SUPERPARAMAGNETIC NANOPARTICLE TECHNOLOGY

AN ANALYSIS OF WATER, WATER-TREATMENT, HEALTH-RISKS OF CONTMINATED WATER, AND A PROPOSED SOLUTION

By

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Superparamagnetic Nanoparticle Technology

An Analysis of Water, Water-treatment, Health-risks of Contaminated Water, and a Proposed Solution

By

ZACHARY T. ESCHWEILER

Abstract

Sygenia LTD is a start-up company founded in Cleveland, Ohio that was formed for the sole purpose of commercializing a novel technology developed at Case Western Reserve University (CWRU) by Dr. Daniel Scherson and his colleagues. The technology is a superparamagnetic nanoparticle functionalized with covalently-linked surfactants bearing metal binding functional groups on the ends capable of binding metal ions reversibly. The technology contemplated the removal of heavy metal contaminants and possibly other harmful substances from water to obtain a purity level that is safe for human consumption. The technology was introduced in a class titled Commercialization and Intellectual Property Management as part of the Fusion program taught at CWRU by Theodore Theofrastous. Sygenia LTD already existed and was led by Theodore Theofrastous and Daniel Scherson to commercialize the superparamagnetic nanoparticle technology. The group that considered the nanoparticle technology created two specific paths to commercialization that had real market potential including a residential and an industrial application. After completion of the class, Ted Theofrastous reached out to three of
the students that found the market potential for the nanoparticle technology and offered them the opportunity to join Syngenia LTD to spearhead the project as the commercial arm of the start-up company. The foundational work started in the class analyzes the opportunity that a like-innovation has in the space of water, water-treatment, and detection/monitoring.
Chapter One: Introduction

Understanding the Problem of Water Contamination

In order to understand the need for a solution, the problem at large must be identified. Contamination in our water supply presents a large problem for households all over the United States. The majority of Americans get their water from a public water supply. More particularly, about 86% or 258 million Americans get their water from the public water supply, while 14% or 43 million Americans self-supply through wells or another local underground water source (Perlman, 2016). Due to the number of Americans that drink water from the public water supply and in an effort to protect the health of American citizens, the Environmental Protection Agency (EPA) regulates drinking water by stipulating legal limits on the level of over 90 contaminants in the water (EPA, 2016).

The Safe Drinking Water Act (SDWA) was established in 1974 and amended in 1996 to ensure the health safety of American citizens by protecting water quality in all the states. The SDWA has 4 sections that outline guidelines for public water standardization: Public Water Systems, Protection of Underground Sources of Drinking Water, Emergency Powers, and General Provisions (Senate, 2002). Under the Public Water Systems section; the coverage, the national drinking water regulations, state primary enforcement, variances, exemptions, monitoring, and prohibition of lead pipes, solder, and flux are outlined. Under the Protection of Underground Sources of Drinking Water; regulations and enforcement of state programs, as well as regulation of underground injections are required. Additionally, state programs are to establish wellhead protection areas, and state ground water protection grants. Under the
Section B of the SDWA, state governments are free to set and enforce their own legal limits for water contaminants but those limits must meet minimum EPA legal limits on each respective contaminant (Senate, 2002; EPA, 2016).

The legal limits for water contaminants are delineated through published rules separated by their contaminant type: chemical contaminants and microbial contaminants. The rules under chemical contaminants are: the arsenic rule, the chemical contaminants rule, the lead and copper rule, the radionuclides rule, and the variance and exemptions rule. The rules under the microbial contaminants are separated into: the aircraft drinking water rule, the ground water rule, the stage 1 and stage 2 disinfectant/disinfection byproducts rule, the surface water treatment rules, and the total coliform rule and revised total coliform rule (EPA, 2016).

Despite these standards and regulations having been set and enforced, there are still many instances of drinking water contamination that are leading families to purchase water filtration devices and systems such as the Brita™ system that ensure the safety of their children. Disasters have struck in Flint, Michigan and St. Joseph, Louisiana and have exposed issues with State government oversight; and have raised an even greater issue which is our nation’s crumbling infrastructure. Recently, these occurrences of contamination have become “buzzwords” and spurred political protests and debates nationally.
The Disaster in Flint, Michigan

The problem started in June 2012 when city officials in Flint, Michigan began looking for a cheaper water source than the currently used Detroit Water and Sewerage Department. City officials created an alternative to their current water situation that would save the city upwards of $200 million over the next 25 years by creating their own pipeline and connecting it to the Karegnondi Water Authority (Kennedy, 2016). The city of Flint decided that this alternative plan was a good idea and declared to the state treasurer that the city of Flint will be joining the Karegnondi Water Authority. In response, Detroit’s water system declared that they would stop supplying Flint with its water effective April 2014 (Kennedy, 2016).

The city of Flint stopped receiving water from Detroit’s water system as of April 25, 2014, but the city still needed another water source until it could build and operate a pipeline that connected to the Karegnondi Water Authority. The Flint River was the city’s water source until the 1960s, so it decided to use the river as an interim water source until the connecting pipeline was completed (Kennedy, 2016). City authorities decided not to treat the water immediately because they worried that it might corrode the city’s pipes and create problems. More particularly, city officials said they did not want to treat the water immediately because they were unsure of the Flint River water chemistry compared to Detroit’s water system and did not want to over-treat the water with chlorine and cause the pipes to corrode. This inaction was dubbed as the “wait-and-see” approach by Michigan Radio (Kennedy, 2016; Smith, 2015).

In just the next month—May, Flint city officials started receiving complaints about the color and odor of the new water source. The new water from the Flint River was reported to be 70% harder than Detroit’s water system (Smith, 2015). Water hardness is associated with the
mineral content within the water; thus soft water has less mineral content, while hard water has a much higher mineral content. Water becomes harder or higher in mineral content when it passes through soil and rock and slowly corrodes the material surfaces it passes against while absorbing minerals that come from those sources. Hard water is usually recognized as containing high contents of calcium and magnesium (Oram, 2014). Outside of health effects, hard water almost always presents problems for households and machinery. Hard water can create problems when doing laundry by leaving the clothes feeling scratchy and rough. Washing dishes and bathing with hard water can be a nuisance because the hard water mixes with the soap and tends to leave a film on the skin or any glass after being washed. Lastly, perhaps the largest problem hard water creates is its effect on water-using household appliances and machinery. When hard water is heated, the calcium and magnesium forms a scale and can ruin hardware was well as pipes which will eventually lead to replacement of those devices and pipes (Oram-Hardness, 2014).

Again, while hard water has negative effects on household items, machinery, and pipes; it has quite the opposite effect on the human body. Consuming hard water can be beneficial to maintaining good calcium and magnesium levels in the body. Some studies even propose that higher levels of calcium and magnesium correlate with a lower probability of cardiovascular disease (Rosenlund et al., 2005), but this is not widely accepted. It was found in some studies that high concentrations of calcium and magnesium have protective effects against gastric cancer, though other studies found that the higher hardness level of drinking water was associated with colon cancer (Sengupta, 2013). Hardness levels in water associated with divalent and multivalent cations of aluminum, barium, strontium, iron, zinc, and manganese
have been associated with negative health effects and disease. For example, some studies associate extremely high levels of aluminum intake with effects similar to the pathology of Alzheimer’s disease (Sengupta, 2013). Lastly, extremely high levels of calcium intake can eventually be harmful to the body, particularly to men in the development of kidney stones. While the formation of kidney stones is only partly the result of environmental effects such as high salt (e.g., calcium) intake, it is overall a combination of several additional factors such as an individuals’ genetic traits, his/her metabolic traits, as well as his/her nutrition. Overall, hard water has beneficial effects on the human body as long as the dissolved ions are primarily magnesium and calcium (Sengupta, 2013).

In August of 2014, reports surfaced that *E. Coli* and total coliform bacteria had been detected in Flint’s water supply. In response, the city quickly moved to resolve the problem by first advising residents to boil their water before use, and then added chlorine to the water supply in an effort to reduce the bacteria levels (Kennedy, 2016). Chlorine is often added to public water sources such as municipal drinking water, public and private water supply, and public swimming pools as a disinfectant. Therefore, increasing the chlorine levels in Flint’s public water supply from the Flint River would effectively eliminate/reduce the total coliform levels that potentially cause sickness (Oram-Chlorination, 2014).

Later in October of 2014, General Motors decided that it would stop using water from the Flint River due to the higher levels of chlorine in the water (Kennedy, 2014). Tom Wickham of GM had explained that the company was worried about the higher chlorine levels in the water and the decision to discontinue Flint River water use within the plant was a preventative measure to ensure corrosion would not occur in their machinery (Fonger, 2014). That
particular GM plant uses about 75,000 gallons of water a day and though the chlorine levels were still within the public health guidelines, the continuous usage of the highly-chlorinated water required the GM plant to further treat the water to bring chlorine levels down to their machine-standards (Fonger, 2014).

On February 25, 2015; high lead levels were discovered in the water supplies of residential households in Flint, Michigan. The city conducted water tests in residential households of Flint, Michigan and found when they tested the home of Lee Anne Walters, a Flint resident, there was a lead content of 104 parts per billion (ppb). This lead level in the drinking water was almost 7 times the legal limit, as the EPA mandates a threshold limit of 15 parts per billion for drinking water (Kennedy, 2014.) After this eye-popping report was released, the EPA inquired about the city of Flint’s water treatment process, in which Flint responded by saying they were doing everything correctly. Later in April of 2015, Lee Anne Walters announced that her child had lead poisoning. In addition, due to all the news about Flint’s water problems, an independent study was conducted by Virginia Tech that found lead levels of 13,200 ppb (Roy, 2015). This was further negative press for the city of Flint as water is considered hazardous at 5,000 ppb (Kennedy, 2014). All of this negative press caused quite a stir for the residents of Flint as the water smelled and looked different in their households, even if it was an isolated incident as the city suggested. Negative press continued and the city even started to be seen as covering up the problem. The city took samples to test for lead levels within residential homes but decided to exclude two of the highest lead-containing samples because they didn’t meet federal criteria—one home had a water filter and the other was taken from a business. Including even one of the samples would have put them over the
federal action level, so the public started thinking Flint was covering up the problem (Kennedy, 2014). In September 2015, Virginia Tech researches came to Flint and tested hundreds of homes and found “serious levels of lead” during preliminary tests (Kennedy, 2014). Based on all the recent polarizing news, on September 24, pediatrician Dr. Mona Hanna-Attisha of Hurley Children’s Clinic decided to look into the problem herself and started testing the clinic’s patients for lead exposure. Before the switch to the Flint River for drinking water, 2.1% of tested children had elevated lead levels in their blood; but after the water switch, she found 4% of tested children had elevated lead levels in their blood (Kennedy, 2014; Smith, 2015). All the patients were children under the age of 5. Because her initial sample size was not large enough to draw reliable statistical conclusions, she decided to gather as much data from the area as possible and collaborated with other doctors to collect the information so they could collectively make a public statement (Smith, 2015).

This act of doctors going public with their information on elevated lead levels in the residential children in Flint served to significantly shift public opinion since the information did not come from political activists, but rather from a group of doctors worried about the health of the city’s youth (Smith, 2015). The press conference that Dr. Mona Hanna-Attisha held was widely attended and many came to see the data that she gathered and presented upon with the concluding request for the city of Flint to switch back to its previous water source. The state of Michigan initially attempted to convince reporters that Dr. Hanna-Attisha’s numbers were inaccurate and many reporters approached her to present the state’s conflicting data. Eventually the state admitted that her data was accurate (Smith, 2015).
In response to the doctor’s pediatric lead survey, the city issued a lead advisory. In the lead advisory the city admitted to no wrong-doing while stating their compliance to the SDWA, yet concurrently stated that lead in drinking water is not safe. In response to the lead advisory the city and state began offering free water filters and water testing for residential households that were worried about potential contamination of their water supply (Kennedy, 2014). Finally, on October 16, 2015; the city of Flint capitulated to the public demand and switched back to the Detroit Water Supply (which is now known as the Great Lakes Water Authority) (Kennedy, 2014).

After the switch back to the previous water supply, which the residents of Flint trusted as there was actually corrosion control (chemicals) within the water, the public wanted answers as to why city officials allowed this to happen. In an attempt to clarify why corrosion control was not used for water drawn from the Flint River, MDEQ (Michigan Department of Environmental Quality) director Dan Wyant said that the Flint River water was not treated when the switch occurred because they believed they were following protocol correctly, but realized they were only following protocol for a community under 50,000 residents. For communities over 50,000 residents, it is required that the city use maximum corrosion control for the water supply (Kennedy, 2014). Overall, the MDEQ chalked up their ignorance to confusion and misunderstanding.
How did lead actually enter the water supply?

In order to understand how lead actually entered the households of the Flint residents, one must understand the infrastructure of the pipes in the Flint water system as well as additives regularly added to water systems for corrosion control. Previously, the hardness of water was discussed and its potential effects on machinery, clothing, and the human body. To reiterate, while hard water is generally believed to have beneficial effects on the human body, its effects on machinery, clothing, dishes, and metals are generally adverse (Oram-Hardness, 2014). Among water sources most commonly used for a city’s water supply, drinking water is usually taken from ground water or surface water. Surface water, in general, is more difficult to treat due to its continual exposure to different elements (Olson, 2016). The Flint River is no exception; in fact, it is a good example of an extremely difficult water source to treat. The Flint River is naturally high in corrosive chloride which immediately started causing problems for the pipes as soon as the switch occurred (Olson, 2016). As soon as the Flint water started flowing through the Flint pipes, the pipes began corroding the protective barrier that itself prevents pipe corrosion. The pipes in the water distribution system were mostly made of iron, but the water service lines to residential households were made of lead, as was common prior to the 1960s (Olson, 2016).

As has been noted, there has been many different aftereffects from switching to the Flint River as the primary water source for the City of Flint, Michigan. These effects include: discolored and odorous water, increased coliform levels, and lead contamination (Kennedy, 2014). All of these problems came about due to the water quality of the Flint River. The first complaint from residents of Flint came in May 2014, just a month after the switch to the Flint
River, that the water was discolored, cloudy, and smelly (Kennedy, 2014). This problem can be attributed to the untreated water of the Flint River which immediately started corroding the iron pipes of the city’s water distribution system. The corroded iron particles that were then continuously entering the water system caused this discoloration and odor and lead to another problem—the rise in *E. coli* and total coliform bacteria level (Olson, 2016). These corroded iron particles not only affected the physical characteristics of the water entering residential households, they also reacted with the residual chlorine that was added to the water in order to kill microorganisms. This reaction rendered the chlorine unable to function as a disinfectant for bacteria (Olson, 2016). Since the iron particles had in effect, “neutralized” the chlorine, levels of bacteria such as *E. coli* and total coliform bacteria rose enough to be detected in the water distribution system (Olson, 2016). Since higher levels of bacteria were detected, the city sent out multiple advisories to the residents informing them of the bacteria detection and recommending everyone should boil their water until further notice. This problem with bacteria was remediated simply by raising the chlorine levels in the water but raising chlorine levels has its own negative effect in leading to greater formation of trihalomethanes which are known to be carcinogenic (Kennedy, 2014; Olson, 2016). The last, most deadly, and widely-known problem that switching to the Flint River water was the lead contamination. As was previously discussed, the untreated Flint River water caused the iron pipes in the water distribution system to corrode and release iron particles into the water. In the same way, the untreated water caused the corrosion of the lead service pipes which caused lead and copper particles to leak into the water distribution system (Olsen, 2016). Many of the service lines in Flint were older distribution systems and as was common during the time they were installed,
the pipes were constructed of lead and copper. When Flint was using water from Detroit’s water system, the water was treated with corrosion control, which creates a thin protective coating layer on the pipes that the water travels through to prevent corrosion. Since Flint did not treat the Flint River water with corrosion control treatment when they made the switch, the water destroyed that protective layer that had built up from previous years of corrosion control usage and immediately started decaying the lead pipes, releasing lead and copper particles into the water supply (Smith, 2015).
Chapter Two: Contaminants in our Water Supply

The disaster in Flint, Michigan is just one of many examples of heavy metal contaminants entering the water supply. There are other occurrences in world history as well as the world today of heavy metal contaminants entering the water supply and subsequently negatively affect the environment, its surrounding habitats, and the people dependent upon said habitats and environments. Some examples of this problem, aside from Flint, are lead contamination in St. Joseph, Missouri; mercury poisoning in the 1950s in Minimata Bay, Japan; arsenic, copper, lead, cadmium in the Animas River in Southwestern Colorado; chromium in Mature, Zimbabwe; and arsenic poisoning in Bangladesh today. Each of these contaminants, along with other heavy metals, can be extremely toxic to animals and human beings if ingested. Heavy metal contaminants can have different effects on humans, depending on their stage of development—whether they are children or adults.

While the effects of each type of heavy metal contamination vary, the pathophysiology of heavy metal toxicity is relatively similar for all the metals (Adal, 2016). What happens is the heavy metals will enter your body through ingestion—whether it be by air, water, or food and bind with oxygen, nitrogen, and sulfhydryl groups in proteins (Adal, 2016). The binding of the heavy metals to each of these results in changes of enzymatic activity—for example; the binding of heavy metals to the sulfhydryl group causes the body to increase its production of metalloproteins, which are binding-proteins that have high-affinity for metals because they contain “thiol ligands” (Adal, 2016). This is the body’s way of combatting heavy metal poisoning and maintaining homeostasis. The heavy metals will bind with proteins that are
involved in both excretion and transportation because ligand formation is the prerequisite for both. By binding to metalloproteins involved in excretion, the heavy metals are quickly disposed of, but problems occur when heavy metals compete with important metals that the body demands, such as calcium and zinc (Adal, 2016). Lead can be used as an example of this phenomenon as lead will follow the same pathways as calcium and deposit into the bone and other organs that require calcium. This process follows with other heavy metals that are similar in ionic radius to the usual required metals the body needs (Adal, 2016).

Metal exposure in your body isn’t always harmful. For example, metals such as zinc and iron are extremely beneficial to the body. Zinc is important to your body’s immune system and aids in the healing process when you suffer wounds as it benefits the structural integrity of dermal tissue and mucosal membranes by aiding in the division of cells (Tissue, 2014), while iron is needed for the transportation of oxygen throughout your body. While these two metal minerals are extremely important for your body, it is possible that in large quantities they can be toxic to you—but this normally only occurs by intentional ingestion of zinc and iron tablets.

**Heavy Metal Contaminant: Lead**

Lead, on the other hand, has no benefits whatsoever to the human body. As discussed previously, it has similar properties to calcium so it binds to the same transport proteins and is carried to wherever calcium would normally be taken. This presents problems because lead is now mimicking the actions of calcium as well as inhibiting calcium from its normal duty in the body. Calcium primarily plays a role in strengthening the body’s bones but it also plays an
important role in regulating blood vessels as well as sending messages with hormones throughout the nervous system (NIH, 2017). As one understands the importance of calcium to the nervous system, it becomes easier to see how high levels of lead in the human body can negatively impact different parts of human body. Lead has different effects on a person dependent upon their developmental stage—ranging from a young child to an adult. Lead also can affect almost every organ in the human body and can have some debilitating neurological effects as well (Registry, 2007). Lead has harsher effects on children as opposed to adults as lead poisoning can lead to developmental effects including intellectual disabilities and growth delay as the child matures. There is no threshold level for lead poisoning in adolescents as even the smallest amount of lead exposure can effect neurological and developmental processes. It has even been shown in a couple studies by researchers Needleman and Nevin; that an extremely small amount of lead exposure can be correlated to social issues such as juvenile delinquency and even violent crime (Registry, 2007). The Agency for Toxic Substances and Disease Registry has gather information from peer-reviewed studies that have delineated the differences between effects and threshold for lead exposure in child and adults. The following table will summarize the information gathered on the webpage to illustrate the results. For reference, BLL is the abbreviated form for Blood Lead Levels. Also, encephalopathy can be defined as a disease or disorder of the brain. In this case, encephalopathy is describing any damage or effect on the brain as a result from lead toxicity.
Table 1: The table below is describing the threshold BLL (Blood Lead Level) believed to produce the neurological effects and encephalopathy in children compared to adults as well as other potential effects and symptoms from intense lead exposure (Registry, 2007).

<table>
<thead>
<tr>
<th></th>
<th>Children</th>
<th>Adults</th>
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<tr>
<td><strong>Threshold Level for Neurological Effects</strong></td>
<td>&lt; 10 µg/dL</td>
<td>40 to 120 µg/dL</td>
</tr>
<tr>
<td><strong>Threshold Level for Encephalopathy in BLLs</strong></td>
<td>70-80 µg/dL</td>
<td>460 µg/dL</td>
</tr>
</tbody>
</table>
| **Potential Effects of Intense Exposure** | ▪ Ataxia  
▪ Coma  
▪ Convulsions  
▪ Hyperirritability  
▪ Stupor  
▪ Death | ▪ decreased libido  
▪ depression/mood changes, headache  
▪ diminished cognitive performance  
▪ diminished hand dexterity  
▪ diminished reaction time  
▪ diminished visual motor performance  
▪ dizziness  
▪ fatigue  
▪ forgetfulness  
▪ impaired concentration  
▪ impotence  
▪ increased nervousness  
▪ irritability  
▪ lethargy  
▪ malaise  
▪ paresthesia  
▪ reduced IQ scores  
▪ weakness |

As one might observe, children are at a much higher risk for lead poisoning than adults—not just because the BLL threshold is lower, but also because they are still developing and are more likely to come into contact with lead through dust that can absorb through their skin with ease.
Not only does lead poisoning have neurological and encephalopathic effects on the human body in children and adults, but lead poisoning affects almost every organ and system in the human body. Lead poisoning has renal effects, hematological effects, endocrine effects, gastrointestinal effects, cardiovascular effects, reproductive effects and developmental effects on the human body (Registry, 2007). The following table describes each possible effect mentioned previously and summarizes the information collected from different studies giving threshold levels of toxicity, possible effects, treatments, differentiations, and resolutions as compiled by the Agency for Toxic Substances and Disease Registry.

**Table 2:** This table details the type of effect that occurs as a result from lead toxicity and also gives a summarization of information of each respective effect (Registry, 2007).

<table>
<thead>
<tr>
<th>Categorized Effect</th>
<th>Summarization of Related Information</th>
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| **Renal Effects**  | - There is no threshold BLL for the onset of adverse effects although most cases have been a result of high-dose exposures from workers that measure > 60 µg/dL  
- Renal toxicity is typically asymptomatic so workers that are commonly exposed to lead should get their kidney's tested often  
- Reversible if caught early but irreversibly if untreated and develops into chronic neuropathy |
| **Hematological Effects** | - Lead causes problems by inhibiting hemoglobin production  
- Adult threshold BLL = 50 µg/dL  
- Child threshold BLL = 25 – 40 µg/dL  
- Lead toxicity can cause two types of anemia: hemolytic anemia and Frank (normocytic) anemia  
  - Hemolytic anemia = RBC destruction  
  - Frank anemia = hemoglobin levels decreased |
| **Endocrine Effects** | - There is an inverse correlation with high BLL and Vitamin D levels due to lead blocking vitamin D conversion to its hormonal form  
- Vitamin D in its hormonal form is responsible for intra and extracellular regulation of calcium  
- Mostly restricted to children with BLL > 62 µg/dL |
| **Cardiovascular Effects** | • Increased BLL over longer periods of time have been correlated to Hypertension  
• Those that have lead poisoning as children at 50 times more likely to develop hypertension as adults  
• Estimated that blood lead can account for 1% to 2% variance in blood pressure. This is a high correlation, especially for those genetically pre-disposed to hypertension |
| **Reproductive Effects** | **Men**  
• Threshold BLL for effects = 40 µg/dL  
• Effects include lower sperm count, higher rate of abnormal sperm, and higher rate of sperm mortality  
**Women**  
• Most studies show only small evidences of increased spontaneous abortion correlated with higher BLL but there are contradicting studies as well  
• Study shows that women with 5-9 µg/dL are three times more likely to have spontaneous abortions compared to women with BLL < 5 µg/dL |
| **Developmental Effects** | • Prenatal exposure to lead at maternal BLL of 14 µg/dL is thought to increase the rate of congenital defects at birth but there is not enough concluding evidence  
• Learning disabilities have been shown to occur in children of parents who were affected by lead poisoning at a young age |
Chapter Three: A Proposed Solution

The route in which the solution came about was much different than most situations. Most often, solutions evolve out of a need that has been pre-identified. Identifying a need is much more complicated than one might think. When identifying a need, one must look at several dimensions before deciding to pursue a marketable solution. One must identify the core problem itself, the population affected by that problem, and lastly the desired outcome. Once all three of these questions can be answered, a needs statement can be constructed that will help funnel the possible solutions to that problem (Zenios et al, 2010). In this case, a perceived solution towards an existing problem had already been created and published by Dr. Daniel Scherson. The problem was pre-identified as the “presence of heavy metal contaminant species in consumable water.” Dr. Daniel Scherson and his graduate student colleagues co-invented a solution to this problem. The invention is was made with the goal of removal of heavy metal contaminants and potentially other hazardous species in water to levels low enough to make it suitable for human consumption.

Superparamagnetic Nanoparticles

The technology is detailed and unique through utilization of superparamagnetic nanoparticles, bearing covalently-bonded surfactants containing functional chemical groups, which are capable of binding metal ions reversibly. This translates to meaning that these nanoparticles are able to target a specific metal ion, bind it, and then unbind it under specific
conditions. Below is Figure 1, which gives a concept of what the superparamagnetic nanoparticles look like.

![Figure 1: The above illustration is describing a superparamagnetic nanoparticle bearing covalently linked surfactants with metal binding groups at the ends.]

The center largest circle represents the iron oxide core which is superparamagnetic. The wavelike features stemming out form the iron oxide core are the surfactants. These surfactants have covalently-bound the smaller circles on the ends, which are functional groups, such as
carboxylate. These functional groups have the capability of binding specific metal ions, depending on what the functional group is.

**What is Superparamagnetism?**

Superparamagnetism is defined as a form of magnetism “A phenomenon in which particles under a certain critical size and having a single magnetic domain can exhibit behavior similar to paramagnetism despite being below the Curie temperature—for a ferromagnetic substance, or the Néel temperature—for an antiferromagnetic or ferrimagnetic substance (Oxford, 2017).” In order to really understand this definition, one must understand the terms: paramagnetism, Curie temperature, ferromagnetic substance, Néel temperature, and antiferromagnetic substance.

The Curie temperature, also known as the Curie point, is named after Pierre Curie who was able to show that magnets lose their magnetic properties once it reaches a certain temperature—thus, the Curie temperature is the temperature in which a magnet loses its magnetism. For Iron(III) oxide (Fe$_3$O$_2$), the Curie temperature is 948 K, which equates to about 674°C.

Paramagnetic materials can be defined as, “Materials that are attracted by an externally applied magnetic field and form internal, induced magnetic fields in the direction of the applied magnetic field (Boundless, 2016)” Paramagnetism occurs when electrons are alone in an orbital. If there is two electrons in an orbital, the spin gets canceled out, but if there is only one electron in the orbital, the atom is paramagnetic and has a net spin. Furthermore, because of
this net spin, the atom is attracted to any externally applied magnetic field but does not retain any magnetic properties when that magnetic field is later removed (Boundless, 2016).

Ferromagnetism is a somewhat simple concept and process by which two materials are attracted to one another and form permanent magnets or are attracted to a magnet (Boundless, 2016). Perhaps a better way of thinking about it would be if you place a magnet onto the refrigerator. The magnet sticks because the refrigerator is made of ferromagnetic materials. On a complex level, the reason the magnet will stick to ferromagnetic material is because the ferromagnetic material is composed of regions called domains. These domains are randomly oriented in different directions while unmagnetized, but when an external magnet comes in contact with the ferromagnetic material, those domains grow and align—thus inducing magnetization in the material (Boundless, 2016).

The Néel temperature is analogous to the Curie temperature, except with antiferromagnetic material. It is the temperature at which antiferromagnetic materials becomes paramagnetic (Rinaldi-Montes, 2016). Antiferromagnetic materials’ atoms have spin that have magnetism but are cancelled out by other sets of atoms aligned in the reverse direction. This means that antiferromagnetic materials are not attracted to magnets (Britannica, 1998). But, when antiferromagnetic materials are heated and brought to a specific temperature, depending on the metal, the antiferromagnetic material becomes paramagnetic (Rinaldi-Montes et al, 2016). Lastly, ferrimagnetic materials are similar to antiferromagnetic materials in that they have opposing magnetic domains, but they are slightly unequal so the domains do not cancel each other out and instead maintain a weak magnetization (Britannica, 1998).
Now that we understand what each of these terms, we can better understand what Superparamagnetism is and the significance of it. Superparamagnetism can only happen in sufficiently small nanoparticles. When these nanoparticles come under the influence of a specific temperature, the magnetization of the nanoparticles can randomly flip direction. So for instance, a ferromagnetic or ferrimagnetic material at a nanoscale under the Curie temperature with no external magnetic field shows no magnetic susceptibility, it is paramagnetic. But if this same material shows high magnetic susceptibility—it is ferromagnetic (TutorVista, 2017). This is an example of Superparamagnetism. “Superparamagnetism is defined by the property due to which in some materials, magnetic moments change their direction at nanoscale and behave like a paramagnet even below Curie temperature when no magnetic field is applied, and at the same time they show high magnetic susceptibility, like ferromagnets.” (TutorVista, 2017). To summarize this concept, a material in a superparamagnetic state behaves very similarly to a paramagnet and can magnetize nanoparticles, but has a much higher magnetic susceptibility than paramagnets—like ferromagnets.

How exactly will these Nanoparticles be utilized for Innovation?

Let us remember that the problem that we are trying to solve: “The Presence of heavy metal contaminant species in consumable water.” Dr. Daniel Scherson and his colleagues created a concept and proof-of-concept in a lab setting that they could use superparamagnetic nanoparticles bearing covalently-linked surfactants with metal binding groups at the ends to remediate this problem and create safe, consumable water.
In this constructed operation there is a cell in the form of a chamber. Inside the cell a concentrated batch of superparamagnetic nanoparticles is placed onto a flat carbon electrode, which is the cathode. Then, an electromagnet is placed behind the carbon cathode to immobilize the nanoparticles upon the carbon cathode.

![Diagram of a cell with an electromagnet behind the cathode](image)

**Figure 2:** A closed cell contains an electromagnet that is placed behind a carbon cathode in which the superparamagnetic nanoparticles have agglomerated upon.

After this, the cell is opened up so that effluent may enter the chamber. Once the effluent enters, the chamber is closed to isolate the effluent and the nanoparticles, and the electromagnet is then removed or deactivated. The removal/deactivation of the electromagnet releases the previously-immobilized superparamagnetic nanoparticles so that they are able to thoroughly disperse within the effluent solution (Scherson et al., 2013). Depending on the pH of the effluent solution, the pH can be adjusted using a gas-permeable electrode in
order to ameliorate the solution for maximal binding between the metal ions present in the effluent solution and the functional chemical groups of the superparamagnetic nanoparticles. If the solution is too acidic, the gas-permeable electrode is polarized sufficiently negative to promote reduction of dioxygen from the atmosphere, generating hydroxyl ions until the desired pH is achieved (Scherson et al., 2013).

After allowing some time to allow for maximal binding of the metal ions by the nanoparticles, the electromagnet is reintroduced directly behind the carbon cathode and the nanoparticles agglomerate on the surface of said cathode.

![Diagram](image)

**Figure 3:** In Panel A of the diagram, the effluent solution has entered the cell and the magnet has been removed to allow the superparamagnetic nanoparticles to disperse within the solution and allow sufficient uptake of metal ions by said nanoparticles. Next, in Panel B, the Magnet has been reintroduced to the cell so the nanoparticles have agglomerated on the surface of the carbon cathode.

While the nanoparticles are magnetically suppressed on the cathode by the electromagnet, and after the carbon cathode is polarized sufficiently negative, the chamber behind the gas-permeable electrode is purged with pure nitrogen to remove oxygen (Scherson et al., 2013).
Concurrently, a solid-state electrolyzer is activated to generate hydrogen within the chamber, which is then oxidized by the gas-permeable electrode, thus lowering the pH of the substrate. Under these conditions, the nanoparticles are forced to release the metal ions that they had previously bound. As the metal ions are released by the nanoparticles they are plated onto the carbon cathode—effectively cleansing the previously contaminated solution.

Figure 4: While the nanoparticles are magnetically suppressed in Panel C, and the cathode is polarized sufficiently negative, the chamber behind the electrode is purge with pure nitrogen in order to remove oxygen. Also the electrolyzer is turned on to generate hydrogen within the chamber, as shown in Panel D, which is then oxidized on the electrode—thus, lowering the pH of the solution. This change in pH forces the superparamagnetic nanoparticles to release their metal ions as they are simultaneously plated onto the cathode. The cleansed effluent is pushed out of the cell by the magnet and cathode, new solution enters, the magnet is once again removed, and the superparamagnetic nanoparticles once again disperse and bind metal ions (Panel D).

Lastly, the carbon cathode and magnet assembly work as a piston to force the cleansed solution toward the gas-permeable electrode and out of the chamber. A new heavy metal ion contaminated effluent solution is introduced, the magnet is removed, and the entire process is repeated (Scherson et al., 2013).
Potential Routes to Commercialization for the Innovation

This process for removal of heavy metal ions from contaminated effluent using superparamagnetic nanoparticles can be marketed as a product in several different applications, namely water remediation and metal ion detection. Though the intended purpose for the invention was the remediation of water that has been contaminated by heavy metal ions, a heavy metal ion detection product has been evaluated as the most profitable direction for this innovative technology.

To get a perspective in how these commercialization routes came about, let us backtrack to the origination of the needs statement. During the fall of 2015 at Case Western Reserve University, a group of students were given an invention disclosure on the superparamagnetic nanoparticle technology. The group was tasked with analyzing their invention disclosure and coming up with a needs statement that, as previously mentioned, identifies a core problem itself, the population affected by that problem, and the desired outcome.

The first, most obvious commercialization route, was utilizing the innovated technology as a heavy metal remediation device in a residential or industrial setting. Heavy metal remediation is most commonly practiced in an industrial setting as the Environmental Protection Agency (EPA) has set cleanliness standards for effluent before it leaves the plant. If this innovation were to be used in an industrial setting it would need to be less expensive and more effective than the best current solution on the market. The industrial remediation market is highly competitive and mature which makes introducing a new technology extremely difficult. Our group decided to delve a bit deeper into finding a less obvious route to
commercialization that could potentially yield a more profitable and desired outcome. In probing potential uses for this innovation, we wanted to stay within the same market, but perhaps utilize the product differently. Instead of using the innovation for heavy metal remediation, because it would be far too expensive compared to the top membrane precipitate technologies most popularly used, we speculated as to whether the innovation could be used for heavy metal detection. The EPA has made efforts to clean up our public water system but, local rivers and lakes that are often the “dump sites” for industrial effluent.

**Needs Statement**

After first looking into the broad heavy metal ion remediation market, which includes both remediation of heavy metal ion from wastewater effluent as well as remediation of heavy metal ions residentially, we decided that the superparamagnetic nanoparticle technology be used to respond to a market demand which has as of now gone unanswered: real-time, in-line, post-remediation, heavy metal ion detection and monitoring. In constructing the needs statement we were able to answer the three core questions. The core problem identified is the process of real-time wastewater effluent monitoring to meet EPA standards. The population that this innovation could possibly be utilized in is quite large—every industrial setting that is required to take measurements of their wastewater effluent to ensure they do not exceed the threshold level for metal contaminants. The desired outcome of this innovation is two-fold: first, to ensure that all wastewater is continually monitored so that our lakes and rivers can be even cleaner; and second, to save industrial companies thousands of dollars by limiting over-
remediation while also eliminating labor required for measurement and remediation. After identifying and answering these core questions, the following needs statement was constructed:

“Entities responsible for remediating heavy metal ions from waste water supplies need a more cost effective (less expensive), and potentially portable, method for meeting EPA standards.”

Currently, the most common method used to test the effluent of industries that use heavy metals is Atomic Spectroscopy. Other methods are also used, but this heavy metal detection device utilizing superparamagnetic nanoparticles we propose is more cost effective, which will be expanded upon in further sections.

Heavy Metal Detection Product Requirements and Industry Description

My group had reached out for professional opinions on such a device and whether large and small industrial companies would be interested or not. We interviewed professionals from the Northeast Ohio Sewer District, City Plating, and Waste & Wastewater Labs all in Cleveland, Ohio; and from Digital Analysis Corporation located in Skaneateles, New York. Each interviewee indicated a need for such a product that we had detailed to them—one of the interviewees
even went as far as to say that they would purchase the product right then and there if we could demonstrate a working product in their facility.

**Currently, monitoring of post-remediation wastewater in the metal industry is conducted on an average, once-a-monthly basis by an outside contractor.** While this current technique satisfies the federal and local clean water requirements, once-a-month monitoring leaves massive data holes in the water remediation processes utilized. According to Randy Solganik, who sits on the Board of the Ohio Association of Metal Finishers, this superparamagnetic nanoparticle device could be used to indicate out-of-range situations in the wastewater effluent. What he meant by this, is that since this device is constantly monitoring the wastewater effluent, it can alert the operators of the remediation techniques of the situation. Sometimes in an industrial setting, accidents can happen such as leaks of raw materials. An alert of this nature will allow operators to immediately address the problem and remediate errors in the upstream filtration and maintain upper and lower specification levels for the water remediation processes. Solganik suggested that there is currently no device on the market that offers this type of solution, despite the need for something like this. He mentioned off-hand that $10,000 per unit would be a reasonable price if this solution were to be put on the market and operate successfully with minimal additional operating costs. Moreover, Solganik outlined a basic requirement list that this type of solution must meet in order to be successful:

*A successful post-remediation, heavy metal monitoring device must be:*

1. Robust and reliable in a widely fluctuating industrial setting
2. **Easy to use**—the product should not require extensive training and/or additional operational costs.

3. **Cheap**—the product should not be a huge upfront capital expense, nor a new, ongoing operational expense

Currently, the EPA requires industrial companies to measure their wastewater effluent to a specific parts-per-million, depending on the measured contaminant. The overwhelming majority of companies utilize Atomic Spectroscopy to achieve this requirement. Atomic Spectroscopy is an accurate technique, but it is also extremely inefficient. The technique requires labor, chemicals, and time to achieve the desired results. The superparamagnetic nanoparticle technology would allow for a product that can surmount many of the inefficiencies linked with Atomic Spectroscopy by exploiting the technology as a continuous, real-time monitoring device. If industrial companies were to replace Atomic Spectroscopy with our device, they could reduce their expenditures in labor, chemicals, and remediation techniques used in order to fulfill the required EPA standards as will be expanded upon in the Value Proposition section. To gain a better understanding of an industrial setting that this technology would be used at and where the technology would be situated—please refer to Figure 5 on the next page.
Figure 5: In a typical industrial plating plant, process water goes through many different rinse baths and plating bath before taken through remediation (which is labeled as neutralization and precipitation in the figure) before being discharged as waste water effluent. The proposed device would be inserted in line right before the water is discharged (Roy, 1988).
As discussed, industrial plants that discharge heavy metal ion contaminated effluent—such as metal plating and electroplating factories, are required to measure and report the level of contamination within the effluent that is discharged. The EPA has provided limits and regulations for these types of facilities as shown below in Table 3, Table 4, and Table 5.

Table 3: In this table the EPA given limits for Metal plating are represented for each element (EPA, 1984).

<table>
<thead>
<tr>
<th>Metal</th>
<th>Limit for one day (mg/L)</th>
<th>Monthly Average Limit (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>0.69</td>
<td>0.26</td>
</tr>
<tr>
<td>Chromium</td>
<td>2.77</td>
<td>1.71</td>
</tr>
<tr>
<td>Copper</td>
<td>3.38</td>
<td>2.07</td>
</tr>
<tr>
<td>Lead</td>
<td>0.69</td>
<td>0.43</td>
</tr>
<tr>
<td>Nickel</td>
<td>3.98</td>
<td>2.38</td>
</tr>
<tr>
<td>Silver</td>
<td>0.43</td>
<td>0.24</td>
</tr>
<tr>
<td>Zinc</td>
<td>2.61</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Table 4: In this table the EPA given limits for Electroplating metal facilities discharging 38,000 liters or more a day are represented for each element (EPA, 1984).

<table>
<thead>
<tr>
<th>Metal</th>
<th>Limit for any one day (mg/L)</th>
<th>Average of daily values for 4 consecutive monitoring days (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>4.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Nickel</td>
<td>4.1</td>
<td>2.6</td>
</tr>
<tr>
<td>Chromium</td>
<td>7.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>4.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Lead</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Cadmium</td>
<td>1.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Table 5: In this table the EPA given limits for Electroplating metal facilities discharging less than 38,000 liters a day are represented for each element (EPA, 1984).

<table>
<thead>
<tr>
<th>Metal</th>
<th>Limit for any one day (mg/L)</th>
<th>Average of daily values for 4 consecutive monitoring days (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Nickel</td>
<td>1.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Meeting EPA Standards

As previously mentioned, Randy Solganik had suggested that a reasonable price point for the device would be $10,000. The cost of manufacturing and operating the device are directly correlated with the size of the device—the larger the device, the more expensive it will be for materials (also more nanoparticles required) and the more energy it will take to operate the device. Due to this, the obvious goal would be to manufacture the device as small as operationally possible. The EPA requires a minimum sample size in order to accurately reflect the contamination of the effluent leaving the industrial complex, but that size is unclear as there has never been a product that operates in the manner that this superparamagnetic nanoparticle device operates. The EPA would have to approve the device as a valid and accurate measurement method so that it can be used publicly and nationally in industrial companies. Although, EPA approval of our device is not required in order to market the device, EPA approval is of paramount importance as companies would be allowed to use our method to indicate that they are meeting EPA standards. Since our technology only services one category—aqueous solutions; our technology would follow the Tier 2 Alternative Test procedure Approval Process, as described in 40 CFR part 136 which is outlined on the next page:
40 CFR part 136 --- EPA Alternative Test Procedure (ATP) Approval Process

1. Within sixty days of the receipt by the Director of the Analytical Methods Staff, Washington, DC, of an application for an ATP for nationwide use, the Director of the Analytical Methods Staff shall notify the applicant in writing whether the application is incomplete, the applicant shall be informed of the information necessary to make the application complete.

2. Within ninety days of the receipt of a complete package*, the Analytical Methods Staff shall perform any analysis necessary to determine whether the alternate method satisfies the applicable requirements of this part, and the Director of the Analytical Methods Staff shall recommend to the Administrator that he/she approve or reject the application and shall also notify the applicant of such recommendation.

3. As expeditiously as practicable, an alternate method determined by the Administrator to satisfy the applicable requirements of this part shall be proposed by EPA for incorporation in subsection 136.3 of 40 CFR part 136.

4. Following a period of public comment, EPA shall, as expeditiously as practicable, publish in the Federal Register a final decision to approve or reject the alternate method.

*NOTE* A Tier 2 application requires three lab validation studies for nationwide use for one analyte in one matrix type. It also requires ATP justification, a method comparison table, and method development information. The gathering of these requirements is estimated to take approximately one year.

Sources: (EPA, 2015; Speth, 2015)

Superparamagnetic nanoparticles have been used successfully in many different capacities recently. They have most notably been used as a contrast agent for MRI imaging, demonstrating that they have a high variance of functionality. They are also often used for magnetic separation of components and as a platform for targeted drug delivery. Superparamagnetic nanoparticles have not yet been approved for usage in heavy metal ion detection, but hopefully with its approval, it will become a popular commercial utilization of superparamagnetic nanoparticles.
Protectability

For this superparamagnetic nanoparticle technology, the technology transfer office of Case Western Reserve University worked in tandem with Dr. Scherson and his colleagues to gain protection of their unique idea. On March 17, 2014 CWRU filed a PCT patent application titled “System and Method for Removal of Metals from Solution” with the application number, PCT/US2014/030250. The application can also be found on the USPTO or google patents under the application number, WO2014145477 A1. It was published on September 18, 2014 while the priority date is shown as March 15, 2013. The names of the inventors on the application are Daniel Scherson, Anna Cristina Samina, and Zhange Feng.

PCT stands for the Patent Cooperation Treaty, which was signed on June 19, 1970. This treaty makes it possible for an inventor to file for one patent that establishes international protection for his or her invention rather than having to file for multiple patents for different countries or regions (WIPO, 2015). One hundred and fifty-two (152) parties are incorporated with the PCT. The application must be written in one language and the inventor/author of the patent must be a resident of a PCT contracting state/party (WIPO, 2015). By establishing PCT protection, Dr. Scherson has protected his invention internationally and has opened up the potential for international market exposure for this product and any application thereof.

Though previously described in preceding sections, I will briefly describe the process described within the application so that we can understand the main Protectability issues therein. The patent application describes a processes of extracting heavy metals such as lead, manganese, cobalt, cadmium, and others, by using functionalized magnetic nanoparticles to bind with metal ions in a water-based solution (Scherson et al., 2014). The pH of the substrate
can be adjusted by either oxidizing hydrogen or by reducing the amount of oxygen, which respectively encourages the binding and separation of the heavy metal ions with the nanoparticles and plating of the heavy metals on a cathode. The pH of the substrate can be adjusted by either oxidizing hydrogen or by reducing the amount of oxygen, which respectively encourages the binding and separation of the heavy metal ions with the nanoparticles and plating of the heavy metals on a cathode. After the pH is adjusted for metal ion uptake, the nanoparticles are magnetically drawn to the cathode (magnet is behind the cathode) where an electrical current is applied to the cell which plates the metal ions onto the cathode. The pH can be adjusted to promote the release of the nanoparticles from the metal ions before the plated metal ions are collected (Scherson et al., 2014).

With respect to novelty, the unique aspect of the invention lies within part c of claim 1 as well as claim 6, which discusses the adjustment of the pH solution to promote the binding (claim 1) and the release (claim 6) of the metal ions from the superparamagnetic nanoparticles prior to plating the heavy metal ions on the cathode. This release of the metal ions, after they had previously been bound to the nanoparticles, by changing the pH of the solution effectively makes the nanoparticles reusable and eliminates the need for new nanoparticles. The patent application identifies this innovation in the scope of water remediation, not metal ion detection. This should not pose any problem for patent protection as the applications for the innovation are not restricted by the application described as long as the novel aspect of the innovation being claimed remains the same.

The patent office will review the patent application for Dr. Scherson’s technology and during its prosecution, the examiners will search for prior art. Prior art includes patents,
publications, or public disclosures, that may have described the novel process within the patent application before the patent was filed. This would render the patent invalid on the grounds of novelty. It was important for our group to search for any possible prior art reference to make sure that Dr. Scherson’s innovation won’t meet any legal problems, which can be quite costly for business development, for both money and time. On the next page, Table 6 summarizes the relevant prior art references that should be cited on the patent application and given due diligence.
Table 6: This table compares Dr. Scherson’s innovation (the top, separate table) to the relevant prior art found by giving the scope, a brief description, the similarities, and the contrasts.

<table>
<thead>
<tr>
<th>Patent No.</th>
<th>Patent Title</th>
<th>Scope</th>
<th>Description</th>
<th>Similarities</th>
<th>Contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCT/US2014/030250</td>
<td>System and Method for Removal of Metals from Solution</td>
<td>Water Remediation</td>
<td>Binding metal ions with nanoparticles onto a cathode, then releasing the nanoparticles before capturing the metal ions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/051,774</td>
<td>Electrowinning apparatus and process</td>
<td>Water Remediation</td>
<td>Applies electrochemistry to a conveyor belt system to bind and capture metal ions</td>
<td>Both employ the utilization of electrically conductive cathodes to attract metal ions</td>
<td>Does not employ means of changing pH to promote the binding or release of metal ions</td>
</tr>
<tr>
<td>13/093,315</td>
<td>Liquid purification using magnetic nanoparticles</td>
<td>Water Remediation</td>
<td>Introduces nanoparticles into liquid solution wherein the particles bind to metal ions and charge is applied to extract the conjugate</td>
<td>Prescribes the release of the bind between nanoparticle and metal ion, wherein the nanoparticles can be reused</td>
<td>Does not prescribe changing the pH of the solution to foster the release of nanoparticles from the metal ions</td>
</tr>
<tr>
<td>US06579733</td>
<td>Method for monitoring metal ion concentrations in plating baths</td>
<td>Metal Ion Detection</td>
<td>Introduces a known amount of voltage to two solutions, wherein one concentration of metal ions is known and the other is not</td>
<td>Utilizes a cathode during its process in determining the concentration of metal ions in a solution</td>
<td>Scherson’s innovation does not require a second solution as a reference to determine the concentration of metal ions in another solution</td>
</tr>
<tr>
<td>PCT/EP2000/005458</td>
<td>Apparatus and Method for Sensing Metal Ions</td>
<td>Metal Ion Detection</td>
<td>Measures the mass of metal ions collected upon a sensor layered with a specific ligand</td>
<td>Both attract and bind the metal ions before determining the concentration of metal ions in the solution</td>
<td>Rather than utilizing a specific ligand, Scherson’s innovation utilizes nanoparticles to bind with metal ions</td>
</tr>
</tbody>
</table>
Chapter Four: The Market

In the fourth and final chapter of this report, important business topics associated with the superparamagnetic nanoparticle technology will be covered including: Market analysis which encompasses value proposition, total addressable market, the target market and application, market size, and competing manufacturers and solutions; as well as the Market Valuation which encompasses the operation strategy, exit strategy, stages of value, and potential risk factors.

Syngenia LTD

Much of the data in this section comes, not only from the group tasked with the technology in the Commercialization and Intellectual Property Management class at CWRU during the fall of 2015, but also from the commercialization team employed at Syngenia LTD. To clarify; at the end of the fall 2015 semester, Theodore Theofrastous approached members of the group tasked with the Superparamagnetic Nanoparticle technology and offered equity participation in exchanged for involvement in the start-up, Syngenia LTD, in which he was partnered with Dr. Daniel Scherson. Zack Eschweiler, Brian McDonald, and Jon Lucas all verbally agreed to a collective 21% (each getting 7%) vesting over a 1-year period contingent upon specific milestones. It was decided that a contract affirming our verbal agreement would be written up and the capitalization table for Syngenia LTD would be re-structured with the entrance of the new members once the technology transfer office at CWRU and Dr. Daniel Scherson agree to license the technology to Syngenia LTD.
Once Syngenia LTD obtains the license to the superparamagnetic nanoparticle technology, they would have the option to sub-license to third-parties that are interested. Part of the Intellectual Property Protection Strategy is deciding whether it would be beneficial to go forward with an exclusive license with one company, or multiple non-exclusive licenses with numerous interested parties. Syngenia LTD decided that once they received the license from CWRU, they would go ahead and pursue an exclusive license to the residential market segment with an interested third party that was already established within said market segment. An exclusive license would allow Syngenia to receive higher percentage royalty rates (25%) as well as a higher upfront payment on the licensing deal. After striking the deal for an exclusive sub-license with a third party, Syngenia LTD would have more funds to aid in going forward with pursuing the industrial application of the device.

**Market Requirements**

In order to gain a concrete understanding of what a product requires in order achieve success in the market, our team reached out to interview several experts in the market within the Cleveland, Ohio and Skaneateles, New York areas as previously mentioned. In an effort to condense and summarize the information gathered from these interviewees, we created a list of required characteristics for our technology in order for it to be successful:
The Technology must be:

1. **Robust**—it must be able to perform regularly in a widely-fluctuating industrial setting.
2. **Sensitive**—it must be capable of detecting targeting ions at 1/10 parts per million (ppm)
3. **EPA Approval**—the device must meet all the requirements of EPA Office of Water (OW) Code of Federal Regulations (CFR) – 40 CFR part 136
4. **Minimum Operational Expense**—the device and its implementation should not significantly increase the current operating expense
5. **Turbidity**—the device must be capable of operating properly and accurately with highly turbid effluent
6. **Tunable**—the device must be able to target specific ions
7. **Reusable Filtrate**—the nanoparticles must persist for the lifecycle of the product itself
8. **Lifecycle**—the product should remain operative and working for at least 10 years before replacement
9. **Small Footprint**—must be capable of being installed within current infrastructure
10. **Low Capital Expense**
11. **Integration**—electronically it must be integrated into the existing control panel

**The Value Proposition**

A value proposition is required for a product to be marketable—why should the company invest in this product? This Superparamagnetic Nanoparticle device’s value lies within its ability to reduce the operation expenditure associated with the current heavy metal ion remediation
industries. Typical metal plating operations spend 7.5% of their gross revenues on heavy metal ion remediation (Solganik, 2015). Delving a bit further into that 7.5% in an effort to better understand expenditures; 3% goes to chemicals and polymers used for remediation, 2.2% goes to disposal of captured heavy metal ions, and 2.3% goes to labor to manage remediation operations (Solganik, 2015). The value of our superparamagnetic nanoparticle device lies within the reduction of expenses associated with the chemicals and polymers used for remediation and the labor that is required to manage the remediation operations.

In calculating the potential value of our product we found the number of companies in which our technology was applicable within one industry, the gross revenue across that industry, and the average gross revenues per year, per organization. Finding each statistic allows us to calculate the total amount of money per year spent on chemicals and polymers in the remediation of heavy metal ions. The electroplating and metal finishing industry had sales of $29 billion in 2014 (IBISWorld, 2014). So after finding each of the statistics:

1. 9,188 organizations in the industry
2. Gross Revenues across the industry of $29.7 billion
3. Average $3.23 million gross revenues per year, per organization

Then **$96,870.00 per year** is spent on chemicals and polymers in the remediation of heavy metal ions. This is calculated by multiplying the 3% spent on chemicals and polymers per year by $3.23 million, which is the average gross revenue of each applicable industrial company.

Users of chemical precipitate for heavy metal ion remediation typically over-remediate to ensure that they meet EPA requirements (Solganik, 2015). These companies over-remediate by estimated value because they do not have a real-time, in-line monitoring device to give them the
actual values that they are remediating to. If our proposed superparamagnetic nanoparticle device were to be used in this situation, these companies could calculate the exact amount of chemical precipitate that they should use so that over-remediation is not needed. We proposed that our device could reduce the use of chemistry up to 10% total current costs each year. This means that year one cost reductions would be about $9,700.00 (10% of $96,870.00). If an industry were to purchase two superparamagnetic nanoparticle devices targeting two different metal ions for a total $40,000; assuming a 10 year life cycle, the capital expense on these products is 4.12 years. During the remaining 5.88 years, costs savings for the industrial company will amass to a total of $57,036.00 with a Net Present Value (NPV) of $6,284 at a 15% corporate discount rate, indicating a positive corporate investment.

A Necessary Service

The value of our real-time, in-line heavy metal ion monitoring not only lies within the cost savings on chemical precipitates for industrial companies but also the opportunity to eliminate the management overhead required to report to the permit-issuing regulatory authorities currently required in industry business models.

Wastewater management systems managers are currently required to maintain relationships with these permit-issuing regulatory authorities. Additionally, there may be many of these regulatory officials as there may be many levels of management authorized by the permitting authority to sign for the company that they are indeed meeting government requirements. In The Operation and Maintenance of Surface Finishing Wastewater Treatment Systems, Clarence Roy states, “Managers may experience some difficulty in obtaining analytical
results from an outside laboratory in time to comply with deadlines. Many laboratories, particularly those certified by the EPA or the state may be subject to a backlog of work. When this situation arises, managers should inform their supervisor and/or the ‘authorized representative’ so that the problem becomes known to the proper authorities” (Roy, 1988).

Multiple agencies may require reporting and managers of the operations of the plants need to maintain relationships with these authorities and their different delivery schedules (Roy, 1988). One can infer that this can be somewhat of a burden of responsibility for the manager of the plant whilst they are already managing the operations within the plant itself. This bothersome task presents an opportunity in and of itself. Our group saw this issue and probed further to see if our superparamagnetic nanoparticle device could perhaps address this issue in addition to the value proposition already proposed. Since the nanoparticle device will already be doing real-time monitoring of the effluent exiting the industry and they will be using those measurements to report to those various authorities, Syngenia LTD proposed that we could provide those reporting services as well. This elimination of reporting could potentially further reduce operation expenses associated with heavy metal ion remediation in two different ways. Firstly, this service would eliminate the constant deadline management with constant report and delivery. Second, this service reduces risk for the plant operators and management if our device can operate consistently and Syngenia LTD can design a system where reporting will never be missed, and in the case of a missed report, Syngenia LTD would just cover the cost of the violation.

While the superparamagnetic nanoparticle device is the only proven method, this proposed service presents an attractive additional value proposition. Furthermore, one can envision an entire network of reporting within industries across the nation with a central
database at headquarters where the data is gathered, organized, and distributed to each respective authority in a timely and consistent manner. It is worth noting that all of this potential is completely contingent upon EPA approval of the superparamagnetic nanoparticle device and the service. If the service came to fruition; it would effectively become a significant and the primary source of income for Syngenia LTD, which would present a whole new set of possibilities for the company moving forward.

The Total Addressable Market

The total addressable market refers to every target market that the superparamagnetic nanoparticle device could be used in. The factors of each market segment that played into what customer market we decided to target were: revenue, profit, market growth and number of businesses. The numbers in and of themselves are not perfect indications of the best market to target, but rather the numbers allow us to see which market has high a ceiling potential and with further analysis, we can find the market that best.

Below, there is Table 7, which gives a breakdown of the addressable market by industry. The table shows all the market segments that the superparamagnetic nanoparticle technology is applicable to. Syngenia LTD has chosen the metal plating market as our primary target market because it had the largest profit margin, growth rate and number of businesses available. Furthermore, the technology service value proposition and service fits this target market better than the rest.
Table 7: The total addressable market of industries requiring heavy metal ion remediation of wastewater effluent

<table>
<thead>
<tr>
<th>Industry</th>
<th>Number of Firms</th>
<th>Growth 2015-2020</th>
<th>Weighted Growth</th>
<th>Market Size - $000’s</th>
<th>Profit – in $000’s</th>
<th>IBIS Reported Margins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Finishing</td>
<td>9,165</td>
<td>2.300%</td>
<td>0.281%</td>
<td>$29,700</td>
<td>$2,600</td>
<td>8.754%</td>
</tr>
<tr>
<td>Printing, Textiles</td>
<td>2,995</td>
<td>-2.500%</td>
<td>-0.100%</td>
<td>$3,500</td>
<td>$127</td>
<td>3.629%</td>
</tr>
<tr>
<td>Jewelry</td>
<td>2,155</td>
<td>1.100%</td>
<td>0.031%</td>
<td>$8,500</td>
<td>$407</td>
<td>4.788%</td>
</tr>
<tr>
<td>Coal Mining</td>
<td>1,276</td>
<td>5.800%</td>
<td>0.099%</td>
<td>$34,800</td>
<td>$2,200</td>
<td>6.322%</td>
</tr>
<tr>
<td>Iron Ore Mining</td>
<td>21</td>
<td>3.000%</td>
<td>0.001%</td>
<td>$6,600</td>
<td>$829</td>
<td>12.561%</td>
</tr>
<tr>
<td>Copper Lead Zinc Mining</td>
<td>43</td>
<td>1.800%</td>
<td>0.001%</td>
<td>$12,700</td>
<td>$5,200</td>
<td>40.945%</td>
</tr>
<tr>
<td>Gold &amp; Silver</td>
<td>177</td>
<td>2.400%</td>
<td>0.006%</td>
<td>$10,200</td>
<td>$3,300</td>
<td>32.353%</td>
</tr>
<tr>
<td>Mineral and Phosphate Mining</td>
<td>241</td>
<td>2.600%</td>
<td>0.008%</td>
<td>$6,100</td>
<td>$52</td>
<td>9.049%</td>
</tr>
<tr>
<td>Molybdenum and Metal Ore Mining</td>
<td>46</td>
<td>4.700%</td>
<td>0.003%</td>
<td>$2,500</td>
<td>$740</td>
<td>29.600%</td>
</tr>
<tr>
<td>Water Supply and Irrigation</td>
<td>3,028</td>
<td>2.100%</td>
<td>0.085%</td>
<td>$68,700</td>
<td>$10,300</td>
<td>14.993%</td>
</tr>
<tr>
<td>Dye and Pigment</td>
<td>191</td>
<td>2.800%</td>
<td>0.007%</td>
<td>$9,600</td>
<td>$423</td>
<td>4.406%</td>
</tr>
<tr>
<td>Remediation</td>
<td>7,511</td>
<td>-1.900%</td>
<td>-0.190%</td>
<td>$18,000</td>
<td>$1,100</td>
<td>6.111%</td>
</tr>
<tr>
<td>Structural Metal</td>
<td>4,462</td>
<td>2.700%</td>
<td>0.160%</td>
<td>$43,800</td>
<td>$2,400</td>
<td>5.479%</td>
</tr>
<tr>
<td>Mining, Oil and Gas</td>
<td>763</td>
<td>4.200%</td>
<td>0.043%</td>
<td>$26,000</td>
<td>$2,100</td>
<td>8.077%</td>
</tr>
<tr>
<td>Aluminum Manufacturing</td>
<td>411</td>
<td>2.800%</td>
<td>0.015%</td>
<td>$42,300</td>
<td>$1,600</td>
<td>3.783%</td>
</tr>
<tr>
<td>Battery</td>
<td>140</td>
<td>1.500%</td>
<td>0.003%</td>
<td>$12,500</td>
<td>$824</td>
<td>6.595%</td>
</tr>
<tr>
<td>Ferrous Metal Foundry</td>
<td>606</td>
<td>3.800%</td>
<td>0.031%</td>
<td>$20,800</td>
<td>$2,400</td>
<td>11.538%</td>
</tr>
<tr>
<td>Iron and Steel Manufacturing</td>
<td>408</td>
<td>0.080%</td>
<td>0%</td>
<td>$106,300</td>
<td>$6,900</td>
<td>6.491%</td>
</tr>
<tr>
<td>Leather Tanning</td>
<td>1,450</td>
<td>-0.300%</td>
<td>-0.006%</td>
<td>$2,000</td>
<td>$63</td>
<td>3.140%</td>
</tr>
<tr>
<td>Industry</td>
<td>Market Size</td>
<td>Growth Rate</td>
<td>Profit Margin</td>
<td>Revenue</td>
<td>Profit</td>
<td>Profit Margin</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-------------</td>
<td>-------------</td>
<td>---------------</td>
<td>---------</td>
<td>--------</td>
<td>---------------</td>
</tr>
<tr>
<td>Concrete Block and Pipe</td>
<td>620</td>
<td>3.700%</td>
<td>0.031%</td>
<td>$7,000</td>
<td>$476</td>
<td>6.800%</td>
</tr>
<tr>
<td>Glass Mfg.</td>
<td>4,652</td>
<td>1.900%</td>
<td>0.118%</td>
<td>$25,700</td>
<td>$1,100</td>
<td>4.280%</td>
</tr>
<tr>
<td>Textile Mills</td>
<td>12,584</td>
<td>0.800%</td>
<td>0.134%</td>
<td>$51,000</td>
<td>$2,000</td>
<td>3.922%</td>
</tr>
<tr>
<td>Steel Rolling</td>
<td>335</td>
<td>1.100%</td>
<td>0.005%</td>
<td>$10,400</td>
<td>$551</td>
<td>5.298%</td>
</tr>
<tr>
<td>Sugar</td>
<td>47</td>
<td>2.200%</td>
<td>0.001%</td>
<td>$11,700</td>
<td>$2,200</td>
<td>18.803%</td>
</tr>
<tr>
<td>Ready Mix Concrete</td>
<td>2,024</td>
<td>3.400%</td>
<td>0.092%</td>
<td>$24,700</td>
<td>$989</td>
<td>4.004%</td>
</tr>
<tr>
<td>Auto Parts Manufacturing</td>
<td>1,289</td>
<td>1.100%</td>
<td>0.019%</td>
<td>$65,000</td>
<td>$4,200</td>
<td>6.462%</td>
</tr>
<tr>
<td>Nonferrous Metal Rolling</td>
<td>499</td>
<td>1.900%</td>
<td>0.013%</td>
<td>$25,300</td>
<td>$1,300</td>
<td>5.138%</td>
</tr>
<tr>
<td>Copper Zinc Rolling</td>
<td>173</td>
<td>1.300%</td>
<td>0.003%</td>
<td>$23,800</td>
<td>$1,300</td>
<td>5.462%</td>
</tr>
<tr>
<td>Sand/Gravel Rolling</td>
<td>1,652</td>
<td>3.500%</td>
<td>0.077%</td>
<td>$13,700</td>
<td>$1,500</td>
<td>10.949%</td>
</tr>
<tr>
<td>Stone Mining</td>
<td>1,327</td>
<td>3.900%</td>
<td>0.069%</td>
<td>$14,000</td>
<td>$1,900</td>
<td>13.571%</td>
</tr>
<tr>
<td>Sewage Treatment Facilities</td>
<td>13,832</td>
<td>1.200%</td>
<td>0.221%</td>
<td>$42,400</td>
<td>$12,600</td>
<td>29.717%</td>
</tr>
<tr>
<td>Coal and Natural Gas Power</td>
<td>247</td>
<td>1.600%</td>
<td>0.005%</td>
<td>$114,300</td>
<td>$26,900</td>
<td>23.535%</td>
</tr>
<tr>
<td>Mining Oil and Gas Machine Manufacturing</td>
<td>763</td>
<td>4.200%</td>
<td>0.043%</td>
<td>$26,000</td>
<td>$2,100</td>
<td>8.077%</td>
</tr>
<tr>
<td>Total Market Size</td>
<td>75,093</td>
<td>1.307%</td>
<td>1.307%</td>
<td>$919,600</td>
<td>$3,181</td>
<td>11.220%</td>
</tr>
</tbody>
</table>

**Alternative Solutions and Competing Manufacturers**

Identifying the biggest competitor to the superparamagnetic nanoparticle technology would allow us to further scope our potential for a successful entry and penetration into the existing market. After contemplating the current remediation technology landscape, it was quite easy for us to see that the barrier for entry was extremely high and dominated by efficient and
relatively cheap options. The heavy metal ion remediation landscape was mostly dominated by membrane technologies that utilize microfiltration, reverse osmosis, and ultrafiltration techniques. Furthermore, 12 companies have collectively dominated the market for manufacturing these high performance membrane technologies: E.I. Dupont De Nemours and Company, The DOW Chemical Company, Asahi Kasei Corporation, Hyflux Ltd., Merck Millipore corporation, LG Water Solutions, Koch Membrane Systems Inc., GE Water & Process Technologies, Toray Industries Inc., Polypore International Inc., Solvay S.A., and 3M Company (IBISWorld, 2014). As one can infer; the heavy metal ion remediation market is much too crowded to attempt entrance, especially for a technology that would most likely cost more to construct. The 12 companies recently mentioned would not be direct competitors for our technology, but the market they occupy is a similar space and they may contain technologies that pose competition in the future.

With regards to the heavy metal ion detection market—which is the broader target market; we must discuss the most common techniques currently utilized. Currently, most companies utilize third-party laboratories to conduct the required analyses on their effluent. Lab engineers will take a sample of the water downstream from a remediation station and send it out to a contracted third party lab who will analyze the sample. The third party lab most commonly uses one of two methods for heavy metal ion detection: Atomic Absorption Spectroscopy or Electrochemical Detection (Pinkowski, 2015).

Atomic Absorption Spectroscopy is a procedure for the determination of chemical elements using the absorption of optical radiation by free gas-phase atoms (Chemicool, 2017). “The atoms absorb ultraviolet or visible light and make transitions to higher electronic energy
levels. The analyte concentration is determined from the amount of absorption” (Chemicool, 2017). For the purposes of our market analysis, virtually any laboratory that can perform an atomic absorption spectroscopy is a competitor of our nanotechnology. Furthermore, competitors who manufacture the flame atomic absorption spectrosopes used for this analytical method include: PerkinElmer, Shimadzu, SpectroLab Systems, Angstrom Advanced, ThermoScientific, and Lumex (IBISWorld, 2014).

Electrochemical Detection is the most sensitive and selective mode of liquid chromatography detection for the measurement of oxidizable or reducible compounds. It was initially developed for the separation and detection of aromatic metabolites in catecholamine. The two primary manufacturers of electrochemical detectors are ThermoScientific and PerkinElmer.

While these two analytical methods are currently the most common method used in these targeted industries, there are also other in-line detection methods available. The first of these methods are Ion Selective Electrodes. They require an electrode to be dipped into the effluent to monitor a target compound or heavy metal such as: fluorine, ammonium, copper, cadmium, and lead. Additionally, they can also detect the acidity of the solution. Ions that cannot be measured by this method are chromium, zinc, and nickel. This detection method requires a highly conditioned environment in order to work properly so it isn’t the most practical method for turbid industrial setting (Pinkowski, 2015). The second in-line method used is an Online Titrator device. A great benefit from this method is that samples are taken every 5 minutes, so there can be a continual analysis of the water quality. Conversely, this method requires a great deal of maintenance to keep it running—almost two hours per week, per machine (Pinkowski,
The last in-line method was developed at Arizona State University in 2004. Four students collaborated to develop a High-Resolution Differential Surface Plasmon Resonance Sensor. In this device, the sensor surface is divided into reference and sensing areas, and the difference in the SPR angles from the two areas is detected with a quadrant cell photodetector as a differential signal. In the presence of metal ions, the differential signal changes due to specific binding of the metal ions onto the sensing area coated with properly selected peptides, which then provides an accurate real-time measurement and quantification of the metal ions (Zhang, 2002). This technology was made for a residential audience, but could easily be applied industrially as well. Even so, the technology hasn’t been brought to the market and its current state of development is unknown.

**Operational and Exit Strategy**

Syngenia LTD had decided to operate as a Market and Research and Development agency. New product ideas would be innovated and cultivated till a working prototype is developed while also conducting all the marketing research required to commercialize the new products. Once a prototype is created, proven, and ready to be manufactured; the manufacturing will be outsourced to industry leading providers. Sales channels will be established regionally with solution engineering service providers similar to Digital Analysis in Skaneateles, NY, Liquid Treatment Technologies in Lawrence, MA, and Water and Wastewater Laboratories in Cleveland, OH.
Three exit strategies had been developed before Zack, Brian, and Jon had joined Syngenia LTD:

1. Continue stand-alone operations and focus on Research and Development and marketing to introduce multiple products based on the underlying technology

2. License the de-risked technology to an able player currently operating in the market

3. Successfully launch one iteration of the detection product and sell within 5-7 years to an able player already selling into the market

After the addition of Zack, Brian, and Jon to Syngenia LTD, the start-up decided each exit strategy was possible, but to go forward with the third option first and start with the development of the prototype and pursuit of investment to do so.

Investment is available in many forms: friends, family, fools, investors, and publicly available funds. The first order of business was to create a prototype and Syngenia LTD wanted to find and use as much “free money” as possible—meaning not pursuing an investor yet as that would require giving up equity in Syngenia LTD. Innovation Fund America, which is partnered with Glide at Lorain County Community College in Elyria, Ohio is a nonprofit company that aims to accelerate the growth of technology startups through early-stage funding. They have two options in which start-ups present their business with the chance or received $25,000 (option a) or $100,000 (option b) contingent upon meeting certain milestones pre-emptively set for the business. Ohio Third Frontier also offers similar opportunities for startups with the goal of accelerating growth in early stage technology companies. If a startup company is approved for funding through Ohio Third Frontier, they will receive $100,000 to help jumpstart the technology startup.
Syngenia LTD planned to apply for both programs and use the money, contingent upon receipt, for the creation of a prototype superparamagnetic nanoparticle device that would detect a targeted heavy metal and give a green light/red light indication of whether the water is safe for consumption within households. This prototype would then be used for demonstration in striking an exclusive licensing deal with a company that has an established connection with the target residential market.

**Conclusion**

While invention of a new technology is invaluable, that new technology means nothing without the tandem process of commercialization. As seen with the superparamagnetic nanoparticle device, a projected solution was preconceived at the conception of the innovation, but with further investigation, Syngenia LTD found that the target market for heavy metal remediation was highly crowded and difficult to penetrate. Furthermore, Syngenia LTD found a better route to commercialization—detection. They found that there was an unanswered need in the market that the superparamagnetic nanoparticle technology could answer for an extremely conservative market.

This superparamagnetic nanoparticle device has the potential to save industrial companies large sums of money in chemicals used for remediation and labor expenditures. Furthermore, the device can also be utilized residually as a detection device and alert households when lead contamination exists within their water supply and prevent lead poisoning in children for situations like Flint, Michigan.
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overview?pa=Oml5n6vJmuOgyfC3Ew0oqzXM7H4FLEi6R4GG92QHNUuDwgc5MX0RVR5
YCK%2FZnIGiJd4icz6dvMCveA42Oh%2Ffl%2FDMAtBBAsM6eN9kpLn%2Fas%3D#a5
EPA.gov: https://www.epa.gov/dwreginfo/drinking-water-regulatory-information
Chemistry: https://www.boundless.com/chemistry/textbooks/boundless-chemistry-
textbook/periodic-properties-8/electron-configuration-68/diamagnetism-and-
paramagnetism-320-10520/
https://www.boundless.com/physics/textbooks/boundless-physics-
textbook/magnetism-21/applications-of-magnetism-160/ferromagnetism-565-6305/
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