMaker production is moving to a much larger facility in Burnaby, BC, to allow the construction and commissioning of multiple SaltMakers at once. Staff numbers in the production and supply chain departments are also expanding to enable construction of several SaltMakers and large sub assemblies at once to reduce lead-times. To meet the performance and production goals Saltworks has set, the company's engineering department is developing the next generation SaltMaker plant, designed for reduced manufacturing and site assembly times. The supply chain department is working with suppliers to reduce the lead-time of specialized components and to outsource production activities that are not core to Saltworks business. As demand for ElectroChem and SaltMaker increase, the new production facility layout has to be flexible enough to produce other kinds of water treatment plants, such as ammonia removal plants, in high volumes.

2.3 Feasibility Analysis of Saltworks Entering the Ammonia Removal Market

This section analyses the feasibility of Saltworks entering the ammonia removal market. This analysis focuses on the qualitative advantages and disadvantages the company is likely to face. We utilize the SWOT framework to analyse Saltworks' Strengths, Weaknesses, Opportunities, and Threats it will encounter and compile a list of potential advantages and disadvantages. This will help to determine if it is feasible for Saltworks to continue development of its ammonia removal system.

The SWOT framework is a business strategy tool used to evaluate a business opportunity or potential market by considering all the relevant internal factors (strengths and weaknesses) and the external factors (opportunities and threats). By reviewing these factors, we can better understand the relative position and options Saltworks has in relation to the ammonia removal market. The exact origin of the SWOT analysis is unknown but the most commonly cited sources for developing the initial SWOT framework in the early 1950s is a pair of Harvard Business School Policy Unit professors: George Albert Smith Jr. and C Roland Christensen.[33]

2.3.1 Strengths in Saltworks: IP portfolio, Corporate Culture, Development Approach, and Customer List

Saltworks has several strengths that provide sustained competitive advantages and differentiate it from its competitors. First, the company has a very strong intellectual property (IP) portfolio. It holds over forty international desalination related patents and has several more pending. Saltworks possesses the patents for the core innovations of ElectroChem and SaltMaker as well as several process, application, and membrane patents. These patents ensure that the technology used in the SaltMaker and ElectroChem devices and plants are only available from Saltworks. This raises barriers of entry to other firms and provides a sustainable competitive advantage for the company.

Another advantage Saltworks enjoys is its strong company culture, guided by its key values of safety, quality, and productivity. Saltworks employs a multinational, multidisciplinary team of talented managers, engineers, technicians, and plant operators that collaboratively develop solutions for the world's toughest water challenges. The Saltworks team supplies insight and experience from a diverse range of perspectives and personalities. Staff are encouraged to interact with teammates to solve problems, identify and eliminate risks, ensure the safety of all

[33] Marketing Teacher. http://www.marketingteacher.com/history-of-swot-analysis/

staff and improve the quality of the final product. Project teams take ownership over the entire project to ensure the highest quality product is delivered. At its core, Saltworks culture is focused on quickly and iteratively innovating to provide quality solutions. This culture drives Saltworks abilities to quickly develop new solutions for customers; from concept to working prototype in a few weeks.

Saltworks has built an international reputation for tackling tough problems and quickly implementing custom solutions. The company has a prestigious list of customers for whom it has already successfully designed, developed and implemented water treatment solutions. Several of Saltworks industrial shareholders are also its customers. BP, Conoco Philips, Cenovus and Teck Resources have all piloted their wastewaters problems at Saltworks' R&D facility. Saltworks has also developed highly customised solutions for especially unique customers such as the Canadian Armed Forces and NASA.

The company's strongest advantage however, is its unique approach to developing new technology for challenging wastewaters. Saltworks' technology development process is staged, results based and customer focused. After initial contact with a customer, Saltworks performs a free desktop feasibility study. After confirming the feasibility, a customer is offered a free bench top study using the customer's wastewater in a test device at the Saltworks R&D facility. The next step is to deploy a mobile pilot plant to a customer's site to treat a customer's water under actual operating conditions. After a few months of pilot testing, customers can commission Saltworks to design, build, and deliver a customized water treatment system. This stepped method of testing and development has several advantages: it significantly reduces the risk to customers by delaying their full investment until after testing has confirmed feasibility; it allows both parties to explore the real nature of the treatment challenges involved; and finally, it enables the company to engage with its customers firsthand and build strong relationships.

2.3.2 Weakness in Saltworks: Small Size, Departmental Separation, Large Custom Products, and Entrenched Competitors

Saltworks has some inherent disadvantages it must overcome to succeed. First, the company's relatively small engineering and production facilities limit production to a handful of full sized plants per year. To meet the expected demand, Saltworks must grow several of its business operations simultaneously. There are various risks inherent in such quick growth. Saltworks must carefully balance capital, materials, and labour to ensure smooth operations during expansion. Production staff must increase in number to meet demand; at the same time, Saltworks must protect its strong culture as it grows. Improperly socialized new employees can dilute the focused company culture and potentially create detrimental sub cultures.

It is highly likely that the company's need to grow will result in the separation of different departments in separate facilities. This presents another potential disadvantage to overcome. Saltworks' unique need for access to saltwater for plant commissioning severely limits its options for expanding its test facilities. Ocean front industrial property in Vancouver is limited and expensive - the available space is small and not configured for manufacturing and engineering operations. As a result, Saltworks' operations currently span across three separate facilities. Separating interrelated parts of a small business creates inefficiencies and can compromise quality. Errors and miscommunications can occur between separated departments and these can affect quality. Material and people must move between the facilities, increasing costs and reducing productivity. Overcoming these disadvantages requires organization and planning but eventually consolidating as much of the business in a single location is critical to Saltworks' success.

Another disadvantage Saltworks must address relates to the limitations inherent in its main commercial product: large-scale water treatment plants. Saltworks builds its wastewater plants to order for customers and configures them for the customer's specific water chemistry. The high level of customization prevents the production of completed water treatment plants for inventory. Generally, production and ordering only begin after receiving a purchase order. This serial process produces long production lead-times. Fully assembled plants are assembled at Saltworks production facility for testing and tuning before shipment to a customer's site. Saltworks plants have significant lead-times and require large amounts of factory space for the production and assembly of completed plants. Large-scale production requires significant investment in tooling and facilities, reducing the company's net profits. In addition, these long lead times can damage the attractiveness of Saltworks water treatment plants to customers.

The last disadvantage is the superior position of incumbent competitors in the ammonia removal market. Large engineering firms such as GE, Siemens and Veolia have dominated the large-scale desalination and water treatment markets for decades. These large firms have several advantages in the ammonia removal market including the advantage of scale, a large existing customer base and established infrastructure. Incumbent firms also have greater access to financing. To compete with these giants, Saltworks needs to be flexible and respond quickly to market changes to out-manoeuvre the larger and slower engineering giants.

2.3.3 New Opportunities for Saltworks to Seize in Ammonia Removal Market

Saltworks has several opportunities for growth; the challenge is selecting the best ones. First, regulations limiting the concentration of ammonia in discharged wastewater around the world are increasing, causing entire industries to search for new solutions to their ammonia wastewater challenges. Many industries are now required to treat their wastewater for the first time; others need to increase their treatment processes to meet new regulations. Saltworks' position as a world leader in challenging water treatment technologies allows it to take advantage of these changing regulations by rapidly developing solutions for these new markets. Saltworks is expecting strong growth for many years as existing regulations in developed countries tighten and developing nations implement new regulations.

Another opportunity for Saltworks lies in the fact that developing nations are growing at a much faster rate than developed ones. These developing nations have rapidly growing populations and growing GDP, resulting in greater demand for energy, water, consumer goods, and natural resources. This has prompted the growth of several industries that produce ammonia impaired wastewaters. In turn, the increased volumes of wastewater along with increasing wastewater regulations have created significant demand for wastewater treatment capacity. These new markets represent a significant opportunity for Saltworks to grow.

Finally, population growth and climate change have inevitably increased global water scarcity. In turn, this has prompted nations and firms to invest in securing their future water sources and has refocused investment on water production, conservation, treatment, and reuse. The increased awareness of the vulnerability of global water supplies is a significant opportunity for Saltworks, as firms and nations seek to reduce their industrial water consumption. Reusing the freshwater recovered from industrial wastewater yields several benefits including reduced water consumption and reduced cost of water disposal.

2.3.4 Threats to Saltworks Development

Saltworks will face many threats as it grows and enters every new markets; the ammonia removal market is no exception. The types of threats Saltworks may encounter include the threat of a disruptive new competitor arising, intellectual property theft and imitation, global economic downturns in key markets, and entrenched incumbent competitors. Saltworks must guard against these threats by maintaining close contact with its markets and by diversifying across multiple markets.

Disruptive technological innovations can threaten any established business model. Saltworks is often a market disrupter, challenging incumbent water treatment companies. However, the company is vulnerable to disruption itself. Saltworks integrates its plants into its customers' existing industrial process, often as the last step before discharging or reusing the wastewater. Disruptive new technologies could arise that fundamentally change how Saltworks' customers perform their operations, possibly reducing or eliminating the need for Saltworks plants from entire industries. For example, the Saltworks landfill leachate SaltMaker reduces the volume of raw landfill leachate and concentrates it up to ten times its original volume. Landfill leachate is a new and promising market for Saltworks. However, for many space constrained nations and metropolitan areas the incineration of garbage is an attractive solution. Incineration does not produce any wastewater and represents an indirect threat to those that treat landfill leachate.

Another threat to future growth is intellectual property (IP) theft or imitation of its technology. Saltworks' has thoroughly patented its two core ElectroChem and SaltMaker technologies, which has raised the barriers of entry for new competitors in North America and other developed nations. However, in several parts of the world, intellectual property laws are not well enforced. For example, Saltworks recently started to offer its ion exchange membranes for sale to the Chinese market. Saltworks has chosen to offer only the membranes and not the SaltMaker or ElectroChem stacks due to the risk of potential competitors acquiring and reverse engineering its technology. Initial risk analysis of entering China suggested that IP theft was a significant risk and only products that were inherently more difficult to reverse engineer should be sold in that market.

The last threat impeding Saltworks' success originates from providing water treatment plants and services to industries strongly affected by fluctuations in the global demand for their products or key inputs. Commodity prices of oil, minerals, and electricity are cyclical and affect the capital investment strategies of large corporation in these industries as market conditions change. Large infrastructure investments can depend on favourable market conditions that can change quickly. Swings in global demand for commodities ultimately affect the demand for Saltworks treatment plants as large firms invest less capital during uncertain times but invest heavily in the expectation of growth.

2.4 Saltworks Entering the Ammonia Removal Market

This section reviews the preceding internal analysis of Saltworks and outlines the advantages and opportunities facing Saltworks as it seeks to enter the ammonia removal market. The discussion will cover the potential for Saltworks' technologies to develop and provide an effective solution to wastewater issues in this market and the likelihood that Saltworks will be successful.

The ammonia removal market is attractive to Saltworks due to the large potential market size, the lack of a single dominant competitor in this market and to the reality of increasing regulations governing ammonia in wastewater. Moreover, Saltworks has been able to develop unique competencies to address the challenges of treating ammonia-rich wastewaters. The company has already undergone similar experiences in entering other difficult water treatment markets such as the advance oil recovery and hydraulic fracking markets. These relatively new industries use new extraction methods that create unique water treatment challenges that no other company had been able to address. One of Saltworks' strengths is its ability to rapidly develop water treatment solutions for challenging applications, an advantage in new and growing industries. At present, there is no one dominant technology that is universally accepted to remove ammonia from wastewater, leaving the market open for an innovative new solution to become the dominant technology. Last, although most of the customers in the ammonia removal market are medium to large industrial operators, the volume of wastewater they produce is within the capacity of a standard Saltworks plant, giving this small company the ability to serve even very large companies.

The ammonia removal market is attractive to Saltworks due to the higher than average margins it offers. The clients in this market typically have a heightened inclination to pay for ammonia removal services, due to the potential penalties or even shutdowns they face. In addition, these companies also do not have a great number of alternative solutions available to them. Saltworks is uniquely suited to entering this market due to the original process it offers, the promising results of its initial ammonia removal prototype and because this market shares many similarities with other markets that Saltworks has been able to enter. The ammonia removal market is new and growing quickly, driven by population growth and new regulations. Saltworks is well placed to take advantage of this growing market and the opportunities it presents.

3: Review of Current Ammonia Removal Technologies

A wide range of technologies is used to treat ammonia-impaired wastewater, each with their own significant advantages and disadvantages. Some technologies been used for over 200 years while other methods have only been invented only recently. This chapter reviews the most common methods and technologies employed and assess their relative advantages and disadvantages.

3.1 Ammonia Removal Technologies and Processes

3.1.1 Biological Nitrification

Biological nitrification is by far the most common method of removing ammonia, used to treat wastewater in municipal treatment plants, impoundments (mine tailings, fracking fluid, sewage septic systems), landfill leachate (Dedhar and Saleem, 1985), pre-treated drinking water and as a way of cleaning zeolites (Lahav, Green, 1998). The process involves the nitrification of ammonia into nitrate, a less toxic form of fixed nitrogen than ammonia (Romano and Zeng, 2007). It is a two-step process. First, Nitrosomonas bacteria, a family of nutrient eating bacteria, convert ammonia (NH_4) into nitrite (NO_2). Next, Nitrobactor bacteria consume nitrite (NO_2) to produce nitrate (NO_3).[34] Nitrate is a form of fixed nitrogen that plants and microorganisms can absorb. It also readily decomposes into nitrogen gas, making it the desired final product of most biological nitrification processes. Biological nitrification is a simple and cost effective ammonia treatment process that is used to treat the bulk of ammonia pollution today.

The process of biological nitrification requires a significant amount of oxygen to fuel the conversion, requiring extensive aeration systems. Biological nitrification requires approximately 4.6 mg of oxygen per mg of ammonia nitrified. Put another way, removing 1 lb of ammonia requires 4.6 lbs of oxygen. Aeration is often the single largest operating expense of biological nitrification systems, representing an ongoing variable cost that increases linearly with ammonia removal rates. Aeration is one of the major disadvantages of biological nitrification.

[34] The Water Planet Company. http://www.cleanwaterops.com/wp-content/uploads/2014/01/Clean-Water-Ops-_-White-Paper_Nitrogen-Chemistry.pdf

Nitrification also requires time to allow bacteria to consume the ammonia. Nitrobactor and Nitrosomonas bacteria have slow reproduction cycles and are sensitive to temperature and pH values. This ultimately results in wastewater held for extended periods while bacteria reduces the ammonia to sufficiently low levels. For municipal wastewater plants treating large volumes of wastewater, this requires huge concrete tanks, holding millions of litters of wastewater.[35] Typical secondary stage water treatment requires resident times of between 4 - 8 hours. Extended aeration requires between 20 - 30 hours, a longer residency time than many companies or municipalities are willing to commit. The result is that ammonia is removed to levels that are not sufficiently low to meet current regulations. This problem is driving a demand for better ammonia removal technologies.

Biological nitrification yields nitrates, water, energy (heat), and acid. The acid by-product of the nitrification process reduces the alkalinity (pH) of the wastewater. In wastewater with a pH that lower than 7.6, nitrification may be sluggish due to a decrease in bacterial activity.[36] Wastewater with a pH of 9 or greater consists mostly of NH_3, the gaseous form of ammonia which cannot be converted by the Nitrosomonas bacteria. As is mentioned previous, Nitrosomonas bacteria can only absorb NH_4. It is essential therefore, that operators of wastewater plants must maintain the pH of wastewater at the optimal levels. Constant monitoring and adjustment of wastewater pH requires vigilant staff as well as consumable chemicals, adding to operating costs.

Biological nitrification is widely utilized within different systems to treat wastewaters. The most common approaches include activated sludge, extended aeration, sequencing batch reactors (SBR), trickling filters, membrane bioreactors (MBR), and lagoons.[37] Each system embodies the same features: the promotion of bacterial growth that will convert ammonia into nitrates, while also providing sufficient oxygen to drive the process. However, each system utilizes a different approach to minimize some of the disadvantages of biological nitrification. Membrane bioreactors treat wastewater in an enclosed reactor in batches, ideal for customers with low wastewater flow rates. Customers with larger wastewater flow rates use activated sludge and extended aeration in large concrete tanks to treat wastewater. MBR and SBR systems contain the wastewater within a reactor to control the temperature, acidity, and oxygen content of the

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[35] Hach. http://www.hach.com/asset-get.download.jsa?id=7639984562

[36] T.L. Joubert and Associates, https://d10k7k7mywg42z.cloudfront.net/assets/50c39265dabe9d025600360f/NitrificationBasics.pdf

[37] Water World Magazine. http://www.waterworld.com/articles/print/volume-26/issue-3/editorial-features/addressing-the-challenge.html

wastewater to improve nitrification rates. MBR and SBR systems typically require a smaller footprint than conventional open-air concrete tanks.

The advantages of biological nitrification process are numerous. It is simple, robust and effective at removing ammonia from very large quantities of wastewater. Moreover, it is a mostly passive and simple system that requires few moving parts. Operations can easily scale up and there are significant economies of scale when treating larger inflows of wastewater. Another advantage is its adaptability. Many customers can implement biological nitrification in existing wastewater treatment systems by the addition of aeration, the correct nutrients and seed bacteria. Operators may have to adjust process flow rate, oxygen demand and retention time to maintain the optimal conditions for nitrification. A final advantage is perhaps the long and successful track record of using biological nitrification for ammonia removal. Since its discovery by Sergei Winogradsky in 1888, industry has used biological nitrification as its primary method of ammonia removal.[38] It is well understood and accepted and, as a result, parts and expertise are widely available.

Biological nitrification, however, does have some disadvantages, including some that have been touched on already. As is discussed above, residence time for nitrification can be very long. It often necessitates very large tanks, requiring large amounts of land and big infrastructure. These represent the most significant capital costs of biological nitrification systems. Another disadvantage is that the rate of biological nitrification declines sharply with temperature. This is particularly significant as most nitrification systems are located outdoors. Therefore, ambient outside temperature has a significant influence on nitrification rates. As a biological process, biological nitrification is inherently uncontrollable. Oxygen levels, pH, and temperature can be somewhat controlled, however, nitrification systems are prone to upsets and must be closely monitored.[39] Another disadvantage is the expense of consumable chemicals such as oxygen and methane (added to assist in the last step of nitrification[40]). Aeration is the single largest operational expense of biological nitrification. The last and most important disadvantage of nitrification is that it ultimately cannot remove all the ammonia from wastewater. Ammonia removal rates are inversely proportional to ammonia concentration. To remove sufficient ammonia to meet new EPA regulations, impractically long residency times would be required.

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[38] Russia-IC. http://www.russia-ic.com/people/general/w/311/

[39] Waterfacts. http://waterfacts.net/Treatment/Activated_Sludge/Nitrification/nitrification.html

[40] Delft University of Technology. http://tudelft.nl/fileadmin/UD/MenC/Support/Internet/TU%20Website/TU%20Delft/Images/Actueel/Nieuws/2012/jan-feb mrt/LKY_WP_2012_Anammox_Fact_Sheet_Final_070312.pdf

3.1.2 Anaerobic Ammonium Oxidation (Anammox)

Anammox biological treatment is a relatively new yet effective method of biologically processing ammonia and nitrites directly into N_2. Contrasted with biological nitrification, which is a two-step process, anammox bacteria convert ammonia and nitrites directly into N_2 and H_2O, bypassing the traditional denitrification process.[41] Figure 4 illustrates the short cut that anammox presents in the denitrification of ammonia. Researchers discovered anammox bacteria in 1995 when they discovered that a previously unknown bacterium was converting ammonia directly into N_2 in a fluidized bed reactor (Mulder, van de Graaf, Robertson, Kuenen, 1995). Anammox shares many commonalities with traditional biological nitrification and is compatible with much existing infrastructure, allowing existing facilities to retrofit to anammox.

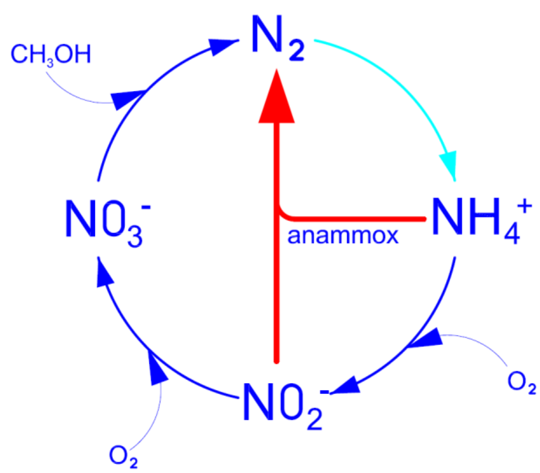

Figure 4: Anammox Nitrogen Cycle

Source: Author, based on diagram from Paques Inc.[42]

Anammox bacteria have several advantages over traditional biological nitrification. First, they produce far less sludge than conventional biological nitrification (Kartal, Kuenen, van Loosdrecht, 2015). Fewer bacteria are required for the anammox process, which translates into less biological material to remove as sludge. Anammox represent significant operational savings: there is less bio waste removal; there are capital cost savings because the process can be carried out in 50% smaller tanks; less mechanical equipment is needed to handle the sludge; and significantly fewer consumable chemicals are required to maintain the process. Oxygen consumption is up to 60% less and no organic carbon is required to fuel the anammox process. Organic carbon (usually methane) is required to complete the final step in conventional biological

[41] Paques. http://en.paques.nl/products/featured/anammox

[42] Paques. http://en.paques.nl/products/featured/anammox

nitrification process, converting nitrates into nitrogen gas using microbes already present in the wastewater. Removing the final step of nitrification also reduces carbon dioxide emissions by up to 90%.

The combined advantages of lower oxygen demand, no organic carbon, less sludge and lower CO_2 emissions makes for a very effective ammonia removal process, reducing the environmental impacts and operating costs of ammonia removal.[43] These advantages illustrate why anammox has enjoyed increased adoption in recent years.

The anammox process does come with some disadvantages however. Anammox bacteria multiply more slowly than Nitrosomonas bacteria. Moreover, they are more slow to rebound from a shock or system upset. Low growth rates of the bacteria can reduce the rate anammox can process ammonia. Therefore, anammox becomes very inefficient in unfavourable environments. Like biological nitrification processes, anammox is most effective in warm applications and with very high ammonia concentrations.

Another disadvantage is that anammox is a biological process and similar to all biological denitrification processes it requires oxygen to aerate the process, incurring similar operating costs to the biological nitrification described above. Aeration equipment is still required, meaning that operating costs may be lower than traditional nitrification but capital costs would be similar due to the initial costs to install the aeration systems. These disadvantages have limited the application of anammox to select situations; however, research continues to improve the anammox process.

3.1.3 Air Stripping

Air stripping ammonia from wastewater can be an effective ammonia removal technology for low ammonia concentration wastewaters. Air stripping involves dispersing wastewater over evaporation material, in a cooling-tower type structure, to promote the evaporation of ammonia from the wastewater into the air stream. The air stream is then exhausted, sent to an ammonia absorber, or thermally destroyed.[44] Exhausting air to the atmosphere is only permissible in locations where local ammonia emissions regulations permit. However, where it is permitted by regulations, it is the most economical disposal option.

[43] Delft University of Technology. http://tudelft.nl/fileadmin/UD/MenC/Support/Internet/TU%20Website/TU%20Delft/Images/Actueel/Nieuws/2012/jan-feb-mrt/LKY_WP_2012_Anammox_Fact_Sheet_Final_070312.pdf

[44] EPA. http://water.epa.gov/scitech/wastetech/upload/2002_06_28_mtb_ammonia_stripping.pdf

Ammonia absorbers are another cooling-tower type device that chemically converts the ammonia vapours into ammonia salts, such as the fertilizer ammonium sulphate. Thermal destruction of ammonia requires heating an oxidizing catalyst to break the ammonia into water and carbon dioxide.

Ammonia air stripping has several advantages. It requires significantly less space than biological nitrification ponds, reducing initial capital costs and allowing for addition to existing facilities. Second, ammonia air stripping can disperse ammonia into the atmosphere, removing the costs of disposal. However, air stripping removes ammonia from the gas stream at a fixed percentage, based on the temperature and pH of the wastewater. Therefore, greater reduction of ammonia simply requires multiple passes through the air stripper. Another advantage of air stripping is due to its simple construction. Air stripping is a simple, easily controlled, easily scaled, and universally accessible method of ammonia removal. The last advantage of air stripping is that it can process water that is impaired or otherwise toxic to biological nitrification. These advantages prove air stripping is an economical method of treating ammonia from small to medium concentration sources, especially those that contain other chemicals toxic to biological nitrification.

Air stripping also has several disadvantages compared to other methods of ammonia removal. It removes a fixed percentage of ammonia from a wastewater stream in a single pass, for a given temperature. Air stripping cannot economically attain very low ammonia concentrations. Multiples passes through the stripper are required for lower concentrations. However, the efficacy of each pass diminishes with the concentration (Huang and Chii Shang, 2006). Another disadvantage is that air stripping exhausts the ammonia into the atmosphere as a final means of disposing of it. Many regions in the world regulate ammonia exhausting, sometimes more so than aquatic ammonia pollution. If regulations prohibit the free exhaust of the ammonia, plant operators must dispose the ammonia vapour another way or convert it to fertilizer for sale[45]. Converting the vapour into ammonia fertilizer requires a consumable anion particle, usually sulphur, or nitrate, to create ammonia salts. The costs of converting vapour into fertilizer, bagging, and distribution often outweigh the profits from fertilizer sales. Another disadvantage of air stripping is that it is an active, mechanical process. Pump, fans, and heating catalysts consume energy, increasing operating costs. At large volumes or concentrations, other means of ammonia removal are more economical, with lower operating costs. The last disadvantage of air stripping is that its efficiency is highly dependent on the process temperature. Removal rates of 90 – 95% are

[45] Branch Environmental corp. http://www.branchenv.com/air_strippers/Ammonia%20Stripping.pdf

possible with 20°C air; however, recovery drops to 75% at 10°C air stream (Cheremisinoff, 1994). Temperature is a significant variable affecting productivity and limiting air stripping effectiveness to warmer climates. The disadvantages we have reviewed explain why air stripping has had limited market acceptance.

3.1.4 Breakpoint Chlorination

Breakpoint chlorination is the process of destroying ammonia by adding chlorine to water. Breakpoint chlorination occurs when enough chlorine is present in the water to react with all of the free organics and ammonia. Free available chlorine residual is the chlorine added to water, beyond the breakpoint of chlorination, which is stays in the water and is available to disinfect the water in the future. Health Canada requires some level of free residuals in drinking water, to keep the water disinfected until it is used.[46] Figure 5 illustrates the relationship between chlorine dosage and free residual chlorine.

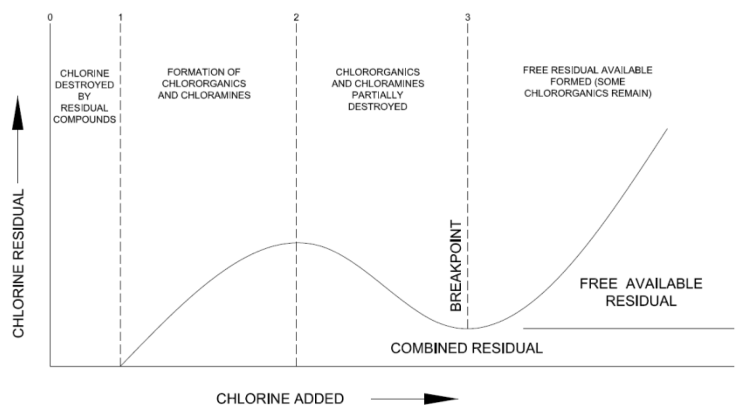

Figure 5: Breakpoint Chlorination, Chlorine Residual vs. Chlorine Dosage

Source: author, based on diagram from Water Treatment Operator Handbook, (Pizzi 2011)

Breakpoint chlorination can remove ammonia by converting it into various chloramines, depending on the pH of the water. Chloramines are mild, non-toxic disinfectants that contribute to the overall free residual chlorine level in water. However, it requires, on average, a ratio of 8:1 of chlorine to ammonia to convert all the ammonia into chloramines (Pressley, Dolloff, and Roan, 1972).

Breakpoint chlorination has several advantages compared to other ammonia removal methods. First, in addition to removing the ammonia from water, chlorine sanitizes the water by

[46] Health Canada. http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/chlorine-chlore/index-eng.php#a3

destroying other pollutants. This could be an advantage for industries, such as cattle and swine rearing, that are already chlorinate their wastewaters to remove biological contaminants. Another advantage is the ability of this process to remove virtually all the ammonia from water, something that is difficult for other ammonia removal systems to accomplish. Another advantage is the very small installation size and simplicity of the operation required for breakpoint chlorination. A typical installation consists of a small tank to hold chlorine, a small dosing pump, some pipe-work, and a control unit. A compact chlorination system can treat a large volume of water. The final advantage of breakpoint chlorination is its ability to completely destroy the ammonia in wastewater, removing any costs and environmental hazards associated with disposing a waste product. These advantages ensure that some industries will utilize breakpoint chlorination as an ammonia removal system.

Breakpoint chlorination also has several disadvantages. First, the amount of chlorine required to remove ammonia depends on water temperature, pH, and the presence of other contaminants. If other contaminants are present in wastewaters, they may consume free chlorine, reducing chlorine's ammonia removal capabilities. Therefore, the volume of every chlorine injection requires careful calculation based on actual water chemistry, to ensure sufficient chlorine is added to destroy the ammonia. Another disadvantage is that breakpoint chlorination cannot remove nitrate and nitrites from wastewater. Nitrate and nitrites are regulated pollutants that are similar to ammonia and are often present with ammonia in wastewaters. Biological nitrification processes naturally remove nitrate and nitrites from wastewater, as they are already intermediate steps of those processes. The last disadvantage is that breakpoint chlorination requires the handling and use of concentrated chlorine, either in gaseous or liquid form. Large volumes of chlorine represent health and environmental risks and invariably increase operating costs due to the safety equipment, training, and infrastructure required. The disadvantages examined above limit the industrial acceptance of breakpoint chlorination as a method of ammonia removal.

3.1.5 Zeolite Ion Exchange

Zeolites are minerals with many microscopic pores that can absorb ammonia from waste streams. They have many commercial and industrial uses as they have a very large surface area due to their micro-porous structure. Zeolites occur naturally as mineral deposits in many parts of the world; there are over 40 different kinds of naturally occurring zeolites. Different deposits produce different kinds of zeolites, with different chemical and mechanical properties.[47] Ion exchange firms also engineer and manufacture synthetic zeolites that have specific features and properties. Ion exchange filtration processes use synthetic zeolites to remove a range of substances. Among their many uses, zeolites can absorb ammonia from wastewater and gas streams. Natural zeolites, particularly clinoptilolite zeolites, are most commonly used to removal ammonia. However, synthetically derived zeolites have been engineered to have the correct pore size to accommodate ammonia particles, making synthetic zeolites potentially more effective than natural zeolites at removing ammonia (Jorgensen, Weatherley, 2013). Zeolites are more effective at removing low concentration ammonia than most other methods, recovering almost 98% of ammonia from a wastewater stream (Chuan, 2000).

Zeolites work by lightly holding harmless cations (positively charged partials) in their pores which then switch places with other cations present in a water passed over the zeolite . This allows zeolites to remove ammonia from a wastewater streams by swapping the ammonia ions in the wastewater with other cations (usually sodium) held in the zeolite. Fresh zeolite systems are full of sodium ions and as the zeolite is used, the sodium swaps with ammonia from the wastewater. Zeolite resin is often packaged into cartridges for easy sizing and replacement. Eventually the zeolite cartridge is full of ammonia and must be replaced or regenerated.

Replacing zeolite is a simple operation as most disposable zeolite cartridges are small and designed for easy replacement. However, larger systems can regenerate zeolite saturated with ammonia. There are multiple methods of regenerating zeolite, depending on the system and type of zeolite used. In the first method, a caustic brine solution washes the zeolite. The caustic removes the ammonia ions and the sodium ions in the brine take their place. The wash fluid produced by regenerating zeolite saturated with ammonia is disposed of or is regenerated by biological nitrification (Cooney and Booker, 1999). Some systems regenerate by promoting the growth of bacteria on the zeolites to consume the ammonia, eventually cleaning the zeolite rendering it useable again (Lahav, Green, 1998).

Zeolites have several advantages over other ammonia removal systems. First, similar to breakpoint chlorination, zeolites are able to remove virtually all the ammonia present in wastewaters. For this reason, final polishing steps in ammonia removal systems often use zeolites (Wang, Kmiya, Okuhara, 2007). Another advantage is that its operation is insensitive to wastewater temperatures. This means that zeolites are ideal for colder climates, where outdoor biological nitrification is impossible. Another advantage is that zeolites do not require any

[47] USGC. http://minerals.usgs.gov/minerals/pubs/commodity/zeolites/zeolimyb04.pdf

consumable chemicals for normal operation. They absorb ammonia with no chemical pre-treatment, reducing system complexity and risks of chemical handling. Avoiding chemical injections into the wastewater permits zeolites to be used in situations where changing the wastewater chemistry is undesirable, such as in aquaculture and chemical production applications. The last advantage of zeolites is that systems are small in size, very simple to operate, but can be easily scaled up by adding more modules to increase capacity. Zeolites are an effective means of removing, making it popular ammonia treatment option for consumers, laboratories, and industrial users as a final polishing step.

There are several disadvantages of Zeolites compared to other ammonia removal solutions. First, full zeolite cartridges require regular regeneration or disposal. Replacing disposable cartridges is a simple exercise but would be a significant operating expense over time. Regenerating zeolites may produce an ammonia wastewater stream. This waste stream needs disposal or treatment, which increases operating costs. Next, the capacity of any zeolite system is dependent upon its volume of ion exchange material. Large-scale users would need to install a very large system or regenerate the zeolite material frequently, increasing process downtime. Another disadvantage of zeolites is that other alkali metals reduce the ammonia absorption rate. Zeolites have a slight negative charge, creating a natural affinity for most alkali metals such as calcium and magnesium. As a result, zeolite systems will not remove ammonia as effectively with harder or saline wastewaters. The other, less harmful, ions occupy space within the zeolites, reducing the system's capacity to remove ammonia. These disadvantages limit zeolites to small-scale consumers, aquaculture, swimming pools, and industrial polishing.[48]

3.1.6 Liqui-Cel® Membrane Contactors

Liqui-Cel membrane contactors are a new proprietary technology that can efficiently remove ammonia from wastewater streams and convert into ammonium sulphate ($(NH_4)_2SO_4$), a fertilizer that can be resold. Liqui-Cel membrane contactor devices utilize membranes, formed into tubes, to promote ammonia diffusion into a sulphuric acid stream flowing inside the tubes. The device is similar in construction to shell and tube heat exchangers; wastewater passes through the outer shell of the device and sulphuric acid flows inside the tubes.[49] The tubes are hydrophobic (water repellent) but are punctured with microscopic pores. Water cannot enter the pores because of hydrophobicity and surface tension. However, ammonia is able to enter the

[48] Lenntech. http://www.lenntech.com/zeolites-removal.htm
[49] Liqui-Cel. http://www.liquicel.com/applications/ammonia-removal.cfm

pores and reacts with the sulphuric acid inside the tubes to produce ammonium sulphate as the waste product of the process (Chou, Rostam-Abadi, and Lytle, 1996). Osmatic pressure of the ammonia passing into the tubes, to react with the sulphuric acid, drives the process. Because the Liqui-Cel device removes ammonia and converts it into an ammonia salt in a single step, it is attractive to some market segments that prefer to convert their waste ammonia into fertilizer for re-sale.

Liqui-Cel has several advantages over conventional ammonia removal technologies. First, Liqui-Cel systems have smaller capital and operating costs. A compact footprint requires a smaller building and process infrastructure. Simple installations are easy to operate, reducing operator training and maintenance. Next, Liqui-Cel systems are insensitive to process temperature, making them especially attractive to northern applications where an outdoor process is impractical. Another advantage is the ability to remove ammonia regardless of the ammonia concentration in the wastewater. The ammonia removal rate of conventional systems decreases proportionally with ammonia concentration. These advantages position Liqui-Cel devices as a viable alternative to traditional ammonia removal and ammonia salt production systems.

The Liqui-Cel ammonia removal devices also have inherent disadvantages. Liqui-Cel systems require several consumable chemicals to operate. The pH of the wastewater requires adjustment to a pH value of 10 with a caustic chemical pre-treatment.[50] The sulphuric acid stream requires continual replenishment as the acid reacts with the ammonia to form ammonium sulphate. The consumable chemicals required for normal operation of the Liqui-Cel system increase the systems' operational costs. The resulting ammonium sulphate can be profitably sold in some markets, however the high capital costs of processes equipment, safety equipment, sulphuric acid storage and handling, and the fluctuating price of bulk ammonium sulphate mean that the costs of producing ammonium sulphate often outweighs the potential profits from selling it.[51] However, it is often required as the only practical way to dispose of ammonia produced by some industrial processes (Chou, Rostam-Abadi, and Lytle, 1996), (Nemerow, 2010).

Liqui-Cel provides a superior process to remove ammonia and convert it into an ammonium salt in a single step. In a case study, Liqui-Cel ammonia removal devices was able to successfully remove 95% of the ammonia present in a 132 GPM wastewater stream with an inlet ammonia concentration of 500 mg/L. Based on the recovery rate, the discharge emissions were 25 mg/L. Liqui-Cel also provides examples of an implementation of its device in manufacturing

[50] Liqui-Cel. http://www.liquicel.com/uploads/documents/TB74-Ammonia-Removal-10-09.pdf
[51] SunSirs. http://www.sunsirs.com/uk/prodetail-236.html

plants. The Liqui-Cel device processed a 44 GPM wastewater stream with an inlet ammonia concentration of 1100 mg/L, discharging an effluent stream with 55 mg/L of ammonia.[52] Although Liqui-Cel is limited to situations where the production of ammonium salts is desirable, additional analysis can determine if the Liqui-Cel process is superior to Saltwork's ammonium salts process.

3.1.7 Summary of Current Ammonia Removal Technologies

This chapter reviews the most widely utilized methods of ammonia removal and disposal. Appendix A provides a summary of ammonia removal technologies and their relative advantages and disadvantages. A wide range of technologies and processes serve the market for removing ammonia from wastewater. However, each removal technology comes with advantages and disadvantages that make them particularly suited to some applications but not to others. As a result, there is no single dominant technology and overall customer needs in this market are not being satisfied. An example of a technology dominating an entire market would be the way reverse osmosis has dominated the seawater desalination market for decades.

Most established ammonia removal technologies primarily rely on some form of biological nitrification. This group of technologies include conventional biological nitrification, anammox, MBR, SBR, and the regeneration step for some zeolite processes. These systems are cost efficient as they are simple, easily scalable and do not require significant amounts of energy to maintain. However, biological nitrification has several limitations. As a biological process, it is inherently non-controllable, which leads to system upsets, process crashes, and headaches for plant operators. Because of the nature of biological nitrification, ammonia removal rates decrease at lower temperatures and with too high or too low pH. Another major limitation is that the bacterium that consumes ammonia requires long exposure times for it to consume all the ammonia. This usually results in large tanks for long residency times. This means installations are large and costly. Retrofitting existing facilities with more biological nitrification is often impossible due to space restrictions. These limitations increase the overall cost of biological nitrification, especially retrofit systems, and reduce the attractiveness to customers building new plants.

Several alternative technologies have been developed to overcome the shortcomings of biological nitrification. Established alternative technologies include air stripping and breakpoint

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[52] Liqui-Cel. http://www.liquicel.com/uploads/documents/TB53%20Rev1%20Referral%20Sheet%2010-05.pdf

chlorination. Zeolite ion exchange materials and Liqui-Cel membrane contactors are prime examples of new technologies that have been recently developed to remove ammonia. These alternative technologies have varying advantages and disadvantages however most are compact and easier to control than biological nitrification. However, most alternative technologies convert the ammonia to another product that must be collected and sold or disposed of. Many of these technologies also require extensive pre-treatment systems. Together these limitations increase the relative cost of alternative ammonia removal technologies and have prevented them from dominating biological nitrification.

The most commonly utilized ammonia removal technologies force important tradeoffs for plant owners. No single technology has dominated the entire market; each market segment utilizes different technologies. Saltworks has an opportunity to provide a product that has fewer tradeoffs, better technical performance, and can equally serve multiple market segments. As world regulations tighten on ammonia discharge levels, industry will require better solutions. Saltworks has an opportunity to revolutionize the market and grow its reputation as a world leader in water treatment technology.

4: Competitive Analysis of Ammonia Removal Industry

The competitive landscape of the ammonia removal market is complex as there is much overlap between treatment plant builders, conventional wastewater technology manufacturers, and innovative new technology developers. This chapter analyses the competitive landscape of building and installing ammonia removal systems. We use a modification of Porter's five forces model to map the influence of suppliers, customers, new entrants, substitutes, and direct competitors in the ammonia removal market (Porter, 2008). Figure 6 depicts Porter's framework applied to the ammonia removal market. However, in the wastewater industry government policy also has a very big impact. New regulations have lowered the limits for many pollutants, including ammonia, which has significantly affected the water treatment and ammonia removal industries. Therefore, we consider government regulations to be a sixth force (McGinn, 2010). This chapter analyzes each of these six competitive forces as they affect the ammonia removal market, in order to understand the risks and hazards for Saltworks.

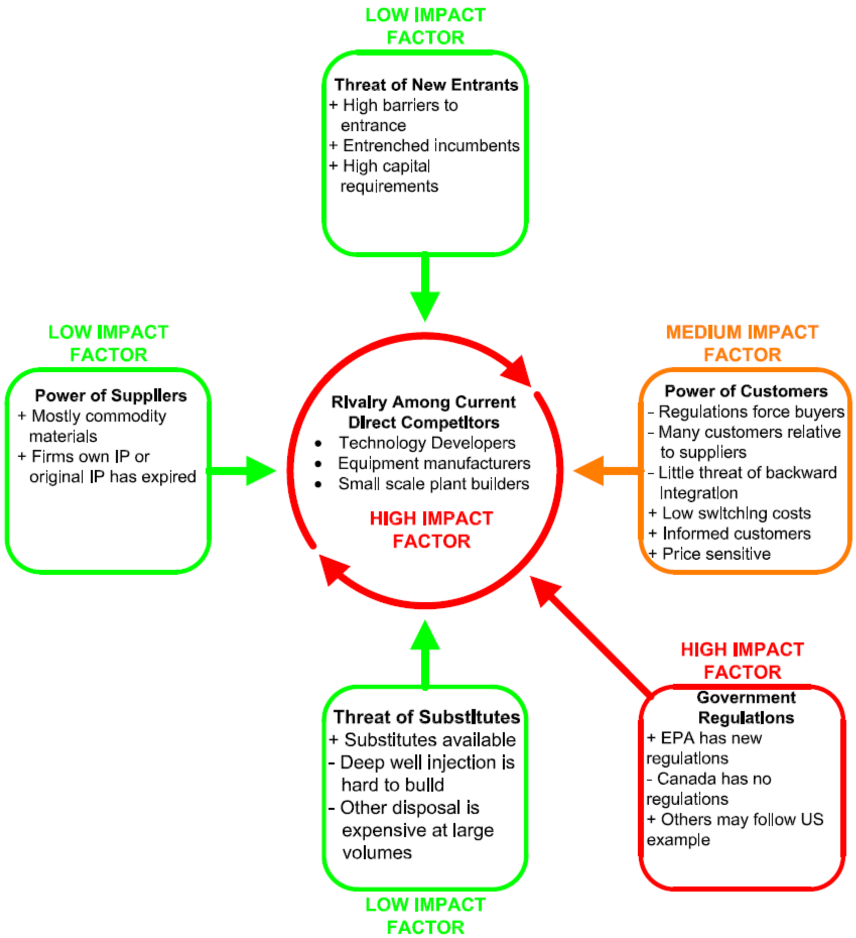

Figure 6: Porters 5 Forces of Competition
Source: Author, adapted from Porter, 2008[53]

4.1.1 Current Direct Competitors: High Impact Factor

Direct competition in the ammonia removal market is fierce as there are many different types of firms competing for the same customers. The primary kinds of competitors in this market are specialized technology developers, generic equipment manufacturers, and large and small plant packagers. These firms provide varied and overlapping services to industry and WWTPs requiring ammonia treatment systems. Technology developers often begin as start-ups, developing a proprietary ammonia removal technology to compete with conventional technologies provided by established equipment manufacturers. Plant packagers large and small build ammonia removal systems using purchased technologies from the technology developers and equipment manufacturers. Table 1 provides examples of each type of firm and the type of technology utilized.

[53] Harvard Business Review. https://hbr.org/2008/01/the-five-competitive-forces-that-shape-strategy/ar/1

Firm Classification	Technology Developer, Plant Packager	Technology Developer	General Equipment Manufacturer	Plant Packagers Biological Nitrification
Technology	Proprietary Ion Exchange	Transmembrane Chemisorption	Air stripping	(MMBR, SBR)
Example Firm	**Saltworks**	**Polypore / Liqui-Cel**	**Delta Cooling Towers**	**Veolia**
Threat Level	NA	High	Medium	Low

Table 1: Current Direct Competitors in the Ammonia Removal Market
Source: compiled by author with information from:
http://www.saltworkstech.com/ammonia-splitter
http://www.liquicel.com/applications/ammonia-removal.cfm
http://www.deltacooling.com/air-strippers-degassifiers
http://technomaps.veoliawatertechnologies.com/hybas/en/

Specialized technology developers are firms that have developed proprietary ammonia removal systems and manufacture the core of their technology to sell to end users and plant packagers. Examples include firms such as Polypore International that produce Liqui-Cel contactors[54] and Paques, which distributes anammox bacteria.[55] Technology developers' business model is to develop and manufacture the core elements of their technology and provide engineering support to assist in its implementation at customer sites. They do not construct the infrastructure or most of the process equipment utilized in their processes. Specialized technology developers compete by developing new solutions for market segments where conventional technology is deficient. These firms enjoy several advantages over the other kinds of competitors. First, they have developed a differentiated technology that is technically capable of more than the existing technology. Next, as technology developers do not build or install their products at end user's facilities, these firms are able to focus more resources on developing their core product. Last, technology developers can more easily reach significant economies of scale in production than plant packagers can. Technology developers manufacture standardized components (or vials of specialized bacteria) and can easily use automation and assembly line practices to gain economies of scale. Plant packagers always have to cope with some degree of customization,

[54] Polypore International. http://polypore.net/Pages/default.aspx
[55] Paques. http://en.paques.nl/products/featured/anammox

which reduces their productivity. For the reasons discussed, the threat presented by technology developers is high. They have the capabilities to create innovative new products and they control the distribution of the core elements of their technology.

The devices produced by technology developers have different technical abilities and limitations compared to Saltworks' technology. Saltworks device is small, requires no consumable chemicals, is insensitive to temperature, and can convert ammonia into multiple products by design. No competing technology has all the same features packaged into a single system. Because of these advantages, Saltworks technology is very attractive for demanding applications. Saltworks can compete more efficiently in these demanding market segments than other technology developers. Another factor favouring Saltworks is its unique customer engagement process. It combines an innovative and customizable technology with substantial in-house manufacturing capabilities to deliver and integrate ammonia removal plants into a customer's process. Saltworks manufactures, installs, and commissions its own plants. Therefore, it is more easily able to control the quality of its final product, something other technology developers can do only indirectly. This also allows Saltworks to directly engage and build relationships with customers. Although technology developers have several advantages, Saltworks unique technology allows it to compete effectively in select markets, particularly those with high ammonia concentrations, even against incumbent technology developers.

Conventional equipment manufacturers are firms that design, manufacture, and install medium to small ammonia removal systems at customer sites, typically as modular components. Examples of these types of competitors include manufacturers of air strippers (Delta Cooling Tower[56]), membrane bioreactors (Lenntech[57]) and ion exchange cartridges (ResinTech[58]). These technologies are well established and the core process patents have expired. Many of firms perform R&D and develop proprietary enhancements such as the patented air-stripping tower packing media developed by Lantec[59], or KUBOTA membrane bioreactors[60]. Many independent firms manufacture and market similar ammonia removal processes. These firms compete by incrementally improving their products and building brand reputation among end users and plant packagers. They sell both the main components of ammonia removal systems, such as membrane bioreactors or air-stripping towers, and provide some installation and support services. Equipment

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[56] Delta Cooling Tower. http://www.deltacooling.com/air-strippers-degassifiers/
[57] Lenntech. http://www.lenntech.com/processes/mbr.htm
[58] ResinTech inc. https://www.resintech.com/products/ion-exchange-resins/specialty/sir600
[59] Lantec. http://www.lantecp.com/w/casestudy/cs49.pdf
[60] Kubota Membrane USA. http://www.kubota-membrane.com/

manufacturers do not provide site infrastructure or other parts of the wastewater treatment process. These firms have relatively few competitive advantages over other equipment manufacturers and there are few barriers to entry, so competition between them is fierce. Ammonia removal is a cost for most industries; customers, therefore, will seek the lowest cost solution (both capital and operational) that meets their discharge regulations. Competition in the equipment manufacturing market is fierce and margins are low. Companies compete mostly on price, reducing the overall profitability of this market segment. For this reason, competing directly in this market will not allow Saltworks to growing as quickly as it could otherwise. The threat presented by conventional equipment manufacturers is moderate.

Saltworks can extract the greatest value from its technology by targeting market segments that face wastewater challenges conventional equipment manufacturers cannot solve but Saltworks is able to offer a technical solution. For example, a shared limitation of both air stripping and bioreactors is their sensitivity to water temperature. Saltworks' technology is indifferent to water temperature, making it ideal for cold climate applications. As Saltworks grows and further penetrates its target markets, it will have to find operational efficiencies to bring down manufacturing costs and increase production rates in order to keep its own prices low.

The last group of direct competitors are plant packagers. Many companies around the world design, build, and operate large infrastructure projects such as wastewater treatment plants. Large firms that specialize in designing and building large infrastructure projects that include the Engineering, Procurement, Construction aspects of infrastructure projects are EPCs. The size and nature of plant packagers varies greatly but includes multinational conglomerates (GE[61]), large construction companies (Kiewit[62], Flatiron[63]), and wastewater plant engineering companies (Veolia, Corix[64], and Doosan[65]). Many large EPCs are also equipment manufacturers. For example, GE and Corix Water Products manufacture membrane reactors and aeration equipment as well as build the general plant infrastructure. Not all EPCs are competitors of Saltworks, some may potentially be partners of sorts. Saltworks can sell the core elements of its ammonia removal system to EPCs that will integrate them with other equipment to form a complete treatment system. Conglomerates consist of independent business units that may compete with each other for projects. The division of GE that builds wastewater treatment plants is separate from GE's membrane bioreactor division. Saltworks can supply GE Construction with technology in

[61] GE. http://www.gewater.com/index.html
[62] Kiewit. http://www.kiewit.com/markets/waterwastewater/
[63] Flatiron Corporation. http://www.flatironcorp.com/index.asp?w=pages&pid=32
[64] Corix Water Systems. http://www.corix.com/products/water-systems/wastewater-treatment-plants
[65] Doosan. http://www.doosan.com/en/business/business.do?bizCode=8045&bizSubCode=8270

competition with other GE divisions. As Saltworks current goal is to enter and grow its ammonia removal technology, it will not be competing with any EPCs to build large-scale projects anytime soon. It will seek to only supply them with equipment. Therefore, EPCs represent a small threat to Saltworks: they are more complementary than competing against Saltworks.

Direct competitors represent the greatest challenge to incumbents' success in the ammonia removal market. Although different categories of competitors represent different levels of threat to Saltworks, the overall threat presented by direct competition is high. Saltworks needs to pick its target markets with care to avoid competing directly against other firms on price in applications with low margins. Instead, it should focus on the most challenging market segments where existing competitors are unable to solve ammonia treatment problems due to technical limitations.

4.1.2 Threat of New Direct Entrants: Low Impact Factor

The threat of new entrants is low in the ammonia removal market. New entrants must contend with established incumbents that have erected several barriers to discourage new comers. However, Saltworks represents the most significant threat from a new entrant in this market.

The most significant barrier to new entrants is the difficulty of achieving sufficient economies of scale to be competitive in this market. Water treatment systems are complex, semi-customized products that require careful engineering, planning, and execution to produce. New entrants cannot build systems as efficiently as experienced incumbents due to operational efficiencies and economies of learning. Increasing production rates to decrease unit costs is also difficult for new entrants to achieve because of the capital required and their lack of market share. Large EPCs typically have a lower cost of capital than smaller or younger firms do. They can achieve efficiencies of scale by building large projects at a lower cost than smaller competitors can. Larger projects allow EPCs to minimize administrative and management overhead on projects. It can be difficult for new firms entering the ammonia removal market to compete against larger firms who can offer lower unit prices and larger volumes.

Saltworks can overcome this barrier by several means. First, Saltworks offers a differentiated product that can demand higher margins. The higher margins allow Saltworks to build its efficiencies of scale by investing in its capabilities, developing its products, and building its customer list. Next, Saltworks needs to be selective about which markets it initially enters to focus its limited R&D and engineering efforts on the most valuable applications. Last, Saltworks needs to grow its organization and improve its engineering, supply chain and production processes to gain operational efficiencies. Simple efforts such as reducing the number of discrete parts required, reducing customization, and building plants from standardized modules can yield significant savings.

Another major impediment to new entrants in the ammonia removal market is the high capital costs associated with manufacturing and installing large wastewater treatment plants. Payments are spaced throughout the project and often based on milestones. Construction of large WWTPs and ammonia removal systems can take many months to complete and require significant wherewithal to fund operations and production of the plants months before receiving complete payment. Increased production rates compound this problem until maximum efficiencies of scale are reached.

To grow within the ammonia market, Saltworks will have to fund its growth through bootstrapping or raising additional capital. Bootstrapping is impractical, given the high value and long leads times for each plant. Saltworks could raise funds from its existing directors or look for a new industrial investor, perhaps a large customer in the ammonia removal market. An IPO would also allow Saltworks to raise money directly from the market to fund increased production to maximize growth. Due to the capital and risk involved with high value, customized goods like water treatment plants, financing is a large challenge for Saltworks in the ammonia removal market.

The last significant barrier to new entrants is the established relationships that institutional customers have with incumbent competitors. Purchasers of large wastewater treatment processes are mostly institutional and large corporate entities. The managers of these entities are risk adverse and conservative in both their investments and interactions with suppliers. Incumbent firms have invested a great deal in building their brand and reputation with institutional customers. As each customer makes relatively few purchases, brand is an important way to convey corporate values to new customers. Therefore, many conservative entities would hesitate to purchase an innovative system from Saltworks due to the perceived risk of purchasing a new technology from an unproven firm.

To overcome this barrier, Saltworks needs to leverage its existing customer list to find the customers who are unsatisfied with existing ammonia removal. These customers are seeking a new solution because conventional technology has been unable to solve their problems. Saltworks technology, with its suite of advantages, offers industry another alternative to consider. Although the relative youth of the company is a disadvantage for some, there are enough motivated early adopters for Saltworks to service in its first few years in the new market. These initial customers would allow Saltworks to establish itself in the industry before targeting more risk adverse customers. Although this disadvantage is significant, the threat presented by conservative customers and their preferred vendors is only medium. The ammonia removal market is vast and Saltworks has many opportunities to prove itself before needing to approach the most conservative customers.

The overall threat that new entrants pose to incumbent firms in the ammonia removal market is low. Saltworks can overcome these barriers due to its highly differentiated product. Saltworks technology can achieve removal levels difficult to achieve with other methods in a cost and space effective package that has very low operating costs. By leveraging those advantages and focusing on the market segments where Saltworks technical advantages are critical, Saltworks can enter and grow within the ammonia removal market, despite the advantages of incumbent firms.

4.1.3 Influence of Customers: Medium Impact Factor

The influence of customers in the ammonia removal market is moderate. Customers tend to be large institutional and corporate entities or small to medium sized industrial facilities. These entities either own wastewater treatment plants that require retrofit to handle additional ammonia pollution or are planning to build a new WWTP that includes ammonia removal systems. For this analysis, we consider customers seeking ammonia removal systems for retrofit to be similar to those seeking systems for new construction.

Due to social, economic, and political trends such as increasing urbanization, growth in population and GDP and increasing regulations, wastewater plant construction is a growing market segment in most parts of the world. Municipalities must invest in WWTPs as population growth and urbanization lead to industrial growth with resulting increases in wastewaters. Industry faces mounting pressure to treat wastewaters from government regulations, environmental groups, and public perceptions of accountability. As a result, demand for water treatment is growing.

Several factors boost the power of customers in the ammonia removal market. First, customers have good access to information. WWTPs are large and expensive so investments are infrequent. The decision to purchase a WWTP is a major one so customers tend to look carefully into the purchasing decision; they are generally well informed about the options available to them. The tasks required to construct a WWTP are well known and costs are relatively easy to determine, therefore costing is transparent. These factors moderately increase the information at the disposal of customers, increasing their bargaining power over suppliers.

Another factor supporting the power of customers is the generic nature of most water treatment processes. Detailed knowledge about treatment processes is widely known. The materials and skills required for construction are also common knowledge. Virtually any construction company could build a WWTP and substitutes exist for almost every firm contracted and component used. Therefore, switching costs are low for customers. Although WWTPs are generic products, they are customized to meet each customer's unique criteria. Customers are not interested in features besides those they have specified. Beyond ensuring that the WWTP is able to address the specific customer criteria, the most important factor determining supplier selection is cost both in terms of construction and thereafter of operation. WWTPs operate as cost centres, whose definition of success is delivering acceptable service as cheaply as possible. This factor contributes a small amount of additional power to customers over suppliers of WWTPs and ammonia removal systems.

However, other factors reduce the power of customers in the ammonia removal market. First, most WWTPs are owned by entities such as municipal governments and large corporations. As WWTP are more efficient as they become larger, most customers only own a handful of WWTPs at strategic locations. Therefore, the distribution of the wastewater plant market is many independent entities that purchase few plants over their lifetime. There are few repeat buyers of WWTPs. The negotiating power of buyers is therefore lower, since each purchase is most likely to be the only one the customer makes.

A moderately impactful factor working against customers is that there are relatively fewer builders of ammonia removal systems compared to the number of customers. Therefore, WWTP builders have more freedom to pick which projects to bid on and accept. If WWTP builders can afford to walk away from bad deals, they have more negotiating power over customers, who ultimately need one of the few qualified entities to build their WWTP.

The last factor that strongly favours the builders of WWTPs over customers is that there is a very low risk of backward integration. Purchasers of WWTP are very unlikely to want to move into WWTP construction themselves. WWTP builders are thus safe from competition from their customers, unlike other industries, such as steel production and automotive manufacturing, where backward integration is common. However, EPC can and do become owners and operators of WWTP. Many large infrastructure contracts include an operation period to ensure the plant is fully functional. Some contracts require the builders to operate the plant for decades; in those cases, the plant builders recover the costs of building the plant by operating it for years before turning over ownership to the municipality the plant serves. The low risk of backward integration is a powerful factor that favours suppliers of ammonia treatment technology and ultimately reduces the power of customers.

The overall power of customers in the WWTP market is moderate due to the information customers possess, the low switching costs, and the generic nature of WWTPs. Overall, the balance of power between buyers and builders of WWTPs is slightly in favour of plant builders. The most important factor giving power to the providers of WWTP is that, ultimately, all customers are purchasing ammonia removal systems because regulations beyond their control are forcing them to do so. The installation of WWTPs is mandatory for most customers, reducing the relative power of customers over suppliers.

4.1.4 Influence of Suppliers: Low Impact Factor

The influence of suppliers on Saltworks and other WWTP builders in the ammonia removal market is low. The materials and components used to build WWTPs and ammonia removal systems are undifferentiated products and commodities such as concrete, piping, and pumps. As a result, suppliers to plant packagers have very little power over their customers. Economic factors beyond the control of suppliers set the prices of building materials. For instance, concrete suppliers are limited in setting their prices or they risk losing business in a highly competitive market. However, firms that exclusively supply key components used in some ammonia removal processes wield disproportionately greater market power.

Some methods of ammonia removal require proprietary components that the plant packagers must purchase from specialized technology developers. These developers are a special case in this market as they do wield significant power over plant packagers. For example, Liqui-Cel membrane contactors are sourced only the Polypore Corporation and anammox bacteria cultures from the Paques Corporation. The patents on these technologies make it harder for other companies to make direct substitutes or competing products. Plant packagers ultimately choose what technologies to install in plants and therefore can choose to reduce their dependence on these few firms. The technical advantages of anammox and Liqui-Cel make them highly desirable in some applications providing them with greater market power than normal suppliers.

Saltworks is both a specialized technology developer as well as plant packager, allowing it to circumvent most of the influence of suppliers. It constructs its ammonia systems from commonly available components such as ISO shipping containers, thermoplastic pipefittings and industry standard electronics. To reduce the impact of suppliers, the company also manufactures the core elements of its technology, the ElectroChem stack, in house. Saltworks manufactures its own membranes on custom production equipment to allow quality control, ensure uninterrupted supply, and maximize the captured value created by the membranes. The company has also backward integrated into the assembly of its WWTPs to control quality and manage supply chain risk. It controls the supply of its core components and purchases the remaining commodity components from external firms. This strategy has removed most of the influence of suppliers.

4.1.5 Threat of Substitutes: Low Impact Factor

The last industry force affecting the ammonia removal market is the small threat presented by substitutes. Substitutes are other products and services that satisfy customers' underlying needs in a different way than the incumbents' solution. The main substitute to onsite ammonia removal processes is deep well injection, offsite disposal, and sewage disposal. Substitutes do have the potential to disrupt all incumbent businesses. However, customers with very small or infrequent flows with high ammonia concentration may find offsite disposal an economical substitute to onsite treatment processes. This reduces the total market size as it effectively removes the low-end customers who would otherwise have to purchase an onsite treatment system if substitutes did not exist.

Of the three substitutes, offsite disposal is the most serious threat to incumbents. One substitute is deep well injection, which involves injecting wastewater into isolated reservoirs in the earth's crust, below the active water table. Access to deep well injection is limited mostly to oil and gas producers who have the expertise and incentives to implement an injection well. Therefore, deep well injection is not a serious threat to incumbents. Sewer disposal is another low threat substitute. The EPA regulates the concentrations of ammonia in wastewater discharged into municipal sewer systems and charges companies a surcharge based on volume and concentration of pollutants. Sewer disposal is by far the most expensive method of disposal of large quantities of ammonia wastewater therefore is not a significant threat.

Offsite disposal is the substitute disposal method of choice for industries with ammonia wastewater issues and the only serious threat to incumbents. Firms offering offsite disposal will remove virtually any wastewater from a customer's site, for a hefty remediation fee. Offsite disposal is often the most convenient solution for customers that produce very little wastewater, or wastewater so toxic that onsite treatment would be prohibitively costly. While not a long-term substitute for onsite treatment for most customers with large flow rates, it remains the primary substitute to Saltworks technology and an important determinant of customer's willingness to pay. For this reason, offsite disposal is an important reference point for customers considering ammonia removal options.

The threat of substitution is not a significant factor threatening the ammonia removal industry because incumbents have created several barriers. First, most substitutes are significantly more expensive than conventional ammonia removal technology at industrial or municipal volumes. On-site ammonia removal processes are inherently cheaper than offsite disposal because transport and transaction costs are minimized. For customers with demanding applications in remote areas, there may be no other substitute available besides onsite treatment. Deep well injection is an attractive substitute to onsite ammonia treatment. However, injection sites are limited in availability and accessibility because of the rarity of the necessary geological formations and the difficulty in mustering public and government approval for such facilities. Dilution through municipal sewer systems is the last substitute and is often more expensive than offsite disposal, when the costs of freshwater and disposal surcharges are taken into account. However, dilution is very convenient for many small to medium sized commercial and industrial users. As water conservation becomes a greater priority for industry and governments, onsite treatment will become even more attractive compared to offsite disposal for more customers.

4.1.6 Influence of Government Policy: High Impact Factor

Government policy in the US and Canada is a strong factor that impacts the water treatment decisions made by industry and municipal wastewater treatment plants. Historically, North America has not regulated ammonia pollution well. In the US, the EPA regulates pollution discharged into sewers and surface waters. It has only recently, and for the first time, discharge limitations for ammonia dumped into municipal sewer systems exist. Before this, there were no regulations at all. There are still no regulations governing safe discharge concentrations of ammonia in wastewater in Canada. The environmental regulations established by the US government are the most critical factor affecting the ammonia removal market. Indeed, these new regulations have profound implications for the entire wastewater industry. America's initiative may result in other countries adopting new ammonia pollution regulation for the first time as well. If Canada does so, or the US further tightens regulation further, the ammonia removal industry could see significant growth. Much of the municipal infrastructure in North America is not currently equipped to handle processing the increasingly high levels of ammonia in sewage. The new regulations have resulted in a dramatic increase in demand for ammonia removal systems from industry and municipal WWTPs. To meet the increase in demand, new wastewater treatment plants are required or existing plants need to be retrofitting to meet the new regulations. In general, Government regulations are a very significant factor governing demand for ammonia removal technology. Tighter government regulations are good for Saltworks as increased regulation increases demand for its technology.

4.1.7 Conclusion to Competitive Analysis

The competitive analysis reveals several factors that identify the ammonia removal market as an attractive opportunity for growth within the wastewater treatment industry. Low supplier power, the low threat of substitution, and government regulations are the main factors that make the market attractive. Although direct competition is strong and the power of customers is moderate, the market is large, diverse, and growing quickly. These factors combined confirm that the ammonia removal market is a profitable one for Saltworks to enter.

One attractive factor in the ammonia removal market is the low power of suppliers of the materials required to build WWTPs, due to the ubiquity of the required construction materials and techniques. Concrete, steel, and standard process equipment are the main building materials required for WWTPs. These materials are commodities, their prices subject to international market forces. In general, suppliers do not present a significant threat to WWTP firms because their products are readily substitutable. Exceptions to this general rule are technology developers who maintain control of distribution of their technology. They wield disproportionately greater power than other suppliers do. However, Saltworks technology does not require other technology developers' products, further reducing the power of suppliers over Saltworks.

Several substitutes exist for current technology solutions and for Saltworks ammonia technology; however, they are generally expensive and not practical for many long-term, large volume applications. Offsite disposal is the most common substitute for many market segments however; it quickly becomes uneconomical for large flow rates of wastewater or low ammonia concentrations. Few substitutes seriously threaten Saltworks' entrance into the ammonia removal market. Most substitutes are costly short-term solutions that Saltworks could price themselves against to prevent substitution of its technology.

Government regulations are perhaps the single greatest positive factor contributing to the markets attractiveness. New US regulations are forcing companies and municipalities to upgrade their treatment systems, including ammonia removal. This has created an increase in demand for all types of wastewater treatment technologies and products. As these customers are essentially forced to buy treatment products, the power is predominantly with the suppliers.

Three forces combine to increase the attractiveness of the ammonia removal market: the low power of suppliers, the low threat of substitutes, and the impact of new regulations. These factors together signal the attractiveness of the ammonia removal market for a new entrant with relevant technological capabilities. Saltworks has a differentiated new product that should be very well received in this burgeoning market.

The single greatest negative factor affecting a new entrant is the high power of direct competition. Direct competitors in the ammonia removal market enjoy several advantages and maintain barriers to entry to the market. Incumbent firms are generally larger and well established. They have developed their brand, reputation, and economies of scale as they have grown. Because they are generally bigger, they have large capital amounts needed to fund larger projects. Technology developers are the greatest threat to the most established firms as they have the resources and capabilities to focus on R&D to deliver a superior product or to invent new technologies that could disrupt the market. Large plant packagers as not really competitors to Saltworks but could become complements if they can be convinced to buy the core elements of Saltworks' technology. This would allow Saltworks to retain most of the value of its technology, increase production rate to achieve economies of scale while reducing the costs associated with building, integrating, and commissioning plants.

The last factor detracting from the attractiveness of the market is the moderate power of customers. WWTP and ammonia removal systems are large, strategic investments and therefore customers purchase them with great care. Customers are generally informed and pricing is relatively transparent. Further, WWTPs require commonly available building components and construction materials, reducing customer switching costs and the risk of supplier holdup. These factors increase the market power of customers over suppliers. However, as each customer purchases few WWTP and ammonia removal systems over their lifetime, the significance of any single project and customer is reduced, reducing the power of customers. Additionally, suppliers of WWTPs need not fear that operators of wastewater plants may forward integrate into their industry. Operators of WWTPs are very unlikely to enter the WWTP construction industry due to the significantly different business models and competencies required. However, WWTP builders can and do operate plants; this is often a contractual requirement to break in the plant, before handing ownership to the customer. Overall, the market power of customers in the WWTP and ammonia market is moderate, due to both positive and negative factors.

The competitive analysis of the ammonia removal market has revealed the dynamics at work within it and has confirmed that it is an attractive and profitable market for Saltworks to enter. However, Saltworks must pick its initial market segment with care and search for early adopter customers in each segment. The ammonia removal market is subject to many factors including strong direct competitors, government regulations, and knowledgeable customers.

5: Market Analysis of the Primary Sources of Ammonia Discharge

This chapter reviews the primary sources of ammonia discharge as a means to understand the ammonia removal market overall. The aim is to use this information to identify attractive market segments for Saltworks to target. First, we examine the primary sources of non-industrial point sources of ammonia discharge. Next, we review the industrial point sources of ammonia discharge. We then categorize each market segment into three groups, based on the concentration of ammonia in wastewater. Last, we identify the most promising market segments based on the typical concentration of ammonia in wastewater.

5.1 Introduction to the Primary Sources of Ammonia Wastewater Discharge

Naturally occurring ammonification (bacterial conversion of nitrogen into ammonia) is the single largest source of ammonia produced in the world.[66] However, human induced sources of ammonia discharge more nitrogen into the environment, much of it in the form of ammonia (Galloway, 1998). Figure 7 summarizes the natural and human sources of ammonia discharge into the environment.

Due to its many commercial uses, human induced ammonia discharges into the environment from a variety of processes and sources, including rainwater runoff from fields, livestock rearing, wastewater treatment plants, and industrial point sources. Environment Canada (EC) and the EPA have published lists of the primary sources of ammonia discharge into the environment. Table 2 lists the activities and industries that discharge ammonia, compiled from both EC and EPA sources.[67, 68]

[66] Britannica. http://www.britannica.com/science/ammonification
[67] EPA. http://www.epa.gov/caddis/ssr_amm_wtl.html#sources 06/22/15
[68] Environment Canada. http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1

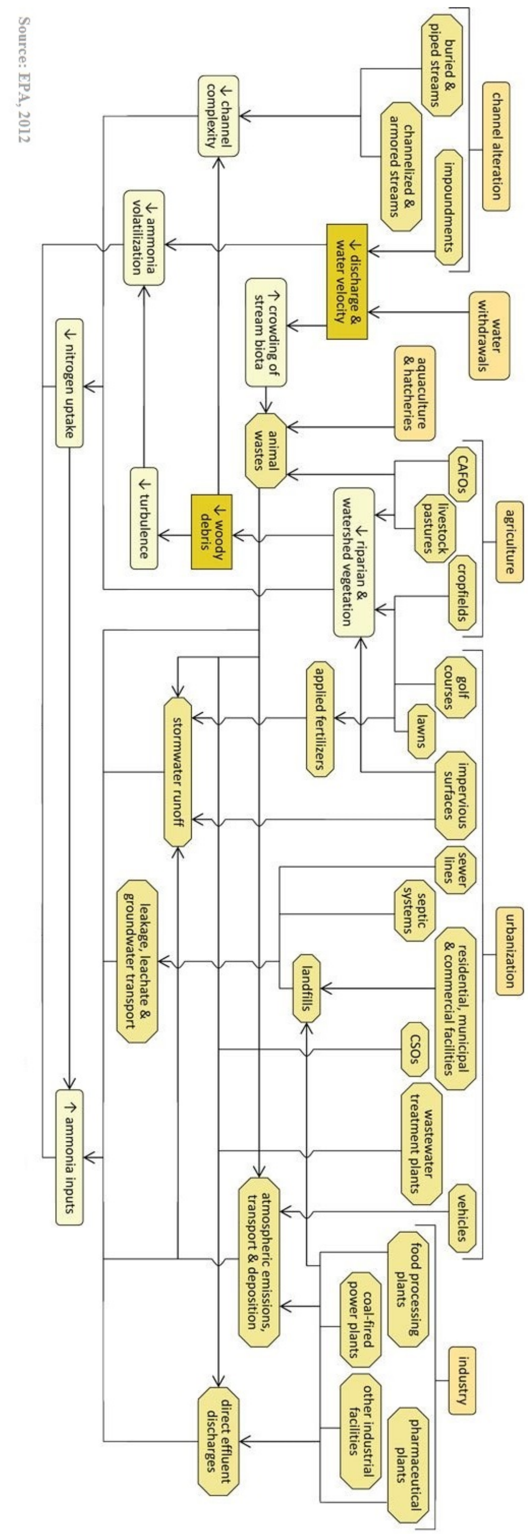

Figure 7: Sources of Ammonia Discharge into the Environment
Source: Modified from EPA diagram, 2012[69]

[69] EPA. http://www.epa.gov/caddis/ssr_amm4s.html

Description	Sources of Ammonia	Ammonia Concentration
Agricultural, Urban and Manure Runoff (fertilizer)	Rainwater washes fertilizers into streams and sewers	Low
Concentrated Animal Feeding Operations	Animal manure significant source of ammonia	High
Landfill leachate	Rainwater percolated through landfill contains high levels of ammonia	High
Food and Beverage production	Ammonia is used as sterilizing agent and micronutrient in many food products	Low
Impoundments	Wastewater holding ponds often contain ammonia from mining, sewage, or oil production	Low
Coal burning power plants	Flue gas scrubbers use ammonia that is disposed or sold as fertilizer	High
Coke production	Coke production generates ammonia, usually removed by scrubbers	Med
Fertilizer Production	Ammonia production facility	Med
Pulp and paper mills	Ammonia used as chemical digester of wood lignin	Med
Municipal Waste Treatment Plants	Ammonia is present is most municipal wastewaters, most plants are unable to fully treat the ammonia	Low
Metal Ore mining	Ammonia is created by explosives residue in mine tailings	Med
Oil and Gas Extraction	Process water from oil extraction contains ammonia	Med

Table 2: Summary of Sources of Ammonia Discharge
Source: Compiled by author with information from:
http://pubs.usgs.gov/circ/circ1182/pdf/06SanJoaquinValley.pdf
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex12064 Blauvelt, 2009
http://eippcb.jrc.ec.europa.eu/reference/BREF/fdm_bref_0806.pdf
http://canadianminingmagazine.com/wp-content/uploads/2011/05/ fall2009.pdf
http://www.epa.gov/air/caa/requirements.html
http://www.metrohm-applikon.com/Downloads/Process_Application_ Note_AN-PAN-1009-WWTP-ammonia-nitrate-nitrite.pdf
Shale, 1974
Alexandersson, 2007
Hammer, 1989

This list is a starting point for our analysis. Industry journals, textbooks, and corporate websites provide multiple perspectives that also contribute. Case studies and cost analysis research helped establish typical ammonia concentrations for each market segment. We excluded those sources of ammonia that are not relevant to Saltworks. Industrial point sources of ammonia discharge were broken down into specific industries. By analysing the sources of ammonia discharge, we can begin to understand the ammonia removal market and to identify opportunities for Saltworks.

5.2 Non Industrial Sources of Ammonia Discharge

Several non-industrial sources of ammonia require extensive wastewater treatment solutions to remove highly concentrated ammonia. The most significant sources of ammonia discharge are urban, agricultural and manure runoff, concentrated animal feeding operations (CAFOs), municipal wastewater treatment plants (MWTP), landfill leachate, and food and beverage production. These segments are distinct from industrial sources as they are not the product of an industrial process. Several of these market segments are attractive to Saltworks due to their high concentration of ammonia discharge and relatively low wastewater flow rates. These highly concentrated sources of ammonia discharge are ideal market segments for Saltworks' ammonia removal technology.

5.2.1 Urban, Agricultural, and Manure Runoff

Urban, agricultural, and manure runoff is the largest non-industrial source of ammonia discharge. Rainwater runoff leaches fertilizer, ammonia, and manure from lawns, golf courses, construction sites, fields, and pastures. Excessive fertilization with ammonia rich fertilizer or improper timing of manure application to a field can lead to excess ammonia washing away with rainwater. Rainwater runoff that enters a sewer system is treated at a municipal wastewater treatment plant. Ammonia rich runoff overloads WWTPs with nutrients beyond its capacity to treat and results in discharges with high levels of ammonia. Rainwater runoff that enters unprotected surface waters is a major source of environmental damage.[70] Rainwater runoff is a difficult environmental challenge, as it is not a single point of pollution but a side effect of industrial agriculture.

For example, the San Joaquin–Tulare Basin, located in the Sacramento valley, has some of the highest surface waters concentrations of ammonia in the US, reaching 50 mg/L in some tributaries. The basin is at the heart of Californian agricultural production and the majority of

[70] USGS. http://pubs.usgs.gov/circ/circ1159/circ1159.pdf

ammonia discharge is from subsurface agricultural water drainage, fertilizer runoff, treatment plant effluent, and dairy farm runoff.

The conservation and protection of surface waters will be a growing priority for municipal and regional governments as water shortages increase. Limited water reserves in highly productive agriculture areas, such as central California, mean that industrial and commercial users of water will face more competition for water resources in those areas. By investing in rural water treatment facilities to treat impaired waters before they enter rivers, lakes and the ocean, the Californian government can increase water quality and the total supply of usable water.

5.2.2 Concentrated Animal Feeding Operations

Concentrated animal feeding operations (CAFOs) are industrial farms that produce animals for meat and animal by-products, particularly eggs and dairy products. For the purposes of this analysis, we consider CAFOs to be a non-industrial source of ammonia as the ammonia they produce is not a by-product of an industrial process, but from animals. CAFOs produce large amounts of high concentration ammonia from animal excretions. Cattle, sheep, poultry, horse and swine manure and urine are high in ammonia and are produced in vast quantities by the pastoral farming industry in the US.[71] The EPA defines CAFOs as facilities that confine animals for at least 1.5 month of the year and do not grow all their animal feed on their premises (EPA, 2014). There are an estimated 9,900 CAFOs in the US.[72]

Traditional animal rearing allows animals to roam about a pasture, grazing on growing plants. In contrast, CAFOs confine animals in pens and bring the feed directly to them. CAFO animal waste is removed directly from the pens using an active sewage management system, such as subfloor drainage or a flooded trough. Operators typically hold animal waste in a lagoon, allowing the ammonia to nitrify to sufficiently low levels before discharging into municipal sewers or offsite disposal.

CAFOs produce significant amounts of ammonia from animal manure and urine. Bovine excrement and urine contain over 1,400 mg/L of ammonia, while swine excrement reaches even higher concentrations, around 1,800 mg/L (Lee, Yates, Robarge, and Bradford, 2013).[73] The high concentration and relatively low flow rates suggest that CAFOs could be a valuable market segment for Saltworks to target.

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[71] Humane Society. www.humanesociety.org/news/resources/research/stats_slaughter_totals.html
[72] UCSUSA. http://www.ucsusa.org/sites/default/files/legacy/assets/documents/food_and_ agriculture/cafos-uncovered.pdf
[73] Alberta Agriculture and Forestry. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex12064

5.2.3 Landfill Leachate as a Source of Ammonia Discharge

Landfill leachate contains significant concentrations of ammonia from rainwater leaching through decomposing garbage. Landfills contain a variety of toxins and chemicals including nutrients, acid, metals, organics, and chemicals. Ammonia enters landfills primary from cleaning chemical residue in containers and from decomposing biological matter. Landfills also generate ammonia naturally, as the landfill material decomposes and biodegrades.

Modern landfills contain the leachate using a subsurface membrane and an engineered drainage system. Older landfills do not have membrane containment systems and allow leachate to enter groundwater (Kjeldsen et. all, 2002). Landfills produce leachate continuously over their entire lifespan, making it a long-term source of pollutants (U. Welandera, Henryssona, and T. Welandera, 1998) . Landfill leachate represents a valuable market segment for Saltworks as it has a low flow rate and a high ammonia concentration. Additionally, Saltworks has existing relationships with the four largest landfill companies in the US.

Ammonia concentrations from landfill leachate can range between 500 – 1500 mg/L, necessitating treatment before discharge (Blauvelt, 2009). Most landfill operators manage leachate by utilizing offsite disposal, biological nitrification lagoons, or constructed wetlands to filter the leachate before discharge it into the environment (J. Nivala 2007). Offsite disposal of landfill leachate is effective and simple but expensive. Onsite impoundments for biological nitrification of wastewater require space and resources to operate. Landfill leachate is a challenging wastewater to treat due to the many toxic constituents including heavy metals, dissolved organic matter, inorganic chemicals, and ammonia.[74]

5.2.4 Food and Beverage Production as a Source of Ammonia Discharge

Food and beverage manufacturers utilize ammonia in small quantities for multiple reasons, mostly as a nutrient for microorganisms and as a pH controller. Uses of ammonia in food and beverage production include as a leavening agent for crackers and biscuits, a nutrient for microorganisms that cause fermentation, a pH controller in cheese production and as a nutrient added to yeast cultures. Another, more unconventional use of ammonia is as a sterilizing agent for finely textured meat, or “pink slime”. [75] Most ammonia used in food and beverage production becomes a part of the food product. Therefore, the consumer excretes most of the ammonia used in food and beverage production. Manufacturers discharge ammonia mostly from cleaning

[74] Ozonia. http://www.ozonia.com/media/pdf/app/leachate-e.pdf
[75] Times Magazine. http://time.com/3176714/pink-slime-meat-prices-bpi-beef/

process equipment, food waste, and from used process water containing low concentrations of ammonia.

A few notable industries are responsible for the majority of food and beverage related ammonia discharge. One large source of food related ammonia pollution is the dairy industry. Dairy producers process cow's milk into various dairy products, many of which require bacterial and yeast cultures. Bacterial cultures require nutrients to kick-start the fermentation process; ammonia based compounds are also sometimes utilized. However most ammonia wastewater produced by dairy producers is due to stringent cleanliness requirements. Dairy companies discharge wastewater with ammonia concentrations of 10 – 100 mg/l from cleaning tanks and process equipment.[76]

Brewing beer also produces large volumes of wastewater with low ammonia concentrations. Most of the water used in beer production is eventually disposed; every litre of beer produced produces 4.5L of wastewater. To produce beer, barley is soaked in hot water to release malt sugars. The malting and mashing steps produce wastewater discharge with a high solids content. Mash water concentrations can vary between 35- 200 mg/L (Smith, Figueroa, 2005), (Brito et. all, 2007).

5.3 Industrial Point Sources of Ammonia

This section will examine the most significant industrial point sources of ammonia discharge. Due to its many uses, ammonia is one of the most abundantly produced chemical in the world. Global ammonia production reached 137,000 tons in 2013[77] and consumed over 1% of global electricity annually.[78] Some industries use ammonia in their products and process. However, for most industries, ammonia is a waste product requiring safe disposal. Environment Canada publishes a national inventory of the pollution released into the environment by industry each year.[79] The pollution inventory includes all the entities that discharge quantities of pollution significant enough to warrant monitoring. One of the chemicals monitored by the Canadian National Pollutant Release Inventory (NPRI) is ammonia. Using this inventory, we identified the entities that discharge the greatest quantities of ammonia.

[76] European Union Integrated Pollution Prevention and Control. http://eippcb.jrc.ec.europa.eu/reference/BREF/fdm_bref_0806.pdf
[77] USGS. http://minerals.usgs.gov/minerals/pubs /commodity/nitrogen/mcs-2013-nitro.pdf
[78] IIASA. http://www.iiasa.ac.at/web/home/research /Flagship-Projects/Global-Energy-Assessment/GEA_Chapter8_industry_lowres.pdf
[79] Environment Canada. http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1

Industrial point sources of ammonia discharge are entities that produce sizable quantities ammonia impaired wastewater that requires treatment before disposal. The list comprises all the producers, users, transporters, and disposers of ammonia. Most industries produce nominal amounts of ammonia dissolved in wastewater, but some industries produce significantly larger amounts and concentrations of ammonia wastewater. Industries that are major dischargers of ammonia include pulp and paper mills, fruit and vegetable packagers, fertilizer and chemical manufacturers, oil and gas producers, steel makers, non-ferrous metal producers, and ammonia scrubbers for removing acid from hydrocarbon combustion exhaust. Each industry deals with their ammonia wastewater differently.

5.3.1 Impoundments as a Source of Ammonia Discharge

Impoundments are manmade holding ponds and are an indirect source of ammonia. Typically built from earthen embankments, impoundments contain industrial wastewaters and other waste material. The types of waste held in impoundments include mine tailings, coal slurry, raw sewage, and bitumen extraction tailings (tar sand tailings). Impoundments are efficient wet material containment for several industries, especially at remote work sites where there are few other disposal options. Impoundments often contain wastewaters with high levels of metal, minerals, organics, and chemicals. Ammonia discharges from impoundments by a variety of mechanisms. All lagoons leak small amounts of water and spills do occur. Lagoons may periodically discharge wastewater, or a reclaimed lagoon may slowly leak high concentration ammonia. The results of each mechanism are the same: the uncontrolled release of large volumes of ammonia into the environment.

Conventional mining for metals, ores, and minerals produces large quantities of wastewater and tailings that discharge into tailings ponds. Such ponds are often the most visible source of the environmental impact of a mine.[80] Conventional mining requires removing the top layer of rock and dirt (overburden) to expose the earth that is rich in a desired material (paydirt). Nitrate based explosives are most commonly used to break up the overburden. Next, paydirt is excavated, crushed, ground to size, then processed. Process equipment separates the valuable material from the waste earth. The extraction process depends upon the material desired and the composition of the tailings. Tailings are the leftover rock, minerals, chemicals, explosives residue, and organics from the mining process. Tailings and wastewater discharges into holding ponds to allow suspended particles in the wastewater to settle. Tailings settle to the bottom of the

[80] Tailings.info. http://www.tailings.info/basics/tailings.htm

pond and mines reuse the clarified wastewater.[81] The ponds eventually fill as the mine ages. When a pond is full, mine operators may increase existing pond embankments, build a replacement pond, or reclaim the pond. Mines reclaim tailings ponds by encouraging them to dry out, which often requires decades before decommissioning. The pond is then covered with earth then seeded with plants and left to be reclaimed by nature.[82]

Some gold and copper mines have tailings ponds that contain significant levels of ammonia from fuel oil and explosives residue. Goldcorp's Red Lake gold mine experiences high levels of ammonia in its tailings pond, especially in the winter months. Ammonia levels drop to approximately 10 mg/L in the spring as the water temperature rises and nitrifying bacteria become more active and consume more ammonia. During the spring and summer months, tailing water discharges safely into the environment due to the reduced ammonia levels. Environment Canada and EPA regulations prevent tailings wastewater with elevated ammonia levels from discharging into the environment without treatment. The Red Lake mine overcomes the challenges of seasonal swings in ammonia concentrations by retaining water during the winter and waiting until spring when bacteria are more active before discharging tailing water with an average concentration of 10 mg/L.[83] This strategy requires the construction of excessively large impoundments to hold seasonal swings in pond volume. A Saltworks removal system could operate year round allowing for regular discharge of tailings water thus smoothing the discharge flow rate, reducing the need for large tailings ponds, and reducing operating and capital costs for owners.

Mine tailings wastewater is a big by-product of work at the Athabasca oil sands in Alberta, Canada. Tar sand is a mixture of water, sand and bitumen, a thick petroleum substance. The bitumen is a form of crude oil and can be refined into common petroleum products. The bitumen in the tar sands is very viscous (resists flow) therefore it cannot be easily pumped as in other petroleum extraction processes. Tar sands are typically mined using two different extraction methods, depending on the depth of the tar sand deposits. The more economical strip-mining method extracts bitumen close to the surface by removing overburden then excavating the tar sand mixture directly. Deeper tar sand deposits require the more expensive but less environmentally destructive steam assisted gravity drainage (SAGD) method. SAGD operates by injecting steam into the ground via a horizontal pipe to heat and liquefy the bitumen. This allows

[81] http://www.ceaa-acee.gc.ca/default.asp?lang=En&n=0a571a1a-1&xml=0a571a1a-84cd-496b-969e-7cf9cbea16ae&offset=7&toc=hide
[82] CAPP. http://www.oilsandstoday.ca/topics/Tailings/Pages/Default.aspx#response
[83] Canadian Mining Magazine. http://canadianminingmagazine.com/wp-content/uploads/2011/05/fall2009.pdf

the bitumen to separate from the sand in the oil field and flow to another horizontal pipe for extraction. Extracted bitumen is mixed with water, sand, and mining chemicals which must be separated before processing. After separating the bitumen from the tailings, the leftover process water contains sand, water, mining chemicals and unrecoverable bitumen. The tar sands separation process recovers approximately 75% of the bitumen in tar sand.[84] The resulting slurry discharges into tailings ponds. Among other toxins, tar sand tailings contain elevated concentrations of ammonia.

In summary, impoundments and tailing wastewater is an attractive market segment for Saltworks ammonia removal technology. The market segment is very large and contains many independent operators as well as large corporations. Willingness to pay is also high due to the challenging water chemistry and remote work sites. However, ammonia concentrations are low and water flow rates can be high. While a valuable market, tailings water is not a good beachhead market for Saltworks' ammonia removal system.

5.3.2 Coal Combustion as a Source of Ammonia

The burning of coal in power plants releases sulphur dioxide (SO_2), one of the main components of acid rain. Regulations in developed counties require power plants to scrub their emissions of the worst pollutants, such as SO_2. Flue gas desulfurization (FGD) is the process of removing SO_2 from power plant emissions. There are several methods of FGD; one common method involves scrubbers washing the exhaust gas stream with ammonia that reacts with the SO_2 to form an ammonia salt, ammonium sulphate, a valuable component of fertilizer. This process can remove up to 90% of SO_2 in flue gas exhaust (Shale, 1974). However, the cost of producing, handling, and distributing ammonium sulphate often exceeds the profits gained from the sale of the fertilizer. Some ammonia FGD scrubbing systems regenerate the ammonia rather than removing the ammonium sulphate for sale. Conventional ammonia regeneration systems are plagued with equipment clogging and poor heat transfer rates due to reagents added to the system, such as zinc oxide (Shale, 1974).

Although new coal power plants use more advanced technology than ammonia FDG scrubbing systems, several such systems are still operating around the world. Saltworks could offer its ammonia removal system as an ammonia FGD scrubber regenerator to regenerate the ammonia, without additional chemicals or by-products that would then require disposal. The

[84] OSTSEIS. http://ostseis.anl.gov/guide/tarsands/

ammonia FGD market is slightly outside of Saltworks wheelhouse of experience however, it is an opportunity to expand into a completely new kind of market.

5.3.3 Coke Production as a Source of Ammonia Discharge

The production of coke releases many pollutants including ammonia vapours removed by acid scrubbing systems. This market is similar to ammonia FGD. There are many kinds and grades of coke, depending on origins and composition. Coal coke is coal with the right chemical composition to produce coke; a high purity source of carbon utilised in steel making and as a reducing agent in producing iron from iron ore. Burning bituminous coal at high temperatures in an oxygen deficient environment produces coal coke.[85] Petroleum coke is another kind of coke that has similar industrial uses and produces similar ammonia emissions. Removing the gas, gasoline and other desirable hydrocarbon products from crude oil, then further processing the remaining substance yields petroleum coke.[86]

Every ton of coke used yields 0.1 kg of ammonia vapours that are exhausted.[87] To remove ammonia vapours from its exhaust emissions, the steel industry utilizes scrubbers, similar to the flue gas desulfurization (FGD) industry. Steel producers typically use a wet spray scrubbing system to remove ammonia emissions. Such systems spray sulphuric acid into the ammonia rich exhaust stream to react with the ammonia to form ammonium sulphate, a component of fertilizer.[88] Selling the by-product of the scrubbing process as fertilizer has similar problems to ammonia FGD, the fertilizer is more costly to produce than sell. Current ammonia regeneration technologies are deficient.

Saltworks can introduce its ammonia removal system as an acid regeneration system that removes the ammonia from the sulphuric acid, allowing reuse of the acid. Saltworks technology has none of the disadvantages associated with conventional ammonia regeneration processes that utilize metallic oxides. As a result, the coke production market could be a valuable market segment for Saltworks to target.

The need for technology to remove ammonia from wastewater exists in the coke production industry as well. Coke is rapidly cooled with water after it is removed from the oven

[85] American Iron and Steel Institute. https://www.steel.org/Making%20Steel/How%20Its%20Made/Processes/Processes%20Info/Coke%20Production%20For%20Blast%20Furnace%20Ironmaking.aspx
[86] National Association of Manufacturers. http://aboutpetcoke.com/wp-content/uploads/2013/12/Petroleum-Coke-Essential-to-Manufacturing.pdf
[87] International Finance Corporation. http://www.ifc.org/wps/wcm/connect/9ecab70048855c048ab4da6a6515bb18/coke_PPAH.pdf?MOD=AJPERES
[88] Pollution Systems. http://www.pollutionsystems.com/ammonia-scrubbers.html

to quench it. The resultant wastewater can contain significant amounts of ammonia. One coke plant in the Peoples Republic of China (PRC) produces 120 m^3 of wastewater per day that contains up to 50 mg/L ammonia (Alexandersson, 2007). Ammonia removal from wastewater in the coke production industry is not an attractive market segment to Saltworks due to its low concentration. However, if Saltworks implements its ammonia scrubbing regeneration systems in this market segment, offering to provide additional wastewater treatment systems could be an easy additional sale.

5.3.4 Fertilizer Production as a Source of Ammonia Discharge

Fertilizer production is the largest industrial use of ammonia, consuming over 85% of ammonia produced globally.[89] Ammonia is a versatile fertilizer: sprayed directly onto fields, it is a cheap and effective source of nitrogen. Alternatively, ammonia can be further processed into dry powder fertilizers, such as ammonium sulphide or ammonium phosphate. Using ammonia as a source of fixed nitrogen in fertilizer is how the world's farmers have increased global cereal yields by 62-66% since the 1970s. Fertilizer is vital to agriculture, to maintain current crop yields. In the future, it has a key role to play in the doubling of global food production to meet the needs of the estimated 9.2 billion people that will exist by 2050 (Roberts, 2010).

Fertilizer producers are a leading source of ammonia pollution.[90] However, fertilizer plants discharge most of their ammonia to the atmosphere as a vapour, not dissolved in wastewater. Ammonia emissions are monitored and there are reporting requirements. However, neither the US nor Canada limit the volume of ammonia vapour that may be discharged.[91,92] There is speculation in some industries that ammonia emissions will be regulated eventually. Fertilizer plants use scrubbing systems to strip the ammonia from the plant exhaust, much like FGD and coke scrubbing processes. The most common method used in fertilizer production plants is a wet acid scrubbing process that sprays acid directly into the exhaust gas stream to react with the ammonia vapour to form ammonia salts. Fertilizer producers can sell the resulting ammonia salts or they can regenerate the solution and reuse the acid in the scrubbing system.

In this market, Saltworks could introduce its ammonia removal system as an acid regeneration system that could efficiently remove the ammonia from the scrubbing liquid to regenerate the acid for reuse. Saltworks technology can do this more effectively than

[89] University of York. http://www.essentialchemicalindustry.org/chemicals/ammonia.html
[90] Environment Canada. http://ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1
[91] Environment Canada. http://ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=26A03BFA-1
[92] EPA. http://www.epa.gov/air/caa/requirements.html

conventional regeneration methods. Conventional systems are plagued with operational issues such as equipment clogging due to the sticky nature of the metallic oxides, such as zinc oxide, used to react with the ammonia (Shale, 1974). Fertilizer production, coke production and coal combustion all face similar challenges of removing ammonia vapour from exhaust streams and the subsequent disposal of the removed ammonia. Saltworks ammonia system could offer these market segments a more effective solution than current industry methods.

5.3.5 Pulp and Paper Mills as a Source of Ammonia Discharge

Pulp mills are a major industrial discharger of ammonia impaired wastewater. The sulphite pulping process (also known as the Kraft paper process) utilises salts from sulphurous acid and a counter ion, often ammonium, to dissolve lignin in wood chips to create a pulp that is almost pure cellulose.[93] The lignin-free cellulose produced from the sulphite process allows for modern, non-yellowing, bleached paper.[94] Ammonia is also an ingredient in the spray coatings that pulp mills apply to paper and cardboard to improve strength, water resistance and printability. Canadian pulp mills discharged approximately 1671 tonnes of aqueous ammonia, and an equal amount of vapour ammonia, in 2013.[95] However, most pulp mills produce large quantities of low concentration ammonia wastewater. Pulp mill effluents should have ammonia concentrations of between 0.5-1.0 mg/l according to a guide of best practices to manage pulp mill wastewater (Marshall, 2008). Due to the low concentrations, high flow rate and presence of many other competing technologies treating pulp mill effluent it is not a very attractive market for Saltworks.

5.3.6 Municipal Wastewater Treatment Plants as a Source of Ammonia

As is discussed above, municipal wastewater treatment plants (WWTP) are the largest source of ammonia emissions in North America. Canada's wastewater treatment plants discharge 62,000 tons of ammonia per year. This includes increasing amounts of ammonia disposed of into sewer systems as well as runoff from storm water systems. These sources contribute to the elevated levels of ammonia seen in WWTP influent across North America.

WWTP infrastructure is one of the most underfunded sectors of government infrastructure in Canada and the US. In 2007, the average age of WWTPs in Canada was 17.8

[93] Shell Cansolv. http://www.cansolv.com/rtecontent/document/1998SULFUR.sulfite.pulp.mill.pdf
[94] Innovateus. http://www.innovateus.net/green-home/what-are-uses-sulfite-paper
[95] Environment Canada. http://ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1

years, up from 17.4 in 2001.[96] Investment in WWTPs has not been sufficient to replenish the national stock and to keep the average age from increasing. Canada built most of its WWTP plants before ammonia removal was an environmental concern. Newer buildings and industry often surround older WWTPs, preventing physical expansion. As a result, WWTPs must periodically retrofit their processes with new technology to meet modern discharge regulations. WWTP managers require process and equipment to do this, within the footprint of the original plant.

WWTPs are categorized by the level of treatment they are capable of. Primary level plants treat sewage by mostly mechanical means, which consists of simply straining larger debris and holding the water in settling tanks that allow the suspended solids to settle to the bottom and the fats and oils to float to the top of the tank for removal. Grating removes large material while filters and screens of decreasing size filter the wastewater before entrance into the settling tanks. Primary treatment can remove up to 20-30% of total suspended solids and 50-60% of dissolved solids.[97]

Secondary treatment further treats sewage with bacteria in another settling tank to consume the dissolved organic material in the wastewater and produce CO2, water and more bacteria. Secondary treatment can remove 85% of the dissolved solids leftover from primary treatment. Tertiary treatment consists of additional treatment steps after secondary treatment to perform a final polish on the wastewater before discharge. Treatments may include final polishing steps such as nutrient removal, water reuse through reverse osmosis, disinfection, or sand filtration. Ammonia removal is often a tertiary treatment step added after the initial construction of the WWTP.

Wastewater treatment plants regulate the concentrations of ammonia discharged in their effluent, along with many other toxic chemicals and substances. A typical wastewater treatment plant with elevated levels of ammonia would require a tertiary, biological nitrification treatment system that would reduce wastewater ammonia concentration from 0-6000 mg/L ammonia influent to 0-60 mg/L ammonia effluent.[98] Additional treatment would require enlargement of the secondary system to increase water residency time. The rate of ammonia removal from secondary

[96] Statistics Canda. http://www.statcan.gc.ca/pub/11-621-m/11-621-m2008067-eng.htm
[97] World Bank. http://water.worldbank.org/shw-resource-guide/infrastructure/menu-technical-options/wastewater-treatment
[98] Metrohm Applikon. http://www.metrohm-applikon.com/Downloads/Process_Application_ Note_AN-PAN-1009-WWTP-ammonia-nitrate-nitrite.pdf

treatment is largely dependent upon geographic location and resident time of water, which requires building larger treatment tanks for a given flow rate.

The unique advantages of Saltworks' ammonia systems are ideal for retrofit of existing secondary treatment WWTPs that require additional nutrient removal, but cannot implement conventional biological nitrification. Due to their compact footprint, Saltworks ammonia systems can bolt onto existing WWTPs and remove the ammonia from the effluent as a final polishing step. Saltworks technology has several advantages over other compact, biological, ammonia removal systems for WWTP owners: the process does not require aeration or large tanks and does not produce a waste product that requires disposal.

5.4 Summary of Market Analysis of the Primary Sources of Ammonia Discharge

The most attractive market segments for Saltworks to target initially are those with the highest concentrations of ammonia in wastewater. This section categorizes each market segment based on its typical concentration of ammonia in wastewater, to clarify and summarise exactly which markets Saltworks should target. There are three categories of ammonia discharge: low concentrations of less than 100 mg/L, medium concentrations between 100 – 500 mg/L and the highest concentrations of greater than 500 mg/L. Table 3 summarizes the market segments in each category.

Low Concentration (< 100 mg/L)	**Medium Concentration (100 – 500 mg/L)**	**High Concentration (>1000 mg/L)**
Municipal Wastewater Treatment Plant	Coke Production Exhaust Scrubbers	Landfill Leachate
Impoundments	Fertilizer Production	Coal Burning Exhaust Scrubbers
Agricultural, Manure and Urban Runoff	Oil, Gas and Coal production	CAFO / AFO
Food and Beverage	Metallic Ore Mining	
Pulp and Paper Mills		

Table 3: Sources of Ammonia Discharge
Source: Compiled by Author with data from:
http://pubs.usgs.gov/circ/circ1182/pdf/06SanJoaquinValley.pdf
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex12064 Blauvelt, 2009
http://eippcb.jrc.ec.europa.eu/reference/BREF/fdm_bref_0806.pdf
http://canadianminingmagazine.com/wp-content/uploads/2011/05/ fall2009.pdf
http://www.epa.gov/air/caa/requirements.html

http://www.metrohm-applikon.com/Downloads/Process_Application_ Note_AN-PAN-1009-WWTP-ammonia-nitrate-nitrite.pdf
Shale, 1974
Alexandersson, 2007
Hammer, 1989

The markets associated with low and medium ammonia concentration discharge are not of sufficient interest to Saltworks. There is one potential exception however. Most ammonia pollution from medium concentration sources of ammonia are from scrubbing systems. This includes FGD, coke scrubbers, fertilizer plant scrubbers. Saltworks could introduce its technology as an efficient new acid regeneration system to the ammonia scrubbing market segments that can efficiently remove the ammonia stripped from exhaust streams, without requiring the cost and hassle of drying, bagging and distributing ammonium sulphate. Although Scrubbing systems are outside of Saltworks current focus, it could become a viable new industry which Saltworks could enter in the future.

The last category in Table 3 consists of the high concentration ammonia polluters, which represent the most attractive market category for Saltworks to target. Industries that produce wastewater with high ammonia concentrations include landfill leachate, coal burning exhaust scrubbers, and animal feeding operations (CAFO). Conventional ammonia removal solutions increase in cost as the ammonia concentration increases due to additional land, infrastructure, consumables, and operating expenses incurred. Therefore, Saltworks can demand higher prices from customers with higher concentration wastewaters due to the lack of viable substitutes. Higher concentration pollutants typically mean lower wastewater flow rates. Lower flow rates result in lower total cost of ownership due to smaller equipment, less land required less energy and fewer consumables used. This gives the Saltworks ammonia removal system a significant cost advantage over incumbent ammonia removal technologies for these market segments. For these reasons, Saltworks should target these high ammonia concentration markets as beachheads when first implementing its ammonia removal technology.

In conclusion, the overall cost for an ammonia removal system is largely driven by the concentration of ammonia in the wastewaters. Higher concentration of ammonia requires larger and more complex treatment systems. Saltworks' ammonia removal system can treat any concentration of ammonia with no technical change to the system and no additional costs. Therefore, the most attractive and profitable market segments for Saltworks are those with the highest treatment costs. This includes landfill leachate, CAFOs, and coal exhaust FGD scrubbers.

Should Saltworks price its systems based on competing technologies, Saltworks can charge a premium for its technology and earn higher rents than it could in other market segments. Customers would be paying the same initial price for Saltwork's system but would realize cost savings through lower operating costs. Targeting the highest concentration market segments will allow Saltworks to grow the most quickly, allowing it to fund its next water treatment innovation.

6: Conclusion and Recommendations

This paper seeks to provide an analysis of the market for ammonia removal from wastewater to identify the most attractive market segments, review current technologies, examine primary competitors, and confirm the feasibility of Saltworks entering this market. The aim is to provide recommendations to assist Saltworks in successfully entering this market with its innovative ammonia treatment technology.

6.1 Conclusions

Ammonia pollution of marine environments is an environmental issue receiving insufficient attention from the public, governments, and corporations. Ammonia pollution over-enriches surface waters, causing fish deaths and long-term damage to fish gills and to fish reproduction. Ammonia pollution is a pressing environmental concern, reflected in the EPA recently setting new ammonia limits for wastewater of 4.9 mg/L. Canada, however, has no legislation governing ammonia pollutions. Increased public awareness to the sources and consequences of ammonia pollution is required to promote understanding of the concerns, push for further regulation, and encourage the development of treatment technologies.

Conventional installed ammonia removal technologies are unsatisfactory to many users of these technologies. Treatment processes that rely on bacteria to biologically nitrify ammonia have stark limitations that reduce existing WWTP capabilities to treat the increasing ammonia concentrations present in modern wastewaters. Bacterial nitrification can only operate within a narrow temperature band and require constant monitoring of oxygenation and pH. It is a slow process that translates into large residence capacity for industrial and municipal WWTPs. Most existing ammonia treatment infrastructure processes cannot handle the high ammonia concentrations in modern wastewater and require retrofitting to comply with new regulations. However, further expansion of biological nitrification systems is often impractical due to space considerations. Other alternative means of ammonia removal such as ion exchange, air stripping and breakpoint chlorination have other disadvantages that ultimately result in increasing capital and operating costs as ammonia concentrations increase. The disadvantages of conventional technology limit the satisfaction of customers and leave some searching for better solutions for their most intractable ammonia problems.

From the competitive analysis, we can conclude that the ammonia removal market is indeed an attractive market for a firm to enter due to rapidly increasing demand propelled by government regulations. Other positive factors include the low power of suppliers and the low threat of substitution. Although competition is fierce and there are several barriers to entry facing new firms such as Saltworks, the ammonia removal market is overall an attractive opportunity. Saltworks greatest competitors are other proprietary technology developers who have developed alternatives to biological nitrification to rival Saltworks in some market applications. They share the advantages of Saltworks' technology over biological nitrification, such as a smaller footprint and lower operating costs. Competition is most fierce in the medium to low ammonia concentration segments. These lower concentration market segments also represent the majority of the ammonia removal market.

The analysis of the primary sources and uses of ammonia reveal that a large portion of ammonia pollution is from uncontrolled rainwater runoff from fields, lawns, and gold courses. Fertilizer improperly applied to vegetation washes off during heavy precipitation and flows into uncontrolled streams and rivers. Ammonia pollution from runoff is extremely difficult to address, as the pollution is not from a single source but rather is an aggregate result. WWTPs and large industries are easier to target with regulations, however, if ammonia pollution is to be truly address, a solution to ammonia runoff is required.

Our analysis of the market suggests that the most attractive market segments for Saltworks to target are those with the highest ammonia concentrations and most challenging wastewater chemistry (see section 5.4). Existing technologies increase in cost as the concentrations of ammonia in the wastewater increase. The nature of Saltworks' technology is such that it is equally able to remove any concentration of ammonia without a significant increase in capital or operating costs. The robust design, and pH and hydrocarbon tolerance membranes mean that Saltworks' ammonia ElectroChem devices can process virtually any wastewater without significant impairments on performance.

Our market analysis also reveals that plant packagers present further opportunities for Saltworks (see sections 4.1.1 and 4.1.7). These firms construct the majority of WWTPs in North America and around the world. Saltworks systems could be complementary to such constructions. Plant packagers could purchase Saltworks' ammonia removal technology for use within the larger ammonia treatment systems they are building. Selling just the key components of these larger systems could yield cost savings through economies of scale and become a profit revenue stream for Saltworks.

We can conclude that there is a significant business case for Saltworks to develop its technology and enter the ammonia removal market. To help with entering this new market, Saltworks can leverage its established relationships with customers such as those in the landfill leachate and oil and gas industries to provide beachhead customers in new market segments. From these conclusions and the insights gained in the course of this analysis, we can outline several recommendations for Saltworks to implement as it enters the ammonia removal market.

6.2 Recommendations

This paper ends with several strategic recommendations for Saltworks to adopt as it develops its technology, enters the ammonia removal market, and continues to grow within the industry. These recommendations outline a strategy for Saltworks in entering and establishing itself within this market.

Our first recommendation is that Saltworks target the market segments with the highest ammonia concentrations and most technically challenging water chemistry. These customers have a higher willingness to pay than other segments and competition is often less fierce due the technical challenges involved. The technical advantages that Saltworks' technology offers give it a substantial competitive edge over other technologies. This will allow Saltworks to more easily enter and grow within the ammonia removal market.

Our next recommendation is that Saltworks leverage its existing relationships with customers and plant packagers to enable it to penetrate and grow in this new market. Saltworks is still relatively unknown and unproven within the ammonia removal market. Therefore, initial customers may be unwilling to take a risk with this new technology. However, firms already familiar with Saltworks, its management team and its technologies, may be more likely to choose the company to help solve its most challenging ammonia removal problems. These first initial customers could also be important sources of referrals as Saltworks builds its reputation and technical expertise in this market.

Our last recommendation is that once Saltworks has entered the ammonia removal market and has begun to grow, it should focus on increasing the competitiveness of its products in preparation for entering other, increasingly competitive markets. Saltworks prototype system still requires substantial development before it is ready as an industrial product. The first plants will be prototypes and pilots themselves. As Saltworks installs additional plants this experience implementing solutions to customers' water challenges will result in efficiencies of production and learning. The production costs of the initial plants will be higher as the company's production capabilities scale up and the technology is refined. The efficiencies gained will be important to drive down production costs allowing Saltworks to offer lower prices to customers. After establishing a presence in the market segments targeted initially, Saltworks could turn to lower end and more competitive market segments, by offering lower prices to compete with established and cheaper solutions.

Together, these recommendations provide a road map for Saltworks as it seeks to enter this new market. The analysis of the existing market has highlighted the need for more effective technologies, such as those offered by Saltworks, so there can be no doubt of the attractiveness of this opportunity. The success of its market initiatives, however, will depend on the company's ability to navigate this challenging new arena.

Appendices

Summary of ammonia removal technologies utilized by industry

Ammonia Removal Method	Primary Advantages	Primary Disadvantages
Biological Nitrification (BN)	• Most economical • Simple operation • Robust build	• High initial capital • Large land area • Temperature sensitive process
Anammox	•Produces less sludge than BN • Requires less volume than BN • Reduces CO2 emissions 90%	• Requires dissolved oxygen to operate • very slow cell growth rate
Air Stripping	• Smaller initial investment • Small footprint • More effective at higher ammonia concentrations	• Higher operating cost from equipment • Temperature sensitive • Exhausts ammonia to atmosphere
Breakpoint Chlorination	• Small, simple installation • Removes virtually all ammonia • Chlorine treats other contaminants	• Process consumes chlorine • Dosage must be calculated every time
Zeolites	• Non chemical way to remove ammonia • Can remove very low concentration ammonia • Small footprint	• Zeolites must be recharged, wash fluid needs disposal • Disposable zeolites are expensive • Does not remove nitrite or nitrate
Membranes	• Small footprint • Can treat high concentration water • Simple operation	• Requires ph changes of wastewa • Produces ammonium salts Sulphuric acid consumable

Source: Compiled by author, material adapted from Water World Magazine.[99]

[99] Water World Magazine. http://www.waterworld.com/articles/print/volume-26/issue-3/editorial-features/addressing-the-challenge.html

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