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Transportation of Shale Gas Extraction Waste Water by Barge

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Sponsoring Agency:
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Abstract

The purpose of this project was to work with the United States Coast Guard (USCG) on an energy related project covered under Executive Order 13605 Supporting Safe and Responsible Development of Unconventional Domestic Natural Gas Resources. The USCG is developing a policy which is under Executive Branch review and cannot be disclosed. We performed an economic and environmental analysis regarding this proposed policy. Using our research, the USCG was able to amend the policy to reduce costs to industry.

Acknowledgements

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Authorship

William Lind was a major co-author drafting and editing the Executive Summery, Background, Methodology, Results, and the Conclusions and Recommendations sections. In addition he conducted research into the background of the report and was the key individual in identifying several of the companies we selected to interview.

Samantha Sargalski was also a major co-author of this report, contributing much of the writing and drafting for each section. Samantha was the main author of the Executive Summary, Background, Methodology, Results, Conclusions, and Recommendations sections. She also annotated many of the interviews that we performed and ran many of the meetings between ourselves, our liaison, and our advisors.

Michael Ruzzi created the figures and formulas used in this report, editing and changing them according to direction and input from the rest of the team. He also acquired many of the quotes and statistics used in the analysis section of this report. Michael was also responsible for managing and directing many of the interviews that this team conducted with various government agencies, private companies, and non-profit organizations.

Travis Van Dale was responsible for the creation and organization of the major presentations we gave throughout this process. Travis also edited sections of the Background, Conclusions, Recommendations, and Appendices. Travis' main contribution was the conception and organization of the Conclusions and Recommendations section.

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Executive Summary

With the United States' increasing demand for fuel for power generation and heating, the demand for inexpensive natural gas has grown. This in turn has led to the exploration of innovative methods to access the natural gas reserves. One such method is the use of a technique known as hydraulic fracturing, used extensively in the Marcellus Shale region of Pennsylvania. Hydraulic fracturing or hydro-fracking is a unique extraction technique that uses millions of gallons of chemically pre-treated and pressurized water injected into rock formations to create cracks and release the natural gas held inside. In addition to natural gas, however, this process also produces wastewater flowback, known as Shale Gas Extraction Waste Water (SGEWW), which contains chemically and radiologically hazardous materials such as salts, radium, and petroleum-like hydrocarbons. The danger of these materials presents itself when the wastewater is transported for offsite disposal, or is not properly treated and cleaned on-site.

This project examines the costs of safely transporting the radioactive, hyper saline SGEWW via barge to deep-injection wells in Ohio according to a new regulatory policy drafted by the United States Coast Guard (USCG). The USCG is interested in the added cost that the new regulations in their policy would impose upon both barge and fracking companies, as they do not want to enforce a policy that places unreasonable costs on these industries. This will eventually be compared to the analogous cost of treating the wastewater at the wellhead using distillation. We also assessed the environmental cleanup fee should a spill occur either during the transportation or distillation process. Barge transport is potentially the easiest and least expensive option for transporting large volumes of SGEWW to deep well injection sites where it can be permanently disposed of.

To determine the added cost of the USCG policy to fracking and barge companies, the team contacted James Guttman of Grandview Barge Lines, a company that has identified itself as interested in shipping SGEWW. Grandview expects to be able to ship SGEWW from a designated mile marker on the Monongahela River to a predetermined end mile marker along the Ohio River for $5 per barrel (charged to fracking companies). The Grandview Company expects to ship a total weekly volume of 60,000 barrels of SGEWW, resulting in a total cost of $300,000. To transport the SGEWW from the wellheads to the barges, fracking companies will face a $700 per tanker cost as well as a $1.95 per mile fee according to the DOT. The team also investigated the cost of a 100% survey for radiation prior to anyone's entrance to the cargo hold. Quotes from two survey companies indicated that the cost of a 100% survey for one of these vessels is around $15,000. Because the policy will require barge companies to survey their barges before USCG inspections, which occur at least once every five years, Grandview will be need to pay $90,000 in that time frame, plus an additional $15,000 should someone need to enter the SGEWW holding area for maintenance or other purposes. The policy will also require that the barge companies test each holding tank of SGEWW prior to transport, which will create a cost of between $6,400 and $14,400 per week, depending on the number of tanks used to fill the barges.

We also investigated the cost fracking companies would face should a barge carrying SGEWW leak its cargo into the Monongahela or Ohio River. Because spills of SGEWW have not yet been documented, the team compiled the costs associated with past cleanups of materials similar to SGEWW, in this case oil brine and petroleum. The remediation of brine water, which approximates the salinity of SGEWW, involves use of chemicals known as sodic reducers which help to wash salt out of a river environment, minimizing harm. The cost for such a method is approximately $2 million for a spill of an equivalent size to the barges' SGEWW cargo, which would also encompass the cost of cleaning the radioactive material contained in the salt. Cleanup of a spill of petroleum in the same quantity as the oily component of SGEWW will likely cost more than $37,000 due to the use of the chemical gellants and mechanical barriers for remediation. It is estimated that between remediation efforts and lawsuits filed by local governments, fracking companies are likely to spend over $3 million to remediate a barge spill.

As an alternative to barge shipment of SGEWW to deep well injection sites, fracking companies may elect to treat the waste at the wells through distillation. This would be accomplished using mobile evaporation units which can vaporize the liquid component of SGEWW, leaving only the salt in the form of sludge to be disposed of. Currently, General Electric offers a unit designed specifically for use by fracking companies to treat SGEWW. These units cost $5.5 million each, and ten units would be needed to ensure adequate treatment of all SGEWW produced. Because distillation requires large amounts of energy to boil water, an electricity cost of about $80,000 per week is anticipated to treat all 2.52 million gallons of SGEWW. Once the liquid waste has been removed, a viscous sludge will be left to be disposed of in specially outfitted landfills. Mr. Paterson of the Marcellus Shale Coalition (MSC) has quoted the price for disposal of such sludge at $35-$50 per ton.

Because a spill of SGEWW may also take place at the well, or at an on-site treatment location, the team also investigated the potential costs a fracking company would face to clean a land-based contamination. The same proxy materials, brine water and petroleum, were investigated to gauge this cost. In the event of a spill of oil brine with similar salt content to SGEWW, it was found that the main method of remediation is to simply remove the affected soil and replace it with new soil capable of maintaining seeded plant life. In some cases, it may also be necessary to chemically remediate the soil with gypsum. This chemical, quoted at $2,000 per acre remediated, reacts with salts in the soil making them easier to remove. Because the radioisotopes are contained in the salt, and because oil is remediated much the same way on land as a brine spill, no added costs are anticipated beyond that of salt cleanup. As with cleanup in a river environment, a fracking company can expect significant costs as a result of governmental law suits. They will likely pay more than $163,000 resulting from both cleanup efforts and litigation following an onsite SGEWW spill.

Based on the total calculated costs to the fracking companies for each of the two SGEWW treatment methods we evaluated, it is clear that barge transport is the significantly cheaper option. The USCG policy requirements only cost the barge companies $6,400-$14,400 per week, a cost that would not cripple the company's profit. Surveys are only required of the barges approximately once every five years, so this necessary cost is also not unreasonable. The total cost to fracking companies for barge transport would be approximately $683,000 per week; encompassing both the barge transport itself at $300,000, and the trucking fee at $383,000. The high startup cost for the onsite method of distillation ($55 million) makes this option unreasonable for fracking companies, as the wells are only expected to yield natural gas for another ten years. Therefore, at this time, barge transport is the most viable option.

In future work, the costs for other vehicular shipment methods for SGEWW should be examined. This report does not compare the costs of barge transport to shipping costs for other modes of transportation such as rail, and full-distance truck transport. Research into mobile evaporation units should also be expanded upon; as on-site treatment could be a more economically competitive method should fracking companies be able to lease or rent the units and avoid the initial cost of purchase. It is also important to examine the specific environmental hazards posed by SGEWW, should a spill occur on the Monongahela or Ohio Rivers, or at the wellhead in the Marcellus Shale region. With the completion of these recommendations, a more complete view of the fracking dilemma can be established, and more educated decisions can be made by the fracking companies when they are choosing how to permanently dispose of their SGEWW.

Chapter 1: Introduction

Hydraulic fracturing of shale deposits to liberate the natural gas contained within is becoming a more viable and widespread natural gas-production technique. With the increased prevalence of hydraulic fracturing, or “fracking”, there has been a corresponding increase in the production of hazardous Shale Gas Extraction Waste Water (SGEWW), a by-product of the fracking process. The modern method of “Slickwater” fracking was born in 1998 and employs the use of high volumes of water with chemical additives to fracture the rock and liberate the natural gas (Trembath, 2012). This resulting “produced water” from well flowback is unsuitable for release into local waterways and has, to date, been recycled back into other wells for reuse, or stored in large outdoor holding ponds (NRDC, 2012). The SGEWW that flows from the well contains numerous dangerous chemicals, including radionuclides and heavy metals in solution or suspension. The presence of these materials makes the SGEWW corrosive, radioactive, hyper-saline and therefore dangerous if handled improperly. Currently, there are no government policies that regulate the safe disposal of SGEWW. Due to this lack of regulation and the large volume of SGEWW produced, the natural gas producers who generate this hazardous wastewater are unsure of how to safely and permanently dispose of it.

In 2011, Pennsylvania gas companies produced 1.3 billion gallons of SGEWW from the process of fracking that needed disposal (NRDC, 2012). Currently, there are five methods for the disposal of SGEWW; the discharge of SGEWW into surface waters, storage in large, open air pits, spreading on roadways to control dust and ice, recycling and reuse in other wells, and storing the SGEWW in deep injection wells. One method that has been explored, but not yet implemented in the Marcellus Shale region, is the distillation of the SGEWW and the storage of the remaining sludge in landfills. Three methods show the most promise and have significantly lower risk if regulated properly: recycling the SGEWW in new wells, storing in deep injection wells, or distilling and storing sludge in landfills. According to an expert on hazardous materials working at the United States Coast Guard (USCG), within the next five to ten years there will be fewer wells drilled, and therefore fewer opportunities to reuse the water, leaving millions of gallons of SGEWW to be disposed of (Dr. Cynthia Znati, personal communication, October 29, 2012). As opportunities for recycling decrease, transport and injection or evaporation and disposal may become the least risky and most efficient ways to dispose of SGEWW. Whether transporting or evaporating SGEWW, strict regulatory policies can help ensure that disposal can be performed efficiently and safely. However, thus far such regulations have not been implemented and their economic feasibility is still unknown.

Previous methods of disposal of SGEWW included the dumping of water into nearby streams. Research conducted by the National Resource Defense Council (NRDC) showed that this led to an unacceptably high level of salt in the water, causing loss of habitat and wildlife (Slusark, 2012). SGEWW was also disposed of by treatment in municipal sewage facilities; however, this led to the violation of discharge permits as the extremely high level of salt destroyed the anaerobic digestion processes of the bacteria used to process sewage (Penn State, 2011). Because of these violations, in October of 2011 the Environmental Protection Agency (EPA) asked all gas producers to voluntarily stop using municipal sewage plants for disposal. Another outdated method of disposal is to spray the wastewater on snow-covered roads as the high salinity of the SGEWW makes it able to melt ice on the roadways. However, run-off from the roads led to the contamination of public drinking water and high levels of salt in treatment facilities (Dr. Cynthia Znati, personal communication, 10-29-2012). The final two options for

SGEWW disposal, transportation to deep wells for permanent injection and treatment through evaporation, have not yet been explored.

Due to high demand for natural gas, SGEWW production has increased as fracking has become more widely used. As more SGEWW requires disposal, a policy to regulate barge shipment of this material must be completed to ensure it is carried out safely. Accordingly, the USCG has begun drafting a policy defining safety procedures and precautions for transporting SGEWW by barge on inland waterways. The central concern with barge transport of SGEWW is the lack of information regarding the safety and the cost of barge operation, inspection, and surveying. These costs must be compared to information available on the costs of evaporation as an onsite treatment method. Normally, the Code of Federal Regulations (CFR) 46 lays out specific regulations that all shipping companies must comply with in order to legally ship any given material in bulk; whether it is clean water, or a type of hazardous waste (46 CFR 151.05). However, 46 CFR currently contains no shipping regulations specific to SGEWW, as there is minimal information available about how this process should be carried out in a safe and cost effective manner. Small scale environmental problems have been noted as current disposal of this wastewater is legally problematic and industry has not found a safe method of disposal thus far (Dr. Cynthia Znati, personal communication, 10-29-2012). Because the methods of barge transport and evaporation have not yet been analyzed for the costs that they will entail, it is imperative that a safe, cost effective SGEWW disposal method be established. To address the need to regulate the safe transport of SGEWW, the USCG has drafted a policy for the transportation of SGEWW by barge.

The goal of our project was to determine the cost that the USCG's newly proposed policy would impose upon natural gas and barge companies, as well as the costs associated with the potential environmental impacts of barge transport of SGEWW should a spill occur during shipment. We also completed a similar cost analysis of the on-site disposal method of distillation in order to compare the two treatment options, to provide fracking companies with information as to which would be the cheaper of the two. These costs were determined through multiple interviews and extensive archival research on multiple case studies. Thus far, the natural gas industry has not been able to dispose of SGEWW in a safe and environmentally responsible way. This project has estimated the financial burden of properly managing SGEWW in two distinct methods, so that an informed decision may be reached regarding cost effective disposal of this toxic material.

Chapter 2: Background

The extraction of natural gas from the Marcellus Shale formation in the United States is a complex and challenging process that can potentially provide many benefits to the American energy industry. In this chapter we will introduce the technical methods behind hydraulic fracturing, the byproducts of the process, as well as the regulations governing the practice. We will describe what is known about the wastewater produced by hydro-fracking, what contaminants are suspended in the waste, and the effects that these toxic materials can have on an exposed ecosystem. In addition, we will also explain the federal, state, and local regulations that govern the hydraulic fracturing industry.

2.1 Hydraulic Fracturing Method

Hydraulic fracturing, commonly known as fracking, is a method used to drill deep into rock formations to liberate the trapped natural gas inside (Propublica, 2012). If perfected, fracking could help the United States become more independent from foreign sources of energy. In order to free the gas trapped deep within rock formations, a large drill is used to reach the shale containing the natural gas, and then pressurized water is forced down the opening in order to lengthen the fissure (Bradner, 2011). The crack is made as deep as necessary to reach the natural gas inside, making this a very precise process. The pressure of the water forced into the shale is extremely important; the higher the pressure, the larger the crack, and vice versa. However, once the fissure is created, it will often not stay open on its own. Therefore, an additive called a proppant is inserted into the fissure to keep it open. The proppant is usually a sand-based mixture, most often silica sand, although recently man-made ceramics have been used. This proppant remains in the fractures and keeps them open, so all the natural gas can be released from the shale rock formation, and then collected and used. A single fracking well can be used repeatedly in order to increase the yield of natural gas. However, this practice also increases the concentration of salts and other proppants found in the resulting wastewater (Cynthia Znait, personal communication, 11-5-2012)

2.2 Types of Fracturing

There are two main types of fracking commonly used in wells today. Vertical fracking is a process that has been used for years and is established in the United States (Bradner, 2011). In this process the well is drilled vertically into the rock, though this often leaves large amounts of untapped natural gas. The practice of drilling horizontal wells is a relatively new breakthrough in which the drilling is done horizontally through the rock, enabling larger amounts of natural gas to be collected. In fact, much of the methane in shale gas rock formations was unavailable until horizontal fracking was accepted as a legitimate method of extracting crude reserves from oil and gas formations.

2.3 Byproducts of Fracturing

Hydraulic fracturing of shale rock to extract natural gas yields many hazardous byproducts (Cynthia Znati, personal communication, 10-29-2012). The water that is used to fracture the rock to remove the gas from the earth becomes contaminated while underground and must be treated before it can be used for any other purpose (Jackson, 2012). The principle danger associated with the wastewater from fracking is that of Naturally Occurring Radioactive Materials (NORM) and salts absorbed into the water from the shale formations.

2.3.1 Methane Gases

The first hazardous by-product of shale gas fracturing is the methane meant to be extracted. This product can pose a danger to nearby groundwater as well as the gaseous makeup of the atmosphere; some methane can remain dissolved in the wastewater until it reaches ground level, and the pressure decreases enough for it to be released from solution (Munro, 2012). Methane is normally a gas, however it is easily dissolved in water when the water is under high enough pressure, and it has the potential to rapidly vaporize when that pressure is removed.

Methane gas is collected and sent into containers for transport and refining, which creates the potential for dangerous accidents. This danger comes from above-ground methane containment vessels and mishandling of the gas product, though this is not unique to fracturing sites.

2.3.2 Radium

The SGEWW derived from the well itself also poses a significant hazard because it contains radioactive material and high salt concentrations. The well water contains the radioactive isotopes radium-226, radium-228 (Rowan, 2011), as well as uranium-235 (Weaver, 2011). These isotopes are found naturally in the shale rock formations from which natural gas is produced and are dissolved into the wastewater during the fracking process. In the Marcellus shale region of the US, about 23% of the radium present is Ra-228, which has a decay half-life of 5.75 years, and the remaining 77% percent is Ra-226 which has a half-life of 1600 years (Rowan, 2011). Commonly, a radioactive isotope is considered to have decayed to negligible amounts after 10 half-lives, meaning that Ra-228 will decay to negligible levels in 57 years.

The most dangerous radioisotopes, however, are those with half-lives of one year to sixty years, because an isotope with a half-life of one year gives off larger amounts of radiation. If the half-life is below a few months, then the waste can be easily stored for a short time. If it has a long half-life, little radiation is given off but when the half-life is greater than a year but less than sixty years the waste may be radioactively hot enough to cause a problem and may remain so for a significant amount of time. The main ecological danger associated with radium is its chemical similarity to calcium. This property allows radium to accumulate in organisms in the same manner as calcium, which may threaten crops and livestock if they are exposed to it (Rowan, 2011). At a meeting of the EPA in Alexandria, VA, in 2011, Dr. Stephen Randtke of the University of Kansas noted that there is “no threshold at which exposure to radiation is safe” (Winston, 2011, p. 19).

2.3.3 Liquid Wastes

The components of SGEWW can be dangerous on an even larger scale than the radioactive constituent. The wastewater often contains elevated levels of dissolved chlorine and bromine salts. When these salts are processed by conventional water treatment methods, they can accumulate on equipment and “lead to disinfection by-product (DBP) formation in water treatment plants” which can build up in potable water, and lead to serious health complications (Rowan, 2011, p. 22). In order to save water, some hydraulic fracturing sites recycle injection water and use it multiple times in the same well or transport it to new wells. When water is recycled without being properly treated between uses, the concentration of contaminants will be much higher than in single-use water. Up to 2 million gallons of SGEWW (in the largest wells) can flow up from the well, and “it can be five times saltier than seawater and contain sulfates and chlorides, which sewage and drinking water treatment plants aren’t equipped to remove” (Levy, 2010, p. 20).

Water contaminated in this way is not only non-potable; it is actively dangerous if consumed by humans. The brominated disinfection by-products can “cause miscarriages and birth defects” if they are released into drinking water sources (Winston, 2011, p. 1). It is becoming evident that these compounds are becoming a threat because of their release by fracking sites. “Research shows that bromine concentrations in the Allegheny River [of Pennsylvania] have increased since fracking began, and several drinking water systems that use water from the river have reported increased concentrations of brominated DBPs, which are more toxic than other kinds of DBPs” (Winston, 2011 p. 2).

The EPA has a disinfection byproduct limit in place for water treatment plants; however, with the recent spike in DBP release from fracturing sites, many are unable to keep up with the contaminants, “Several utilities are in violation of EPA’s DBP regulation” (Winston, 2011 p. 2). With such high potential risk involved with the contaminants of SGEWW, appropriate attention must be paid to chemical and radioactive isotope levels in drinking water.

2.4 Types of Radiation

Radiation is emitted in three main ways; the weakest, alpha radiation, can damage the human body if a source is ingested, but otherwise skin is a sufficient barrier to block alpha emissions (Black Cat Systems, 2012). Beta radiation can penetrate farther into the human body, into the germinal layer of the skin where potentially deadly lymphomas and lung cancers can develop (HPA, 2012). The third type of radiation, gamma radiation, is composed of high energy ionizing electromagnetic waves that can cause several types of damage to human and animal DNA.

2.4.1 Hydrology of Liquid Radioactive Wastewater

Liquid radioactive SGEWW moves through water as it dissolves, migrating with the water and depositing itself in the soil it moves through (WHYY, 2012). Radon has a high activity level, so much so that federal standards suggest that remediation efforts be taken to reduce the concentration of radiation as a result of the radon to 2-4 pCi/l (EPA, 2012) when possible. Contact with radium in the water is also a hazard as it may enter the blood stream, lymph nodes, and bones if ingested. The daughter isotopes most prevalent in SGEWW are radon-220, radium-226, and radium-228 which can migrate with water and deposit into wells and groundwater supplies, thus contaminating commercial use water.

2.4.2 Daughter Products of Radon

Radon undergoes a decay chain beginning with Radon, and ending with the stable isotope of lead (Black Cat Systems, 2012) (Figure 1, Branches of Radon). Radon first emits an alpha particle and decays into polonium-218, which subsequently decays into lead-214, then into bismuth-214. The process continues with a beta decay into polonium-214 and then into lead-210. The decay carries on through bismuth-210, to polonium-210, eventually ends in stable lead-204 (CCNR, 2012). All of these reactions take place in a half-life of twenty-two and a half years, and create many daughter isotopes. These daughter products can then become present in fracking wastewater, and must be contained and treated in addition to the radium and radon components.

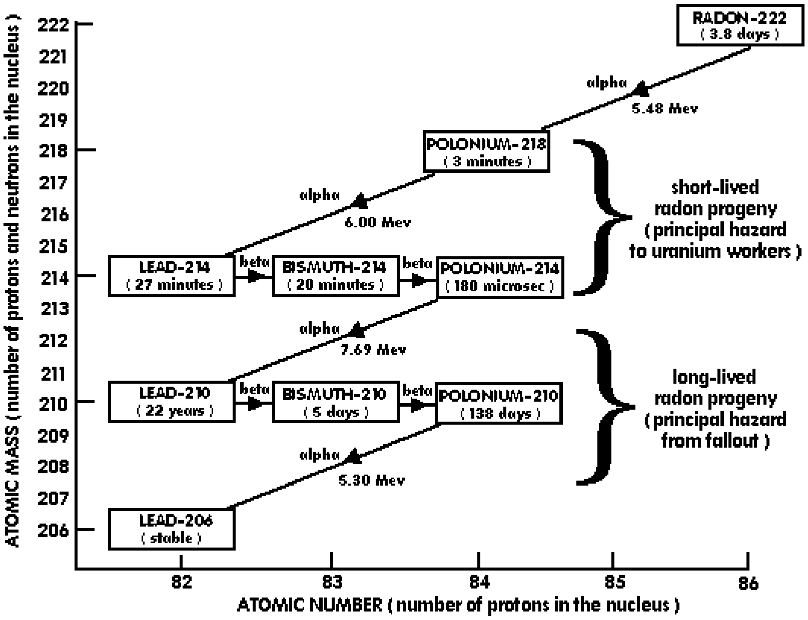

Figure 1: Branches of Radon (CCNR, 2012)

2.5 Regulation

In the United States, laws and regulations are enacted in order to keep both the public and the environment safe. The USCG is charged with the duty to keep the US waterways safe, whether it be from human criminal activity or environmental regulatory concerns. As a result of hydraulic fracking in the Marcellus Shale, the USCG must regulate the transport of the wastewater produced by fracking if the water is transported by any waterborne vessel on the navigable waters of the US. Federal and state regulations impose requirements on the treatment and disposal of this material.

2.5.1 Federal Treatment Regulations

The process of fracking for Marcellus Shale gas is fairly new to the United States (Propublica, 2012). However, the industry is rapidly growing at a rate with which US Federal regulatory bodies have not been keeping up. The process of fracking in the Marcellus Shale does not directly fall under the jurisdiction of the EPA; however the disposal of its wastewater and wastewater treatment does fall under its jurisdiction (Rascoe, 2011). The EPA has announced that it will begin to put in place more regulations on the treatment processes of the SGEWW, due to overwhelming environmental concerns from residents who live near treatment facilities (Rascoe, 2011). Currently, most facilities apply for a permit that allows them to run-off the wastewater into nearby streams after appropriately treating it or holding the water on-site (Hammer & Van Briesen, 2012).

2.5.2 Federal Transport Safety Regulations

To aid in the safe transport of hazardous materials, the USCG has regulations and standards in place to which all applicable vessels must comply. The standards set forth for vessels transporting radioactive material include stipulations of barge length, stability, and safety technology. The specifics are outlined in the American National Standards Institute's (ANSI) Standard N14.24-1985 (USCG, 1987). The barge itself must measure at least 125 feet in length, and meet stringent stability requirements. Barges that handle large amounts of highly-radioactive materials need to carry several pieces of critical safety equipment including: an Emergency Position Indicating Radiobeacon (EPIRB), a passive radar reflector, a sonar transponder with a one-mile range, and an emergency towing wire.

2.5.3 State Treatment Regulations

While Federal Regulations mandate how companies treat SGEWW and dispose of it into rivers and streams, state regulations enforce how the wastewater is stored underground or transported to storage facilities. Some states, such as Pennsylvania, have discontinued issuing permits for the SGEWW to be run-off into streams (Propublica, 2012). This forces the corporations to hold the SGEWW and recycle for later reuse in the wells or find final disposal. States also regulate the amount of water taken from the municipal supply to be used in the fracking process, causing some companies to re-use the already contaminated SGEWW.

2.6 Transportation of Wastewater via Waterways

To understand the implications of transporting SGEWW via barge, it is important to establish the safety of barges operating on United States waterways. In 1999, the national mean incident rate was $1.68*10^{-6}$ incidents per 500-ton shipment per kilometer, compared to $2.47*10^{-7}$ accidents per train car per kilometer (Saricks et al, 1999). Here, an incident is defined by the United States Shipping Code as an event that produces effects ranging from material damage to the vessel, to death of an individual, and including significant harm to the environment (46 CFR 173.6101-6103). Based on these statistics, an incident occurs on average, about once every six-hundred thousand kilometers of transport. Though the statistic for transport via rail indicates a smaller accident rate, this number is "per car." With an increase in the number of cars in a train, there is an increased risk of an accident; therefore a train towing more than six cars will be as accident prone as a barge. The waterway statistic corresponds to transport classified as "Internal," meaning rivers and canals.

2.7 Barge Navigation Safety

The USCG has laid down a series of rules reflecting the safety considerations of barges operating on US inland waters. The Commandant Instruction M16672.2D requires that barges be properly lighted and manned during movement and that certain types of lights need to be displayed in the proper pattern for recognition; this Instruction also identifies where the rules shift from inland to at sea (USCGb, 2012). These rules make sure that barges are safe to operate, as well as safe for recreational boaters. One of the largest dangers is when a towed barge has a large cable strung between the barge and the tug; these cables are often thousands of feet long and can capsize almost any recreational boat. The Commandant Instructions and the Rules of Navigation prescribe different lighting scenarios so that other mariners can recognize the barge and avoid the steel cable (USCGb, 2004, p.60). According to these strict rules, barges must be operated in a conscientious and safe manner, a guideline that has prevented many collisions at sea and has severely reduced the risk of transport by barge.

2.8 Radiation Regulation

To a large extent the exposure limit to radiation for the US public is governed by two bodies, the Occupational Safety and Health Administration (OSHA), which regulates the level of exposure of all persons, and the Nuclear Regulatory Commission (NRC), which sets the exposure limits for radiation workers. The levels of various radionuclides are heavily regulated in city-supplied water, with 15 and 5 pCi/l of alpha and radium radiation allowed, respectively

(EPA, 2012). The total allowable whole body exposure for annual radiation is only one Rem per year, a very small amount (NDT, 2012). Most nations today maintain a policy of radiation exposure "As Low as Reasonably Possible." The total allowable exposure for a radiation worker, as defined by the NRC, is five Rem per year, an amount that could easily be exceeded by the radon emissions from the fracking wastewater if the worker is not carefully protected.

2.9 SGEWW Treatment via Solar Evaporation

One of the ways that SGEWW can be dealt with is solar evaporation, a simple method of treatment commonly used in the Southwestern part of the U.S. (Cynthia Znati, personal communication, 10-24-2012). Large, shallow pits are dug with several layers of plastic lining underneath to prevent the seepage of the wastewater into the ground. The SGEWW is then poured into these ponds. The wastewater is allowed to settle, and the sun eventually evaporates the water (Engberg, 2011). This process leaves behind a concentrated sludge composed of the remaining salts, radium, and soil from the wellhead, which is easily disposed of safely in landfills (Cynthia Znati, personal communication, 10-24-2012). This option is the most clean and environmentally friendly choice, however it is very slow and costly, as the pits take time, money, and land to build. In the Northeast, high rainfall and humidity can inhibit solar evaporation from taking place in a reasonable and practical time frame.

2.10 SGEWW Treatment via Distillation

A second option for treating the wastewater is to induce evaporation by heating the water until it boils. Normally the water is pre-treated before boiling by adding flocculants to the SGEWW to remove gross amounts of dirt, salt, and other contaminants present in the water, reverse osmosis can also be employed (GEA, 2012). General Electric (GE) has developed materials such as inorganic oxides and barium sulphate resins capable of eliminating naturally occurring radioactive materials (especially radium) from SGEWW before the evaporation process (General Electric, 2012b). The wastewater is then boiled via vapor compression, and the steam that is produced from the boiling procedure is clean and free of almost all contaminants with 70-85% of evaporated water recovered for reuse (General Electric 2012b). General Electric has created and begun marketing a truck-mounted evaporation unit specifically for use in the fracking industry, as shown in Figure two. This evaporator is capable of evaporating off 50 gallons of water per minute once in use, and a 3 hour cold-start period before evaporation can begin. GE is claiming that use of this evaporation unit can reduce the energy consumption compared to traditional evaporation techniques such as use of a simple natural gas furnace. The water that is recovered from the evaporator can be reused in a number of ways; for spraying down roads, agricultural uses, fire suppression, or reused in another fracking well.

Figure 2: Mobile Evaporator (General Electric, 2010a)

2.11 Chemicals Added to Well-Water

Before water can be used in a hydraulic fracturing operation it must be treated with a "proppant" mixture to insure that it has the necessary characteristics for use in the well (Reis, 2012). Several large companies such as Halliburton and Tendenka sell mixtures of several dozen chemicals that create these conditions (Beckwith, 2012). As the mixtures themselves are trade secrets and analysis of the wastewater itself is prohibited under the Cheney Exemption, little is known about what is contained in them. The Cheney Exemption is an exception in the 2005 Energy Bill that exempts hydraulic fracturing and oilfield waste from being classified as "hazardous." From a basic analysis of the wastewater, including the proppant, several hazardous materials contained in the produced water can be identified, including benzene, toluene, ammonia, and ethylene glycol (Fox & Fox, 2012). Other materials included in the mixture at lower quantities are guar, borate salts, citric acid, isopropanol, polyacrylamide, and sodium bicarbonate. The most dangerous chemicals are those in the zylene family, as well as the related compounds benzene and toluene all of which are used as industrial solvents (General Electric, 2012a).

Chapter 3: Methodology

In response to the increased prevalence of natural gas fracking, the USCG has begun work on a new policy that will define and enforce safety rules and regulations for transporting SGEWW by barge on US inland waterways. These regulations define safety standards for the barges transporting the SGEWW by ensuring that radiation levels are below acceptable thresholds. The goal of our research was to provide the USCG with an in depth analysis of the cost that this barge transport policy would impose on barge and gas companies, respectively, compared to the cost of the onsite treatment alternative: distillation. The main focus of our analysis was on the barge transport and deep well injection treatment decision as this is the USCG's only area of jurisdiction, though we also estimated the environmental effects of this SGEWW should there be a barge accident or an onsite leak. In this chapter we describe the methodology used for accomplishing our research objectives of determining the economic and environmental impacts of SGEWW transport by barge to deep injection wells as compared with the distillation of this SGEWW onsite.

3.1 Estimating Costs of SGEWW Transport

Because of the USCG's newly drafted policy for transporting SGEWW, the group completed an economic analysis of the costs that this policy would impose upon barge companies. A primary concern of the USCG is the safe disposal of contaminated SGEWW via barge transport to deep well injection sites in Ohio and eventually Louisiana and Texas. Therefore, our group collected economic data that gave us an estimated cost of cleaning and outfitting a barge specifically for SGEWW transport under normal operating conditions. To establish the cost for a worst case incident during barge transport, we collected data and estimated the fees for cleaning and containing the area affected. We established a total transport cost estimate by using archival research and interviews with a barge company that has identified itself and expressed an interest in working under this policy with the USCG. Survey and water testing companies were contacted to estimate the cost of ensuring that the barge conformed to USCG policy safety standards. The economic costs associated with the environmental impacts of a spill were approximated through research into past water pollution incidents and subsequent clean-up efforts.

3.1.1 Economic Variables in Wastewater Transport

The overall cost of general barge transport is a composite of the costs of chartering, and insuring a barge, as well as paying and training the barge operators. All of the aforementioned costs, however, are incurred by the barge companies regardless of what they are shipping and the policies affecting their cargo. The USCG is mainly concerned with the added costs that their new policy may have on the barge companies that transport SGEWW. Through personal communications with Dr. Znati, Ph. D chemical engineer of the USCG (10-29-12) we learned that this total added cost includes the testing of the SGEWW prior to transport to detect the radiation concentration(s) present in the water being transported. Periodic costs arise in surveying the interior of the barge for deposits of radioactive materials before any work is done on the barge, and before USCG personnel inspect a barge once every five years. Further expenses come from holding the SGEWW prior to transport, and the cost of transporting the SGEWW by truck from the point of generation to the barge loading area and then from the barge off-loading area to the deep well injection sites. Preliminary information about the costs and risks of land transport was collected from Jim Williams, a personal contact of Dr. Znati, and representative of the Department of Transportation (DOT). Costs also depend on the preparation the barge would have to undergo prior to transporting SGEWW. In this case, the interior of the barge would need to be coated with anti-corrosion paint to protect against accumulation of radioactive deposits (James Guttman, personal communication, 11-16-12) (Znati, personal communication, 10-30-2012). The total expense would also include the cost of injecting the water into the wells in Ohio and eventually Louisiana and Texas after the Ohio wells have been filled.

To establish costs of transportation, we interviewed James Guttman, owner and representative of a self-identified barge company to verify the costs of all aspects of hiring a barge to transport a hyper saline radioactive material such as SGEWW (see Appendix D for transportation company interview protocols). We also collected information on the costs associated with outfitting the barge personnel with the appropriate equipment to keep them safe from the radiation found in the SGEWW. Information on this equipment as well as its costs was gathered from an interview with Carolyn Onye, Commander Kyle Lim, and Commander Melburn Dayton of the USCG, all industrial hygienists, and experts in protection procedures (see Appendix G for interview protocol with industrial hygienist). The cost of testing the SGEWW for dissolved solids content was estimated through contacting two Pennsylvania certified water testing companies: Phase Separation Systems and Atlantic Coast Labs. We received a quote of the cost to survey the barges for radioactive buildup from Currie Radiation Systems and Chase Environmental Group. The USCG policy letter requires that these surveys are completed before any barge company or USCG personnel enter the liquid holding area, for both repairs and USCG inspections. (See appendix B for USCG policy letter) The goal of contacting these four companies was to get quotes of the total cost of testing the SGEWW and surveying the barges prior to transport. Personal communications were used in this instance, as interviews were unnecessary to simply get a monetary quote; no other information was needed. The objective of this research was to gather information about all of these costs in order to construct a complete analysis of the economic aspects of transporting the SGEWW according to the new USCG policy. Grandview Barge Line agreed to be interviewed regarding the cost they would charge for simply shipping SGEWW from well heads in Pennsylvania to injection sites in Ohio. Grandview's owner James Guttman had expressed interest in obtaining USCG approval for these shipments, and was willing to disclose detailed information about their operating costs via phone interviews and email correspondences.

3.1.2 Environmental Variables in SGEWW Transport

If a spill of SGEWW were to occur, in addition to the negative environmental effects, considerable costs would be incurred to contain the spill and clean the affected area. Due to the fact that no data currently exist on the subject of SGEWW cleanup, we created an estimated cost by using case studies of hazardous waste materials that approximated the individual properties of SGEWW. We investigated petroleum spills to approximate the costs associated with containment and cleanup of high viscosity hydrocarbons, low level radioactive incidents to approximate the costs of cleaning radioactive materials, and case studies of oil brine accidents to estimate the total cost associated with cleaning a SGEWW accident. These case studies were found and examined through archival research in the WPI library's Summon Database. The case studies we found explored previous contaminations, as mentioned and the measures taken and costs associated with remediating them.

In order to gain a more well-rounded understanding of the environmental issues associated with SGEWW transport, we contacted Scott Wilson, an environmental scientist of the EPA, who was identified by the USCG as a subject matter expert knowledgeable in both the specifics of the USCG's barge transport policy and the potential environmental repercussions of a SGEWW spill (see Appendix C for EPA environmental scientist interview protocol). In our meeting, we inquired as to the effects that a release of halogenated and radioactive water would have on various ecosystems along the Monongahela and Ohio River systems through which the barges will travel while carrying the SGEWW. Our interview goal was to gather information from Mr. Wilson which would allow us to narrow our search for case studies to only applicable proxy materials. The results obtained through our case study research provided a thorough understanding of the economics associated with environmental effects of transporting SGEWW by barge according to the policy of the USCG.

3.2 Estimating Costs of SGEWW Treatment On-site

After completing our research regarding the USCG barge transport disposal method for SGEWW, we researched the alternative method of on-site distillation in order to provide a cost analysis for another form of treatment which could then be compared to the cost analysis of the transport option. As in our barge transport analysis, we estimated the standard operating costs for onsite treatment, and collected information on the costs of a spill at an onsite treatment facility. As detailed in Chapter 2 (section 2.10), the USCG and Dr. Znati, our liaison, know that the main alternative to barge transport of SGEWW is treatment onsite through distillation. In order to establish the baseline economic and environmental costs of the SGEWW treatment at the well site we reviewed how the shale gas producers currently treat this unprocessed material and what the costs are for these processes. We used three basic methods to understand the full financial implications of this treatment option, including the environmental costs: interviews, personal communications, and archival research.

3.2.1 Treatment of SGEWW Onsite

Because fracking is a relatively new and proprietary process, most large fracking companies are reluctant to share their information regarding the specific onsite treatment processes for the disposal of SGEWW. Consequently, we acquired all financial data regarding the onsite treatment of fracking wastewater directly from the industry interest group the Marcellus Shale Coalition (MSC), as they are currently the only source of this information. To find the cost of onsite treatment through distillation we researched the energy required to evaporate the water in order to concentrate the contaminants into sludge, and the effort required to initially create and make safe the holding ponds where this process is carried out. Other costs we considered included truck transportation of the water from the extraction site to the holding pond, and the land filling of any resulting sludge.

Interviews with special interest group representatives allowed us to gauge the financial obligations associated with onsite treatment of SGEWW and the resulting sludge. The data gathered from these interviews focused on the treatment method of distillation, and the steps taken to dispose of the SGEWW onsite in this way. These steps then helped us to approximate the total cost fracking companies' face when treating their waste. In addition, we inquired about the cost of the safety equipment used in daily operations (e.g. respirators, disposable hazard suits, etc) from the industrial hygienists, Mrs. Onye, Commander Dayton, and Commander Lim. In tandem with these interviews we conducted internet research to determine the use and cost of safety equipment deemed necessary to protect the workers who handle SGEWW. All of the onsite costs were combined into a lump sum that provided us with an approximation of the total cost of onsite SGEWW treatment, based on the companies' current treatment method.

3.2.2 Environmental Variables in Onsite SGEWW Treatment

To approximate the potential economic impact of onsite treatment of SGEWW, we investigated contaminations of materials which have similar properties to SGEWW: radioactive activity, salinity, and toxicity. As we did in evaluating the environmental cost of barge transport of SGEWW, we used case studies obtained from archival research to estimate the economic and environmental impact of the wastewater. Materials which share individual dangerous properties with SGEWW were investigated to complete a profile of the impact that an accidental release of sludge from the holding ponds at the extraction sites would cause. These case studies were focused entirely on land-based accidents and their subsequent control and clean up; no water spills were included in this portion of the analysis. To estimate the cost of a spill of material that is similarly radioactive to SGEWW, we investigated case studies of geothermal wastewater spills, and the measures taken to clean up the affected area. Oil brine spills were studied to estimate the cost of cleaning up after a spill of a material with similar salinity to SGEWW, and case studies detailing petroleum spill management allowed us to estimate the costs of a cleanup of a high viscosity material that is comparable in toxicity to SGEWW. By investigating these case studies, in which each pollutant shares a property with the SGEWW itself, we created a simulated total cost of cleanup and containment as there are no current data regarding fracking sludge release or cleanup on land.

These case studies showed the specific ways the environment may be harmed and what measures would need to be taken to remediate a SGEWW sludge spill. Information on the type of damage to the environment allowed us to focus our archival research to include only relevant clean up measures. Archival research also allowed us to provide the USCG with a clearer understanding of the potential environmental impact of an onsite accident and the economic costs that would be incurred to counteract these effects.

3.3 Summary

In completing our project, we compiled the economic and environmental effects of two distinct disposal methods for SGEWW. This provided the USCG with a summary of the added costs to barge and fracking companies their new regulations would create for transporting SGEWW, as well as the costs associated with the hazardous nature of the waste. This information helped clarify the costs of the USCG's newly proposed policy on the transport of SGEWW as well as the costs of current onsite treatment methods, including environmental implications and cleanups from accidents. In the following chapter we discuss the results we obtained from our combined research methods.

Chapter 4: Results and Analysis

This chapter presents the results of our research as described in the Methodology chapter. We completed an analysis of the cost of transporting SGEWW by barge on inland waterways according to the USCG's proposed policy. We present our findings on appropriate proxy materials, and the results of our investigation into using these proxies to estimate the cost of cleaning up after a barge spill of SGEWW into US waterways. We verified that the most beneficial method of on-site SGEWW treatment was distillation, and determined the cost of utilizing this method of treatment for the fracking industry. We present the findings of archival research into the financial burdens the fracking companies would incur in the event of a land-based contamination as the result of using distillation to treat the SGEWW.

4.1 Economic Variables in SGEWW Transport

A main objective of our research was to identify all the costs necessary to hire a barge to transport the SGEWW to an appropriate storage site, while conforming to the newly drafted USCG policy outlining rules and regulations for SGEWW transport by barge. This policy is not concerned with costs incurred by the barge company for normal operation, but rather focuses on the added costs the barge companies and fracking companies would incur due to the safety concerns associated with transporting SGEWW. The new policy will require that the SGEWW will be tested and barges surveyed before shipment, thus adding costs to the barge companies.

The following schematic (Figure 3) depicts the generation and transport of SGEWW by barge in compliance with the USCG policy. The water begins at the fracking well-head and is transported by truck to the embarkation point of the barge, where it is temporarily held in holding tanks owned by the barge company. The barge then ships the SGEWW from mile marker 45.3 on the Monongahela River to mile marker 143.2 on the Ohio River. From there it is trucked from the barge to the deep well injection sites in Ohio where it is permanently disposed of. Prior to shipment, the SGEWW must be tested for dissolved solids content, and the barges must be surveyed for radioactive deposits. Each portion of this process is displayed to correspond to the individual sections that follow.

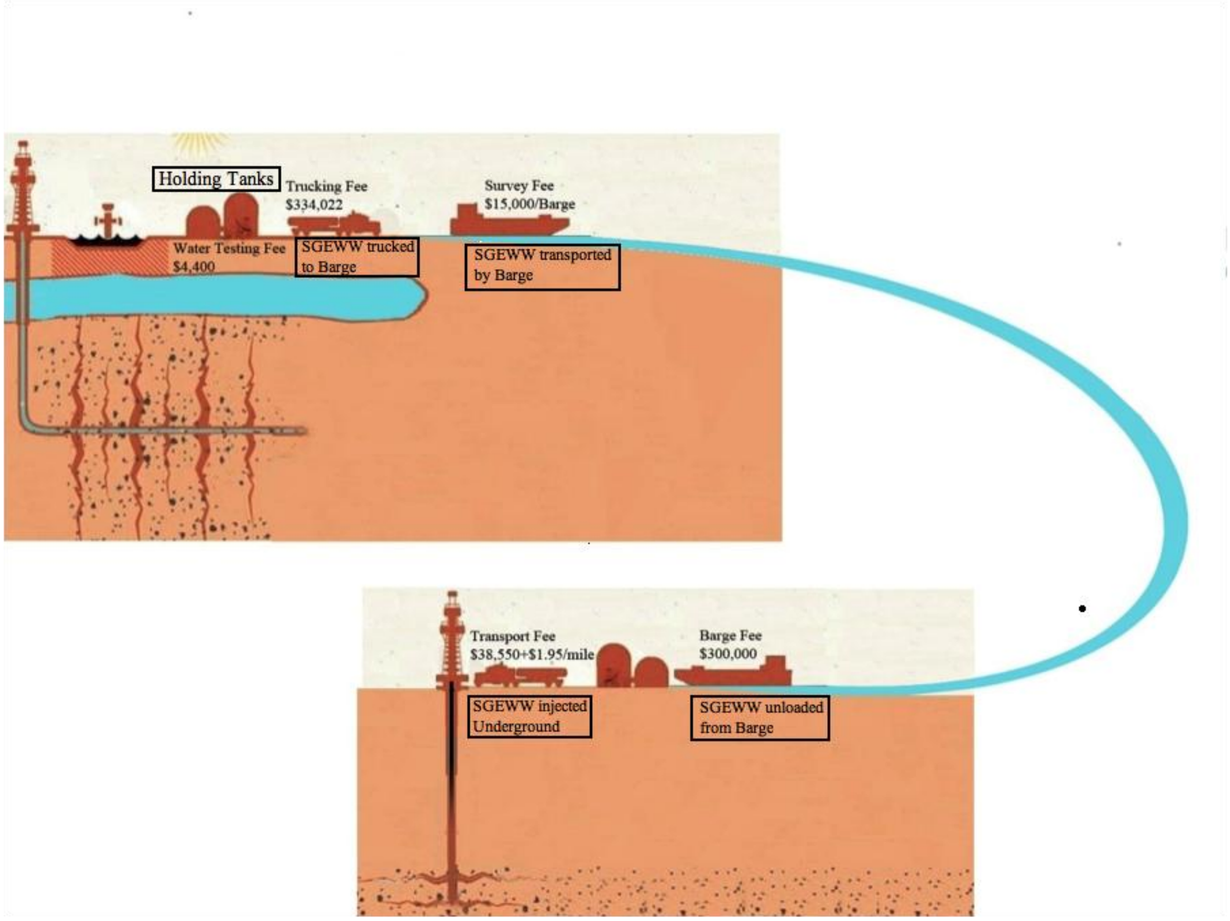

Figure 3: Barge Transport Flow Chart (Barge Transport of Frac Waste, 2012)

4.1.1 Cost of Truck Transport

The first additional cost for disposing of SGEWW is the cost gas fracking companies would pay in order to ship the wastewater from the wellhead to the barge as well as from the barge to the deep injection well sites. Mr. Jim Williams of the Department of Transportation (DOT) provided useful information about the costs and logistics of land transport of SGEWW. When the SGEWW is first brought up from the well, it must be shipped from the well to the embarkation point of the barge. Mr. Williams informed us that the easiest option would be to use rail cars, but that the SGEWW would have to be trucked to the rail yard, loaded into a train, unloaded onto a barge, shipped by barge, then trucked from the debarkation point of the barge to the next rail yard for final transport to a deep injection well (James Williams, See Appendix H for Interview Notes). This complex chain of events creates a situation where it is simply easier to use trucks to transport from the well all the way to the barge. Transport of SGEWW by truck would be more expensive per mile, but this cost would be offset by the fact that it is more expensive and dangerous to transfer this material so many times, between trucks, rail cars, and barges. Mr. Williams passed along a quote from a trucking company of $700 per day to rent a tanker, in addition to $1.95 per mile traveled for each tanker truck used, as well as fuel costs. Each of these trucks can carry about 7,600 gallons of SGEWW at one time, meaning that 55 truckloads would fill one barge.

4.1.2 Radiation Limits for Hazardous Material

For these 55 truckloads per barge of SGEWW, there might also be an added cost should the trucking companies need regulatory and hazardous material permits in order to ship the SGEWW. Jim Williams informed us that these regulations are stipulated in Title 49 of the Code of Federal Regulations, part 173 (James Williams, personal communication, see Appendix H for Interview Notes). Regulations for transport of radioactive materials are defined in subsection 401-403. In its definition of radioactive material, the Code states "radioactive material means any material containing radionuclides where both the activity concentration and the total activity in the consignment exceed the values specified in the table in 173.436 or values derived according to the instructions in 173.433" (49 CFR 173.403). Each radioactive isotope contained in the table that makes up subsection 436 is assigned an activity concentration which defines the highest amount of radiation that can be present per a specified volume of material that is transported. The table also defines the consignment limit for radiation, which is the total activity which can be present in a shipment, regardless of the concentration of radiation per volume. If a shipment of material contains an activity concentration and total consignment activity which are both above the specified values (See Table 1 for Specific Activity and Consignment Limits), the material is classified as a hazardous material, and both the gas company and transport company will be required to have DOT permits in order to transport it (James Williams, personal communication, see Appendix H for Interview Notes). However, if the shipment does not exceed both the concentration and the activity limits, transport companies will not have to pay the DOT registration fees. For registration years 2010-2011, small businesses wishing to transport hazardous materials paid $250, and companies labeled "other than a small business" paid $2,575 to be able to ship this material (49 CFR 107.601). This fee is paid annually, with nonprofit companies being exempt. Isotopes of radium are commonly the only radionuclides companies test for in well water, so we determined whether SGEWW would qualify as a hazardous radioactive material based on radium concentration and activity in well water as reported by the EPA.

The largest data set containing statistically reliable values for activity in a SGEWW sample (standard deviation ~+/-10%) were from an EPA document summarizing and presenting background information and analysis of Atlantic region oil and gas extraction (EPA, 2012). Section 173.436 of Title 49 of the CFR defines the activity concentration limit for radium-226 as 270 pCi/g, and the consignment limit for any single shipment as 270,000 pCi (49 CFR 173.436).

The EPA (2012) reports on data from a set of fracking wells that states that the Ra-226 levels, as of 90 days from well inception, were 1.27 pCi/l. Generally, values in pCi/g are one thousand times smaller than values in pCi/l, however, because the density of SGEWW is not precisely known; no direct unit conversion is possible. The reported level of radioactivity in SGEWW does not exceed the acceptable limits defined by the DOT. Therefore, this concentration limit requires that more than 212,600 liters would need to be shipped in a single shipment to exceed the total consignment limit for this isotope. A SGEWW shipment of this volume is likely, and although it has the potential to violate the consignment limit, it will not approach the activity limit (Table 1). Since the activity concentration limit and the consignment activity limit will not both be violated, there will be no need for hazardous material permits, or for transport companies to pay the DOT registration fees. Similarly, the level of Ra-228 is reported as 1.1 pCi/l for the same set of wells (EPA, 2012). The activity concentration limit for this isotope is 270 pCi/g, meaning that there is no danger of the SGEWW being classified as a hazardous material because of the concentration of Ra-228 it contains (49 CFR 173.436). The total radiation limit for Ra-228 is 2.7 million pCi per consignment, meaning that more than two million liters of SGEWW would have to be included in one shipment to qualify as a hazardous material in this regard. Ultimately SGEWW will not require shipping companies to register for hazardous material permits as both the concentration and activity limit will likely never be simultaneously violated, and all fees will be avoided. Therefore, the regulatory permit cost to ship SGEWW by truck is not applicable.

Table 1: Summary of Recorded Values of Radiation in SGEWW Compared to CFR Limits

Isotope	Activity Concentration Limit	Reported Concentration as of 90 days	Violation	Consignment Limit	Total Allowable Consignment	Possibility of Violation	Failed Both
Ra-226	270 pCi/g	1.27 pCi/l	No	270,000 pCi	212,598 Liters	Yes	**No**
Ra-228	270 pCi/g	1.1 pCi/l	No	2,700,000 pCi	2.4 million liters	No	**No**

4.1.3 Cost of Contracted Barge Transport

We also investigated the cost and process of shipping the SGEWW on a barge through inland water ways from the Marcellus Shale Region to the deep injection wells in Ohio. For information on the barge shipment costs we spoke to Mr. James Guttman, owner of Grandview Barge Line, a private barge company self-identified to the USCG as willing to ship the SGEWW. The barges would be jumbo size, measuring 195 feet long by 35 feet wide and capable of carrying 10,000 barrels at 42 gallons per barrel of SGEWW per shipment (James Guttman, personal communication, see Appendix D for Interview Notes). Prior to shipment, the SGEWW would be held in holding tanks located at one of Mr. Guttman's two facilities located along the Monongahela River in Pennsylvania. At the first facility, there are three holding tanks: one 1,000,000 gallon tank, and two 600,000 gallon tanks. The second terminal contains one 400,000 gallon tank, one 324,000 gallon tank, and one 250,000 gallon tank. The tanks themselves are steel and are currently coated on the outside with anticorrosion cathodic coating. Before he begins transporting SGEWW, Mr. Guttman plans to coat the insides of the tanks, as well as the insides of the barges, with anti-corrosion cathodic paint manufactured by Caboline, or Madison (who markets a similar paint called Coracote). The exact cost of this coating process is thus far unknown as Mr. Guttman has not yet received quotes from the two companies.

In order to use a jumbo barge, Mr. Guttman would charge fracking companies five dollars per barrel to ship the SGEWW from the 43.5 LDB mile markers on the Monongahela River to mile marker 143.2 RDB on the Ohio River, a distance of 186.7 miles. At the conclusion of this shipment process, the SGEWW would be injected into deep underground wells. On their journey, the barges would have to travel through a total of twelve locks on the rivers. While there are no charges for passing through these locks, there are size restrictions, limiting passage through some locks to three barges at a time. Mr. Guttman's current plan is to ship 60,000 barrels of SGEWW per week, or six jumbo barges on one round trip each week, where the barges would return back from unloading the SGEWW with empty tanks. Exact calculations regarding the use of Mr. Guttman's barges for SGEWW transport can be seen in Table 2 below. The trucking costs that would be paid by the fracking industry in a week are shown in Table 3 below.

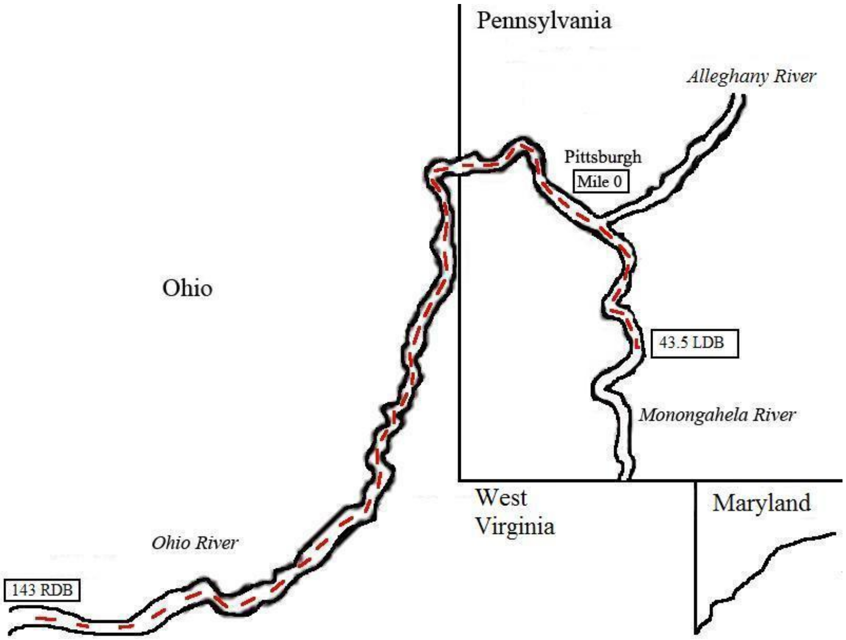

Figure 4: Proposed Route of Barge Transport (Map of Ohio River and its Surroundings, 2012)

Table 2: Calculation of Barge Transport Cost

$$1\ barge = 10{,}000\ barrels \rightarrow 10{,}000\frac{barrels}{barge} * 6\frac{barges}{week} = 60{,}000\ barrels\ per\ week$$

$$6\ barges = 60{,}000\ barrels \rightarrow 60{,}000\frac{barrels}{week} * 42\frac{gallons}{barrel} = 2{,}520{,}000\ gallons\ per\ week$$

$$1\ truck = 7{,}600\ gallons \rightarrow 2{,}520{,}000\frac{gallons}{week} \div 7{,}600\frac{gallons}{truck} = 332\ trucks\ per\ week$$

$$\left[332\ trucks * 700\frac{dollars}{truck}\right] + \left[332\ trucks * \left(1.95\ \frac{dollars}{mile} * 233\ miles\ long\ average\right)\right] = \$383{,}244$$

$$\left[332\ trucks * 700\frac{dollars}{truck}\right] + \left[332\ trucks * \left(1.95\ \frac{dollars}{mile} * 45\ miles\ close\ average\right)\right] = \$261{,}533$$

Table 3: Calculation of Total Trucks Needed for Transport

$$1\ barrel = 42\ gallons \rightarrow 1\ barge = 10{,}000\ barrels * 42\frac{gallons}{barrel} = 420{,}000\ gallons\ per\ barge$$

$$1\ truck = 7{,}600\ gallons \rightarrow 420{,}000\frac{gallons}{barge} \div 7{,}600\frac{gallons}{truck} = 55\ trucks\ per\ barge$$

$$55\frac{trucks}{barge} * 6\frac{barges}{week} = 332\ trucks\ per\ week$$

4.1.4 Cost of Barge Survey

According to Scott Wilson, an environmental expert from the EPA, the SGEWW contains low level radioactivity and has a salt content of almost 45%, or 450,000 parts per million total dissolved solids (ppm tds) as compared to the normal 200,000 ppm tds found in tap water (personal communication, see Appendix C for Interview Notes). Therefore, before anyone enters the barge in order to inspect it for safety, or to make repairs, a radiation survey of 100% of the interior of the SGEWW holding area must be completed. This survey will scan for radioactivity levels in the barge interior, ensuring that the area is safe for workers to enter. Surveying involves scanning a barge with Geiger counters and is very time intensive, as the equipment to scan and mark alpha radiation needs to be held very close to the hull and cannot scan faster than two inches by one foot per second (James Williams, see Appendix H for Interview Notes). Radon samples also need to be taken, and concentrated “hot spots” must be mapped. According to Chase Environmental Group, the hourly cost is $175 for surveying the barge. This is expected to be a two to three day job, and the overnight fee is $400 per night with a $300 travel fee. It costs an additional $700 for a map of any radiation concentrations, along with a $300 fee for the radon detectors. This amounts to a final bill of around $5,000 per barge per day, or $10,000-$15,000 per barge survey. We also received a simplified quote from Curie Radiation Systems for a total cost per survey of $15,000 including overnight and decontamination fees. Surveys would be completed as necessary prior to the barge being repaired or inspected for safety (Cynthia Znati, personal communication, 11-20-12). USCG safety inspections are estimated to occur about once every five years, at which time surveys must be performed to ensure the safety of the inspectors. While a barge is undergoing a survey, it is unable to leave port to transport SGEWW until it has been cleared.

4.1.5 Cost of USCG Personal Protective Equipment

Every five years, USCG inspectors perform barge inspections. In order to get information on the cost of Personal Protective Equipment (PPE) that these inspectors would wear when entering the barges, we spoke to three USCG industrial hygienists: CDR Kyle Lim, CDR Melburn Dayton, and Carolyn Onye. CDR Dayton has not had experience dealing with low level radioactive waste to date, but he is in the process of drafting an applicable policy (Melburn Dayton, personal communication, see Appendix F for Interview Notes). In the past, the USCG has had experience with low levels of x-ray radiation, and any policy regarding radiation exposure for USCG personnel will be based on this experience. CDR Dayton will be working with the Defense Threat Reduction Agency (DTRA) to calculate safe exposure limits for USCG workers. People will be sent into the barge holding area as monitors to gather a representative level of radiation. These monitors will wear radiation badges which record the amount of radiation to which each monitor is exposed. This will allow the USCG to determine the level of radiation danger and regulate the behavior of its workers accordingly. Should unsafe levels of radiation be detected, we inquired as to what safety equipment, or PPE, the USCG would likely require its inspectors to wear. This would have allowed us to calculate the cost of acquiring this equipment and outfitting the inspectors. CDR Dayton informed us; however, that if a barge survey showed that the levels of radiation detected would necessitate PPE, he would not allow USCG inspectors to enter that area, thus the cost of the PPE to the USCG is $0. If a barge showed radiation above the DTRA acceptable limit, CDR Dayton would have the USCG quarantine the barge for enough time to allow the radioactive isotopes to decay until the radiation reached a safer level or until the barge was pressure-washed to remove radioactive material. Only then would he allow USCG inspectors into the barge to check for various safety standards. This quarantine could last up to a few weeks during which the radionuclides in the barge would decay, reducing the radiation present. During this time, the barge would be inoperable, and unable to carry any cargo, thus imposing an economic hardship on the barge company because it would be unable to use this vessel to fulfill any contract.

4.1.6 Cost of Water Content Analysis

In addition to surveying the barges, the barge companies must take water samples from each tank of SGEWW prior to shipment. These samples must then be tested for alkalinity, acidity, radium content, and gross alpha radiation content in order to ensure that they are safe to ship along inland waterways. The price of each test is determined by line item, since tests for different materials range in price based on the difficulty of performing the test (see Appendix J for Water Testing Invoice). The 23 metal tests specified as necessary by the USCG policy cost twelve dollars each, according to Atlantic Coast Labs. Various other properties such as uranium content and conductivity range from seven dollars to $200. The water also must be tested for thorium, though only if the pH of the water is found to be between two and three. If the acidity test result shows that the water is outside of this range, no thorium test is necessary. Should a thorium test be required, an alpha spectroscopy analysis would cost $147.

In addition to naturally occurring materials in the water, the USCG would also require testing for radioactive tracers inserted into the well by the fracking company to track fluid flow. A test for iodine-131, the most common tracer costs $120 according to Radiation Safety Engineering, Inc. Tests for all of the aforementioned metrics are required by the new USCG policy regarding barge transport of SGEWW, as the USCG is requiring that the contents of the SGEWW be reported before it is transported. The total cost for all of these tests according to Atlantic Coast Labs is about $1,600. A second estimate obtained from Phase Separation Systems was $700 to $1,100 for the same tests, which was relatively consistent with the estimate provided by Atlantic Coast Labs. The most time consuming part of this operation is the radon test, which depends on measuring the weight of the sample and detecting the small change in mass due to the decay of radon-222. Since the half-life of radon-222 is only 3.2 days it is possible in two or three days to measure the radon content. All other tests can be completed in a shorter time frame, meaning that the tests could take up to three days to complete depending on the amount of accuracy required.

Before a barge may take on a load of SGEWW, the water must be tested as described above. However, as one batch of SGEWW may require multiple barges, it is possible for the tests to be completed beforehand in time for the barges to leave together as scheduled (USCG Policy, 2012). For example, Mr. Guttman would hold SGEWW in six company owned holding tanks split between two terminals while it awaits shipment (James Guttman, see Appendix D for Interview Notes). At the first terminal, the three tanks' total holding capacity is 2.2 million gallons. The second terminal houses three smaller tanks, whose total capacity is 974,000 gallons (Table 5, below, contains the details of tank holding capacity). If Mr. Guttman filled the largest of the tanks first, only four would be needed to contain all 2.5 million gallons of SGEWW requiring transport every week; therefore only four water tests would be needed. If the smaller tanks were used, nine tankfuls (and therefore nine water tests) would be necessary (these calculations are displayed in Table 4 below). If the water has not been tested, all barges scheduled to transport water from the batch of SGEWW cannot leave port.

Table 4: SGEWW Shipment Cost to a Barge Company

Cost to Barge Companies	
Minimum Water Tests (4)	$6,400
Maximum Water Tests (9)	$14,400
Surveys (6 barges, $15,000 each)	$90,000
Total Normal Week:	$6, 400-$14,400
Total Survey Week (***Once every 5 years***):	$94,400-$104,400

Table 5: Guttman's Holding Tank Calculations

$$1 * 1{,}000{,}000\ gallon\ tank + 2 * 600{,}000\ gallon\ tank = 2{,}200{,}000\ gallon\ gallons$$

$$1 * 400{,}000\ gallon\ tank + 1 * 324{,}000\ gallon\ tank + 1 * 252{,}000\ gallon\ tank = 976{,}000\ gallons$$

4.2 Estimating Environmental Costs of SGEWW Transport

The largest potential cost involved in transporting the SGEWW via barge is the cost for cleaning up an accident. While there are no previous records of SGEWW clean ups (as it has never been transported via barge before), similar materials have been shipped, spilled, and cleaned on inland waterways. Therefore, we used materials with similarities to SGEWW as proxy materials in order to estimate the total cost of cleaning up a SGEWW spill. The chosen proxy materials were hyper-saline and oily in content in order to mimic the effects that SGEWW would have should a spill occur. In our interviews with environmental experts Scott Wilson and Craig Matthiessen from the EPA, we asked them to confirm if our choice of proxy materials used in case studies were appropriate. Although they are experts in environmental policy, they were not able to confirm whether our proxy materials were the best approximations for the properties of SGEWW, so we decided to complete our case study analysis using the proxies that we originally identified.

4.2.1 Clean Up Costs of Proxy Material Spills in Water

When a spill of hyper-saline liquid occurs in an aqueous environment, there are several options for remediating the situation and making the area habitable for aquatic life. In a highly sensitive environment, it may be necessary to remove salts with any of a number of commercial chemical treatments such as sodic converters, and polyacrylamide (polymerized acrylamide), a polymer which removes sodium from the river bed (Colgan, 2004). Use of polymers increases the filtration rate of the bed soil, meaning that the water is more able to move salt and dissolve it into solution, preventing stratification and long-term harm to aquatic life. The more simplistic method for remediation is to simply remove tainted water and store it in an area where it will not threaten the ecosystem. Eliminating the polluted water is a much less expensive option but is appropriate only for smaller-scale spills where the contaminated water can be separated and quickly removed, leaving the river water at a safe salt level. The method of removal of the water is also only acceptable when the more extensive use of chemical intervention is not necessary given the level of contamination.

To approximate the cost of a spill of SGEWW, we investigated past instances of spills involving highly saline liquids. We began by looking into a case in North Dakota in 2006, when more than 1 million gallons of saltwater were released into a creek (MacPherson, 2010). The water released was ten times saltier than seawater, and between the efforts to clean this spill from the banks of the river and remove the water itself, the company spent more than $2 million. The water was dealt with in the simplest way possible; and to avoid the cost of actively treating the water, it was simply relocated.

When dealing with low level radioactivity in the water, different methods are used to remediate the affected area. Exelon, a company based in Limerick, PA, experienced this first-hand when they dealt with a tritium leak due to a clogged drain pipe (Brandt, 2012). The NRC investigated this occurrence, and deemed the low level radiation a non-threat, because radiation levels were nowhere near the 20,000 pCi/l tritium limit. The radiation was instead simply left to mix and disperse in the river water. The solution to the issue was merely to clean the drainage pipe and closely monitor all future maintenance, as well as to use less water when hosing down the factory equipment to create less waste. Overall, Exelon had no clean-up costs as a result of this leak. Because these cases are of a scale similar to that of a SGEWW barge spilling its contents, we believe the costs of these previous spills provide a good approximation of the cost a gas company would have to pay following a breach of a barge carrying SGEWW. Because the radionuclides are found in the salt content of the SGEWW, when remediation techniques are used for salt, the radiation will also be removed with no additional radiation clean-up required.

Because SGEWW is known to contain about 1% hydrocarbons such as those found in oil, we reviewed methods and costs for cleaning a small-scale spill of oil into waterways (Cynthia Znati, personal communication, 11-7-12). One technique for cleaning and containing an oil spill on water is the use of a chemical barrier, which physically reacts with the oil to clump it and make it easier to clean from the surface of the water (Fingas, 2011). These chemical barriers are made up of a mixture of non-aromatic amines, and are known as gelling agents, as they form a membrane around clumps of oil, allowing oil to be removed with less effort (Bahloul, 1979). Use of gelling agents is only appropriate in situations where there is a spill of oil too small to be cleaned with large physical barriers like floating booms; so a spill of SGEWW where only a small percent of the volume is oily is a good candidate for use of this procedure (Fingas, 2011). In addition, application of chemical intervention on waterways must be approved by the state government of the area affected by a spill. A particularly successful chemical barrier is a mixture developed by the Chemical Engineering and Chemistry Departments at the University of Lowell in Massachusetts (Bahloul, 1979). This mixture consists of 15% ethanol, 15% benzyl alcohol and 70% Amine D, a commercially available combination of various aliphatic amines. Based on in-house testing of this combination, at a mixture ratio of .15 liter gelling solution to liter hydrocarbon yields the maximum jellification of the hydrocarbon. This means that for each liter of hydrocarbon spilled, .15 liters of gelling agent should be used. In a jumbo barge containing 10,000 barrels of SGEWW, if 1% of the volume of liquid is made up of hydrocarbons, this equates to 100 barrels or 4,200 gallons. Based on the mixture ratio, this means that 630 gallons of gelling agent would be required for this spill. Of this, the composition of the chemical barrier indicates that 441 gallons of Amine D and 94.5 gallons of ethanol and benzyl alcohol would be needed. Because no case studies specify the cost of using such a gelling agent, we have approximated the cost based on the price of purchasing the constituent parts in bulk from commercial suppliers. Benzyl alcohol is available for $295 for a supply of 19 liters, meaning that the total cost would be $5,589 to purchase enough volume to accommodate a barge spill (Medical and Lab Supplies, 2012). Laboratory purity ethanol can be purchased at $7346 per 200 liter shipment, which equates to $13,222 to treat a barge spill (Spectrum Chemical, 2012). The combination of chemicals in Amine D is available for $41 per gallon, or $18,081 to purchase enough to remediate a spill of the oily material in a single barge of SGEWW (Morris Grain, 2012). Therefore, the cost to simply purchase the chemicals present in enough gelling agent for a spill of SGEWW is slightly less than $37,000 (see Table 6 below for exact calculation). This cost does not cover the overhead or labor required to disperse the chemical over the area of a spill, so it only constitutes a lowest possible threshold for this method of SGEWW clean-up on waterways. The fracking company would pay any clean-up costs, as the SGEWW is their waste, and therefore their responsibility to clean in the event of a spill.

Table 6: Petroleum Gellant Calculation (100 Barrel Spill)

$10{,}000\ barrels * \ 1\%\ hydrocarbon\ content = 100\ barrels\ of\ oil\ proxy$

$100\ barrels * 42\frac{gallons}{barrels} = 4200\ gallons\ of\ oil$

$4200\ gallons\ of\ oil * \ .15\frac{gallons\ of\ gelling\ agent}{gallons\ of\ oil} = 630\ gallons\ of\ gelling\ agent$

$630\ gallons\ of\ gelling\ agent * 70\%\ Amine\ D = 441\ gallons\ of\ Amine\ D$

$\$41\ per\ gallon * 441\ gallons = \$18{,}081$

$630\ gallons\ of\ gelling\ agent * 15\%\ Ethanol = 94.5\ gallons\ of\ Ethanol$

$94.5\ gallons = 360\ Liters\ of\ Ethanol$

$360\ Liters * \frac{\$7346}{200\ Liters} = \$13{,}222$

$630\ gallons\ of\ gelling\ agent * 15\%\ Benzyl\ Alcohol = 94.5\ gallons\ of\ Benzyl\ Alcohol$

$94.5\ gallons = 360\ Liters\ of\ Benzyl\ Alcohol$

$360\ Liters * \frac{\$295}{19\ Liters} = \$5{,}589$

$\$18{,}081\ for\ Amine\ D + \$13{,}222\ for\ Ethanol + \$5{,}589\ for\ Benzyl\ Alcohol = \$36892$

$Total = \$36{,}892\ for\ gelling\ agent$

4.2.2 Lawsuit Costs of Spill of Proxy Materials in Water

After a spill, significant costs come not just from cleaning the spill site, but from lawsuits filed by communities affected by the spill. In the case of the North Dakota saltwater spill, the state fined the company responsible $123,000 for violation of state environmental laws (MacPherson, 2010). A spill occurred in Illinois in 2011 that resulted in similar lawsuits from municipalities (Madigan, 2011). In this case, water with high levels of chloride and cyanide, which is especially dangerous for aquatic life, was continually released into the Illinois River between 2008 and the discovery of the spill three years later. Three civil suits filed by the state government totaled $150,000, and covered multiple violations to chemical release standards. When lawsuits are filed, they are done so only by local and state governments, as federal organizations such as EPA have no jurisdiction at the state level (Cynthia Znati, personal communication, 10-30-2012). The costs of lawsuits were investigated so that our analysis of the cost of transport or treatment could include both the cost incurred during, and after the event of a spill. Table 7 summarizes the above mentioned methods and related cleanup costs and lawsuit fines collected through case studies.

Table 7: Water Spill Cleanup Methods and Costs

Type	**Method**	**Cleanup Cost**	**Pot. Lawsuit**	**Total**
Oil Brine	Sodic Reducers	$2 million	$150,000	$2,150,000
Petroleum	Booms and Gellant	$37,000 per barge load spilled	$1,000,000	$1,037,000
Radiation	Half-Life Decay	No Additional Cost	No Additional Cost	
Grand Total				$3,237,000

4.3 Economic Variables in SGEWW Treatment On-site

By far the most cost effective method for disposing of SGEWW is to simply reuse the water produced in one well to fracture the shale in another (Andrew Paterson, personal communication, see Appendix E for Interview Notes; Scott Wilson, personal communication, see Appendix C for Interview Notes). This method allows for SGEWW to be useful to a gas company without the need for treatment or disposal before its reuse. Companies like General Petroleum use up to 25% recycled water in fracking wells to avoid the cost of treating that water (Scott Wilson, see Appendix C for Interview Notes). According to an estimate from Andrew Paterson, the amount of water recycled could be as high as 60%, further reducing the cost of treatment, and acquiring fresh water for use in a well (Andrew Paterson, personal communication, see Appendix E for Interview Notes). Obviously, this method is only valid as long as new wells are being fractured and are in need of water for injection. There is debate over how far into the future new wells will be dug, and therefore, how long reuse will remain a viable option. The USCG's Cynthia Znati (personal communication, 11-22-12) estimates new wells will stop being dug within the next 5-10 years, while Andrew Paterson of the Marcellus Shale Coalition estimates this timeframe to be sometime over 10 years. After this time, the wells will be fully tapped for natural gas, but SGEWW can continue to flow back for up to 40 years. At this point, SGEWW will still need to be disposed of, but reuse through reinjection will not be an option. The most viable option for SGEWW treatment onsite besides reuse in new wells is through distillation. The process by which the SGEWW would be evaporated and disposed of is depicted in Figure 5 below. The SGEWW is collected from the wellhead and is then placed in holding ponds or storage tanks where mobile evaporation units are used in order to separate and distill out the water from the SGEWW. What is left is a salty sludge, which is then transported to landfills by truck where it is disposed of permanently.

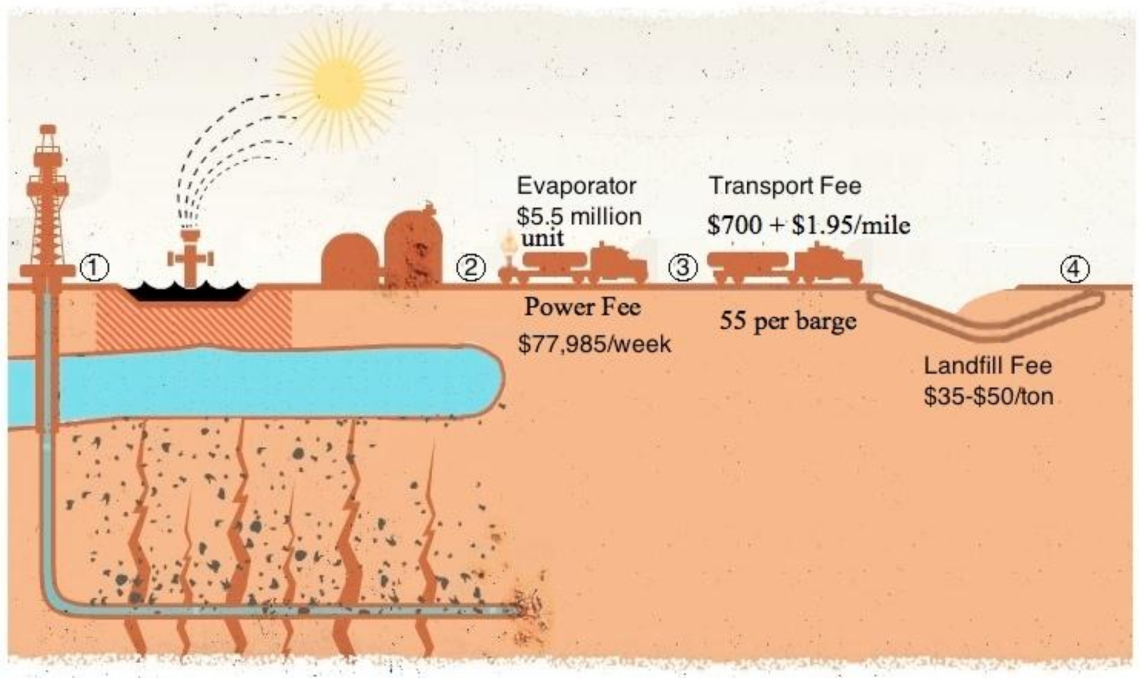

Figure 5: Onsite Evaporation Flow Chart

4.3.1 Treatment on Site by Distillation

When asked about the viability of using water evaporation units to treat SGEWW when it can no longer be reused, Mr. Paterson (personal communication, 11-20-12) of the MSC told us that he believes the high cost of these evaporation units would mean that distillation would need to be carried out at a centralized facility. However, he noted that if mobile units could be made cost- and energy efficient, they would be ideal for treatment at the point of SGEWW production, the wellhead. General Electric has developed such a mobile evaporator specifically for use at fracking wells. From company literature, and through contact with a sales representative, we have found that this evaporator has a maximum working load of 50 gallons of water treated per minute (General Electric Company, 2010b), which equates to 1,715 barrels of SGEWW being treated per day (GE Water, Sales Quote). Because an estimated 60,000 barrels of SGEWW will be produced each week in Pennsylvania (James Guttman, personal communication via Cynthia

Znati), gas companies will need to obtain about ten of these mobile evaporators to accommodate the treatment of all this produced water (see Table 8 below for calculation). This assumption is based on the fact that each unit will experience expected downtime due to cleaning and maintenance. Acquiring ten units will ensure that even during this downtime there will be enough operational units available to meet the demand of 60,000 barrels per week. Currently, each unit is priced at $5.5 million (GE Water, Sales Quote), and will require 1200 BTU of heat per gallon of water treated (Andrew Paterson, see Appendix E for Interview Notes), totaling about $78,000 per week at average grid electricity prices for Philadelphia (see Table 9 below for exact calculations) (Bureau of Labor Statistics, 2012). This estimate is based on use of grid electricity, though the energy can also come from the natural gas being produced.

Table 8: Calculation for Number of Evaporators Needed

$$1\ evaporator = 1{,}517\frac{barrels}{day} \rightarrow 60{,}000\frac{barrels}{week} \div \left(1{,}517\frac{barrels}{day} * 7\frac{days}{week}\right) = 6\ evaporators$$

$$1\ barge = 420{,}000\ gallons \rightarrow 420{,}000\frac{gallons}{barge} \div \left(60{,}000\frac{barrels}{week} * 42\frac{gallons}{barrel}\right) = 6\ barges\ per\ week$$

$$420{,}000\frac{gallons}{barge} * 6\frac{barges}{week} = 2{,}520{,}000\frac{gallons}{week}$$

Table 9: Necessary Evaporator Electricity per Week Calculation

$$1200\frac{BTU}{Gallon} * 42\frac{Gallon}{Barrel} = 50{,}400\ BTUs$$

$$50{,}400\frac{BTU}{Barrel} * .00293071\frac{kWh}{BTU} = 14.77\frac{kWh}{Barel}$$

$$14.77\frac{kWh}{Barrel} * 60{,}000\frac{Barrels}{Week} = 886{,}200\frac{kWh}{Week}$$

$$886{,}200\frac{kWh}{Week} * .16\frac{\$}{kWh} = \$77{,}985\ per\ week$$

4.3.2 Storage in Large Holding Ponds

When SGEWW is produced at a well, it must be stored before it is reused or distilled into a concentrated sludge. SGEWW is stored in large holding ponds dug directly into the well pad, the area around the well head designated for frac drilling activity (Scott Wilson, see Appendix C for Interview Notes). The EPA does not regulate the size or construction of these holding ponds, as this falls under the jurisdiction of individual states. Because there is no size limitation (only construction standards for ponds above a size threshold in PA), one large pond would be used to accommodate all the water that needs to be stored at any particular site (Andrew Paterson, see Appendix E for Interview Notes). The amount of water which must be stored depends on several factors including: the use of the water (ponds holding water for reuse will store less water than a pond holding water for treatment), and the buffer size. The largest ponds in Pennsylvania hold 13.5 million gallons of SGEWW, accommodating water from multiple frac sites. The amount of land needed for these ponds is inconsequential, as fracking companies obtain hundreds of acres of land when fracking a site, far more than is needed for the fracking equipment. To contain the SGEWW in these ponds, they are lined with two layers of non-permeable plastic sheets.

4.3.3 Final Disposal Methods for SGEWW Treated on Site

Depending on the consistency of the SGEWW after its treatment or storage, it can be disposed of in different ways. When solid (high viscosity) sludge is created, it is sent to a landfill, where it can be disposed of for $35-50 per ton (Andrew Paterson, see Appendix E for Interview Notes). Because the sludge is the product of concentrating the SGEWW, only a relatively small amount (compared to the amount of water it came from) will need to be landfilled. Once the sludge is disposed of in a specially outfitted landfill, no further action is required to prevent it from contaminating the environment. The lower viscosity liquid will be disposed of via deep well injection, as previously discussed. Though some small costs are associated with deep well injection, Mr. Paterson does not believe these costs will influence the decision of how to dispose of this liquid.

4.4 Estimating Environmental Costs of SGEWW Treatment On-site

As with spills of SGEWW in waterways, release of this material on land could cause a significant impact on the environment, require payment of the costs of cleaning the affected area, and involve settling lawsuits filed by local municipalities. Large-scale releases of SGEWW from the wellhead remain a possibility. In 2011, a natural gas fracking well in Pennsylvania experienced a small breach, releasing thousands of gallons of fracking fluid onto cattle grazing fields (Huffington Post, 2011). Though this incident was not at a large enough scale to cause major environmental damage, it nonetheless shows the potential for failure at these wells, and the contamination they can cause. Thus far there have been no reports of fracking wells releasing any material in large quantities, so to estimate the cost of a large-scale remediation of a SGEWW spill on land, we investigated spills of proxy materials-brine water and petroleum.

To approximate the cost of cleaning a spill of a hyper-saline material like SGEWW, we investigated past incidents of spills involving brine water, which is produced in the consumer products industry and is also high in saline content. When there is a spill of material containing high levels of dissolved salts, the main environmental damage is to plants and the soil in the affected area (Sublette, 2012). Salts in soil disturb the osmotic balance in plants making them unable to take in water through their roots, and affect the sodicity (sodium content) of the soil making it unstable and prone to erosion. "Successful remediation of saline soils depends upon the ability to leach salts to depths below the rooting zone" (Colgan, 2004, p. 5). The most common solution is to flush the affected soil with fresh water to clean away the salts. A 100-fold dilution with fresh water is considered the standard for wholly flushing the salt to a depth beyond which it will not affect plant growth (Colgan, 2004). In most cases, six feet below the rooting depth of the deepest rooted plant species present is sufficient for revegatation (Sublette, 2012). This dilution may cause short term erosion, but it will allow for revegatation, which will protect the area from long-term erosion issues.

The cost to execute this fresh water flushing depends on the size of the affected area, the amount of salt released, and the depth to which the salt has penetrated and must be further diluted (Sublette, 2012). A rough estimate from Sublette Consulting, Inc. indicates that the cost to treat a patch of land half an acre large by flushing, excavating to a depth of two feet, and replacing contaminated soil with fresh soil, is about $85,000 plus the added cost of revegetation to prevent erosion. The majority of this cost comes from the high volumes of water needed, and because flushing soil is a very time-intensive remediation method. In a more simplified clean-up method, contaminated soil is simply removed to an area designated safe for disposal, such as a landfill (MacPherson, 2010). When a saltwater spill occurred in North Dakota, the company responsible for the contamination spent more than $2 million on clean-up efforts. The main technique used to remediate the spill area was to remove soil and water contaminated by the spill. When hyper-saline (250,000 parts per million total dissolved solids), geothermal produced water breached a holding pond at a plant in Mexico, it contaminated and killed parts of a forest nearby (Birkle & Merkel, 2000). Though geothermal wastes are known to contain low levels of ra-226 and ra-228, the methods of clean-up and disposal would be the same as for a purely briny contamination (EPA, 2012). The estimated cost to clean the several hundred acres affected by the Mexican spill of geothermal produced water is between one and two million US dollars (Birkle

& Merkel, 2000). This amount would cover the removal of contaminated soil, and its shipment to a landfill facility. The similarity in costs for cleanup of spills in North Dakota and Mexico indicates that should a breach of SGEWW occur at a well head in Pennsylvania, the cost of clean-up for the gas company would fall within a similar price range (between one and two million dollars), depending on the magnitude of the spill and the methods of clean up deemed appropriate for the situation.

When cleaning a brine spill, there are two distinct methods to choose from. The first option is relatively cheap, as it entails ripping, or perforating the soil of the affected area, laying hay on top of the ripping, and digging a down slope remediation trench to catch the brine as it flows out of the ripped earth. This method was examined in a remediation of a produced fluids oil pipe leak in Osage County, Oklahoma. The total cost for this method topped at about $200 per acre of land cleaned up, with a 73% reduction in salt inventories over a time span of three years (Sublette & Moralwar, 2012). Previously, oil brine was cleaned with gypsum, a chemical which is contracted at about $2,000 per acre of clean-up. Contractors who specialize in its delivery inject gypsum into the earth where it then binds to the salt from the brine water and removes it from the soil, thus remediating the area. While large scale spills often must turn to chemicals in order to get an approved clean-up, small independent oil producers can turn to the option of soil ripping to clean small scale spills (Sublette & Moralwar, 2012).

Significant costs would also come from law suits and fines levied on companies that allow spills of dangerous materials. In the case of the 2006 spill in North Dakota, the fine of $123,000 was brought against a company by the state government (MacPherson, 2010). In this case, this fine was imposed because the company released highly saline water into a creek and onto the adjacent land. Based on the scale of this spill, the lawsuit fees associated are a fair estimate of those resulting from a SGEWW spill. Table 10 summarizes the techniques a fracking company would be likely to employ, and the costs associated with a spill on land.

Table 10: On Land SGEWW Clean Up Methods and Costs

Type of pollutant	Clean-up Method	Clean-up Cost	Fines/lawsuits	Total
Oil Brine	Ripping, Hay, trenches, gypsum	$200	$123,000	$143,000
	Injection of gypsum	$2,000		
Petroleum	Booms and Gellant	$200 per acre	N/A	$20,000
Grand Total for 100 acres				$163,000

4.5 Total Cost Calculations

If SGEWW is to be shipped via inland waterways to deep well injection sites, fracking companies will need to contract with trucking companies as well as barge companies. The trucking companies will be responsible for moving the SGEWW from the wells to the river for shipment to the disposal sites. For this service, we received a quoted price of between $260,000 and $380,000 depending on distance required, to transport the full volume of SGEWW expected in one week. We were also given a quote from a barge company stating that they would charge a fracking company $300,000 per week to ship the SGEWW. When establishing this price, Grandview Barge Lines must take into account the cost of safety tests they must perform to ensure the safety of the cargo and the vessel. Barge companies will be required to pay $90,000 once every five years to survey their barges, and up to $14,400 each week to test the water they intend to ship.

If a barge were to spill its contents, the fracking company which produced the SGEWW would be liable for the cost of cleaning the affected waterway. We estimate that the cost to clean a spill of SGEWW containing the volume of one barge to be about $2 million to clean up the salt content, and more than $37,000 to clean the oil component of the spill. We have calculated that the cost of lawsuits to a fracking company following a spill of SGEWW will likely be on the order of $150,000.

Because we found that on site disposal of SGEWW could best be accomplished using mobile evaporation units, we investigated the potential cost a fracking company might pay for use of such a method. In order to treat all the SGEWW that would otherwise be shipped by barge, a fracking company would need to purchase approximately ten evaporators, from General Electric who charge $5.5 million dollars for each unit. This leads to a total onetime cost of $55 million to acquire all the necessary distillation equipment. Though purchasing evaporation units avoids costs after the initial purchase, the evaporators would require $78,000 per week in grid electricity to treat all the SGEWW required.

To parallel the cost of a spill form a SGEWW-carrying barge, we investigated the cost a fracking company could expect if a spill were to occur at the well-head, either because of the evaporation units failing, or because of leaks in the large, in-ground holding tanks used to contain SGEWW awaiting distillation treatment. A cleanup effort following a spill of SGEWW from the fracking well would cost between $1 million and $2 million, depending on the method of remediation used. In cases where the release of salt is low, and close to the surface, the cost may remain as minimal as $200 per acre. If a large scale release occurs, though, more drastic and costly methods of cleanup will be required, and may cost up to from $2000 per acre for use of gypsum to $85,000 per half acre for the most extensive remediation procedure. In the event of an on land spill of SGEWW, we found a representative municipal lawsuit amount to be around $123,000 resulting from violation of state environmental laws.

4.6 Summary

Based on our research, we can see that there are a variety of cost factors to consider when deciding which method of SGEWW treatment to use, truck and barge transport to deep well injection well sites or distillation on-site. The information on different costs for this process came from a multitude of interviews, personal communications (including phone calls and emails), quotes, archival research, and case studies (see Table 11 below for exact calculations). A complete price comparison of the methods as well as many recommendations for the future of this research are discussed in the following chapter in order to both allow fracking companies to decide which method of treatment is more cost effective, and make this analysis of treatment methods more complete for future SGEWW disposal decisions.

Table 11: Total Costs to Fracking Industry: Barge Transport vs. Onsite Evaporation

Barge Transport	**Evaporation**
Carrier fee per barrel x 60,000 barrels: $300,000	Evaporators (10 needed): $55 million
Transport fee ($1.95/mile, $700/tanker) for 332 tankers : $383,244	Electricity: $77,985 per week
	Initial Cost: $55 million
Total cost per week: $683,244 per week	Weekly Outlay: $77,985 per week

Chapter 5: Conclusions and Recommendations

In this chapter we present conclusions based on our results and provide recommendations on ways in which the topic of SGEWW disposal can be further studied. We present the overall costs of barge transport and onsite treatment through distillation, and conclude which would be the more prudent option for fracking companies to pursue at this time. We also provide conclusions about estimated SGEWW remediation methods both in water and on land based on our proxy materials, and how costly these remediations proved to be. Finally, based on our cost analysis, we provide the USCG with recommendations of how to both further study, and perfect SGEWW disposal in the future.

5.1 Cost of Barge Transport Method vs. Distillation Treatment Method

Throughout this process, the USCG was mainly concerned with coming to a conclusion on whether or not their newly proposed policy for barge transport of SGEWW would create costs making barge transport prohibitively expensive. Through our research we have concluded that the cost that the policy requires of barge companies does not in any way prevent the barge companies from profiting off of SGEWW transport. We established that each week the barge companies would incur a cost associated with testing each holding tank of SGEWW prior to its shipment by barge. This cost would range between $6,400 and $14,400; however, Grandview Barge Lines anticipates charging fracking companies $5.00 for each of the 60,000 weekly barrels of SGEWW shipped. This means that even with this water testing cost, barge companies will make a normal weekly profit of between $293,600 and $285,600. The largest cost required by the policy is that of surveying the barges for radiation prior to USCG inspection, quoted at a price of $15,000 per survey, which comes into effect for all the barges once every five years. Therefore, on a week when all surveys are performed barge companies will still make a profit of between $195,000 and $203,600. Clearly, the SGEWW transport policy will not in any way prevent barge companies from making an extensive profit by contracting with fracking companies to ship SGEWW to final disposal in Ohio.

Using the results of our research into the costs of barge transport of SGEWW, the USCG has already made several informed additions to their SGEWW transport policy letter draft. The USCG had originally planned to require surveys of barge interiors for each individual shipment of SGEWW. Previously Dr. Cynthia Znati was unaware of the exact costs associated with surveying a barge holding area in accordance with the originally proposed mandate. When presented with our results of $15,000 per survey, Dr. Znati edited the policy so surveys are only required prior to a person entering the barges cargo hold.

Our group was able to make further conclusions comparing the two SGEWW disposal methods we researched: transport by barge and onsite distillation. The process of transporting the SGEWW by barge will cost fracking companies a total of approximately $683,000 weekly, including the $300,000 transport fee to the barge company and the $383,000 trucking cost to the trucking company. However, the onsite method of distillation has a huge upfront cost, $55 million in order to initially purchase ten mobile evaporation units to dispose of the weekly quota of 2.52 million gallons of SGEWW. The distillation method does have a relatively low weekly cost, about $80,000 per week for the grid electricity necessary to run the mobile evaporation units. The fracking process is a relatively short term one, though, as the wells are only expected to yield natural gas for another ten years (Scott Wilson, see Appendix C for Interview Notes). Therefore, though distillation costs less per week, it would be unreasonable for fracking companies to spend the $55 million up front to make distillation possible, and then $80,000 weekly on top of the startup cost. Overall due to the short life span of the fracking industry, we concluded that barge transport is currently the most reasonable SGEWW permanent disposal method.

5. 2 Recommendations for Additional Research: Cost of Barge Transport Method vs. Distillation Treatment Method

Our group recommends that a risk assessment of barge transportation be completed to determine whether barge transport is the safest means to ship SGEWW. This risk assessment could be completed by looking at how many barges are used, e.g. six per week, in comparison with the number of tanker trucks it would take to ship an equal volume of SGEWW to the final destination point. In this case, that volume is exactly 60,000 barrels or 2.52 million gallons per week which must be transported. This assessment could determine the frequency of accidents that occur with truck shipment versus the frequency of accidents that occur with barge shipment. Using this information, a determination could be made on whether or not shipping SGEWW by barge has a higher or lower risk factor compared to shipping SGEWW solely by truck.

We would also recommend that any future work focus on the cost of leasing the mobile evaporation units instead of buying them outright. Our conversation with Mr. Paterson indicated that leasing would be preferable to fracking companies, as they would be able to avoid the high initial cost of this method. By pursuing the option of leasing equipment, the total immediate cost of distillation to fracking companies that would otherwise purchase evaporation units would decrease. This option would give fracking companies a more financially feasible permanent treatment alternative that could greatly reduce the total expenditure necessary to distill the SGEWW. Finally, we recommend that an investigation be undertaken to evaluate a fracking company’s contingency plans should on-site treatment methods break down and stall treatment. Research could determine other options of treatment that may be suitable to replace the current process, should a problem arise.

5.3 SGEWW Spill Remediations: On Inland Waterways vs. On Land

Based on our research into SGEWW spill remediations, we have concluded that there are currently no case studies or explicitly identified costs directly associated with cleaning up a SGEWW spill. After investigating oil brine and petroleum remediation methods and cleanup costs, both on inland waterways and on land, we have estimated final costs to clean up both types of SGEWW spill. We concluded that these costs would depend very heavily on the size and concentration of the contaminants in the spill, as the main constituent of these costs are fines and lawsuits to the fracking companies by the states and community members affected. Therefore, fracking companies should be prepared to face a large total fee should a SGEWW spill occur via barge transport, or onsite at the wellhead. Based on the information that we researched, it is only possible to approximate the cost of a SGEWW spill using proxy materials. The estimated cost to clean an onsite or in water SGEWW contamination will fluctuate with the size of the spill, and consequently the overall hazard.

5.4 Recommendations for Further Study: SGEWW Spill Remediation

We strongly recommend that an environmental analysis analogous to our economic analysis be completed for SGEWW transport by barge. While our group determined the cost to clean up a SGEWW spill, we did not look into the environmental repercussions as this is outside the USCG's area of jurisdiction. The environmental hazards are important to note in order to determine if shipping SGEWW by barge is safe enough for all the ecosystems that face possible harm should a barge leak or spill the SGEWW it carries. Similarly, an environmental analysis should be completed for SGEWW disposal by distillation. The potential exists for the SGEWW to either leak out of the holding ponds where it is held or leak out of a damaged mobile evaporation unit. An analysis should be done to determine exactly how the SGEWW seeping into the groundwater would affect the surrounding wildlife. It is possible that stricter regulations will be forced upon these disposal methods by the state governments after the completion of these analyses in order to adequately protect the environment for the hazards of the SGEWW.

5.5 Summary

In this report we calculated final costs that barge and fracking companies would be required to pay in order to safely and legally ship SGEWW by barge from Pennsylvania to deep injection wells in Ohio. We also estimated minimum costs fracking companies would face should the SGEWW be released into the environment either on land or on inland waterways. Finally, we determined the total cost involved in purchasing and powering enough mobile evaporation units to dispose of 2.52 million gallons (equivalent to 60,000 barrels) of SGEWW per week. Based on these costs we have come to an ultimate conclusion that SGEWW transport by barge is currently the most fiscally responsible choice for fracking companies, as the initial cost of mobile evaporation units makes the distillation method unreasonable. Using our recommendations, we hope that the process of SGEWW disposal can eventually become even cheaper to fracking companies, as well as safer for the river and on land ecosystems involved.

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Appendix A: Sponsor Description: United States Coast Guard

The mission of the United States Coast Guard is one that has been changed and shaped by the dynamics of their ever changing call of duty. From acting as homeland security during wartime, to patrolling the coasts of our nation for boats and swimmers in danger, the USCG can always be counted on to help a vessel or swimmer at risk. As the fifth branch of the military, operating under the navy, the USCG has legal rights at sea in order to prevent nautical threats to the United States; whether that is through the trafficking of drugs, people, or weapons. It is the mission of the USCG to be prepared for anything, which led them to the mission statement "Always ready, for all hazards and all threats" (USCG, 2012c) Fundamentally, it is the mission of the USCG to protect and serve our nation by keeping it safe from maritime threats of any form, working with the Department of Homeland Security, and saving the public from any type of nautical peril. All active members of the USCG must be prepared for anything and everything, as it is often never know what will be expected of them on any given day.

The USCG is a government funded military organization within the United States Department of Homeland Security. The USCG is currently classified as an armed forces organization, though they are separate from military operation under the auspices of the Department of Defense, (DOD). That is, they serve a peripheral support duty in the DOD's Operation New Dawn and Operation Enduring Freedom (USCG, 2012c). In 2012, the USCG requested a budget of over $10 billion from the Department of Homeland Security (DHS, 2012a).

Apart from the USCG, the problem of radioactive wastewater from hydraulic fracking has piqued the interest of the Department of Energy (DOE). At this time it appears as though the DOE is interested in and is researching the Marcellus shale fracking sites. However, they are investigating the improper cementing of the wells, while the USCG is investigating how to properly dispose of or cleanse the radioactive wastewater produced by the wells. The USCG is not working with the DOE as partners at this time, but they are not competitors either. Both organizations are independent of one another; they simply happen to be both performing research about the Marcellus Shale fracking.

The USCG became a member of the DHS on March 1, 2003, transferring from the DOT. This move went into effect after President George W. Bush signed the Homeland Security Act on November 25, 2002, following September 11. The USCG is headed by its current Commandant, Admiral Robert J. Papp, Jr... The Commandant is responsible for the oversight of 42,000 active duty military personnel, 8,000 civilian, full-time employees, 8,000 part-time reserves, and 30,000 civilian, auxiliary volunteers. As seen in Figure 6, the Commandant is responsible for six major departments, with each of these departments having many departments that fall under and report to them.

Our project was completed under the Assistant Commandant for Prevention Policy (CG-5P) shown which is categorized under the Deputy Commandant for Operations (Figure 6). While working under CG-5P, the office which we corresponded with on the project was Hazardous Materials (CG-ENG-5) headed by Commander Roldan. An organizational chart of for CG-5P can be seen in Figure 7.

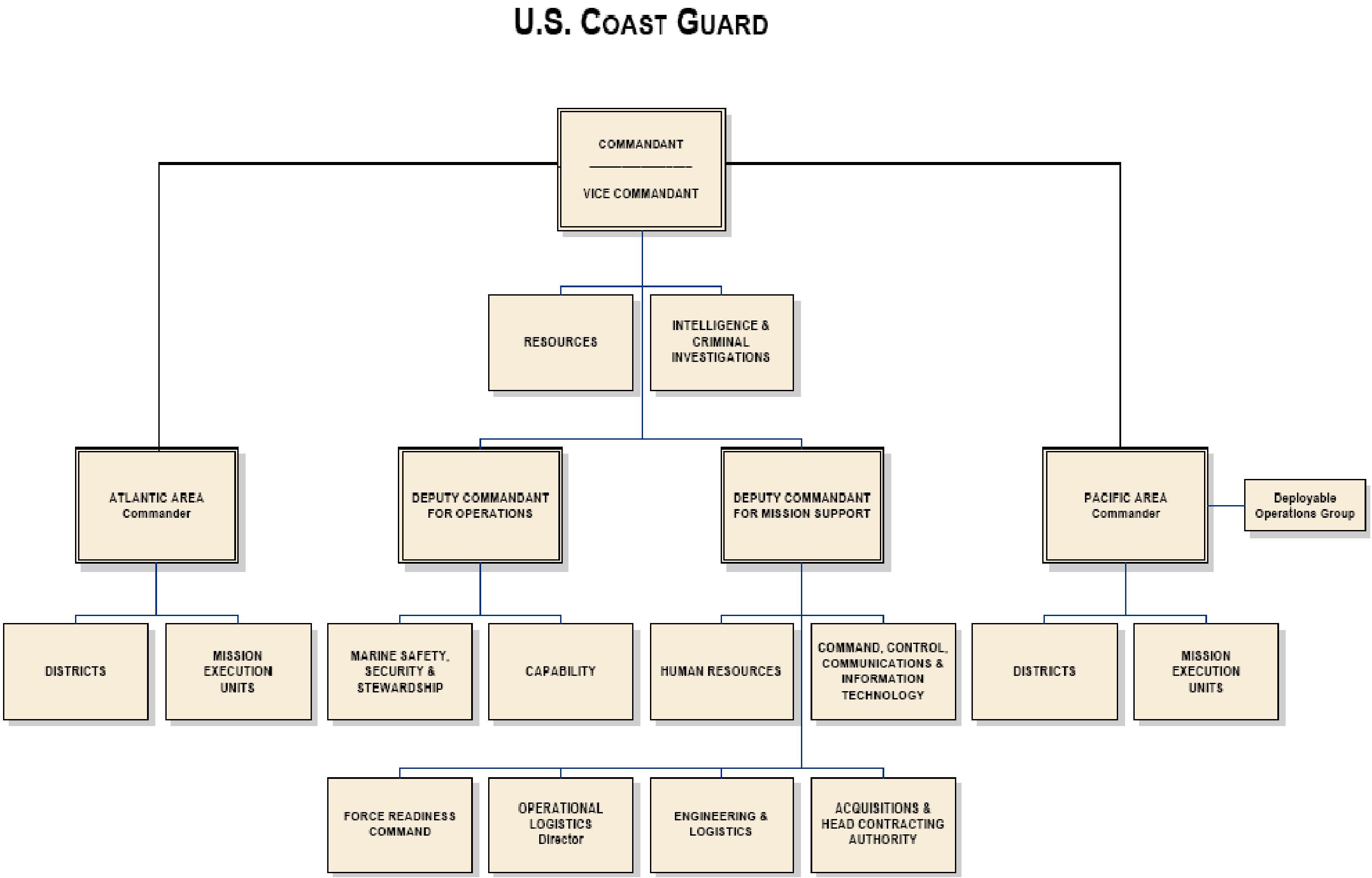

Figure 6: Organizational Chart of USCG High Command (DHS, 2010b)

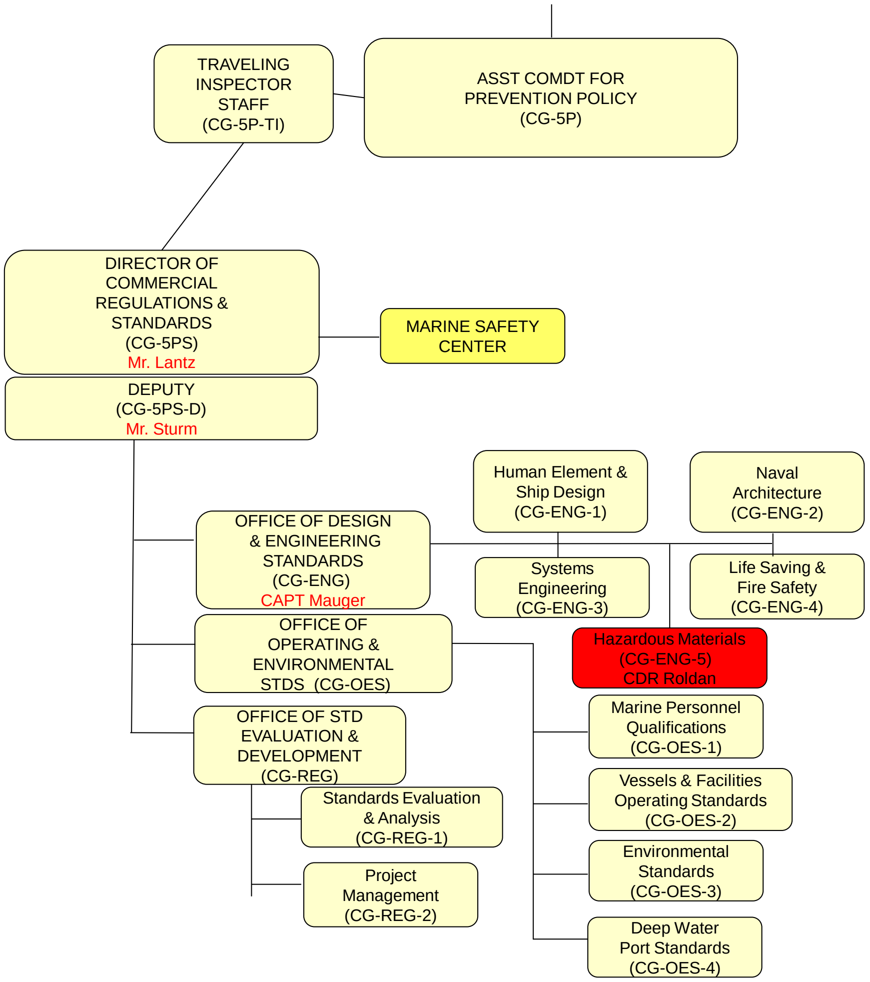

Figure 7: Organizational Chart of Assistant Commandant for Prevention Policy

Commandant of the Coast Guard
Admiral Robert J. Papp, Jr.

Vice Commandant
Vice Admiral John P. Currier

Deputy Commandant for Operations (DCO):
Vice Admiral Peter V. Neffenger

Assistant Commandant for Prevention Policy (CG-5P).
Rear Admiral Joseph A. Servidio

Appendix B: CARRIAGE OF CONDITIONALLY PERMITTED SHALE GAS EXTRACTION WASTE WATER IN BULK

16710

From: J. W. MAUGER, CAPT
COMDT (CG-ENG)

To: Distribution

Subj: CARRIAGE OF CONDITIONALLY PERMITTED SHALE GAS EXTRACTION WASTE WATER IN BULK

1. PURPOSE. The purpose of this policy letter is to clarify when shale gas extraction waste water (SGEWW) can be carried under 46 CFR 153.1(c) as Conditionally Permitted SGEWW.

2. LEGAL BASIS. The legal basis for this policy letter is supplied by Coast Guard regulations in 46 CFR part 153 (Ships Carrying Bulk Liquid, Liquefied Gas, or Compressed Gas Hazardous Material) which apply to tank vessels[1] to which 46 U.S.C. chapter 37 (Carriage of Liquid Bulk Dangerous Cargoes) applies. Those regulations are authorized by 46 U.S.C. 3306, which requires the Secretary to prescribe necessary regulations for the operation, etc., of vessels (including tank vessels) subject to 46 U.S.C. chapter 33 (Inspection Generally); and by 46 U.S.C. 3703, which requires the Secretary to prescribe regulations for the operation, etc., of tank vessels carrying liquid bulk dangerous cargoes and subject to the provisions of 46 U.S.C. chapter 37, if those regulations are "necessary for increased protection against hazards to life and property, for navigation and vessel safety, and for enhanced protection of the marine environment." The Secretary's authority under these statutes has been delegated to the Coast Guard, DHS Delegation No. 0170.1(92)(b).

3. ACTION. District and Sector Commanders shall use the guidance in this policy letter to ensure compliance with 46 CFR Part 153.

4. DIRECTIVES AFFECTED. This policy letter complements but does not otherwise affect Navigation and Vessel Inspection Circular (NVIC) 2-87 (Domestic Barge Transportation of Radioactive Materials/Nuclear Waste) and NVIC 7-87 (Guidance on Waterborne Transport of Oil Field Wastes), neither of which addresses waterborne transport of SGEWW.

5. DEFINITIONS.

a. Conditionally permitted SGEWW means the name of a cargo of SGEWW that meets the criteria specified in enclosure (1) to this policy.

b. Consignment activity limit means a limiting upper value of radioactivity per consignment load.

c. Radiation monitor means a person who is trained and has met standards (10 CFR 835.103) for measuring and monitoring radiation hazards for personnel or objects. Radiation monitors must be, at minimum, registered

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[1] Per 46 U.S.C. 2101(39) a tank vessel is a "vessel that is constructed or adapted to carry, or that carries, oil or hazardous material in bulk as cargo or cargo residue, and that—(A) is a vessel of the United States; (B) operates on the navigable waters of the United States; or (C) transfers oil or hazardous material in a port or place subject to the jurisdiction of the United States."

radiation protection technologists. If a team of radiation monitors is used, at least one must be a registered radiation protection technologist.

d. Specific activity limit means a limiting upper value of radioactivity per unit mass.

e. Total radioactive activity means the maximum amount of radioactivity due to a particular isotope allowed to be in a single barge for a specific shipment and is the quotient of the transport limit divided by the actual concentration of the isotope in the shipment.

f. Transport limit means the product of the specific activity limit and the consignment activity limit for each radioactive isotope present in a consignment load.

6. DISCLAIMER. This policy letter supplies guidance to the Coast Guard and the regulated public on how to determine if SGEWW meets the criteria to be Conditionally Permitted SGEWW. This policy letter is not a regulation and is not binding on the regulated public. SGEWW that falls within the criteria described in Enclosure (1) of this policy letter is considered Conditionally Permitted SGEWW. SGEWW may also be shipped if the shipper, through means other than those described in this policy, can show to the satisfaction of the Coast Guard Commandant (CG-ENG-5) that it meets an equivalent level of safety to the criteria contained in this policy letter.

7. BACKGROUND.

a. SGEWW, also known as "frack water," is a by-product of drilling for natural gas using unconventional hydraulic fracturing (or "fracking") technology, which involves the injection of water, sand, and chemical additives. The sand remains in the well but a substantial portion of the injected fluid re-surfaces after the drilling and must be handled as SGEWW. At present, this SGEWW is either stored at the drilling site or transported by rail or truck to remote storage or reprocessing centers. There is commercial interest in transporting SGEWW from northern Appalachia via inland waterways to storage or reprocessing centers and final disposal sites in Ohio, Texas, and Louisiana. Waterborne transportation in bulk via barge may provide an environmentally preferable alternative to on-site storage and a safer, more economical transportation alternative to rail or road transportation.

b. SGEWW may contain one or more hazardous materials as defined in 46 CFR 153. The specific chemical composition of SGEWW varies depending on the chemicals present in the initial drilling fluid, the specific site being drilled, and the age of the well. In addition, consignment loads of SGEWW can be mixtures of SGEWW from different wells. Furthermore and of particular interest for this policy letter, some SGEWW may include radioactive isotopes such as radium-226 and -228 (Ra-226, Ra-228). Because of the presence of radium Ra-226 and Ra-228, SGEWW is not currently approved for waterborne bulk liquid transportation under 46 CFR 153. This policy letter clarifies how SGEWW may be transported by tank barge as Conditionally Permitted SGEWW without the need for further specific approval by the U.S. Coast Guard Commandant (CG-ENG-5).

8. DISCUSSION. Enclosure (1) to this policy letter establishes minimum acceptable analysis, criteria and safety requirements to carry SGEWW. The analysis and criteria provided are intended to enable shippers to determine if, for purposes of radioactivity hazard, their consignment of SGEWW can be transported by tank barge as Conditionally Permitted SGEWW. If so, this policy letter serves in lieu of the letter referenced in 46 CFR 153.900(d). Similar to such letters, enclosure (1) also includes safety requirements related to carriage of Conditionally Permitted SGEWW. Alternative analysis, criteria and safety options equivalent or superior to those in enclosure (1) may be approved on a case by case basis by the U.S. Coast Guard Commandant (CG-ENG-5) per 46 CFR 153.900(d). The reporting requirements contained in paragraphs 1 and 3 of enclosure (1) are intended to enable the U.S. Coast Guard to monitor the contents of SGEWW and to ensure that each consignment meets the criteria to be transported as Conditionally Permitted SGEWW.

9. ENVIRONMENTAL ANALYSIS. The development of this policy letter and the general policies contained within it have been thoroughly reviewed by the originating office in conjunction with the Office of Environmental Management, and are categorically excluded (CE) under current USCG CE # 33 from further environmental analysis, in accordance with Section 2.B.2. and Figure 2-1 of the National Environmental Policy Act

Implementing Procedures and Policy for Considering Environmental Impacts, COMDTINST M16475.1 (series). This policy letter will not have any of the following: significant cumulative impacts on the human environment; substantial controversy or substantial change to existing environmental conditions; or inconsistencies with any Federal, State, or local laws or administrative determinations relating to the environment. All future specific actions resulting from the general policies in this letter must be individually evaluated for compliance with the National Environmental Policy Act (NEPA), Department of Homeland Security (DHS) and Coast Guard NEPA policy, and compliance with all other environmental mandates.

10. UNIT RESOURCES. Units with ports along inland river waterways that may experience barge traffic carrying SGEWW should designate appropriate staff and procure necessary to effectively implement this policy. Coast Guard personnel, including boarding team members and marine inspectors, expected to board vessels subject to this policy letter will need to be enrolled in an active respiratory protective program.

11. QUESTIONS. Questions or concerns regarding this policy may be directed to Commandant (CG-ENG-5) at (202) 372-1412 or emailed to HazmatStandards@uscg.mil.

Enclosures: (1) Analysis, Criteria and Safety Requirements to Transport Conditionally Permitted SGEWW.
(2) PA Form 26R
(3) Sample Calculations for Maximum Allowed Volume
(4) Interim Minimum Requirements for the Carriage of Unmanned Barges

Enclosure (1) to CG-521 Policy Letter 12-XX
Minimum Acceptable Analysis, Criteria and Safety Requirements to Carry SGEWW

1. ANALYSIS FOR HAZARDOUS MATERIALS INCLUDING RADIOISOTOPES. Before transporting SGEWW by barge, a shipper conducts an analysis described in this paragraph. The analysis must be conducted at a state-accredited laboratory.[2] The analysis must include either the analysis procedure outlined in Pennsylvania Department of Environmental Protection Form 26R (PA Form 26R) (enclosure (2)) or another procedure that provides as much or more detailed information about the SGEWW composition. The analysis identifies all chemical components listed on PA Form 26R as well as any other components in the SGEWW, specifically including any chemical components that were injected into the well and/or produced by reactions or decompositions of those injected components.[3] The submitted analysis includes the laboratory name, the date and location the samples were taken, and the date the samples were analyzed. If the analysis indicates the presence of any "hazardous material" as defined in 46 CFR part 153, the shipper must comply with all applicable regulations under that part. If the SGEWW contains hazardous material, other than Ra-226 and Ra-288 that is not listed in 46 CFR 153, it may not be transported in bulk without the prior specific approval of the Commandant pursuant to 46 CFR 153. In all cases, the Coast Guard requests the shipper to submit via email all analysis results to the Coast Guard Commandant (CG-ENG-5) at HazmatStandards@uscg.mil.

2. CRITERIA TO DETERMINE IF SGEWW CAN BE CARRIED AS CONDITIONALLY PERMITTED SGEWW.

a. As an initial condition to determine if SGEWW can be carried as Conditionally Permitted SGEWW the specific activity limit and the consignment activity limit for each radioactive isotope present in the SGEWW may

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[2] Labs accredited by any state are acceptable. For a list of labs accredited by the State of Pennsylvania, see http://extension.psu.edu/naturalgas/publications/DEP%20labs.pdf/view .

[3] Gross alpha and gross beta may be substituted for Ra-226 and Ra-228, respectively. Gross alpha is a measurement of the total alpha particles present in the sample. It is a sum of all alpha-emitting isotopes. Likewise, gross beta is a measurement of the total beta particles present in the sample and is the sum of all beta-emitting isotopes.

both not be above the values established below. Furthermore, consignment barge loads of Conditionally Permitted SGEWW may not exceed transport limits established below. The specific activity limit, consignment activity limit, and transport limit should be determined for each isotope present in the SGEWW. Values for Ra-226 and Ra-228 are given below. The specific activity limit and consignment activity limit for other isotopes are found in 49 CFR 173.436 (called “activity concentration for exempt material” and “activity limit for exempt consignment”, respectively), and the transport limit is calculated from these values.

(1) The specific activity limit for Ra-226 and Ra-228 is 2.7×10^{-10} Ci/g . This is equal to 270 pCi/g which is 2.7×10^{5} pCi/l if we assume a density 1 g/ml. Shippers should use actual SGEWW densities for their calculations.

(2) The consignment activity limit is 2.7×10^{-7} Ci for Ra-226 and 2.7×10^{-6} Ci for Ra-228. These limits are equal to 2.7×10^{5} pCi and 2.7×10^{6} pCi respectively.

(3) A transport limit is the product of a specific activity limit and a consignment activity limit for each isotope present. For Ra-226, the transport limit is 7.29×10^{7} pCi^2/g; for Ra-228, it is 7.29×10^{8} pCi^2/g. Maximum consignment loads of SGEWW allowed for barge transport may not exceed transport limits for any radioactive isotope.

b. With the above limit values and analytical results obtained per paragraph 1 of this enclosure, the shipper should calculate the total radioactive activity for each isotope present in the SGEWW. The total radioactive activity allowed to be transported for each isotope is the isotope’s given transport limit divided by the analytically determined concentration of that isotope in the SGEWW. The permissible volume of SGEWW for shipping based on a given isotope is the total radioactive activity for that isotope divided by the concentration of that isotope in the SGEWW. This volume calculation should be repeated for each isotope. The final maximum consignment volume is the smallest of the permissible volumes calculated for each isotope. See enclosure (3) for sample calculations.

c. Shippers can use enclosure (4) as interim minimum carriage requirements for exempted SGEWW assuming the exempted SGEWW is not subject to other non-radioactive carriage hazards.

3. <u>SAFETY CONDITIONS AND PROCEDURES TO PROTECT PERSONNEL</u>.

a. The Coast Guard’s concern with respect to radioisotopes is to ensure through continuous monitoring that radiation exposure duration and levels are both kept as low as reasonably achievable, within the meaning of Nuclear Regulatory Commission regulations, 10 CFR 20.1101(b). The procedure described in this paragraph is specifically intended to mitigate the danger of cumulative radiation that may be present in SGEWW.

b. Prior to any personnel entering a barge tank used to transport SGEWW, the shipper must verify that the barge is safe to enter and that its radioactivity level does not exceed contamination limits established in PHMSA’s regulations (49 CFR 176.715 and 49 CFR 173.443) for fixed and non-fixed radioactive contamination. The shipper accomplishes this verification by having a radiation monitor survey the barge interior to assess the radioactivity present. The radiation monitor uses properly calibrated instruments that are routinely tested for operability. The shipper must then submit the survey data via email to the Coast Guard Commandant (CG-ENG-5) at: HazmatStandards@uscg.mil. If the radioactivity level exceeds contamination limits, the shipper must ensure that the barge is cleaned. Cleaning includes removing any precipitated solids to reduce the radioactivity level. After cleaning, the shipper will have the radiation monitor conduct a new survey to confirm reduction of radioactivity to within permissible contamination limits established in PHMSA’s regulations. The shipper must ensure that water used during and collected from cleaning the barge, including solids, is treated and disposed of in the same manner as SGEWW. The shipper must retain survey records for at least 2 years and make them available for Coast Guard inspection on request. Prior to any personnel entering a barge tank used to transport SGEWW, all personnel must wear appropriate radiation badges as determined by a radiation monitor, to facilitate radiation exposure monitoring.

Coast Guard personnel should contact CG-1133 for radiation badge information.

c. If a barge has carried SGEWW, the barge must be surveyed as in paragraph b of this enclosure and must meet the contamination limits established in PHMSA's regulations (49 CFR 176.715 and 49 CFR 173.443) before a different cargo can be carried.

d. Barge tanks must have open venting to prevent accumulation of radon, a daughter radionuclide of both Ra-226 and Ra-228, in the tank head space. Care must be taken by all personnel to avoid areas where gas from the tanks may escape, especially during loading and offloading.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF WASTE MANAGEMENT

FORM 26R
CHEMICAL ANALYSIS OF RESIDUAL WASTE ANNUAL REPORT BY THE GENERATOR
INSTRUCTIONS

GENERAL INFORMATION

General Instructions. This package is designed to assist an *existing client with DEP* in completing the annual report form. This form must be fully and accurately completed. All required information must be typed or legibly printed in the spaces provided. Attach additional sheets as necessary.

General References: 287.54

Date Prepared/Revised. Provide the date the application was prepared and/or revised. When additional sheets are attached to include additional information, identify each attached sheet as Form 26R, reference the item number and identify the date prepared/revised. The “Date Prepared/Revised” on any attached sheets needs to match the “Date Prepared/Revised” on the completed annual report form. Please type or print clearly when completing the form.

SECTION A. CLIENT (GENERATOR OF THE WASTE) INFORMATION

Company Name. Identify the company name. Include the company’s mailing address, phone number and email address.

Subsidiary/Parent Company. If the company identified is a subsidiary, identify the name of the parent company and the EPA Generator ID number.

Company Contact. Identify the company’s contact and include the contact’s phone number and email address.

Waste Generation Location. If the waste generated is not at the company’s mailing address, describe the location of the waste generation; and provide the township, county, and state.

SECTION B. WASTE DESCRIPTION

Residual Waste. Enter the code that represents the type of residual waste. The list of Residual Waste Codes (RWC) can be found on the ‘Codes Residual Waste’ document included with this package. Also include the code’s description, the amount of waste; the unit of measurement, and the timeframe for disposal/processing. If the timeframe is ‘one time’ check the box; if other than ‘one time’ provide the appropriate timeframe.

1. GENERAL PROPERTIES

a. pH Range. Indicate the pH range based on analyses or knowledge.

b. Physical State. Check appropriate box to indicate physical state.

c. **Physical Appearance.** Describe the color and odor of the waste. Enter the number of solid and/or liquid phases of separation and describe each phase. For example, two phases: one yellow oily liquid and one gray granular solid.

2. CHEMICAL ANALYSIS ATTACHMENTS

Check the appropriate box to indicate if required information is attached to the completed annual report form.

The analytical methodologies used shall be those set forth in the most recent edition of the EPA's Test Methods for Evaluating Solid Waste (SW-846), Methods for Chemical Analysis of Water and Wastes (EPA 600/4-79-020), Standard Methods for the Examination of Water and Wastewater (prepared jointly by the American Public Health Association, American Water Works Association, and Water Environment Federation), or a comparable method subsequently approved by EPA or the Department.

The person taking the samples and the laboratory performing the analysis shall employ the quality assurance/quality control procedures described in the EPA's Test Methods for Evaluating Solid Waste (SW-846) or Handbook for Analytical Quality Control in Water and Wastewater Laboratories (EPA 600/4-79-019).

All analyses submitted must specify the method used and any special preparation, deviation from the method, or pertinent observations. Each analysis sheet must include: *date of sampling, date of analysis, name of laboratory performing test, laboratory accreditation number, laboratory contact person and phone number*. Analytical determinations should be run on the samples, as is, unless otherwise specified in the cited method. Report the analyses in mg/kg on a dry weight basis for solids or in mg/L for liquids, or as otherwise specified in cited method.

No single analytical method is applicable for all waste streams and some modifications may be necessary for unusual waste types. Any modifications, however, must be approved by the Department.

If the sample is of unknown origin or characteristics, contact the appropriate Department regional office prior to analysis.

Chemical analysis of the waste must include the following unless the generator certifies, in writing, either the concentration of the parameter or the absence of the parameter based on his/her knowledge of the manufacturing or pollution control process:

a. **Gross Analysis.** The total concentration of any constituent present at 1% or greater.

b. **Trace Analysis.** The total concentration of any constituent listed in Appendix VIII (40 CFR 261.34(e), as incorporated by reference at 25 Pa. Code 261a.1) which, based upon generator knowledge of the waste and the process generating the waste, are likely to be found in the waste at concentrations exceeding 50 ppm.

c. **Hazardous Waste Determination.** As required under 40 CFR262.11, and as incorporated by reference at 25 Pa. Code 262a.1.

1) pH
2) Ignitability
3) Reactive Sulfide
4) Reactive Cyanide
5) Toxicity Characteristic Leaching Procedure (TCLP) - include all parameters found in 40 CFR 261.24, as incorporated by reference at 25 Pa. Code 261a.1, as well as pH of extract. Report all results in mg/L or as otherwise specified in method.

d. **Wastewater Produced from the Drilling, Completion and Production of a Marcellus Shale or Other Shale Gas Well.** In lieu of the Trace Analysis described in subsection b., the chemical analysis of wastewater produced from the drilling, completion and production of a Marcellus Shale or other shale gas well must include the following:

Acidity
Alkalinity (Total as CaCO3)
Aluminum
Ammonia Nitrogen
Arsenic
Barium
Benzene
Beryllium
Biochemical Oxygen Demand
Boron
Bromide
Cadmium
Calcium
Chemical Oxygen Demand
Chlorides
Chromium
Cobalt
Copper
Ethylene Glycol
Gross Alpha
Gross Beta
Hardness (Total as CaCO3)
Iron – Dissolved
Iron – Total
Lead
Lithium
Magnesium
Manganese
MBAS (Surfactants)
Mercury
Molybdenum
Nickel
Nitrite-Nitrate Nitrogen
Oil & Grease
pH
Phenolics (Total)
Radium 226
Radium 228
Selenium
Silver
Sodium
Specific Conductance
Strontium
Sulfates
Thorium
Toluene
Total Dissolved Solids
Total Kjeldahl Nitrogen
Total Suspended Solids
Uranium
Zinc

Additional constituents that are expected or known to be present in the wastewater.

*Note - All metals reported as total.

For impoundments and tanks, the chemical analysis must represent the volume of wastewater stored in the impoundment or tank. A representative analysis is based upon the frequency, location and number of samples. Samples of an impoundment should be taken from various locations and wastewater depths as identified on a grid. Grab samples should be used for pH volatile organic compounds, phenolics, and oil and grease. Composite samples should be used for other analytes. If multiple loads of wastewater are removed from the same impoundment or tanks for transfer, processing, treatment or disposal, the same chemical analysis of the wastewater may be used repeatedly without further analysis, provided the analysis remains representative of the impoundment. If large volumes of water, wastewater or other fluids are added to the impoundment, a new chemical analysis must be performed that is representative of the impoundment.

e. Additional Analyses. Any additional parameters as required.

1) On Form U (if waste is managed at a Pennsylvania facility)
2) By conditions in a permit or approval, for management of the waste.
3) By the facility(ies) managing the waste.

3. PROCESS DESCRIPTION & SCHEMATIC ATTACHMENTS

a. Manufacturing and/or Pollution Control Processes. Check the appropriate box to indicate if a detailed description of the manufacturing and/or pollution control processes producing the waste is attached.

Describe the manufacturing process that produced the waste and any pollution control methods involved. This must include the raw materials used in the process, any intermediate products formed, final products, and any substances added during treatment. For non-hazardous waste, provide sufficient detail to demonstrate the waste is not a listed hazardous waste. For example:

"Resol Resin Manufacture"

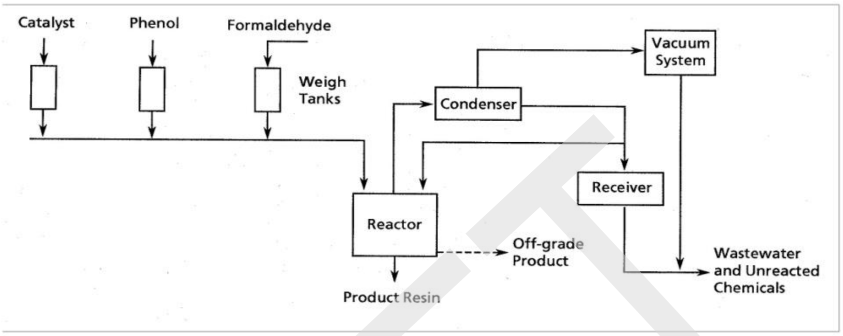
"These resins are formed by reacting phenol, or a substituted phenol with formaldehyde which contains an excess of formaldehyde. An alkali (sodium hydroxide) is used to catalyze the polymerization which takes place at a pH of between 8 and 11 and at a temperature of 60°C."

"When the desired degree of polymerization has occurred, the kettle is cooled to about 35°C to inhibit further reaction. The caustic may be neutralized in the kettle with sulfuric acid at this time. The water from this distillation forms a concentrated waste of unreacted materials and low molecular weight resin."

"The batch is dumped, and depending on the specific resin, the batch may be washed several times and a vacuum may be used during the dehydration cycle. It is important that molten resin be handled quickly to avoid its setting up to an insoluble, infusible mass which would become a waste."

b. Schematic of Manufacturing and/or Pollution Control Processes. Check the appropriate box to indicate if a schematic of the manufacturing and/or pollution control processes producing the waste is attached.

Provide, on 8½ x 11" size paper, flow schematics of the manufacturing and/or pollution control processes generating the waste stream starting with the raw materials and ending with the final products. (See example on next page.)



c. Confidentiality Claim. Check the appropriate box to indicate if the substantiation for a confidentiality claim (if portions of the information submitted are confidential) is attached.

Information submitted to the Department in this portion of the form may be claimed as confidential by the applicant. If no claim is made at the time of submission, the Department shall make the information available to the public without further notice.

Claim of confidentiality shall address the following:

- The portions of the information claimed to be confidential.
- The length of time the information is to remain confidential.
- The measures taken to guard undesired disclosure of the information to others.
- The extent to which the information has been disclosed to others and the precautions taken in connection with that disclosure.
- A copy of pertinent confidentiality determinations by EPA or any other federal agency.
- The nature of the substantial harm to the competitive position by disclosure of the information, the reasons it should be viewed as substantial, and the relationship between the disclosure and the harm.

SECTION C. MANAGEMENT OF RESIDUAL WASTE

1. PROCESSING OR DISPOSAL FACILITY(IES)

On the annual report form, Items a through d are repeated twice (to accommodate identification of two facilities). Attach additional sheets if necessary to identify all facilities being utilized.

For each facility identified, include the facility name and address; the municipality and county in which the facility is located; the facility's contact person (name, title, phone, and email address); and the volume of waste shipped to the processing or disposal facility in the previous year.

2. BENEFICIAL USE

Indicate whether the waste has been approved for beneficial use; and include the general permit number or approval number. Also identify the volume of waste beneficially used in the previous year.

SECTION D. CERTIFICATION

In accordance with 25 Pa. Code 287.54(f), information required in "Waste Description", if previously submitted to the Department, may be omitted from the annual report form, provided the generator certifies that this information has not changed from that set forth for the previous year. The generator is to check the appropriate box(es) in this area of the annual report form, identify the form(s) and date(s) of submission on which the information is found, and sign the certification statement.

If none of the "Waste Description" information is omitted, do not check any of the boxes; but do sign the certification statement.

The completed annual report form shall be signed by a responsible official for the facility that generated the waste.

Department of Environmental Protection

Southeast Regional Office
2 East Main Street
Norristown, PA 19401-4915
Phone (484) 250-5960

Northeast Regional Office
2 Public Square
Wilkes-Barre, PA 18711
Phone (570) 826-2516

Southcentral Regional Office
909 Elmerton Avenue
Harrisburg, PA 17110
Phone (717) 705-4706

Southwest Regional Office
400 Waterfront Drive
Pittsburgh, PA 15222
Phone (412) 442-4000

Northcentral Regional Office
208 W. 3rd St., Suite 101
Williamsport, PA 17701
Phone (570) 327-3653

Northwest Regional Office
230 Chestnut Street
Meadville, PA 16335
Phone (814) 332-6848

Enclosure (3) to CG-521 Policy Letter 12-XX
Sample Calculations for Maximum Allowed Volume

Example 1: Low Radium-226 Concentration

Ra-226 concentration = 150 pCi/l
Density = 1.4 g/ml = 1400 g/l

Ra-226 specific activity limit: 270 pCi/g * 1400 g/l = 3.78x10^5 pCi/l
Ra-226 consignment activity limit: 2.7x10^{-7} Ci = 2.7x10^5 pCi

Water does not exceed specific activity limit (150 pCi/l < 3.78x10^5 pCi/l)

Ra-226 transport limit = 270 pCi/g * 2.7x10^5 pCi = 7.29x10^7 pCi^2/g
Converting from gram basis to liter basis: 7.29x10^7 pCi^2/g * 1400 g/l = 1.02x10^{11} pCi^2/l

Total radioactive activity = transport limit /actual concentration
= $(1.02x10^{11}\ pCi^2/l)/(150\ pCi/l)$ = 6.8x10^8 pCi
So barge cannot exceed 6.8x10^8 pCi
Maximum volume allowed = 6.8x10^8 pCi/concentration
=(6.8x10^8 pCi)/(150 pCi/l) =4.536x10^6 l = 28,571 bbl
Since the barge can only hold 10,000 bbl, the entire barge may be shipped with water at 150 pCi/l.

Example 2: High Radium-226 Concentration

Ra-226 concentration = 550 pCi/l
Density = 1.5 g/ml = 1500 g/l

Ra-226 specific activity limit: 270 pCi/g * 1500 g/l = 4.05x10^5 pCi/l
Ra-226 consignment activity limit: 2.7x10^{-7} Ci = 2.7x10^5 pCi

Water does not exceed specific activity limit (550 pCi/l < 4.05x10^5 pCi/l)

Ra-226 transport limit = 270 pCi/g * 2.7x10^5 pCi = 7.29x10^7 pCi^2/g
Converting from gram basis to liter basis: 7.29x10^7 pCi^2/g * 1500 g/l = 1.09x10^{11} pCi^2/l

Total radioactive activity = transport limit/actual concentration
= $(1.09x10^{11}\ pCi^2/l)/(550\ pCi/l)$ = 1.99x10^8 pCi
So barge cannot exceed 1.99x10^8 pCi
Maximum volume allowed = 1.99x10^8 pCi/concentration
=(1.99x10^8 pCi)/(550 pCi/l) =361,000 l = 2277 bbl
The maximum volume of water at 550 pCi/l that can be shipped in one barge is 2277 bbl.

Example 3: Multiple Isotopes

Ra-226 concentration = 275 pCi/l
Ra-228 concentration = 400 pCi/l
Density = 1.4 g/ml = 1400 g/l

Ra-226 specific activity limit: 270 pCi/g * 1400 g/l = 3.78x10^5 pCi/l
Ra-226 consignment activity limit: 2.7x10^{-7} Ci = 2.7x10^5 pCi

Ra-228 specific activity limit: 270 pCi/g * 1400 g/l = 3.78x10^5 pCi/l
Ra-228 consignment activity limit: 2.7x10^{-6} Ci = 2.7x10^6 pCi

Water does not exceed Ra-226 specific activity limit (275 pCi/l < 3.78x10^5 pCi/l)
Water does not exceed Ra-228 specific activity limit (400 pCi/l < 3.78x10^5 pCi/l)

Ra-226 transport limit = 270 pCi/g * 2.7x10^5 pCi = 7.29x10^7 pCi^2/g
Converting from gram basis to liter basis: 7.29x10^7 pCi^2/g * 1400 g/l = 1.02x10^{11} pCi^2/l

Ra-228 transport limit = 270 pCi/g * 2.7x10^6 pCi = 7.29x10^8 pCi^2/g
Converting from gram basis to liter basis: 7.29x10^8 pCi^2/g * 1400 g/l = 1.02x10^{12} pCi^2/l

Ra-226
Total radioactive activity = transport limit/actual concentration
$= (1.02x10^{11}\ pCi^2/l)/(275\ pCi/l)$ = 3.71x10^8 pCi
So barge cannot exceed 3.71x10^8 pCi due to Ra-226
Maximum volume allowed = 3.71x10^8 pCi/concentration
=(3.71x10^8 pCi)/(275 pCi/l) =1.35x10^6 l = 8501 bbl

Ra-228
Total radioactive activity = transport limit/actual concentration
$= (1.02x10^{12}\ pCi^2/l)/(400\ pCi/l)$ = 2.55x10^9 pCi
So barge cannot exceed 2.55x10^9 pCi due to Ra-228
Maximum volume allowed = 2.55x10^9 pCi/concentration
=(2.55x10^9 pCi)/(400 pCi/l) =6.38x10^6 l = 40,179 bbl

The lowest volume calculated is 8501 bbl for the Ra-226 limit, so the barge may ship up to 8501 bbl of water contain Ra-226 at 275 pCi/l and Ra-228 at 400 pCi/l.

Enclosure (4) to CG-521 Policy Letter 12-XX
Interim Minimum Requirements Proposed for the Carriage on Unmanned Barges, 46 CFR 151

This commodity has been assigned to Group 43 (Miscellaneous Water Solutions) as listed in 46 CFR Part 150.

Minimum Requirements Proposed for the Carriage on Unmanned Barges, 46 CFR 151

Cargo Name	Shale Gas Extraction Waste Water
Press	Atmosphere
Temp	Ambient
Hull Type	III
Cargo Segregation Tank	1 i 2 i
Tanks	
Tank Type	Integral Gravity
Tank Vent	Open
Gauging Device	Open
Cargo Transfer	
Piping Class	II
Control	G-1
Environmental Control	
Cargo Tanks	Ventilated (natural)
Cargo Handling Space	Vent N
Fire Protection	No
Special Requirements	N/A
Electrical Hazard Class and Group	I-C
Temp Control Install	NA
Tank Internal Inspection Period	G*

*Note: See 46 CFR 151.04-5(b)(4). If experience demonstrates that less frequent inspections are warranted the Commandant will increase the time between inspections.

Properties Data Sheet

Date of Classification: March 19, 2012

Cargo Name: Shale Gas Extraction Waste Water

Compatibility Group: 43 (Miscellaneous Water Solutions)

Flash Point: N/A

Boiling Point: 100°C, approximately that of water

Freezing Point: 0°C, approximately that of water

Specific Gravity: ~1.25@20°C

Solubility: N/A

Flammability Grade: N/A

CHRIS Code: DRS

Appendix C: Interview Protocol and Interview Notes for Scott Wilson (EPA)

Background
Date: 11/14/12
Name: Scott Wilson
Job Title: EPA Environmentalist
General Questions:
Can you recommend a radioactive waste that would be relevant to research involving SGEWW?
Are the proxy materials we have relevant to the SGEWW material?
If not, what materials can we look at that are better?
What is the cost to clean and contain a spill of petroleum/oil brine in water?
What methods are used to clean and contain a spill in water?
Are these methods specific to the waste that is spilled?
If so, what are the specific cleanup methods for petroleum and oil brine?
What costs might lawsuits bring about as a result of a petroleum or oil brine spill in water?
Are there any relevant case studies that you can recommend us to look at concerning our proxy materials?
Is there a possibility that the sludge would stratify when released into a river due to its hyper salinity?
What methods are currently used to treat SGEWW?
How cost efficient is the methods?
How many holding ponds would be needed to store SGEWW at an on-site facility?
What would be the cost to dig these holding ponds?
What are the dimensions of these ponds?
How much would it cost to line ponds?
Would it require a special permit?
Are the ponds double lined?
What regulations must be followed when lining the ponds? (Clean Water Act)
If an evaporating method were to be used, what would be done with the leftover sludge?
What are the costs to store it in landfills?
Would more landfills need to be created in the future?
Roughly when will wells stop being drilled?
(When will the wells run dry)?
What is done to recycle it the water currently?
What is the cost to recycle the water?
Are fracking companies thinking of using evaporators onsite, or moving the water to evaporation facilities?
Are fracking companies planning on renting the evaporators, or buying them outright?
How much energy is required to run the evaporators?
Does this energy come from natural gas extracted onsite, or another energy source?

How much does it cost to run the evaporators?
(How much does the energy use cost?)
How long would the evaporators have to run in order to fully evaporate the water and leave only sludge**?**
Are you familiar with the shale fracking process and the waste it produces?
How can radioactive water be contained safely?
If water with these contaminants is spilled into the ecosystems of the Allegheny or Ohio River, what effects would it have?
What costs are associated with clean up in a riparian environment?
What costs are specifically related to clean up of radioactive material? Of saline water?
Can you quantify these costs/who can quantify these costs?
Can you recommend others we should contact who may have different knowledge than you?

Notes from Interview with Scott Wilson

What is in the SGEWW?

- We will have to go to public data, though metals are known to be present in the water, though the amount of metals will depend on the exact rock formation.
- Pennsylvania may be a good source for information on water pollutants, but data may not be available yet
- SGEWW has up to 450,000 ppm total dissolved solids, normal water has 200,000 ppm.
- Radionuclides, SGEWW has higher levels than normal, the highest levels are from black shale, like the Marcellus shale.

Suggestions of proxy materials

- Texas and Oklahoma have big oil and programs to handle spills.
- Superfund sites (Craig Matthiessen) will know more about specifics of spills
- National Spill Response Center also catalogs spills and cleanup incidents.
- Oil extract water may be a good proxy
- Deposits and pipe scale, so we might want to look into decontamination

Possibility of stratification

- SGEWW could stratify; water at different density will not mix, but actual amount of stratification will depend on turbulence of water.
- A release could harm wildlife and plant life at the bottom of a waterway.

Methods of disposal for SGEWW

- Distillation is probably the best option, while reverse osmosis may be useful in some cases (less than 50,000 ppm TDS) but not for highly concentrated SGEWW
- A contact at General Petroleum has informed Mr. Wilson that 20-25% of water can be reused from an old well into a new one. A larger amount of water is being reused, as companies have begun to understand that this can reduce their costs for clean water. However, as gas prices go down, the production of new wells is decreasing, (as more companies are drilling for oil instead) and there are concequently less opportunities for reuse of water. It is estimated that in about 5-10 years fracking for natural gas will end as

the wells will dry up, and then the only option for treatment of this water will be final disposal.

- Most cost effective in the east currently is re-use of fracking waste in other wells
- Most cost effective in the west currently is the distillation/evaporation process

Holding Ponds

- Migratory birds land on holding ponds full of sludge and die
- The holding ponds are not always well designed, but they are typically any size that the fracking company desires. There are no set size regulations. Therefore, it is believed that the ponds are dug per pad of well, rather than per well.
- The holding ponds are regulated on the state level; they are not regulated by the EPA unless they are on federal land.
- The resulting sludge from the holding ponds post evaporation is land-filled. The sludge is not considered a hazardous waste so it avoids being regulated through RCRA.
- The capacity of the ponds that are dug is good for now. There is no immediate need for more to be created.

Evaporation as an Option

- The costs of evaporators are lower than previously, but he had no concrete information
- Basically, the water must be boiled and separated from the sludge but the time and cost would depend on the equipment chosen

Treatment through Transport

- He had not previously heard of anyone using transport as an option
- Knows of high capacity injection wells in Louisiana and Texas that are designed to have deep water barges deposit waste directly into
    - Mostly used for produced water from oil flowback

Appendix D: Interview Protocol and Interview Notes for James Guttman

Background
Date: 11/16/12
Name: James Guttman
Job Title: Owner of Grandview Barge Lines
General Questions:
How many tanks would be needed to store the SGEWW?
What kinds of tanks are needed?
Would a special permit be needed?
Will you coat interior of barge with anti-corrosion paint?
If so what would that cost?
How often would the barge need to be repainted?
Would you outfit your crews with radioactive protective equipment?
If so, what is a rough cost to do this?
How much does transporting the SGEWW from the designated mile markers cost?
How many barrels of water can be shipped on one barge?
How often will barges transport the water?
What special training (if any) do operators undergo before transporting hazardous materials?
What about radioactive material? Are there licenses for HAZMATs such as fracking wastewater?
What general safety gear do the barges carry? What safety gear specific to radiation do certified barges carry?
What experience does your company have in transporting hazardous waste? What about Wastewater? Radioactive material? Hyper saline material?
What safety systems do the barges employ? What safety systems specific to radiation do the applicable barges employ?
Are there any other employees who have experience working with radioactive materials?

Interview Notes for James Guttman

What kind of pre-shipment tanks would be needed before the SGEWW is put onto the barge?

- It depends on the facility. Guttman has two facilities; one with a 1 million gallon, and two 600,000 gallon holding tanks. The second terminal has a 400,000 gallon, a 324,000gallon and a 250,000 gallon tank, all of which are along the Monongahela River.
- These are steel cylinders, “above ground storage tanks” and are currently being used to store petroleum.
- The outside of the tanks are coated with anticorrosion cathodic coating. Grandview is planning on coating the inside with a similar coating to what is used on the outside on the petroleum tanks; manufactured by Caboline, or Madison (which makes Coracote)
- Guttman does not know the costs of these coatings, as he is still in the process of getting quotes.

How often will the coatings need to be redone?

- The companies will know this, but Guttman does not.

What is the cost to transport the SGEWW from the origination point to the disposal area?

- To use a jumbo barge (10,000 barrels) Grandview would charge $5 per 42 gallon barrel transported. Grandview also has 8000 barrel, and 10,000 barrel barges, and is considering purchasing 30,000 barrel barges.
- The barges would have to traverse at least a dozen locks along the way, but there is no fee for traveling through them, only size consideration.

How often will barges be able to transport SGEWW?

- Once per week, a round trip with as many barges as it would take to transport all the water in the contract (he estimate 60,000 barrels).
- On the Monongahela R. they could only tie three barges together, depending on the size of the locks. The jumbo barges are 195 feet by 35 feet.

Appendix E: Interview Protocol and Interview Notes for Andrew Patterson (MSC)

Background

Date: 11/20/12

Name: Andrew Paterson

Job Title: Expert in Shale Gas

General Questions:

What methods are currently used to treat SGEWW?

How cost efficient is the methods?

How many holding ponds would be needed to store SGEWW at an on-site facility?

What would be the cost to dig these holding ponds?

What are the dimensions of these ponds?

How much would it cost to line ponds?

Would it require a special permit?

Are the ponds double lined?

What regulations must be followed when lining the ponds? (Clean Water Act)

If an evaporating method were to be used, what would be done with the leftover sludge?

What are the costs to store it in landfills?

Would more landfills need to be created in the future?

Roughly when will wells stop being drilled?

(When will the wells run dry)?

What is done to recycle it the water currently?

What is the cost to recycle the water?

Are fracking companies thinking of using evaporators onsite, or moving the water to evaporation facilities?

Are fracking companies planning on renting the evaporators, or buying them outright?

How much energy is required to run the evaporators?

Does this energy come from natural gas extracted onsite, or another energy source?

How much does it cost to run the evaporators?

(How much does the energy use cost?)

How long would the evaporators have to run in order to fully evaporate the water and leave only sludge**?**

Interview Notes for Andrew Paterson

What is the easiest way to deal with the SGEWW?

- Easiest way is to simply not treat the water, and reuse it in other fracking wells. The next level would be filtration to take out solids before reuse in a new well. Then precipitate out solids, removing all contaminants before reuse. The most difficult at this point is evaporation of water.

Holding ponds information

- Size depends on the system of disposal being used. If water is reused in wells, less water has to be held, if water has to be treated, more storage is needed, so above ground tanks and holding ponds are used. The disposal process being used also determines whether ponds or tanks will be used.
- Pennsylvania, the largest ponds are centralized impoundments, and can hold up to 15 million gallons, but only ever hold 13.5 million gallons. The impoundments resemble small dams. These are so big because 3-4 million gallons are used to frac a single well.
- In Penn, strict regulations are followed regarding lining. They must be double lined with non-permeable synthetic material, and they must have leak detection
- If a pond is over the size limits there are more strict design regulations.

Sludge/brine

- Landfill solid waste (sludge), and deep well inject the liquid waste (brine)
- To landfill, the cost will be 35-50 dollars per ton, but the amount of sludge is much less than the brine waste.
- Trying to turn salt from the waste in to consumable salt. They would like to use crystallization to precipitate out the salt, then sell as salt cakes.
- Brine is $1 per hour per barrel to transport by truck, but Mr. Paterson didn’t know the price to deep well inject.

Evaporators

- The energy to run one is about 1200 btu/gallon of water evaporated, and companies employing this strategy will use any available source of energy to run the evaporators.
- Because they are expensive, it is likely that centralized facilities will be build, but evaporator technology is not yet available.
- Most fracking companies will not own their own evaporators, but rent or contract from another company. If a company went through the treatment facility option, they would pay by the barrel treated instead of buying their own equipment

Well futures

- As natural gas prices decrease, there will be less drilling of wells, and as prices increase, there will be more drilling.
- Wells are expected to be drilled in Penn for the next ten years
- Wells can produce wastewater for up to forty years, but produce the most water in the first couple of year of use, and flattens off as time goes on.

Most efficient method of treatment

- Recycling into the next frac because shipping is too expensive
- The next best option would be to use deep well injection because this cost less than $10 per barrel
- After that would be evaporation, which would most likely be more than $10 per barrel, though mobile evaporators would be the best way to do this, but he thinks there is no way to do this at this time.

Appendix F: Interview Protocol and Interview Notes for Commander Melburn Dayton/Carolyn Onye/Commander Kyle Lim

Background

Date: 11/15/12

Name: Melburn Dayton, Carolyn Onye, Kyle Lim

Job Title: Industrial Hygienists

General Questions

What policies are in place for cleaning/containing radioactive materials?

If you are handling low-level radioactive materials, what safety gear should one wear?

What are the exposure limits for alpha, beta, and gamma radiation workers?

How should alpha radiation be handled? How should gamma radiation be handled? How should beta radiation be handled?

What is the containment protocol for radioactive waste?

Are members of the public exposed to alpha or beta radiation by handling the wastewater?

How far could contaminated material travel during a spill incident?

If you are handling low-level radioactive materials, what safety gear should one wear?

What are the exposure limits for alpha, beta, and gamma radiation workers?

How should alpha radiation be handled? How should gamma radiation be handled? How should beta radiation be handled?

What is the containment protocol for radioactive waste?

Are members of the public exposed to alpha or beta radiation by handling the wastewater?

How far could contaminated material travel during a spill incident?

Interview Notes for Commanders Dayton/Lim and Carolyn Onye

Current Policies for Cleaning/Containing Radioactive Materials

- Commander Dayton has no previous experience handling low level radioactive waste, so there are no coast guard regulations as of right now.
- He is trying to get regulations and policies put in place, but there are no policies currently
- The Coast Guard has dealt with low level x-ray radiation, so they are basing these new policies off of that. They communicate with DTRA (Defense Threat Reduction Agency) to calculate the potential exposure. DTRA can run the likelihood of exposure, but there is no information so far.
- To move forward: CMDR Dayton plans to let the process begin, and start to monitor the radiation with radiation badges on the workers. He will then collect the badges and develop the film to see the levels of radiation they are working in, and go from there creating regulations if any are even necessary. (There may be a super low radiation level which would require no regs.)

Safety Gear for Handling Low Level Radiation

- To keep from getting exposed there is a set line of controls. The first control is the engineering control. This control ensures that the workers are unable to even reach the radioactive hazard; it places shields up so there is no way to get close enough to experience the radiation. The second control is administrative policies, which consist of signs and policies that inform the workers about the risk so they are not apt to go near it without proper protections. The third control is PPE or personal protective equipment which is used only if it is absolutely necessary to go near the radioactivity. The PPE is used to limit exposure. However, Dayton tries to eliminate the need for PPE by using the first two controls.

- If levels are high enough for PPE Dayton doesn't want his people going in
- Because barges are an unknown environment for radioactivity after SGEWW exposure, a coast guard member shouldn't have to expose themselves to a potentially hazardous situation.
- The plan is to have the workers wear badges, which will be monitored to calculate exposure and limit exposure as necessary, and use PPE only if absolutely necessary. A conservative approach will be taken when dealing with the barges exposed to SGEWW.
- Look at the risk, look at reasons for entering
  - If no emergency, no entrance.
  - Rather clean barges to the point where there is no need for PPE as there is then to worry of radiation

Exposure Limits

- Frac water may never trigger any limits; if it approached half of the limit control measures would be taken.
- Exposure limits for frac water are unknown at this time, typically it is 5 millirems but frac water will never approach this.
- The USCG can set their own limits, and decide what necessary precautions are.
- Again, they plan to send in monitors with badges who will report the radiation levels, and then limits will be decided.
- Again, this is a kind of new world for the USCG

Concerned with Inspections

- Dayton is concerned with inspections because the DOT doesn't consider SGEWW to be a hazardous material
- He would rather rely on CFR-49 than go into new regulations if at all possible
- BUT, the USCG can develop their own policy to abide by concerning radiation if necessary

Handling Alpha Radiation

- The USCG wont handle this waste, they're only concerned with the barge itself
- If a spill occurs they would hand this off to the NRC or DTRA who have more expertise to deal with radioactive materials.
- The USCG has limited ability to clean spills of radioactivity
- Generally, alpha radiation can be blocked easily with shielding. Dayton would want to let the area sit for long enough until it was no longer dangerous, so anti corrosion paint would be a necessity.
- Under OPA 90 most barges are double hulled as they are dual purpose, and don't just have one job.

How Far Could SGEWW Travel

- The amount of the loads are determined by the USCG, and the loads can’t exceed this limit
- Therefore, the salt won’t stick around for long should it be spilled the load will be small enough that it should dissipate quickly killing little marine life.
- The risk to the water itself is speculative, as it depends on an area and the areas contingency plans.
- The goal is to keep the water out of sensitive areas, so out of ecosystems full of wildlife of any kind, and out of places where the water is used for drinking, plumbing, etc.
- Try to steer more through the dead zones where there is already no use and no wildlife. (i.e. middle of Mississippi)
- If the density of the materials is less than one it is very hard to recover once it is lost in a spill as it sinks. It is easier to recover oil and material that floats in the water.

Appendix G: Interview Protocol for Surveying Company

General Questions:
How often will the barges have to be surveyed if they transport SGEWW?
What is the cost per survey?
How long will it take to complete a full survey?
What happens if a barge fails the survey the first time?
How long could the barge be out of service for?

Appendix H: Interview Protocol and Interview Notes for Jim Williams (DOT)

Background
Date: 11/8/12
Name: Jim Williams
Job Title: Radioactive Materials Expert
General Questions:
What routes will the trucks or rails take to transport the SGEWW?
How many rails/trucks will be needed to make the trips to the barges?
Will SGEWW be considered a hazardous waste for rails/trucks?
If so, would permits be required to transport the SGEWW?
How much would a permit cost?
What would be the costs associated with running these trucks/rails?

Interview Notes from Jim Williams (DOT) 8 November 2012

Is this water considered a hazardous material?

- He doesn't know, but the information exists in 46 CFR 173.401-403. This contains the definition of haz mat
- Transport companies are obligated to follow DOT regulations when transporting. If they do not abide, the fine is approximately $100,000

What if the material is a haz mat?

- Registration web page (PHMSA), when a company is required to register, the fee is based on the size of the company. Most registration fees are a few thousand dollars for large companies.
- With reg. the companies can legally ship material when they abide by the transportation laws
- DOT actively enforces registration violations
- If a company needs a special permit, that is free. Needed if the cargo is oversized.
- Both the Fracking company and the shipping companies have to pay the fee of registration

Are water tests required for the DOT?

- No, the DOT doesn't test shipments. Companies are on the honor system to get the registrations they need and abide by the CFR, the companies self-certify train employees to transport that type of material properly.

Williams' experiences in alpha testing

- He is a certified Health Physicist, and tested for alpha radiation in industry for 40 years
- Survey if time/cost intensive, to scan for alpha radiation, a 1 foot probe is used which can only move along the wall at 1-2 inches per second

- Alpha particles don’t travel far so the tester looks for spikes in readings form the detector
- They can test only trouble spots in the barge (outlet point analogy: tub drain), and extrapolate to estimate a 100% survey
- Have to keep surveying until the radiation shows up on the meter (if no clear build up)
- Alpha spectroscopy equipment can cost up to $100,000

Estimation of the survey of a barge

- $30/hour-$50/hr for one surveyor (actually charged to client)
- Estimate for a barge, four surveyors might take a whole day and charge $5000-10000
- Radiation probe costs $2000, and lasts up to 10 years

Radon air testing

- DIY test can be $200, but for a real test, expect $500-1000

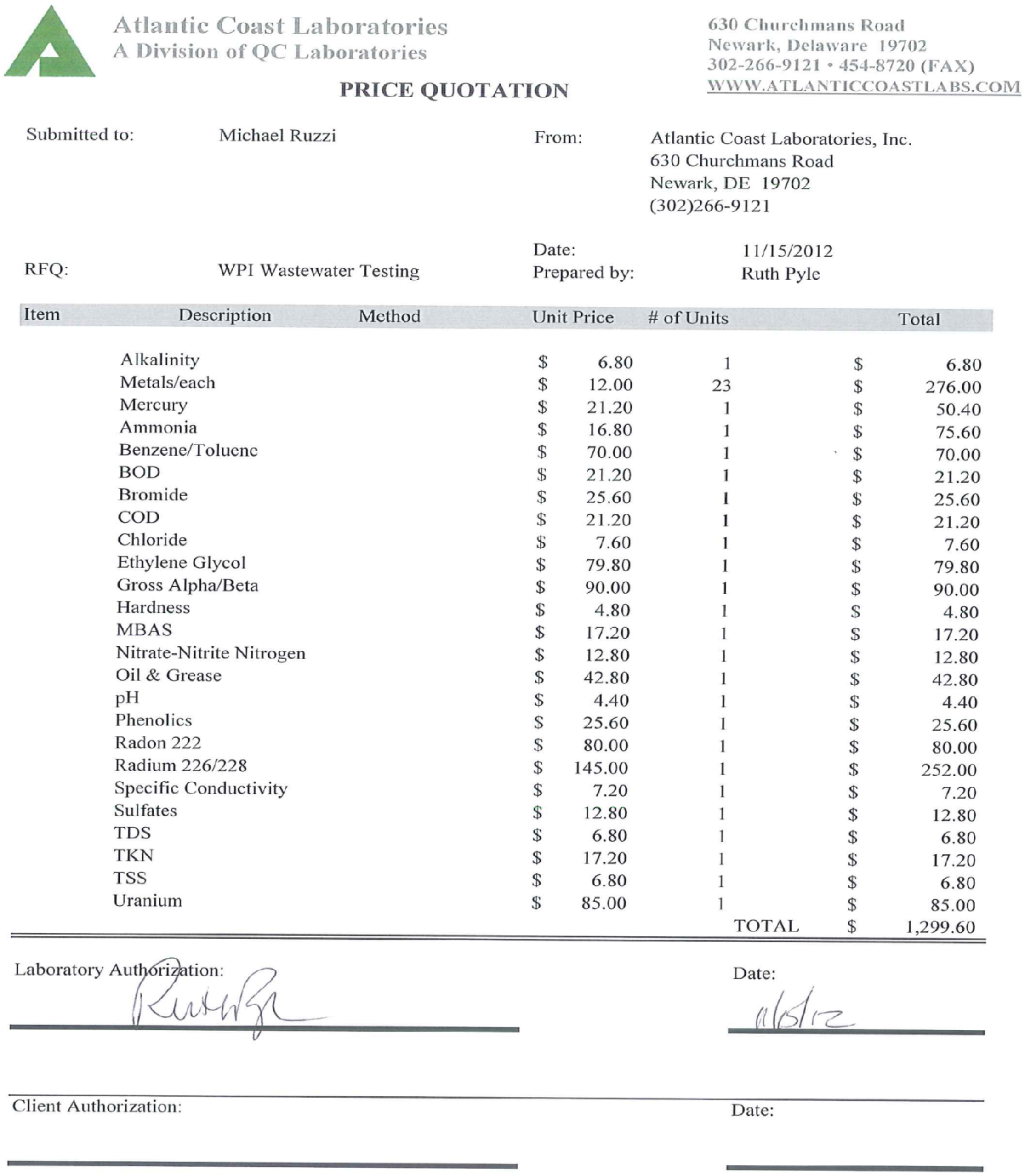
Transportation

- Rail is much cheaper, but road is easier because there are less transfer points when only using trucks (opposed to well→truck→barge→truck→well), and especially because the trucks would only be in one state
- If a truck would be classified as oversized, that would be classed by state
- In a separate email communication, Mr. Williams indicated that he had an estimate Mark Lewis of Energy Solutions Trucking Division quoting $700 flat rate per truck, plus $1.90 per truck mile traveled.

Appendix I: Interview Protocol for Water Testing Company

General Questions:
How often would the water have to be tested before transport?
What is the cost of each water test?
How long does the test take?
Which chemicals do you test for in each test?

Appendix J: Water Testing Invoice from Atlantic Coast Laboratories



Atlantic Coast Laboratories
A Division of QC Laboratories

630 Churchmans Road
Newark, Delaware 19702
302-266-9121 • 454-8720 (FAX)
WWW.ATLANTICCOASTLABS.COM

PRICE QUOTATION

Submitted to: Michael Ruzzi

From: Atlantic Coast Laboratories, Inc.
630 Churchmans Road
Newark, DE 19702
(302)266-9121

Date: 11/15/2012

RFQ: WPI Wastewater Testing

Prepared by: Ruth Pyle

Item	Description	Method	Unit Price	# of Units	Total
	Alkalinity		$ 6.80	1	$ 6.80
	Metals/each		$ 12.00	23	$ 276.00
	Mercury		$ 21.20	1	$ 50.40
	Ammonia		$ 16.80	1	$ 75.60
	Benzene/Toluene		$ 70.00	1	$ 70.00
	BOD		$ 21.20	1	$ 21.20
	Bromide		$ 25.60	1	$ 25.60
	COD		$ 21.20	1	$ 21.20
	Chloride		$ 7.60	1	$ 7.60
	Ethylene Glycol		$ 79.80	1	$ 79.80
	Gross Alpha/Beta		$ 90.00	1	$ 90.00
	Hardness		$ 4.80	1	$ 4.80
	MBAS		$ 17.20	1	$ 17.20
	Nitrate-Nitrite Nitrogen		$ 12.80	1	$ 12.80
	Oil & Grease		$ 42.80	1	$ 42.80
	pH		$ 4.40	1	$ 4.40
	Phenolics		$ 25.60	1	$ 25.60
	Radon 222		$ 80.00	1	$ 80.00
	Radium 226/228		$ 145.00	1	$ 252.00
	Specific Conductivity		$ 7.20	1	$ 7.20
	Sulfates		$ 12.80	1	$ 12.80
	TDS		$ 6.80	1	$ 6.80
	TKN		$ 17.20	1	$ 17.20
	TSS		$ 6.80	1	$ 6.80
	Uranium		$ 85.00	1	$ 85.00
				TOTAL	$ 1,299.60

Laboratory Authorization: Ruth Pyle

Date: 11/15/12

Client Authorization:

Date:

Appendix K: Acronyms

Acronym	**Meaning**
ANGA	America's Natural Gas Alliance
CDR	Commander
CFR	Code of Federal Regulations
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DTRA	Defense Threat Reduction Agency
EPA	Environmental Protection Agency
GE	General Electric
LDB	Left Descending Bank
MSC	Marcellus Shale Coalition
NORM	Naturally Occurring Radioactive Material
NRC	Nuclear Regulatory Commission
OSHA	Occupational Health and Safety Administration
PA	Pennsylvania
pCi/g or PCi/L	Picocuries per Gram or Picocuries per Liter
PPE	Personal Protective Equipment
Ppm	Parts Per Million
Ra	Radium
RDB	Right Descending Bank
Rn	Radon
SGEWW	Shale Gas Extraction Waste Water
U	Uranium
USCG	United States Coast Guard
WPI	Worcester Polytechnic Institute