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National Grid Waste Analysis

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Investment Recovery Granulator Waste Stream Cost Analysis at National Grid

*Major Qualifying Project Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In Partial Fulfillment of the Requirements for the Degree of Bachelor of Science
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Abstract

This MQP report examines the issue of copper recycling and its associated waste stream at the National Grid Investment Recovery Facility. The objective of the project was to perform a financial analysis on an industrial copper granulator and to turn the machine waste into a salable commodity. The team approached this problem using axiomatic design, interviews, historical data and invoices, vendor consultations, and cost-benefit analyses. Results showed that the rubber insulation waste from the machine is contaminated with lead but could be purified using electrostatic separation. This separation would result in a drastic reduction in waste removal costs and also enable the insulation to be sold on the commodities market. In conclusion, the team recommends that National Grid install an electrostatic separator to remove the impurities. The new process is projected to provide the company with additional revenue from savings of approximately \$ and generate profit of approximately \$ annually.

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Chapter 1: Introduction

The National Grid Investment Recovery and Recycling Services facility, located in Liverpool, New York is a division of the company that specializes in processing decommissioned equipment, such as raw materials, vehicles, and tools. The facility assesses their present monetary value, and either sells, recycles, redeploys, or disposes of them to minimize surplus inventory and maximize company revenue (Investment Recovery Manager, Personal Communication). The facility owns and operates an industrial copper and aluminum granulator daily, which processes pole line material and overhead wire into copper and aluminum granules. These granules are then sold on the commodity market and are the largest source of revenue for the facility (Investment Recovery Manager, Personal Communication).

1.1 Problem Statement

In recent years, the granulator has brought about high maintenance costs and National Grid decided to replace the machine with a new one. Part of the focus of this project was to analyze and make improvements to the processes in place to source a new machine. The granulator also produces rubber insulation waste called “fluff”. The fluff waste is currently being disposed and is costly to the facility. The investment recovery group at National Grid asked our team to analyze the costs associated with the insulation waste stream and develop recommendations to turn the fluff into a profitable commodity.

They also asked the team to help develop strategies for sourcing improvement for machine replacement. Axiomatic design and cost-benefit analyses were used to accomplish these objectives.

1.2 Project Goals

The goals for this project were to:

1. Understand the sourcing processes National Grid uses for acquiring and replacing machinery
2. Understand the investment recovery facility processes of copper granulation including component parts, drawings, inputs, outputs, lab testing, and waste removal
3. Improve the efficiency of granulator replacement sourcing process
4. Analyze historical waste removal data and generate a time vs. cost savings analysis

1.3 Project Deliverables

The following items were delivered by the team:

1. Throughput data and machine constraint document
2. Financial analysis of “fluff” insulation waste stream
3. Recommendations for cost reduction and increased revenue

1.4 Project Scope

The team reviewed all available invoices, purchase orders, lab results, facility and machine drawings, sourcing software, and also consulted external vendors to obtain these deliverables. This project compiled throughput data and machine constraints to expedite the granulator sourcing event and determine the best process for increasing revenue from commodity sales at the facility.

1.5 Project Timeline

This project was completed over the course of A term 2017 and B term 2017. A-term 2017 began on August 24, 2017 and B-term 2017 concluded on December 15, 2017. The majority of our focus during A-term consisted of research, data mining, and problem solving, whereas B-term consisted of performing cost analysis, determining a recommendation, and writing our report.

Chapter 2: Background

Our team found the following research useful in achieving our project deliverables.

2.1 History of the National Grid Investment Recovery Facility

In 2000, National Grid acquired Niagara Mohawk Holdings Inc., a power generating company located in Syracuse, New York (Banerjee, 2000). The purchase expanded National Grid in the New York region; prior to the purchase, Niagara Mohawk was the second largest electricity and gas utility company in the state of New York. One of Niagara Mohawk's biggest assets was the copper granulator, located in what became National Grid's Investment Recovery facility. The Investment Recovery facility now employs over 30 people, many of whom are hired through a partnership with Monarch, a local vocational employment agency that provides job opportunities for people with developmental disabilities. Since nascency, the facility has found use for over 25 million pounds of decommissioned material and brought in over \$ in revenue (Investment Recovery Manager, Personal Communication).

2.2 Aluminum and Copper Granulator

In 1984, Triple/S Dynamics designed and installed the copper and aluminum granulator at the investment recovery facility. The machine operates five hours a day and processes roughly 2.5 million pounds of copper wire annually. The copper granulator is a

roughly eighty feet long and forty feet tall machine, which is fed manually five days per week. The granulated copper and aluminum is then resold on the commodities market.

Figure 1 below shows the flow of the component processes that transform the wire inputs into commodity and insulation waste outputs. This process is further explained later on in this report. Machine component drawings are shown in Appendix A.

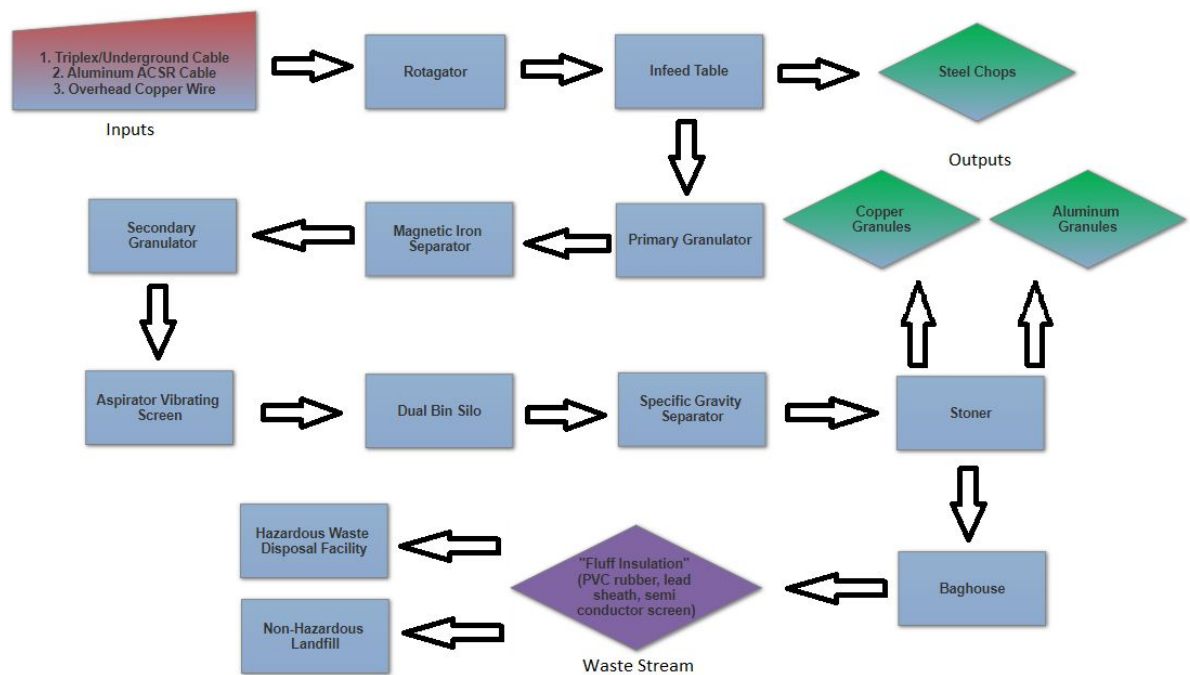


Figure 1: Flow diagram of granulator functions

2.3 Lean Manufacturing

Lean manufacturing is a methodical procedure of running a process with the intention of eliminating all waste. Time, money, or resources could all be considered forms of waste. Lean manufacturing creates more value overall, while diminishing the

amount of resources (Towill, 2010). It can also reduce the number of employees needed for a process if automation can improve the effectiveness. Ultimately, lean manufacturing is intended to improve the efficiency and profitability of a company's process.

2.4 Axiomatic Design

Axiomatic design is a hierarchical decomposition process intended to reduce unnecessary iterations during design activities (Baldwin, 1994). The resulting coupling matrix shows the interactions between the design parameters and functional requirements. The method uses two design axioms, the Independence Axiom and the Information Axiom, as its governing principles (Suh, 2001). The Independence Axiom states that the process must maintain the independence of the functional requirements (FRs). The Information Axiom demands that the design uses the least amount of information content possible. Axiomatic design begins by taking a set of customer needs (CNs) and creating FRs that represent them in the proposed system. The sum of FRs address all of the needs that the design solution must incorporate. The functional requirements are complemented by design parameters (DPs), as shown in Figure 2, that exist as physical means to achieving the FRs. Lastly, the process variables (PVs) are the manufacturing processes that go into creating the DPs that are chosen for the design solution (Suh, 2001; Towner, 2013).

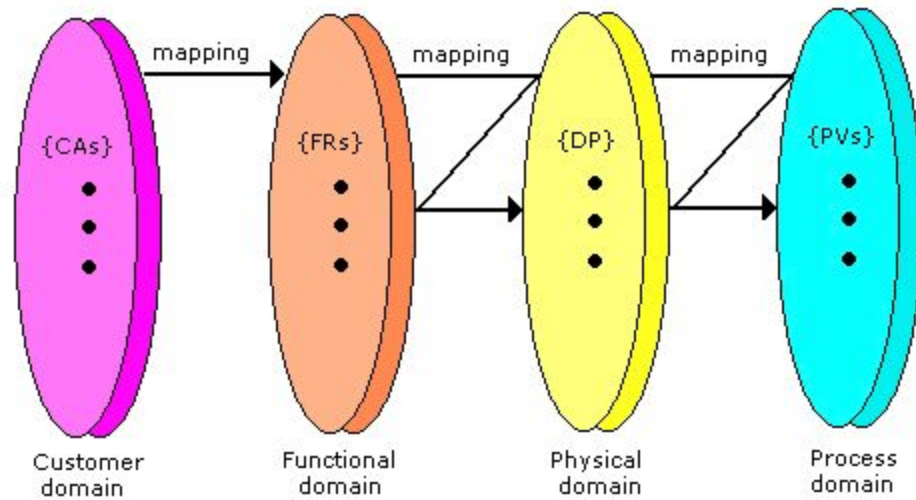


Figure 2: Axiomatic design map (Source: Axiomatic Design Technology, n.d.)

The top-down approach to synthesize the system breaks down each functional requirement into “children” that represent individual components of the “parent” FR. Each FR is cross examined with each DP to create a design matrix, similar to the one shown below in Figure 3. Any FRs that are affected by a given DP are marked with an X and considered to be coupled. Using these couplings, the designer of the system can decide the structural hierarchy of the process. (Suh, 2001; Towner, 2013).

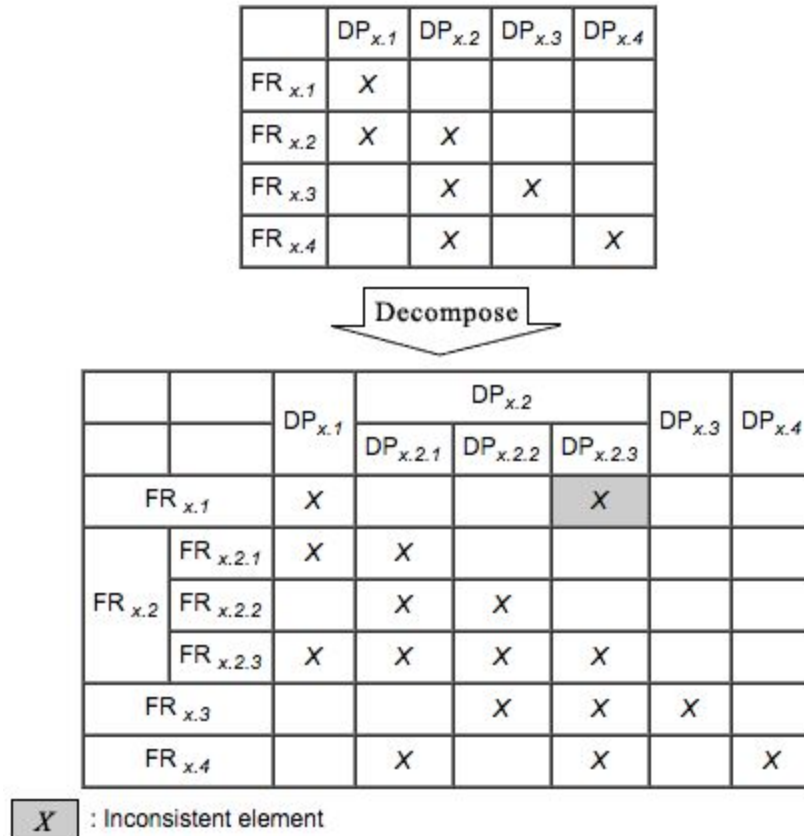


Figure 3: An example of a decomposed axiomatic design matrix (Source: Suh, 2001)

Seven Wastes of Lean Manufacturing

In an attempt to become a lean process, cost reduction opportunities are often found within waste. According to Ohno, there are seven wastes in manufacturing that can decrease the speed of a process and increase the cost of production (Ohno, 1988). The seven wastes shown below are known by the acronym: TIMWOOD (George, 2010). These opportunities for cost reduction are able to be seen within a process through extensive analysis.

T - Transportation: Transportation refers to the movement of any process inputs, active processes, or outputs of the system. The waste is normally due to the layout of the system. If a facility is not strategically set up to optimize production, then the system could have waste that raise costs and lower production. Companies often face transportation wastes because they are restricted by the infrastructure, forcing employees to transport parts of the process.

I - Inventory: Inventory waste is physical inventory that is not being used in the process. The inventory can consist of raw materials or finished goods; anything that is not being sold or processed. Inventory waste can be a result of mismanaging production or a lack of understanding the customer.

M - Motion: Unnecessary physical movement of employees is considered motion waste. Different from transportation waste, motion waste is specific to employees moving themselves, rather than moving something else. For example, if an employee has to walk to the other side of a factory to log data into a computer. This unnecessary motion can create possible delays, defects in production, or increase employee health risks.

W - Waiting: Waiting waste refers to any interruption in the flow of the process. If a process requires unnecessary waiting time for the customer, then there is opportunity for improvement. For example, if a customer has to wait two weeks to receive their order, whereas a competitor only requires one week, the company will lose business. By identifying the causes of delay and constraints within the process, a company can

improve their value-add time, lower production costs, increase customer satisfaction and in turn increase profit.

O - Overproduction: Overproduction is the act of producing much more of a product than the customer demand. This waste can result from having a poor understanding of the existing market. Companies can overproduce their products if their process is not designed correctly or regularly controlled, due to changes in demand.

O - Overprocessing: The act of overprocessing is delivering more to the customer than what they want. Adding more value to a product does not always yield more return. For example, a company produces umbrellas for \$10 each, selling them at the market on rainy days for \$20. Of their manufacturing costs, it costs \$5 to print the design on the outside. The company profits are \$10 per umbrella sale. However, if they did not print the design on the outside, and continued to sell the umbrellas at \$20 each, their profits would increase by 50%. The printed design can be seen as over processing, because the customer will still buy the umbrella if it is raining; the design does not alter the functionality of keeping the customer dry. Understanding the customer need throughout an entire process is key to avoiding overprocessing.

D - Defects: Lastly, defects are errors in production that result in faulty products reaching consumers. Depending on the product, defect can result in grave consequences for the company financially. For example, from 2009 to 2011, Toyota recalled 14 million vehicles due to “unintended acceleration” (Bagley, 2016). There was a recurring issue of the floor mats getting stuck between the gas pedal. Toyota was forced to recall the vehicles, pay massive fines to the National Highway Traffic Safety Administration, and

faced litigation from insurance companies and vehicle owners involved in accidents.

Companies can become more lean by increasing their inspection costs. This creates lowers their defects per million opportunities (DPMO) rate, sequentially lowering rework and repair costs, and increasing customer satisfaction. (Ohno, 1988; George, 2010).

Chapter 3: Methodology

The team used the following materials and methods to approach the problem statement.

3.1 Site Visits

The team travelled on multiple occasions to National Grid's Investment Recovery facility in Liverpool, New York. On these visits, we were able to observe the granulation process both while dormant and in operation. This allowed us to gain a better understanding of the day to day efforts that go into the granulation of copper. Most importantly, it allowed us to understand why the waste was being created.

3.2 Interviews

Many interviews were conducted throughout the duration of this project. Investment recovery managers at the facility were able to educate the team on how each component of the machine operates as well as the inputs and outputs of the process. They also helped the team to understand the current system in place for non-hazardous and hazardous waste removal at the facility. Interviews with environmental engineers were valuable in determining the material composition of the insulation waste. The team also interviewed project managers and procurement buyers from National Grid to understand the strict procedures that they must follow in financing a project like this one.

3.3 Internal Software and Procedures

The team spent time navigating National Grid's internal procurement processes to better understand the project plan and timeline occurring in parallel to our project. Learning the time constraints and approval process required to move the granulator replacement forward led us to place our efforts into improving efficiency of the RFP (Request for Proposal) process and minimizing wasted time. An RFP is typically a package of documents that a company uses to provide a project statement, a scope of work, and other supporting documents to a base of suppliers capable of completing it. The team created a data sheet outlining all of the machine requirements and spatial constraints that the replacement granulator must meet, which National Grid distributed in the RFP package.

3.4 Invoices and Lab Results

We used invoices from landfill shipments and hazardous waste disposal facilities to obtain costs for our financial analysis (see Appendix I). The team also received chemical test results from an environmental waste analysis lab that provided us with the concentration of metal contaminants that was acceptable in a container of insulation waste in order to pass as non-hazardous. An example of a TCLP lab result is located in Appendix B.

3.5 Vendor Consultation

In conjunction with our own research, the team reached out to several rubber recycling and manufacturing firms, as well as industry leaders in metal separation technology. These discussions provided the team with a deep understanding of the different methods used for metal sorting and purification. They also gave the team an understanding of the regional market for recyclable commodities in upstate New York.

3.6 Acclaro®

To create our axiomatic design decomposition and coupling matrix, the team used a software named Acclaro®. Acclaro® was created by a company called Functional Specs, Inc (Acclaro® Software DFSS, 1998). It has a friendly user-interface, shown in Figure 4, that enables users to model design problems for tools, systems, and services and works to generate solutions for them.

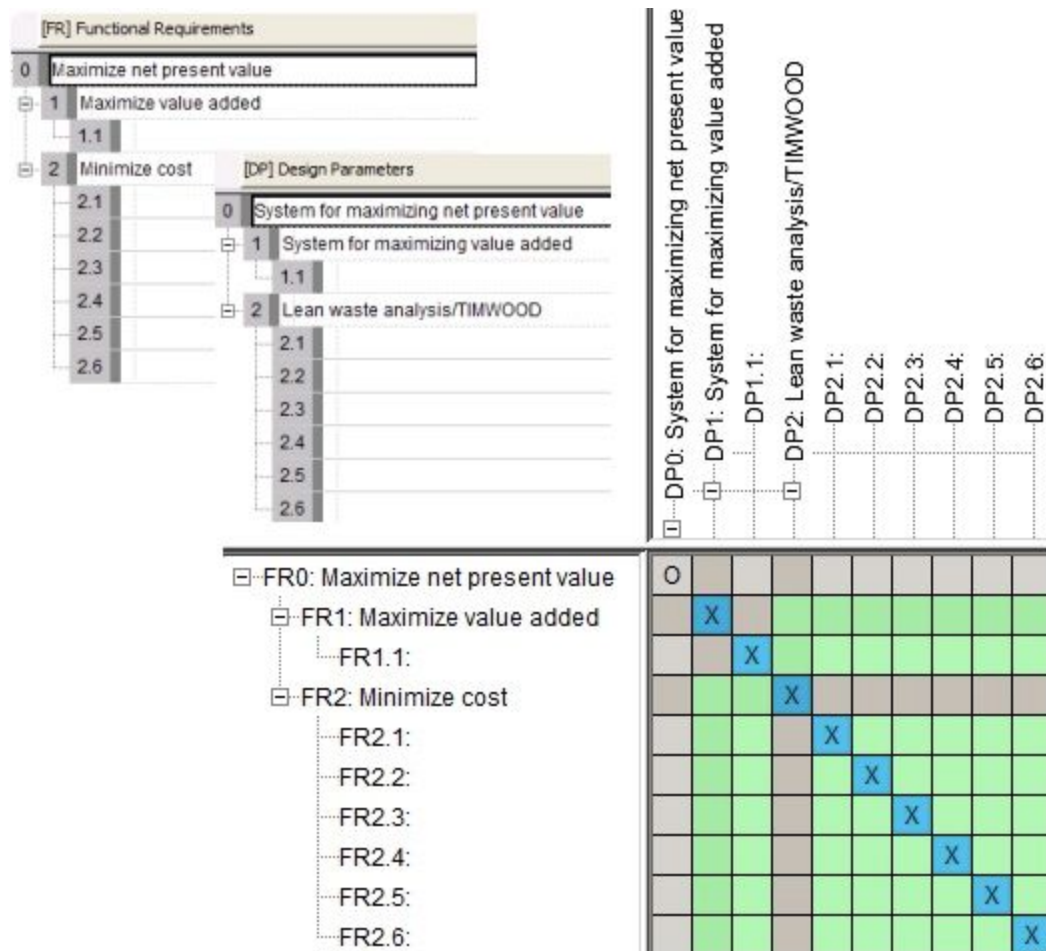


Figure 4: Acclaro® software interface (Source: Acclaro® Software DFSS, 1998)

The Acclaro® software interface allows the user to easily modify their decomposition and coupling matrix. The blue boxes state that the corresponding FR and DP are coupled. This enables the user to view and edit the hierarchical structure of the process, helping to optimize the chosen solution.

Chapter 4: Results

The following are our team's findings in improving the granulator sourcing process and minimizing the cost for waste removal at the investment recovery facility.

4.1 Understanding National Grid's sourcing process

The National Grid team also asked for our help in preparing their RFP document to send out to potential suppliers. In order to accomplish this, we needed to familiarize ourselves with the internal processes in place within National Grid as well as the base of potential vendors that could accomplish the construction and installation of this machine. We were able to gain access to National Grid's sourcing database called Ariba®, which is an application developed by SAP®. We spent time navigating the platform and learning its functions. Understanding how to use the platform enabled us to view the process that upper management was using to approve the project. After reviewing the approved project proposal and timeline, we learned that there was an aggressive timeline associated with this project, in an effort to ensure the project spend was associated with the upcoming fiscal year. This meant that the RFP would need to be assembled and distributed by November 1st of this year (Senior Buyer, Personal Communication). Other important information that we gained from the Ariba® system was that the internal stakeholders associated with the project preferred the selection of a single source vendor capable of delivering a turnkey system. The project also requested that any modifications

to the baghouse be limited to \$ (National Grid’s Strategic Sourcing Process, 2017).

This would prove to be an important constraint to our cost analyses for waste removal solutions later on in the project.

4.2 Understanding the granulation process

We learned that the process begins with loading bales of wire coil and free-flowing pieces of wire into the rotagator, or “pre-shredder.” It is the responsibility of Operator 1 to load the rotagator via a manually operated forklift, as seen in Figure 5. The hydraulically powered rotagator uses stainless steel chops to cut up the wire inputs into smaller scrap wire parts within minutes. This is necessary to reduce the strain put onto the primary granulator further down the process. These pre-chopped pieces of wire are then dropped onto a vibratory infeed shaker table, as shown in Figure 6.



Figure 5: Rotagator being loaded by forklift to begin the granulation process



Figure 6: Shaker table sifts the smaller chopped wire, before entering the primary granulator. Large pieces of steel are removed by an operator.

The table transports the chopped wire to the primary granulator with at high speeds with minimal assistance by the operators. The wire then passes through the primary granulator, where it is more finely chopped into 1-2 inch lengths. From there, the wire passes under a magnetic separator before being transported to the bucket elevator. This magnet removes the steel contaminates from the chopped wire in order to reduce wear-and-tear on the secondary granulator and deposits them in a cardboard box along the side of the machine. Figure 7 shows how the steel-free wire chops are now lifted by a bucket elevator and deposited into the secondary granulator.



Figure 7: Bucket elevator lifts the material to the second granulator

This second granulator further refines the wire to the size of the hole located on the inner discharge gate, separating metal granules from the insulation granules. The granules then pass onto an aspirator vibrating screen that works to further separate fine metal particles into two size groups and separates metal from insulation waste even further. The two size groups of metal are stored in a dual bin silo and await operator release for gravity separation. Operator 2 then empties the wire and insulation pieces onto the gravity separator table. The operator manages air flow and vibration speeds to ensure the division of the pieces into three products: clean metal granules, insulation, and a

mixture of some metal and insulation. The mixed product goes through this process repeatedly until it is also separated into metal nuggets and insulation.

From there, the metal granules and the insulation are nearly completely separated. The metal nuggets, consisting of aluminum and copper, are processed through the stoner. The stoner is the final quality control point of the system that separates the metal commodities from each other before it is ready for market, shown in Figure 8 below (Investment Recovery Manager, Personal Communication).



Figure 8: Fine cut aluminum as a final product

4.3 Understanding the waste removal process

The insulation “fluff waste” is transported from the granulator through a 210-foot air duct along the side of the granulator room and into the adjacent baghouse. The historical data readily available for the team to analyze on this process was so minimal that we used a measuring wheel to determine the length of the air ducts along the building. Figure 9 shows where the fluff leaves the duct, falling into a 30-yard roll-off container, which is shipped off to a landfill when full. The baghouse is nearly empty, except for the rollout container that fills with insulation and a second container that fills with dust (Investment Recovery Manager, Personal Communication). This opens up opportunity for machine installation as a potential solution. If a shipment contained a lead concentration of five parts per million or higher, it would need to be declared as hazardous. Through invoices and lab results, the team determined that the “fluff” National Grid produces is deemed hazardous waste about 30% of the time. Figure 10 shows the metal contaminants that make up the hazardous fluff waste. The cost for removing this waste is significantly more expensive to the company than shipping non-hazardous waste.



Figure 9: Baghouse where the “fluff” waste is dispensed



Figure 10: Hazardous fluff material with lead concentration over five parts per million

We also learned that there had been attempts at eliminating the cost of burying the insulation waste in a landfill by selling the fluff to recycling vendors. The vendors could then use it for adhesive and non-adhesive molding. National Grid managed to sell a few trial containers of fluff waste to two separate recycling vendors during spot market times, but the metal contamination did not make the waste stream desirable enough to vendors to build a long term revenue stream (Environmental Engineer, Personal Communication). Upon further discussion, the team learned that effort was abandoned due to a lack of available human resources as well. The marketing crew at the facility had been reduced from four to two employees (Investment Recovery Manager, Personal Communication).

4.4 Determining ways to improve efficiency of sourcing process

Knowing that National Grid's main priority for sourcing the new machine was to achieve RFP distribution by November 1st, 2017, our team helped find ways to minimize wasted during the sourcing event. This would enable the National Grid team to stay on target for installation of the new machine and designate the project costs to the desired fiscal year. The fact that the National Grid internal sourcing team had never worked on installing a granulator before meant there were no pre-existing document frameworks to populate and speed up the procurement process. Our team worked with National Grid employees and potential vendors to determine the necessary constraints that the new machine needed to adhere to into a single concise document. The throughput data shown in Figure 11 below was included in RFP distribution to vendors and enabled them to most accurately price replacement machines while minimizing time wasted due to inefficient

communication between companies. A drawing of the existing granulator, found in Appendix C, was also provided by National Grid in the RFP. The time saved in compiling throughput data was a key factor in the National Grid team's ability to meet their target date.



Figure 11: IR granulator throughput data provided by National Grid

4.5 Waste removal process problem decomposition

In order to gain a better understanding of the existing waste removal process, the team used the Acclaro® software to analyze the system. The team created a hierarchical decomposition where FR_0 is National Grid's goal to maximize revenue. National Grid desired to improve their existing copper and aluminum commodity revenue streams, but was not aware of the potential monetary benefits of waste removal process. The functional requirements for improving the waste removal process are shown in Table A.

Functional Requirements (FR)		
FR_0	Maximize net present value for fluff waste stream	
FR_1	Maximize the value added to the granulator waste	
FR_2	Minimize cost of creating fluff	

Table A: Functional requirements of decomposition

The design parameters for each of the functional requirements for improving the waste removal process are shown in Table B.

Design Parameters (DP)		
DP_0	System for maximizing net present value of fluff waste stream	
DP_1	System for maximizing value add of fluff waste	
DP_2	Lean waste analysis	

Table B: Design parameters for the functional requirements of the decomposition

We determined that our top-level functional requirement (FR_0) was maximizing the net present value for the fluff waste stream. Our FR_1 was broken down into two parts: $FR_{1,1}$ being to maximize the monetary value of fluff product, and $FR_{1,2}$ to maximize safety of creating fluff waste. Generating cash flow from the fluff, as well as the safety of the National Grid employees, remained a top priority of the company. FR_2 was broken down into six parts, modelled after the applicable six of seven wastes of manufacturing. DP_2 was the conduction of lean waste analysis, in order to fulfill the functional requirement. The decomposition can be found in Appendix D.

- **$FR_{2,1}$ - Reduce transportation of fluff from separator to baghouse**
 - The system that carries the fluff from the separator to the baghouse is unnecessarily long, due to the infrastructure of the building. By reducing the transportation of the fluff from the separator to the baghouse, there is less of a chance of the system becoming clogged, causing a maintenance shutdown.
- **$DP_{2,1}$ - System for storing fluff by output conveyor**
 - With the installation of the new granulator, the vent system could be rearranged to store the fluff by the output conveyor and shorten the travel of the fluff.
- **$FR_{2,2}$ - Reduce inventory of fluff sitting in warehouse**
 - Currently, the fluff inventory causes spatial problems for the facility and health issues for employees. By reducing the inventory of the fluff, there

will be less contaminated material and more space for the operators or work, lowering their health risks.

- **$DP_{2,2}$ - System for maximizing the fluff exported per sale**
 - This can be accomplished by creating a good relationship with a buyer.
The companies should be in contract with each other to allow National Grid to maximize their exports
- **$FR_{2,3}$ - Reduce movement of fluff waste**
 - The fluff waste is moved around by the employees without knowledge of the existing lead content in the given batch. If the movement of the fluff waste is reduced, the employees will face lowered health risks.
- **$DP_{2,3}$ - System for minimizing the length of travel between the separator**
 - This can be accomplished by systematizing what happens to fluff once it is created, such as having a set time of when it should be moved and to where.
- **$FR_{2,4}$ - Reduce waiting caused by machine filter maintenance**
 - Waiting periods often result from maintenance on the filters. By reducing the waiting, operators will be able to run the granulator more often, increasing productivity.
- **$DP_{2,4}$ - System for minimizing shutdowns for filter clearing**
 - This can be accomplished by having scheduled maintenance cleanings of all filters. This will prevent buildup on the filters, reducing the number unnecessary shutdowns.

- **$FR_{2.5}$ - Reduce over-processing of fluff creation**
 - Currently, the fluff is being produced and sent out in different sized batches. By reducing the overprocessing of the fluff, the company will be able to better track their shipments.
- **$DP_{2.5}$ - A system for efficiently separating fluff from the product**
 - This can be accomplished by implementing another material separation machine to the end of the granulation process.
- **$FR_{2.6}$ - Reduce defects of fluff waste**
 - The fluff waste is considered hazardous about 30% of the time. By reducing this number, National Grid will save money on shipping costs to hazardous waste facilities.
- **$DP_{2.6}$ - A system for reducing defects of fluff waste**
 - This can be accomplished by lowering the led content in the fluff, thus increasing the chances of passing the TCLP tests.

4.6 Determining ways to minimize waste removal costs

4.6.1 TCLP Testing

The toxicity characteristic leaching procedure (TCLP) is a chemical test on a sample of waste that measures how well the analytes, both organic and inorganic, will percolate in a landfill (EPA, 2015). If there is a high concentration of a regulated compound in the makeup of the waste then it is considered hazardous, and can not be

disposed in a landfill without treatment. The lead concentration in the fluff from the granulator is costing National Grid more often than not. The cost to dispose of the non-hazardous waste is roughly \$ per shipment. However, the cost of disposal for a shipment that was deemed hazardous (lead concentration of five parts per million or higher) is roughly triple the amount at around \$. Therefore National Grid is wasting around \$ for each hazardous waste shipment. To create savings, National Grid could ensure the passing of the TCLP testing 100% of the time. The following separation methods could produce that outcome.

4.6.2 Water Bath Separator

A water bath separator uses the density of the materials in a mixture to separate its contents from one another, as shown in Appendix E. Using a water tank and multiple conveyor belts, a water bath separator allows for like material that will float along the top of the shallow water line to be lifted out of the mixture, and the more dense material to be conveyed away in a different direction (Boer, 2005). The conveyor belt process is angled in the water so that the floating material can easily be separated. With the fluff in the baghouse, a water bath separation process could be implemented to allow the rubber pieces to float atop the waterline and allow the metal to fall to the bottom as it is more dense than the rubber.

4.6.3 Density Separator

A density separator uses mechanical vibration and air fluidization to remove unwanted material from a mixture (Triple/S Dynamics, Inc., 2017). Currently, there is a

density separator in the granulator process, shown in Appendix F. Triple/S Dynamics, Inc. were the first to invent dry material separation equipment; the same company who installed the granulator that National Grid operates. Constraints of size, shape, and density are set by the operator in order to properly separate the mixture. National Grid could add a second density separator to the process, specifically located in the backhouse, in order to focus on the separation of material in the fluff.

4.6.4 Magnetic Separator

Magnetic separation uses magnetic force to remove metals from a mixture, as material that is not magnetic will not stick to the magnet, as shown in Appendix G. According to Minerals Engineering, “ferromagnetic and paramagnetic mineral particles will both be attracted along the lines of an applied magnetic field whereas a diamagnetic mineral particle will be repelled along the magnetic field lines” (Jordens et al., 2014). If a process was created in the baghouse where the fluff could be conveyed on a belt, directly under several powerful magnets, the rubber (diamagnetic) could be easily moved to a determined location. The magnetic field that is created should have the ability to be turned on and off, therefore when the magnetic force is turned off, the material can fall orderly back to the conveyor belt in order to be moved into a separate location.

4.6.5 Electrostatic Separator

Electrostatic separation removes crushed particles from material by using low-energy, electrostatic charges, utilizing the corona discharge principle (Tennal et al.,

1999). The principle of corona discharge is the electric discharge on one conductor or between multiple conductors that is caused by the ionization of the surrounding gas (Goldman et al., 2009). This electrical charge is luminous and is often seen as a beam between transmission lines. The same type of electrically charged beam is used in an electrostatic separator to remove pieces of the material that will not conduct energy, shown in Figure 12 below. Having an electrostatic separator process in the baghouse would separate the rubber particles away from the fluff, attracting only the electricity conducting metals.

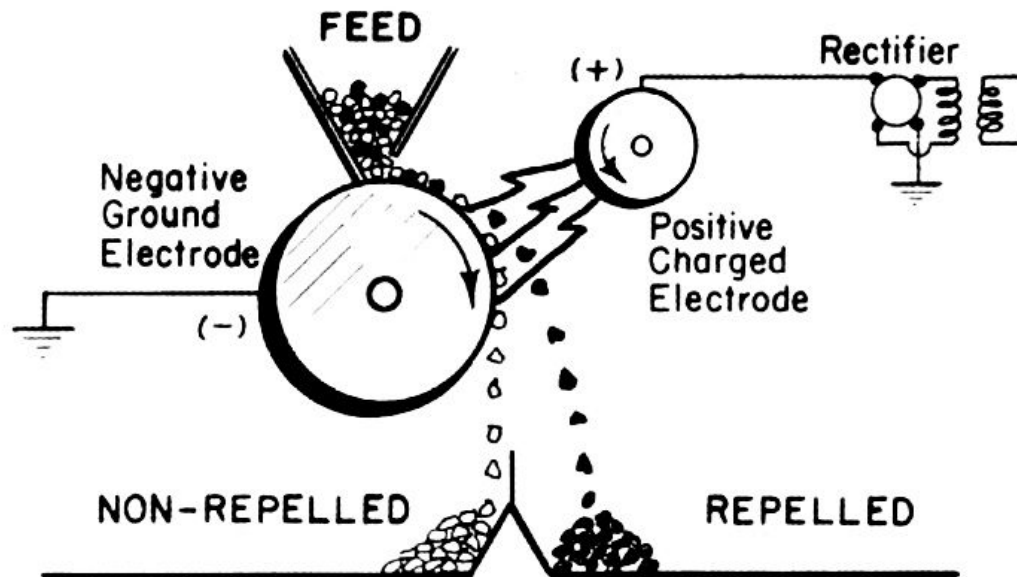


Figure 12: Electrostatic separator design (Electrostatic Separation, n.d.)

4.7 Determining ways to maximize value add of fluff waste

Our team discussed with managers at the facility the potential for using the insulation internally at National Grid, but there are no areas of the company that derive value from manufacturing rubber products. We then moved on to determine the feasibility of selling the fluff waste to a local rubber recycling vendor. We were able to obtain invoices from the few shipments that were sold to recycling vendors in 2014. These invoices were used to calculate our potential revenue analyses below. The team also reached out to eleven rubber recycling manufacturers throughout upstate New York. We believed these companies would be interested in purchasing the insulation waste from National Grid if we could obtain the desired purity. Most of the vendors the team contacted directly were not looking for new rubber suppliers. However, there were a couple of companies that expressed interest in developing a relationship with National Grid in the future, if the purity of the insulation was able to be met consistently.

4.8 Cost benefit analysis

4.8.1 Cost savings from hazardous waste elimination

The team was able to compile and analyze 90 insulation waste invoices from the last few years. The facility pays to remove about 23 containers of waste annually on average. Of these containers, about 7 are deemed hazardous and 16 are deemed non-hazardous. From reviewing the invoice amounts and discussing with National Grid's

environmental engineers, the team determined it costs ~\$ per non-hazardous container removal and about \$ per hazardous (Environmental Engineer, Personal Communication). This means that hazardous waste containers make up 29% of all waste shipments, but 59% of the cost of removal. This leaves potential for 41% in cost savings by implementing a system to ensure all waste containers are labeled as non-hazardous. This would result in annual savings of ~\$ or ~\$ over the next decade.

4.8.2 Revenue stream creation from rubber recycling sales

Between the provided invoices and interviews with facility managers, the team was able to project estimates for selling the fluff insulation to external rubber recycling vendors. The four trial sales the team was provided averaged in weight at 21,525 lbs per sale and sold at a rate of \$ /lb, for a total of ~\$ in revenue per container (Office Technician). The team reached out to 11 recycling vendors in the upstate New York area and through them determined that it is feasible for National Grid to establish a long term relationship as a rubber commodity supplier with a recycling vendor if internal resources were dedicated to it.

We created a model to reflect the costs spent on waste removal as containers sold to a recycling vendor increases. If National Grid were to choose to not sell any containers of rubber insulation, they would be spending ~\$ annually on container shipments to non-hazardous waste landfills. At the current market rate, the facility would breakeven on waste removal costs after selling 17 shipments, using the new system. Assuming the annual number of containers remains at 23, this allows for National Grid to generate up to

\$ in revenue selling the remaining containers after breaking even. Figures 13 and 14 below show the results of the calculations.

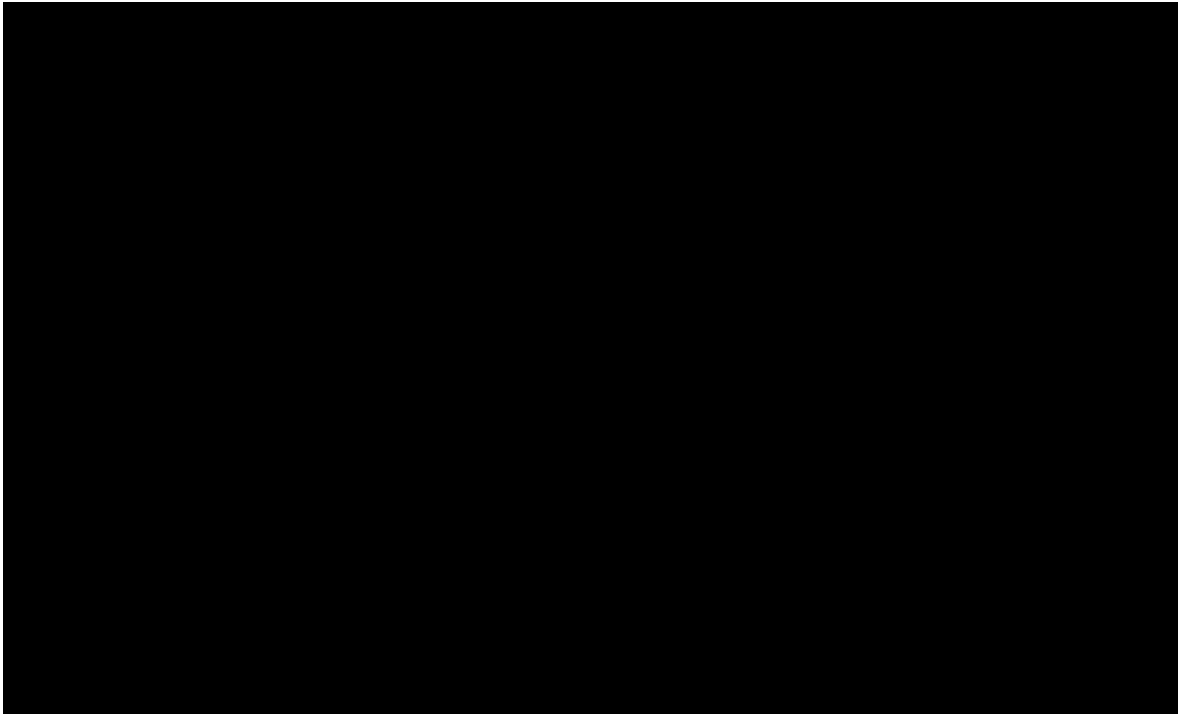


Figure 13: Landfill expenses vs. recycling sales graph

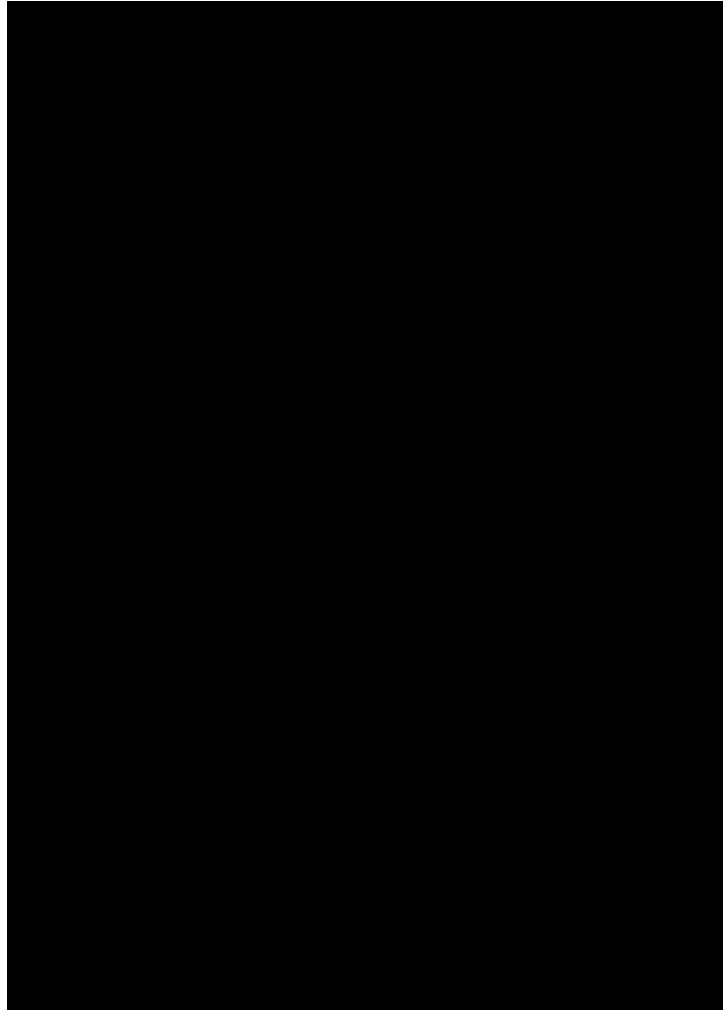


Figure 14: Revenue stream showing the breakeven point of the rubber recycling sales

The team also calculated the revenue that National Grid could bring in by selling all of its insulation waste to an external vendor over the next decade. The rubber and tire recycling industry, although considered a volatile market, is expected to grow 1.9% annually due to popularity of recyclable commodity markets (Peters, 2017). This increase in return rate over time is reflected in Figure 15. Using \$ /lb as the base rate and the projected growth rate of 1.9% annually, the average sale price per container would

increase from ~\$ to ~\$ over the next decade. If all fluff insulation containers could be sold during this time, it would result in ~\$ in accrued revenue through 2026, as shown in Figure 16.

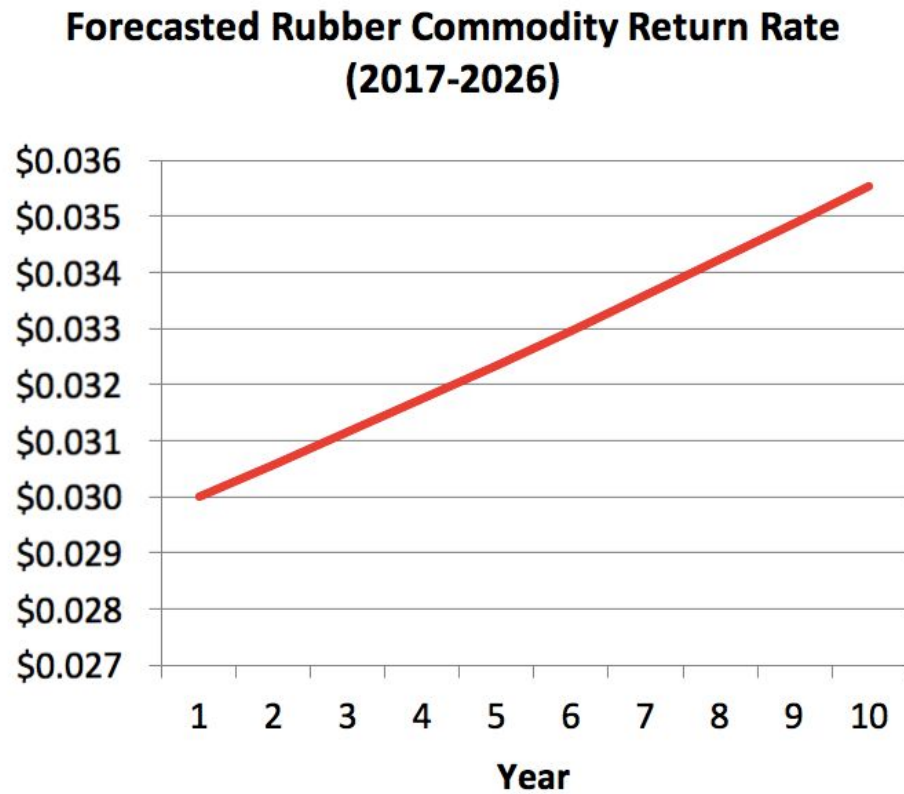


Figure 15: Forecasted return rate on rubber over the next 10 years

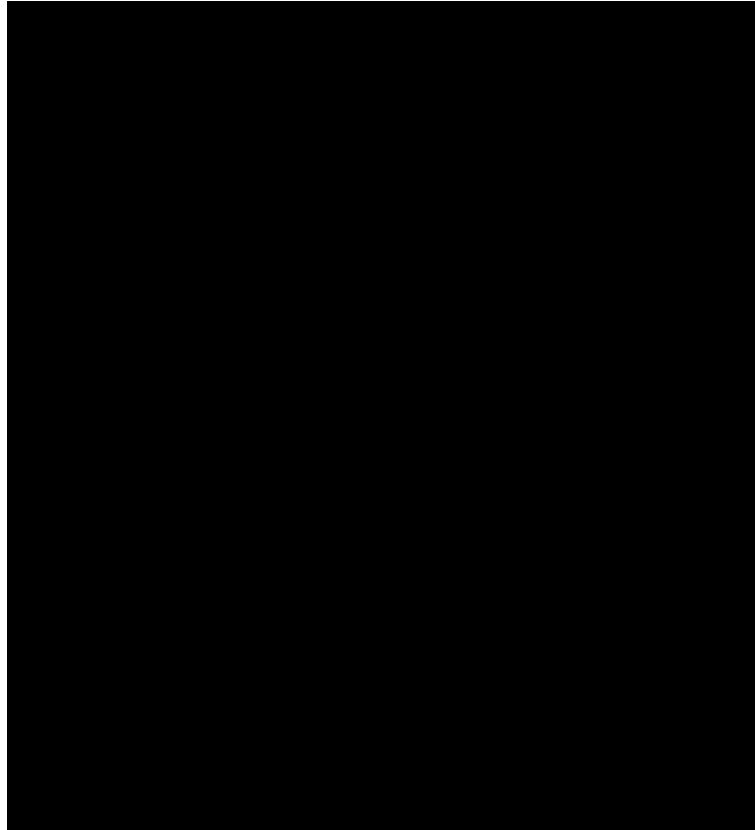


Figure 16: Revenue stream over the next 10 years from the fluff insulation

4.8.3 Total cost of electrostatic separator ownership

The team consulted several manufacturing firms that are familiar with waste separation. We provided them with throughput data, the content of the fluff insulation, and the concentration of metal that we needed to achieve in order to pass the TCLP test. To obtain our desired results, the most cost efficient machine was found to be an electrostatic separator (Sales Associate, Personal Communication). The team priced both new and used units from different vendors and came to the conclusion, with cost in mind, that a used Hamos 2 Stage Electrostatic Sorter would be best fit for National Grid's purposes (Machine Manufacturer, Personal Communication). Currently the machine is

priced at \$65,000 for the unit alone, not including shipping and installation (see Appendix H). The team contacted Alan Ross Machinery to obtain pricing for shipping, installation, and maintenance. Shipping and installation costs were estimated to be \$2,500. Maintenance costs typically run about \$200 annually, due to electrode replacements that might occur throughout the year. We added these together and compared the total cost of machine ownership to the savings it would bring the company, as shown in Figure 17. By combining the cost savings from eliminating waste removal with the revenue taken in from selling the insulation, the machine would be paid off about 10 months after purchase.

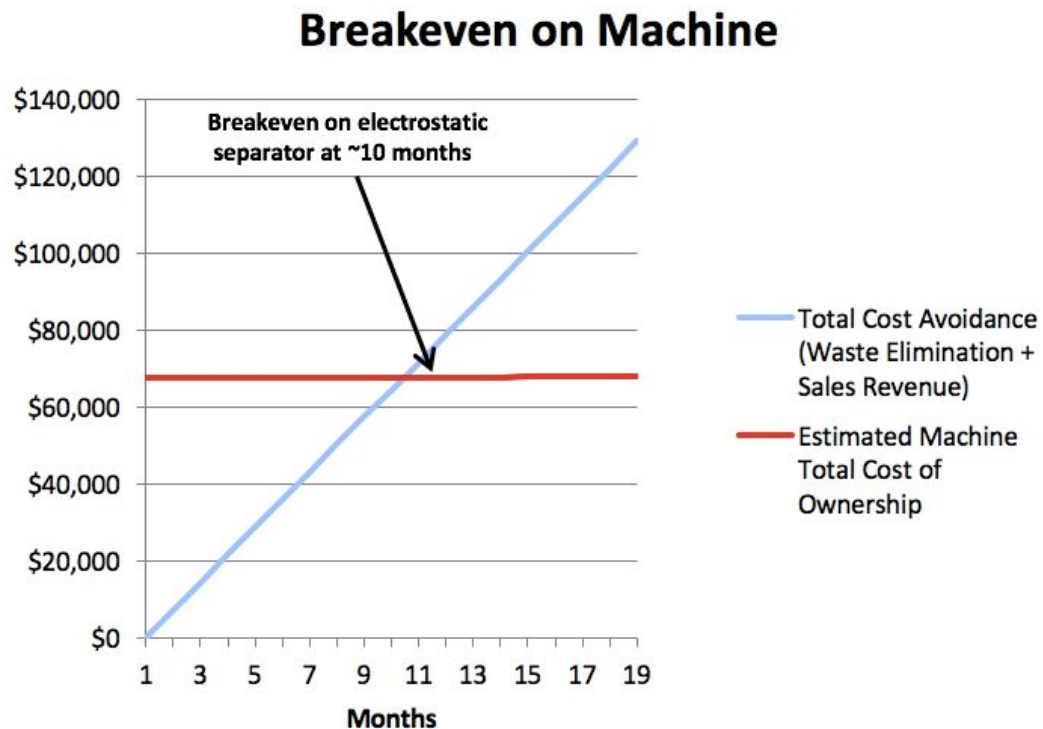


Figure 17: Breakeven point on electrostatic separator machine

Over ten years, this would result in a total financial impact of roughly \$ back in National Grid's pocket and a 1293% return on investment. See Figure 18 below.

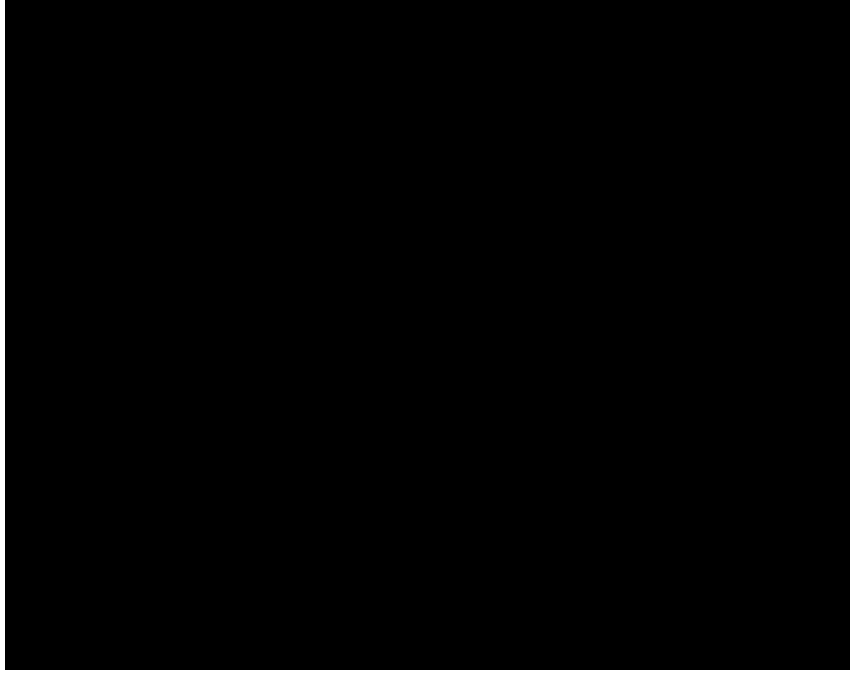


Figure 18: National Grid's total financial impact over the next 10 years

Chapter 5: Discussion

5.1 Coursework Application

In our efforts of addressing National Grid's waste stream costs from the granulator, the team used the knowledge that we had obtained from several courses over our tenure at WPI.

5.1.1 BUS 3010: Creating Value Through Innovation

One course that assisted in our process was BUS 3010: Creating Value Through Innovation. This course teaches students the different ways to innovate an existing technology, service, or process; as well as, where to look for the opportunities to innovate. According to Haag, in order for an innovation to be successful it must create value, either through financial profits or social welfare (Haag and Cummings, 2013). We used this thinking to create an incremental innovation of improving the efficiency of National Grid's existing process. We began our process of creating an incremental innovation by using the technique of benchmarking. Benchmarking is the process of continuously measuring a system's results, in order to help identify procedures that can be taken to improve the system's performance (Haag and Cummings, 2013). Our group used the throughput data of the granulator, provided by National Grid, in order to measure how much fluff waste is being created on average. We recognized that the amount of waste the accumulates over time was too large and costly for National Grid to ignore. Many

incremental innovations have come from the growth of science and technology that may not have existed when a process began. Therefore, our group decided to research material separation technology that had been developed after the installation of the granulator in 1984. We were able to identify an excellent material separation technique to implement into the granulation process. The rubber, when separated from the metal material, avoids the need for human contact with any lead contaminated metal. Therefore, the revenue stream that can be created through our improvement was a successful innovation because it created value for the company, in both financial profit and social welfare.

5.1.2 BUS 3020: Achieving Effective Operations

The ongoing maintenance costs and age of the machine forced National Grid to examine the decision of replacing the existing granulator. Through our groups communication with the National Grid team, we realized the importance of maximizing profit to be National Grid's overall goal. In the course BUS 3020: Achieving Effective Operations, students learn to analyze a process and to implement new processes within the constraints of the business and its resources. Our group's main constraint that we faced was the physical limits of the National Grid facility. Originally, the building was built around the granulator in order to fit the machine. Even after a new machine is implemented, the waste output would still travel to the baghouse. We measured the size of baghouse and its existing components with a tape measure. The dimensions of the building constrained our group from implementing any solution that would exceed the physical limits of the building. The Achieving Effective Operations course focuses

primarily on process improvement by identifying value and eliminating waste. Our group used the axiomatic design method to understand the goals of the company and to know of any solutions would be impactful. We were able to improve profit from the waste stream through the use of strategic sourcing. According to Jacobs and Chase, strategic sourcing improves the needs of a business by developing relationships as a supplier (Jacobs and Chase, 2008). Our group used strategic sourcing in finding a local company that would purchase the rubber from National Grid's waste stream. The rubber sales satisfy National Grid's need to get rid of the waste, while generating cash flow. For the local buyer, they receive a salable commodity at low shipping costs.

5.1.3 BUS 4030 Achieving Strategic Effectiveness

Many large corporations develop and utilize their own strategies to promote smart decision making when faced with new challenges. There are several strategic influencers that companies should consider when evaluating viable solutions. Some of these influencers include the network of stakeholders attached to the project, any external competitors, investor motivations, ethical implications, operational execution, and financial projections (Levenson, 2015). The team witnessed many of these influencers occur at National Grid over the course of this project. Stakeholder consideration was frequently addressed during weekly project meetings. A \$ million budget was approved for replacing the granulator and the work schedule spanned across several departments at National Grid, each with their own stakeholders. The associated departments included project management, investment recovery, procurement, facilities operation and

management, safety, environmental, and security. Ethical implications were discussed frequently during weekly team meetings. National Grid often expressed concern for the conditions that machine operators work in. A request to minimize air pollution and noise levels was added to the RFP. The team observed strategies for operational execution through National Grid's use of the Strategic Sourcing Process (SSP). The SSP was developed by the company's procurement employees and encompasses benchmarks called "gates" that the company uses to measure the progress of procurement projects. Each gate requires approval by project stakeholders before the project can continue. The SSP also incorporates a checklist that defines safety and security risks, schedules, negotiation strategies, and supplier scorecard rankings for individual projects (National Grid's Strategic Sourcing Process, 2017). This ensures accuracy of forecasted capital outlay, project deliverables, and alignment to core business functions. It also promotes transparency across the team and delineates responsibilities to individual team members. Having the opportunity as students to view the core internal processes of such a large company was valuable in preparing for our post-academic careers.

5.2 Axiomatic Design

By incorporating the axiomatic design approach into our project, the team was able to better understand and analyze the granulator waste stream. It gave us the tools to systematically approach different methods of bringing money into the facility. At the start of the project, the team was focused only on reducing disposal costs. It was not until we broke down the objective of maximizing the net present value of the fluff waste and

developed functional requirements to support it, that we realized there were potential alternatives to solely disposing of the insulation. Incorporating lean manufacturing into our axiomatic design decomposition also helped the team think through ideas to minimize the cost of producing the insulation waste. The coupling design matrix showed the team that the greatest opportunity for improved efficiency of the system was in finding a solution to the TCLP test failure. Using the axiomatic design method helped the team to view the problem statement from a solution neutral perspective.

5.3 Biggest Challenges

The biggest challenge that the team faced throughout the project was the geographical location of the facility relative to WPI. With the Investment Recovery building located outside of Syracuse, NY, it slowed our understanding of the processes that the granulator uses. It also meant that we had to rely on emails as our main form of contact with the sponsor team. The team often experienced lags in response time from the sponsor, which a manager attributed to the facility being understaffed. Another challenge our team faced was the data handling processes in place at the facility. The investment recovery facility hasn't been upgraded to the SAP® systems that the rest of the company enjoys, and are often forced to rely on pen and paper forms of data collection and sharing. This made it difficult for us to track down the location of invoices, drawings, and lab test results over the course of the project.

5.4 Project Changes

When we started our project, it began as an overall evaluation of the granulation process. The team intended to perform cost analysis on the possibility of purchasing a new granulator, along with evaluating various different ways granulating copper. However, when the team arrived for the first time in Syracuse, NY to meet with the National Grid team and to see the granulator in operation, the project had taken a different turn. National Grid had decided that their team would create the proposal for the replacement of the granulator, and wanted us to focus our efforts on the fluff waste stream. Having refined the scope of our project, we had more background knowledge on the machine and were better able to understand the process as a whole.

Chapter 6: Conclusion

This project revealed that there are opportunities for National Grid to both significantly decrease their costs of recycled copper wire and increase their annual revenue from adding the sale of recycled rubber at their Investment Recovery facility. We recommend that the company implement a separation process to further refine the output of their rubber insulation and sell it on the commodity market.

There were four key findings:

1. Constraints inherent in the machine and building it is housed in, as well as the throughput requirements, were identified. This enabled potential vendors to provide their competitive pricing on replacement granulators.
2. The elimination of hazardous waste removal costs alone would result in annual savings of roughly \$.
3. Purchasing a Hamos 2 Stage Electrostatic Sorter was determined to be the most cost efficient solution for refining the hazardous waste needed at the facility with a payback period of less than one year.
4. It is economically feasible for National Grid to sell its insulation “fluff” waste to external vendors on the rubber commodities market that could result in about \$ of annual revenue and about \$ in annual savings.

This project produced cost analyses for the sponsor team to support the decision making process changes for impacts to their granulation and waste removal systems.

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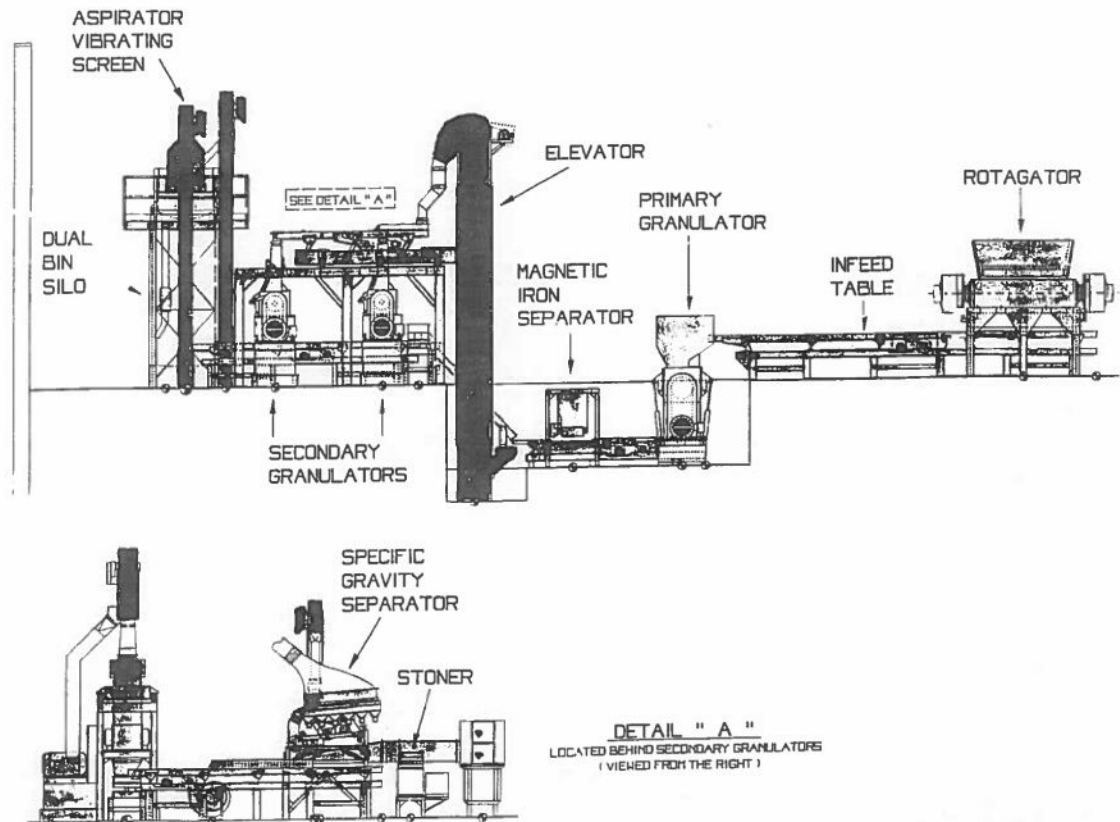
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Appendices

Appendix A: Existing Granulator Components




(Source: Diagram of Granulator, n.d.)



Appendix B: TCLP Lab Results of Fluff Waste

(Source: Sun Environmental TCLP Lab Results, 2017)

(Note: Personal contact information may have been removed to protect the identities of individuals)

<div><p>Analytical Report For Sun Environmental Corp. <i>For Lab Project ID</i></p><p><i>Referencing</i> Investment Recovery, 4651 Crossroads Park Dr. H-2 <i>Prepared</i> Thursday, November 2, 2017</p><p>Any noncompliant QC parameters or other notes impacting data interpretation are flagged or documented on the final report or are noted below.</p><hr/><p>Certifies that this report has been approved by the Technical Director or Designee</p><p>179 Lake Avenue • Buchanan, NY 14608 • (815) 647-2630 • Fax (815) 647-3211 • ELAP ID# 10958</p><p>This report is part of a multipage document and should only be evaluated in its entirety. The Chain of Custody provides additional sample information, including compliance with the sample condition requirements upon receipt. <i>Report Prepared: Thursday, November 2, 2017</i></p></div> <div>1 of 6</div>	<div><p>Lab Project ID:</p><p>Client: Sun Environmental Corp. Project Reference: Investment Recovery, 4651 Crossroads Park Dr. H-2</p><table><tr><td>Sample Identifier: H-2</td><td>Date Sampled: 10/25/2017</td></tr><tr><td>Lab Sample ID:</td><td>Date Received: 10/27/2017</td></tr><tr><td>Matrix: TCLP Extract</td><td></td></tr></table><p>TCLP Metals (ICP)</p><table><tr><th>Analyte</th><th>Result</th><th>Units</th><th>Regulatory Limit</th><th>Qualifier</th><th>Date Analyzed</th></tr><tr><td>Lead</td><td>3.01</td><td>mg/L</td><td>5</td><td></td><td>11/1/2017 16:10</td></tr></table><p>Method Reference(s): EPA 8210C EPA 8211 / 8055A 10/31/2017 Data File: 171101B</p><p>Recognizing that the nature of many samples is unknown and that some may contain potentially hazardous components, LAB warrants only that it will perform testing services, obtain findings, and prepare reports in accordance with generally accepted analytical laboratory principles and practices at the time of performance of services. 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Such taxes will be added to invoice prices when required.</p><p>Compensation for services performed will be based on the current LAB Analytical Fee Schedule or on quotations agreed to in writing by the parties. Turnaround time based charges are determined from the time of resolution of all work order questions. Testimony, court appearances or data compilation for legal action will be charged separately. Evaluation and reporting of initial screening tests may incur additional fees.</p><p>In the event of any error, omission, or other professional negligence, the sole and exclusive responsibility of LAB shall be to re-perform the deficient work at its own expense and LAB shall have no other liability whatsoever. 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Such causes and circumstances shall include, but not limited to, acts of God, acts or orders of any government authority, strikes or other labor disputes, natural disasters, accidents, wars, civil disturbances, difficulties or delays in transportation, mail or delivery services, inability to obtain sufficient services or supplies from LAB's usual suppliers, or any other cause beyond LAB's reasonable control.</p><p>Law. This contract shall be continued under the laws of the State of New York without regard to its conflicts of laws provisions.</p><p>This report is part of a multipage document and should only be evaluated in its entirety. The Chain of Custody provides additional sample information, including compliance with the sample condition requirements upon receipt. <i>Report Prepared: Thursday, November 2, 2017</i></p></div> <div>2 of 6</div>	Sample Identifier: H-2	Date Sampled: 10/25/2017	Lab Sample ID:	Date Received: 10/27/2017	Matrix: TCLP Extract		Analyte	Result	Units	Regulatory Limit	Qualifier	Date Analyzed	Lead	3.01	mg/L	5		11/1/2017 16:10
Sample Identifier: H-2	Date Sampled: 10/25/2017																		
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Lead	3.01	mg/L	5		11/1/2017 16:10														
<div><p>Analytical Report Appendix</p><p>The reported results relate only to the samples as they have been received by the laboratory.</p><p>Each page of this document is part of a multipage report. This document may not be reproduced except in its entirety, without the prior consent of Paradigm Environmental Services, Inc.</p><p>All soil/sludge samples have been reported on a dry weight basis, unless qualified "reported as received". Other solids are reported as received.</p><p>Low level Volatiles blank reports for soil/solid matrix are based on a nominal 5 gram weight. Sample results and reporting limits are based on actual weight, which may be more or less than 5 grams.</p><p>The Chain of Custody provides additional information, including compliance with sample condition requirements upon receipt. Sample condition requirements are defined under the 2003 NELAC Standard, sections 5.5.8.3.1 and 5.5.8.3.2.</p><p>NYSDOH ELAP does not certify for all parameters. Paradigm Environmental Services or the indicated subcontracted laboratory does hold certification for all analytes where certification is offered by ELAP unless otherwise specified. Aliquots separated for certain tests, such as TCLP, are indicated on the Chain of Custody and final reports with an "A" suffix.</p><p>Data qualifiers are used, when necessary, to provide additional information about the data. This information may be communicated as a flag or as text at the bottom of the report. Please refer to the following list of analyst-specific, frequently used data flags and their meaning:</p><p>"<" = Analyzed for but not detected at or above the quantitation limit. "E" = Result has been estimated, calibration limit exceeded. "Z" = See case narrative. "D" = Sample, Laboratory Control Sample, or Matrix Spike Duplicate results above Relative Percent Difference limit. "M" = Matrix spike recoveries outside QC limits. Matrix bias indicated. "B" = Method blank contained trace levels of analyte. Refer to included method blank report. "J" = Result estimated between the quantitation limit and half the quantitation limit. "L" = Laboratory Control Sample recovery outside accepted QC limits. "P" = Concentration differs by more than 40% between the primary and secondary analytical columns. "NC" = Not calculable. Applicable to RPD if sample or duplicate result is non-detect or estimated (see primary report for data flags). Applicable to MS if sample is greater or equal to ten times the spike added. Applicable to sample surrogates or MS if sample dilution is 10x or higher. "A" = Indicates any recoveries outside associated acceptance windows. Surrogate outliers in samples are presumed matrix effects. LCS demonstrates method compliance unless otherwise noted. "I" = Indicates data from primary column used for QC calculation. "A" = denotes a parameter for which ELAP does not offer approval as part of their laboratory certification program. "F" = denotes a parameter for which Paradigm does not carry certification, the results for which should therefore only be used where ELAP certification is not required, such as personal exposure assessment.</p><p>This report is part of a multipage document and should only be evaluated in its entirety. The Chain of Custody provides additional sample information, including compliance with the sample condition requirements upon receipt. <i>Report Prepared: Thursday, November 2, 2017</i></p></div> <div>3 of 6</div>	<p>GENERAL TERMS AND CONDITIONS LABORATORY SERVICES</p> <p>These Terms and Conditions embody the whole agreement of the parties in the absence of a signed and executed contract between the Laboratory (LAB) and Client. They shall supersede all previous communications, representations, or agreements, either verbal or written, between the parties. The LAB specifically rejects all additional, inconsistent, or conflicting terms, whether printed or otherwise set forth in any purchase order or other communication from the Client to the LAB. The invalidity or unenforceability in whole or in part of any provision, term or condition hereof shall not affect in any way the validity or enforceability of the remainder of the Terms and Conditions. No waiver by LAB of any provision, term, or condition hereof or of any breach by or obligation of the Client hereunder shall constitute a waiver of such provision, term, or condition in any other occasion or a waiver of any other breach by or obligation of the Client. This agreement shall be administered and interpreted under the laws of the state which services are provided.</p> <p>Warranty. Recognizing that the nature of many samples is unknown and that some may contain potentially hazardous components, LAB warrants only that it will perform testing services, obtain findings, and prepare reports in accordance with generally accepted analytical laboratory principles and practices at the time of performance of services. LAB makes no other warranty, express or implied.</p> <p>Scope and Compensation. LAB agrees to perform the services described in the chain of custody to which these terms and conditions are attached. The parties agree in writing to the contrary, the duties of LAB shall not be construed to exceed the services specifically described. LAB will use LAB default method for all tests unless specified otherwise on the Work Order.</p> <p>Payment terms are net 30 days from the date of invoice. All service payments are subject to an interest charge of one and one-half percent (1 1/2%) per month or a portion thereof. Client shall also be responsible for costs of collection, including payment of reasonable attorney fees if such expense is incurred. The prices, unless stated, do not include any sale, use or other taxes. Such taxes will be added to invoice prices when required.</p> <p>Compensation for services performed will be based on the current LAB Analytical Fee Schedule or on quotations agreed to in writing by the parties. Turnaround time based charges are determined from the time of resolution of all work order questions. Testimony, court appearances or data compilation for legal action will be charged separately. Evaluation and reporting of initial screening tests may incur additional fees.</p> <p>In the event of any error, omission, or other professional negligence, the sole and exclusive responsibility of LAB shall be to re-perform the deficient work at its own expense and LAB shall have no other liability whatsoever. All claims shall be deemed waived unless made in writing and received by LAB within thirty (30) days following completion of services.</p> <p>LAB shall have no liability, obligation, or responsibility of any kind for losses, costs, expenses, or other damages (including but not limited to any special, direct, incidental or consequential damages) with respect to LAB's services or results.</p> <p>All results provided by LAB are strictly for the use of its clients and LAB is in no way responsible for the use of such results by clients or third parties. All reports should be considered in their entirety and LAB is not responsible for the separation, detachment, or other use of any portion of these reports. Client may not assign the lab report without the written consent of the LAB. Client covenants and agrees, at its/their sole expense, to indemnify, protect, defend, and save harmless the LAB from and against any and all damages, losses, liabilities, obligations, penalties, claims, litigation, demands, defenses, judgments, suits, actions, proceedings, costs, disbursements and/or expenses (including, without limitation attorneys' and experts' fees and disbursements) of any kind whatsoever which may at any time be imposed upon, incurred by or asserted or awarded against client relating to, resulting from or arising out of (a) the breach of this agreement by this client; (b) the negligence of the client in handling, delivering or disclosing any hazardous substance; (c) the violation of the Client of any applicable law; (d) non-compliance by the Client with any environmental permit or (e) a material misrepresentation in disclosing the materials to be tested.</p> <p>Client represents and warrants that any sample delivered to LAB will be provided or accompanied by complete written disclosure of the presence of any hazardous substances known or suspected by Client. Client further warrants that any sample containing any hazardous substance that is to be delivered to LAB will be packaged, labeled, transported, and delivered properly and in accordance with applicable laws.</p> <p>Hazard Disclosure. Prior to LAB's acceptance of any sample (or after any revocation of acceptance), the entire risk of loss or of damage to such sample remains with Client. Samples are accepted when receipt is acknowledged on chain of custody documentation. In no event will LAB have any responsibility for the action or inaction of any carrier shipping or delivering any sample to or from LAB premises. Client authorizes LAB to proceed with the analysis of samples as received by the laboratory, recognizing that any sample not in compliance with all current D01-ELAP-NELAP requirements for containers, preservation or holding time will be treated as such on this final report.</p> <p>Disposal of hazardous waste samples is the responsibility of the Client. If the Client does not wish such samples returned, LAB may store and disposal fees to the final invoice. Maximum storage time for samples is 30 days after completion of analysis unless modified by applicable state or federal laws. Client will be required to give the LAB written instructions concerning disposal of these samples.</p> <p>LAB reserves the absolute right, exercisable at any time, to refuse to receive delivery of, refuse to accept, or revoke acceptance of any sample, which, in its sole judgment of LAB is (a) of an unstable nature; (b) may be or become unstable for or may pose a risk in handling, transport, or processing for any health, safety, environmental or other reason whether or not due to the presence in the sample of any hazardous substances; and, whether or not such presence has been disclosed to LAB by Client or (c) if the condition or sample date make the sample unsuitable for analysis.</p> <p>Legal Responsibility. LAB is solely responsible for performance of this contract, and no affiliated company, director, officer, employee, or agent shall have any legal responsibility hereunder, whether in contract or tort including negligence.</p> <p>Assignment. LAB may assign its performance obligations under this contract to other parties, as it deems necessary. LAB shall disclose to Client any assignee (subcontractor) by ELAP ID # on the submitted final report.</p> <p>Force Majeure. LAB shall have no responsibility or liability to the Client for any failure or delay in performance by LAB, which results in whole or in part from any cause or circumstance beyond the reasonable control of LAB. Such causes and circumstances shall include, but not limited to, acts of God, acts or orders of any government authority, strikes or other labor disputes, natural disasters, accidents, wars, civil disturbances, difficulties or delays in transportation, mail or delivery services, inability to obtain sufficient services or supplies from LAB's usual suppliers, or any other cause beyond LAB's reasonable control.</p> <p>Law. This contract shall be continued under the laws of the State of New York without regard to its conflicts of laws provisions.</p> <p>This report is part of a multipage document and should only be evaluated in its entirety. The Chain of Custody provides additional sample information, including compliance with the sample condition requirements upon receipt. <i>Report Prepared: Thursday, November 2, 2017</i></p>																		

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Chain of Custody Supplement

Client: Sun Environmental Completed by: _____
Lab Project ID: _____ Date: 10/27/17

Sample Condition Requirements

For NSLAC/ELAP 110/141/142/145/144

Condition	Yes	No	N/A
Container Type	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transferred to method: unopened container	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Headspace (≤ 1 mL)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Preservation	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Chlorine Alkyl (≤ 1.0 ppm per test strip)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Hold Time	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Temperature	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Sufficient Sample Quantity	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

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SUN ENVIRONMENTAL CORP.

CHAIN OF CUSTODY RECORD

5 of 6

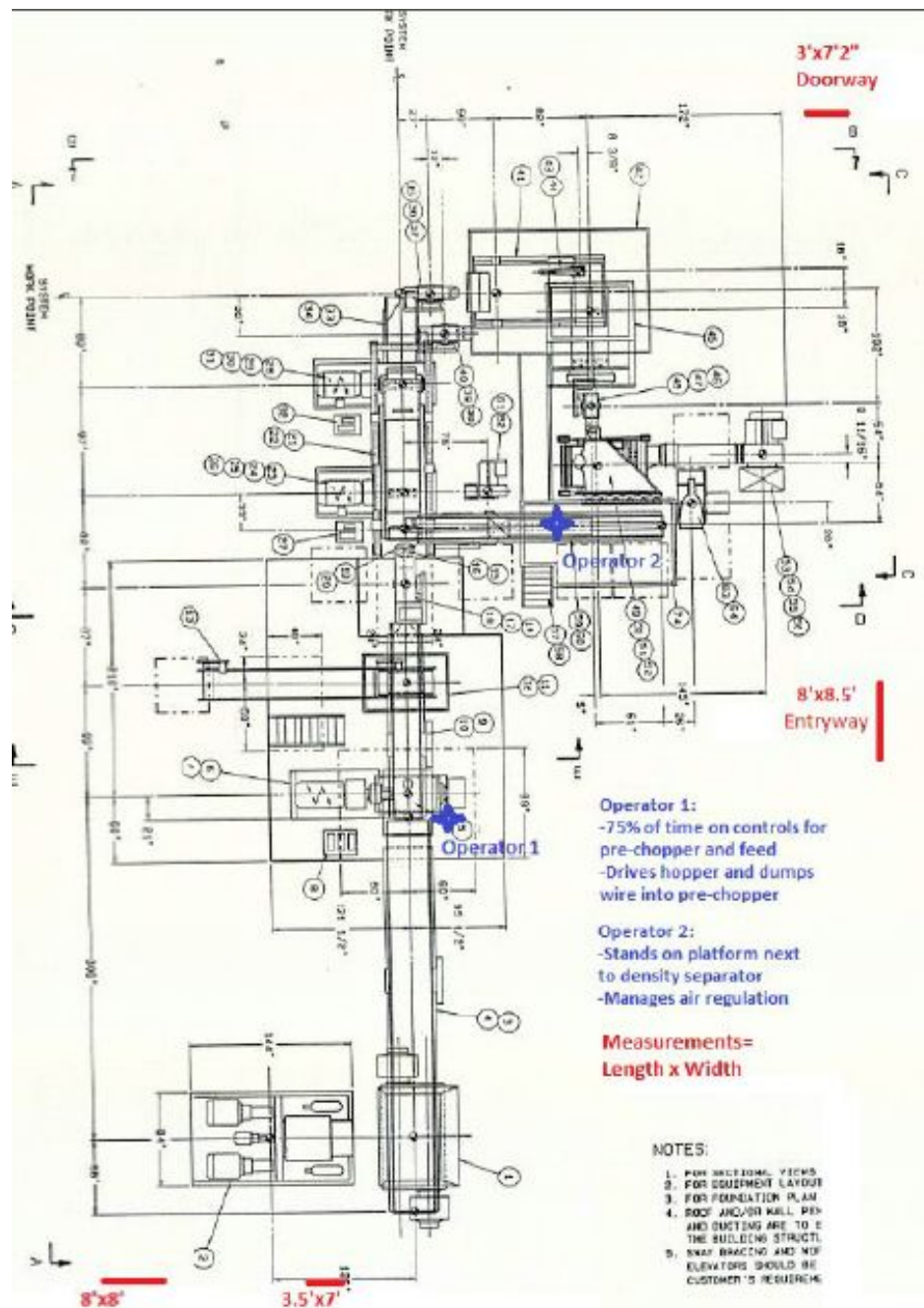
Customer Information		Project Information	
Address: 1575 BAYVIEW DRIVE	City: Santa Ana	Project: SUN ENVIRONMENTAL CORP.	Site: 1575 BAYVIEW DRIVE
Phone: 714-951-2000	Fax: 714-951-2000	Project Manager: J. J. J.	Site Manager: J. J. J.
Customer: SUN ENVIRONMENTAL CORP.	Contract: 1000000000000000	Project Location: 1575 BAYVIEW DRIVE	Project Address: 1575 BAYVIEW DRIVE
Address: 1575 BAYVIEW DRIVE	City: Santa Ana	Project Location: 1575 BAYVIEW DRIVE	Project Address: 1575 BAYVIEW DRIVE
Phone: 714-951-2000	Fax: 714-951-2000	Project Location: 1575 BAYVIEW DRIVE	Project Address: 1575 BAYVIEW DRIVE
Total Sample Time: 10/27/17			
Sample Type: 5 DAY TAT			
Sample Location: 1575 BAYVIEW DRIVE			
Sample Date: 10/27/17			
Sample Time: 10:00 AM			
Sample Temperature: 4°C			
Sample Quantity: 100 mL			
Sample Container: 100 mL			
Sample Label: 100 mL			
Sample Storage: 100 mL			
Sample Transport: 100 mL			
Sample Analysis: 100 mL			
Sample Results: 100 mL			
Sample Comments: 100 mL			

10/27/17 11:46

2.82

Appendix C: Existing Granulator Drawing Included in RFP

(Source: Granulator Install Diagram, n.d.)



Appendix D: Acclaro® Decomposition and Coupling Matrix

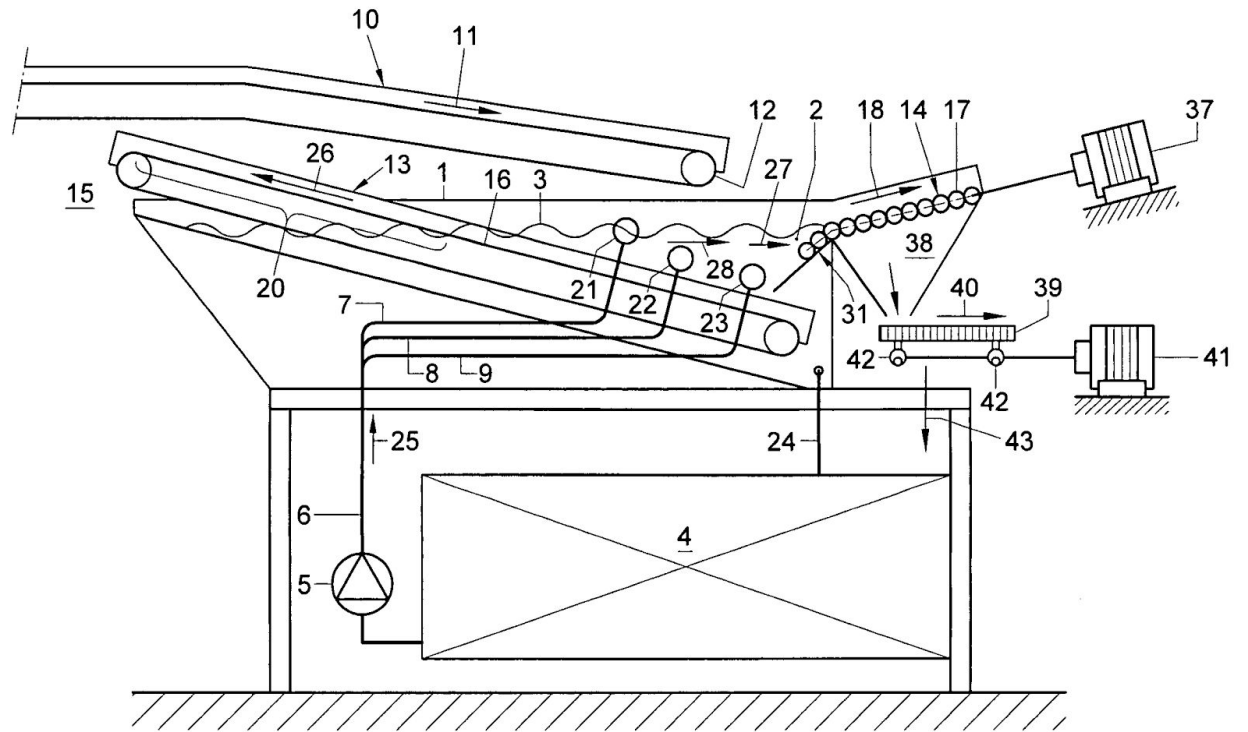
(Source: Acclaro® Software DFSS, 1998)

	DP0: System for maximizing net p	DP1: System for maximizing v	DP1.1: System for maximiz	DP1.1.1: System for se	DP1.1.1.1: Standar	DP1.1.1.2: Standar	DP1.1.1.3: System	DP1.1.2: System for us	DP1.1.2.1: Develop	DP1.1.2.2: Develop	DP1.1.3: System for d	DP1.1.3.1: System	DP1.1.3.2: System	DP1.1.3.2.1: Sy	DP1.1.3.2.2: Sy	DP1.1.3.3: System	DP1.2: Process for maxim	DP1.2.1: System for m	DP1.2.2: System for m	DP2: Lean waste analysis	DP2.1: System for storing	DP2.2: System for maxim	DP2.3: System for minimi	DP2.4: System for minimi	DP2.5: System for efficien	DP2.6: System for reducin	DP2.6.1: System for re	DP2.6.2: System for m
FR0: Maximize net present value for fluff waste stream	X																											
FR1: Maximize the value added to the granulator waste		X																										
FR1.1: Maximize monetary value of fluff product			X																									
FR1.1.1: Sell fluff				X																								
FR1.1.1.1: Measure weight of fluff per load					X																							
FR1.1.1.2: Measure quality of fluff per load						X																						
FR1.1.1.3: Outsource product to outside company							X																					
FR1.1.2: Use fluff internally								X																				
FR1.1.2.1: Use fluff for compression molding									X																			
FR1.1.2.2: Use fluff for adhesive molding										X																		
FR1.1.3: Dispose/recycle fluff											X																	
FR1.1.3.1: Segregate fluff by material												X																
FR1.1.3.2: Bury waste in landfill													X															
FR1.1.3.2.1: Bury waste in non-hazardous landfill														X														
FR1.1.3.2.2: Bury waste in hazardous landfill															X													
FR1.1.3.3: Recycle fluff																X												
FR1.2: Maximize safety of creating fluff waste																	X											
FR1.2.1: Minimize human resources needed																		X										
FR1.2.2: Minimize lead dust in air																			X									
FR2: Minimize cost of creating fluff																				X								
FR2.1: Reduce transportation of fluff from separator to baghouse																					X							
FR2.2: Reduce inventory of fluff sitting in warehouse																						X						
FR2.3: Reduce movement of fluff waste																							X					
FR2.4: Reduce waiting caused by machine filter maintenance																								X				
FR2.5: Reduce over-processing of fluff creation																									X			
FR2.6: Reduce defects of fluff waste																										X		
FR2.6.1: Reduce defects of fluff due to TCLP test failure																											X	
FR2.6.2: Reduce defects of fluff escaping system																												X

#	[FR] Functional Requirements	[DP] Design Parameters	FR M
0	Maximize net present value for fluff waste stream	System for maximizing net present value of fluff waste stream	
1	Maximize the value added to the granulator waste	System for maximizing value add of fluff waste	
1.1	Maximize monetary value of fluff product	System for maximizing dollar value of fluff waste	
1.1.1	Sell fluff	System for selling fluff waste	
1.1.1.1	Measure weight of fluff per load	Standard metric for weighing fluff output	
1.1.1.2	Measure quality of fluff per load	Standard metric for measuring quality of fluff	
1.1.1.3	Outsource product to outside comany	System for selling fluff output to outside company	
1.1.2	Use fluff internally	System for using fluff internally	
1.1.2.1	Use fluff for compression molding	Develop system for internal compression molding	
1.1.2.2	Use fluff for adhesive molding	Develop system for internal adhesive molding	
1.1.3	Dispose/recycle fluff	System for disposing/recycling fluff	
1.1.3.1	Segregate fluff by material	System for segregating fluff by component	
1.1.3.2	Bury waste in landfill	System for burying waste in landfill	
1.1.3.2.1	Bury waste in non-hazardous landfill	System for <5 parts/mil landfill disposal	
1.1.3.2.2	Bury waste in hazardous landfill	System for >5 parts/mil landfill disposal	
1.1.3.3	Recycle fluff	System for outsourcing fluff to recycling company	
1.2	Maximize safety of creating fluff waste	Process for maximizing safety during granulation	
1.2.1	Minimize human resources needed	System for maximizing efficiency of operator's day	
1.2.2	Minimize lead dust in air	System for measuring air quality content	
2	Minimize cost of creating fluff	Lean waste analysis	
2.1	Reduce transportation of fluff from separator to baghou	System for storing fluff by output conveyor	
2.2	Reduce inventory of fluff sitting in warehouse	System for maximizing fluff exported per sale	
2.3	Reduce movement of fluff waste	System for minimizing length of travel between filter/separator and	
2.4	Reduce waiting caused by machine filter maintenance	System for minimizing shutdowns for filter cleaning	
2.5	Reduce over-processing of fluff creation	System for efficiently separating fluff from product	
2.6	Reduce defects of fluff waste	System for reducing defects of fluff waste	
2.6.1	Reduce defects of fluff due to TCLP test failure	System for removing lead <5 parts per million	
2.6.2	Reduce defects of fluff escaping system	System for minimizing exposed areas of process line	

Appendix E: Water Bath Separator Design

(Source: Boer, 2005)



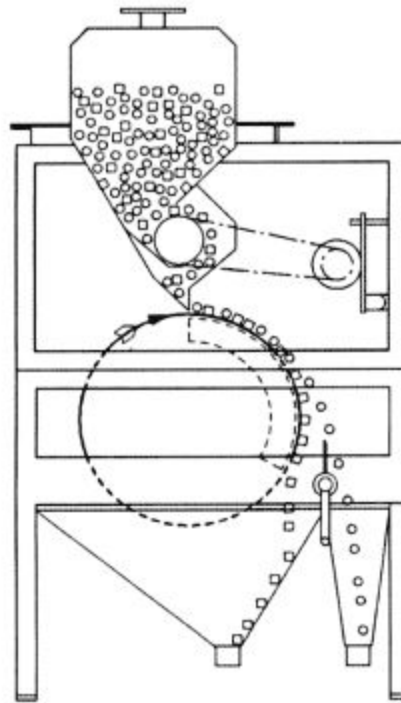
Appendix F: Density Separator

(Source: Triple/S Dynamics, Inc., 2017)



Appendix G: Magnetic Separator Design


(Source: Australian Magnetic Solutions, 2004)



Appendix H: Quote for Hamos 2 Stage Electrostatic Separator by Alan Ross Machinery

(Source: Alan Ross Financial Quote, 2017)


(Note: Personal contact information may have been removed to protect the identities of individuals)

<div></div> <div><div>CUSTOMER</div></div> <div><div>SALESPERSON</div></div> <div><div>QUOTE</div></div> <div><p>11/16/2017 RSN:</p><p>Sorting ferrous or non-ferrous metals? Ask about Magnapower magnetics and eddy sorters. https://prod.alanross.biz/content/magnetic-sortation-systems</p><p>Approximate specifications per manufacturer's literature. Please see this link (https://insight.alanrossmachinery.com/media/identities/Alan_Ross_Machinery_TC_05-21-2012.pdf) for our important terms and conditions of sale.</p><h3>Model KWS 1521-1 Used Hamos 2 Stage Electrostatic Sorter</h3><ul style="list-style-type: none">(2) 3x1500mm DrumsApprox 1000 Kg/Hr Capacity</div>	<p>The Hamos KWS Electrostatic Metal/PET Separators remove any metal from PET flakes and other plastics. Even the finest metal particles can be removed from PET flakes, for optimal separation, the PET flakes must be dry with a residual moisture of less than 0.5%, and a particle size of less than 12mm.</p> <p>Applications: PET Flakes Mixed Flakes Plastic Composites And many other recyclable plastics</p> <p>PHOTOS</p> <p>CLICK HERE FOR PHOTO 1 (HTTP://BIT.LY/2A6NQHLL) CLICK HERE FOR PHOTO 2 (HTTP://BIT.LY/2A6NQHLL)</p> <p>CLICK HERE FOR PHOTO 3 (HTTP://BIT.LY/2A6NQHLL)</p> <p>VIDEOS</p> <p>This equipment has no videos</p> <p>DOCUMENTS</p> <p>REQUEST LITERATURE</p> <p>Request Literature: http://bit.ly/2A6nqHL Use this link to view photos, videos and documents for this equipment: http://bit.ly/2A6nqHL</p> <hr/> <p>Price: \$65,000</p> <p>As low as \$1,312.74/month (subject to credit approval)</p> <p>Condition: As Is Loading: At-Site</p> <p>The sale of this equipment is subject to important terms and conditions available here (https://insight.alanrossmachinery.com/media/identities/Alan_Ross_Machinery_TC_05-21-2012.pdf).</p>
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Appendix I: Invoice For A Non-Hazardous Shipment

(Source: Invoice For Fluff Waste Shipment, 2017)

(Note: Personal contact information may have been removed to protect the identities of individuals)



Faster, smarter, greener solutions.™

Invoice Number:

Invoice Date: **07/28/2017**

Due Date: **08/27/2017**

Customer #:

Work Order #: PO#: Generator: **Niagara Mohawk- Sun Environmental**

Disposal

Date	Description	Quantity	Unit	Unit Price	Line Price
7/24/2017	0009029146-1 / 173082985 / Cyclone Baghouse Load (Just- Haz / Roboff/Dump	12.16	Ton	\$118.00	\$1,434.88

Taxes/Fees

Date	Description	Quantity	Unit	Unit Price	Line Price
7/28/2017	BEI Fee (13.5%)	1.00	Each	\$193.71	\$193.71
7/28/2017	Non-Hazardous Waste Manifest Fee	1.00	Each	\$10.00	\$10.00

Work Order Subtotal: **\$1,638.59**

12.16 Ton(s)

Invoice Total \$1,638.59