Feasibility Analysis of Spent Foundry Sand Reuse for Advanced Cast Products



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Submitted in fulfillment of the senior thesis requirements of the
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and approved by the senior thesis committee.

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Sand is one of the most widely used building commodities in the world, yet little is being done to recycle the material. In the metal foundry industry, spent foundry sand has been shown capable of being reused in soil, asphalt, and concrete applications. This study examined whether Advanced Cast Products, a ductile iron foundry located in Meadville, PA could feasibly sell its spent foundry sand to a company within 115miles of the foundry while spending less money than currently used to dispose of the spent foundry sand**.** Through examining 163 companies for characteristics compatible with spent foundry sand reuse and running cost analyses modeling different scenarios I found that over half the companies were suitable to accept spent foundry sand, and that Advanced Cast Products has the potential of over $166,800 in net earnings. Advanced Cast Products should reach out to the companies scoring a 3.0 or better in the weighted analysis to see if there is interest in establishing a business partnership.

1. Introduction

Deemed "the most valuable nonfuel mineral commodity in the world", natural aggregates such as sand, gravel, and rock are simultaneously creating and destroying the Earth (Drew et al., 2002). Sand is perhaps the worst offender, as over 62.1 million metric tons (Mt) was mined in the United States in 2013, an increase of over 12Mt from 2012 (Dolley, 2015). Extraction rates of virgin sand are currently above the sustainable yield, yet little is being done in the way of recycling sand (Sreebha & Padmalal, 2011;Wilburn & Goonan, 1998). Research within the industrial sector is focused on how to reuse sand and other materials among many different firms, in a process known as industrial ecology (Benson, & Bradshaw, 2011; Michael von Hauff and Peter Wilderer 2007).

The metal forging industry can benefit from implementing an industrial ecology model, particularly as sand makes up a large percentage of waste material in a foundry (Ji, Wan, & Fan, 2001). This *spent foundry sand* (SFS) is a remnant of the casting process,and so long as the sand was used to cast iron, steel, or aluminum, it is safe for reuse in other applications as there is no potential for metal to leach from the SFS (Foundry, 2004). This material's reuse is suitable in three main areas: as a soil amendment for potting soil use, as an aggregate for building materials, and in road construction (Risk, 2014; Alonso-Santurde et. al, 2011; Carpenter, & Gardner, 2009; Using, 2009). Used as a soil amendment SFS has been shown to help plants grow larger than on natural soil (Stehouwer, Hindman, & MacDonald, 2010). Meanwhile if SFS is used in concrete it can strengthen the block by 15% (Siddique et. al, 2015). When used in road construction, SFS abides both mechanical and environmental regulations on top of saving 17,800,000 megajoules of energy from being spent and 1,500 metric tons of carbon from being released into the atmosphere (EPA, 2014; Yazoghli-Marzouk, et. al, 2014).

One company that could implement this is Advanced Cast Products, a ductile iron foundry located in Meadville, PA. The 200 employee operation produces parts for heavy trucks, mining and railroad operations, as well as for construction. The foundry currently disposes of roughly 2,000 tons of SFS annually through Allegheny Recovery Corporation (2015). Seeing a potential business opportunity, Advanced Cast Products has expressed interest in selling SFS for beneficial reuse rather than use its current disposal method. The main concerns are to whether there are companies in the area suitable to sell spent foundry sand to and whether it would result in a net savings for Advanced Cast Products. The purpose of this research is to identify which firms in the area are most suitable for buying Advance Cast's SFS and to quantify how much money could be made by selling the spent foundry sand.

2. Methods

2.1. Identification of Suitable Firms

I located potting soil manufacturers, concrete manufacturers, and asphalt manufacturers within a 115 mile distance of Advanced Cast Products as the literature suggests these industries are compatible with spent foundry sand (SFS) reuse. The distance was chosen because Advanced Cast Products currently disposes of its spent foundry sand 115 miles away from the foundry.

Each firm was examined and ranked on four criterion: distance from Advanced Cast, the distance from Advanced Cast Products to the firm, how much SFS the firm could use, the size of the company, and whether the firm has the means to transport the SFS. The distance to travel from Advanced Cast is a measure of how costly and polluting it would be to transport SFS to the firm. Firms that are closer to Advanced Cast would require less transportation costs and have less

CO_2 emissions associated with travel. The third measure involving the amount of sand each firm can take is necessary as each industry can utilize different ratios of SFS in their products. A firm's ability to haul the spent foundry sand by itself cuts down on costs as Advanced Cast Products would not have to hire a trucking company to move the spent foundry sand. Finally, the size of the firm in question is of importance as smaller firms are more adept to making changes than larger corporations.

Using geographical information systems (GIS) the firms were then ranked in each criterion with scores 1-5 with 5 being the most suitable, and 1 being the least suitable. The ranks and specifications of each criterion are listed in tables 1, 2, 3, and 4.

Table 1 Ranking of firm based on its distance from Advanced Cast Products. Shorter distances are more favorable as it takes less money to transport the spent foundry sand.

Distance (miles)	Rank
< 34.20	5
34.21-55.90	4
55.91-77.30	3
77.31-94.00	2
94.01-115.00	1

The distance rankings were determined using the natural breaks classification system, where the GIS software determines where data is 'naturally' grouped together and sets the intervals based on those groupings.

Table 2 Ranking of Firm based on number of people employed by the firm. Firms with fewer employees may have more flexibility in being able to change business decisions and thus be more capable of using spent foundry sand.

Number of Employees	Rank
1-49	5
50-199	4
200-499	3
500-999	2
1000+	1

The intervals for number of employees were determined manually, however, still following the technique of natural breaks by placing ranks where the data showed clumping.

Table 3 Ranking of firm based on which industry it belongs to. Different industries require different amounts of sand for the output product, with

Industry Type	Rank
Potting Mix	5
Concrete	3
Asphalt	1

The ranking of industry was determined based on the amount of SFS that could be used in the final product of the firm. A good potting mix is roughly 33% sand and research has shown that SFS can be substituted for the all of the sand used in soil. Thus the potting soil industry can utilize the most SFS. Concrete utilizes nearly the same amount of sand; however unlike in potting soil SFS must be blended with at least half virgin sand in order to not compromise the

concrete's strength. Likewise, asphalt needs to be blended with virgin sand in order to not have detrimental effects on strength and durability. However, the SFS to sand ratio is much, much lower with only 15% of SFS able to be used. Furthermore, sand comprises only 10-15% of asphalt. This means asphalt would be able to use the least amount of SFS of industries considered, rendering it a score of 1.

Table 4 Ranking of company based on having infrastructure which would aid in the moving of spent foundry sand from Advanced Cast Products back to the firm

Infrastructure Presence	Rank
Has existing infrastructure (1)	5
Does not have existing infrastructure (0)	1

A dummy variable was used to show whether or not a company had the capacity to transport spent foundry sand on its own, with 1 meaning it has the infrastructure to transport sand while a 0 meant it did not. Having the infrastructure to move the spent foundry sand would be beneficial to Advanced Cast Products as there would be no need to hire an outside firm to transport the SFS to the buying firm. Thus, having the infrastructure received the higher score of a 5 while not having the capacity to move sand received a lesser score of 1.

Table 5 Weighting scheme applied to the individual ranks (listed in tables 1-4) which provides the final ranked score for a firm

Criteria	Weight
Company Size	40%
Industry Type	30%
Distance from Advanced Cast Products	20%
Existing Infrastructure to Move Sand	10%

Those scores were then weighted to show how important each of the criterion was in regards to the other criteria examined. The company size was given a weight of 40%, the amount of sand able to be used was given the most weight at 30%, the distance from Advanced Cast to the firm were given a weight of 20%, and lastly the ability of the company to move the spent foundry sand was given a weight of 10%. After the weights were applied, the firms were ranked from highest score to lowest score.

2.2 Modeling Expected Financial Returns

To achieve the second objective of this study, an economic model had to be constructed. Advanced Cast Products rate for SFS disposal was calculated, which is $43.34/ton through the disposal company Allegheny Recovery Corporation (ACR). Next, trucking costs for SFS to a firm were estimated. The average trucking costs in the Meadville area are $1.57/mile, and the distance of 72.7miles was selected as it was the median distance for companies examined. Furthermore, one truck can carry 19 tons/trip, so the total amount sold was divided by 19 to get the number of trips necessary. Hypothetical prices will be set for the SFS which will include multiple scenarios including 75% of the current cost of virgin sand, half the cost of virgin sand, and 25% of the cost of virgin sand. These leads the price points to be $46.92, $31.28, and $15.64

respectively. Next different output levels, or amounts of SFS sold, would be examined at 25%, 50%, 75%, and 100% of Advanced Cast's Products total SFS available. The prices and amounts sold will then be used to calculate what the net earnings of SFS could be. The economic equation for the net earnings of Advanced Cast Products in regards to SFS is:

[Price of SFS * Amount of SFS Sold] + [($1.57/mile) * 72.7 miles * Amount of SFS Sold / **19** tons per trip] + [($43.34/ton) * Amount of SFS Disposed]

= Net Earnings of Advanced Cast Products

In this equation red indicates a negative figure and black indicates a positive figure. The final earnings variable is listed in grey as it is unknown whether the final outcome will be positive or negative. After finding the net earnings, that number is added to the amount saved by Advanced Cast Products by not disposing of all of its spent foundry sand through Allegheny Recovery Corporation. $85,808.45 is the amount annually saved by not disposing of all the SFS. The net savings equation is seen below:

Net Earnings of Advanced Cast Products + $85,808.45

= Net Savings of Advanced Cast Products

Again, black is a positive figure while grey can be either a positive or negative figure. Using this equation, the expected financial returns from each scenario will be determined.

3. Findings

3.1. Suitable Companies

Figure 1 shows the map of all companies examined in this analysis with a color corresponding to how well suited it is to buy spent foundry sand. Dark green is highly suitable to accept spent foundry sand, while dark red is highly unsuitable. Table 6 shows how each company scored in the different areas of examination, as well as its final weighted rank. Three

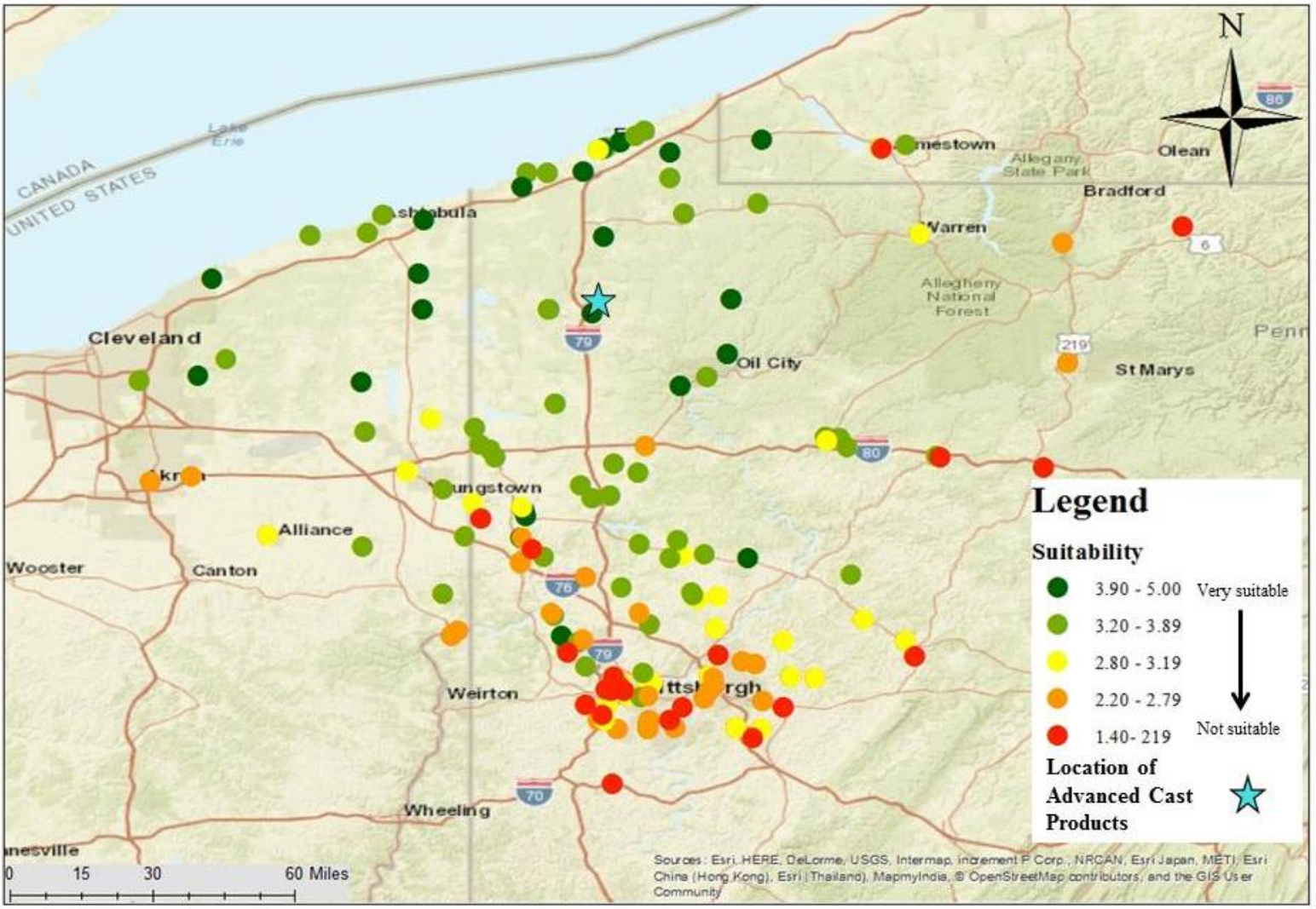

Figure 1 Spatial analysis of firms most suitable to accept spent foundry sand.

companies scored a 5 in the weighted analysis, meaning they fit the ideal standards of suitability for spent foundry sand reuse. Again, the ideal standards for SFS reuse are for the firm to be a potting soil company, located within 34.2miles of Advanced Cast, have less than 50 employees, and have the means to transport the spent foundry sand. Of all 163 companies, 106, or 65% of them, scored a 3.0 or higher in the weighted analysis.

Table 6 List of companies in weighted score order from greatest to least with a breakout of how each firm scored in each individual category

Company	Size Rank	Industry Rank	Distance Rank	Infrastructure Rank	Weighted Final Score
Joe Klapec & Son Inc	5	5	5	5	5.0
McClymonds - Wallace	5	5	5	5	5.0
Northwest Gravel Co	5	5	5	5	5.0
Franklin Concrete Products	5	3	5	5	4.6
Frye Sand & Gravel	5	3	5	5	4.6
WDC Concrete Inc	5	3	5	5	4.6
Meadville Redi-Mix Concrete	5	3	5	5	4.6
Seelinger Topsoil Service	5	5	4	5	4.6
Nelson Sand & Gravel Inc	5	5	4	5	4.6
Conneaut Lake Sand & Gravel	5	3	5	1	4.2
Edinboro Redi-Mix Concrete Co	5	3	5	1	4.2
Titusville Supply Co	5	3	5	1	4.2
Austin Concrete Co	5	3	4	5	4.2
Baycrete Redi-Mix Inc	5	3	4	5	4.2
Castle Builders Supply	5	3	4	5	4.2
Castle Builders Supply Inc	5	3	4	5	4.2
King Brothers Feed & Ready Mix	5	3	4	5	4.2
T C Redi-Mix Inc	5	3	4	5	4.2
Slab City Organics	5	5	3	5	4.2
Topsoil Inc	5	5	3	5	4.2
MRLM	5	5	3	5	4.2
S & S Processing	5	5	3	5	4.2
The Sagamore Companies	5	5	3	5	4.2
J J Kennedy Inc	4	3	4	5	3.9

Dunbar Asphalt-Conneaut Lake	5	1	5	1	3.8
A. Anthony & Sons, Inc.	5	3	4	1	3.8
Akerly Concrete Inc	5	3	4	1	3.8
Ashtabula Concrete Inc	5	3	4	1	3.8
Corry Concrete Inc	5	3	4	1	3.8
North Girard Concrete Works	5	3	4	1	3.8
Elk Creek Ready Mix	5	3	4	1	3.8
M & B Services LLC	5	3	4	1	3.8
Montgomery Block & Ready Mix	5	3	4	1	3.8
Slippery Rock Materials Inc	5	3	4	1	3.8
Cashen Ready Mix	5	3	4	1	3.8
Erie Strayer Co	5	3	4	1	3.8
FORTA Corporation	5	3	4	1	3.8
Warren Concrete & Supply Co	5	3	4	1	3.8
Bessemer Concrete LLC	5	3	3	5	3.8
Crystal Concrete Supply	5	3	3	5	3.8
T C Redi-Mix Inc	5	3	3	5	3.8
Bonsal American	2	3	5	5	3.7
IA Construction-2 Mile Run	3	1	5	5	3.6
Russell Standard-Wheelertown	3	1	5	5	3.6
Joseph McCormick Construction Company	4	1	4	5	3.5
J J Kennedy Inc	4	3	3	5	3.5
Commercial Asphalt	5	1	4	1	3.4
Maybro Asphalt Co	5	1	4	1	3.4
Vincent Cross Paving Inc	5	1	4	1	3.4
Koski Construction Co	5	1	4	1	3.4
Dunbar Asphalt Products	5	1	4	1	3.4
Alfred D Swartzlander Plant	5	3	3	1	3.4
Blank Concrete & Supply	5	3	3	1	3.4
Geauga Concrete Inc	5	3	3	1	3.4
Heade's Ready Mix	5	3	3	1	3.4
Integraspec of Western Pa	5	3	3	1	3.4
Oesterling's Concrete Inc	5	3	3	1	3.4
Semper Concrete Products	5	3	3	1	3.4
M & B Services LLC	5	3	3	1	3.4
M & B Services LLC	5	3	3	1	3.4
DuBrook Inc	5	3	3	1	3.4
DuBrook Inc	5	3	3	1	3.4
Avelli Construction Corporation	5	3	2	5	3.4

Frank Bryan Inc	5	3	2	5	3.4
Frank Bryan Inc	5	3	2	5	3.4
Jamestown Macadam Inc	5	3	2	5	3.4
Jamestown Macadam Inc	5	3	2	5	3.4
Pittsburgh Mobile Concrete	5	3	2	5	3.4
T & J Hopper Building Supplies Inc	5	3	2	5	3.4
Beaver Concrete & Supply Inc.	5	3	2	5	3.4
Chappell & Zimmerman Inc	5	3	2	5	3.4
Concrete Concepts Inc	5	3	2	5	3.4
Paul R. Lipp & Son, Inc.	5	3	2	5	3.4
Carr Brothers Inc	5	3	2	5	3.4
Castle Builders Supply Inc	5	3	2	5	3.4
Riverside Builders Supply	5	3	2	5	3.4
Wine Concrete Inc	5	3	2	5	3.4
R W Sidley Inc	2	3	4	5	3.3
R W Sidley Inc	2	3	4	5	3.3
R W Sidley Inc	2	3	4	5	3.3
IA Construction-Paint	3	1	4	5	3.2
IA Construction-Starbrick	3	1	4	5	3.2
Lindy Paving Inc	3	1	4	5	3.2
Russell Standard-Erie	3	1	4	5	3.2
Mack Industries-Pennsylvania	4	3	2	5	3.1
Wiest Asphalt Products & Paving	5	1	3	1	3.0
Dunbar Asphalt-Hillsville	5	1	3	1	3.0
Hei Way	5	1	2	5	3.0
Jamestown Macadam Inc	5	1	2	5	3.0
Cable Enterprises Ready Co	5	3	2	1	3.0
DCI	5	3	2	1	3.0
Quality Concrete Inc.	5	3	2	1	3.0
Fawn Developers Inc	5	3	2	1	3.0
43rd St Concrete Co	5	3	2	1	3.0
Cooper Trading Inc	5	3	2	1	3.0
Durasteel Abrasive Co	5	3	2	1	3.0
John W Thrower Inc	5	3	2	1	3.0
Cti & Coordinators	5	3	1	5	3.0
JJI Concrete Contractors	5	3	1	5	3.0
Irwin Concrete Co	5	3	1	5	3.0
J. Bazella Concrete Construction Co	5	3	1	5	3.0
Marion Center Supply	5	3	1	5	3.0

Marion Center Supply	5	3	1	5	3.0
West End Builders Supply Co	5	3	1	5	3.0
Shelly Materials	5	3	1	5	3.0
Silhol Builders Supply Co	5	3	1	5	3.0
R W Sidley Inc	2	3	3	5	2.9
IA Construction-West Pittsburgh	3	1	3	5	2.8
Lindy Paving	3	1	3	5	2.8
Lindy Paving-2nd Avenue	3	1	3	5	2.8
Lindy Paving-Big Beaver	3	1	3	5	2.8
Lindy Paving-Koppel	3	1	3	5	2.8
Russell Standard Corporation	3	1	3	5	2.8
DW Dickey & Son	4	3	1	5	2.7
Dw Dickey & Son Inc	4	3	1	5	2.7
J J Kennedy Inc	4	3	1	5	2.7
J J Kennedy Inc	4	3	1	5	2.7
Stone & Co	4	3	1	5	2.7
Stone & Co	4	3	1	5	2.7
Stone & Co	4	3	1	5	2.7
Pittsburgh Asphalt Company	5	1	1	5	2.6
Perrin Asphalt-Perrin Concrete	5	1	1	5	2.6
Tresco Paving Corporation	5	1	1	5	2.6
Glenn O Hawbaker-Barkeyville	1	1	4	5	2.6
3 Dogs Concrete, LLC	5	3	1	1	2.6
D & C Supply Co	5	3	1	1	2.6
Htne Hydro Demolition Svc LLC	5	3	1	1	2.6
Metered Concrete	5	3	1	1	2.6
Modified Concrete Suppliers	5	3	1	1	2.6
Pasquini Nicholas	5	3	1	1	2.6
South Hills Cement Contracting	5	3	1	1	2.6
Eles Bros Ready Mix Concrete	5	3	1	1	2.6
Hosmer Supply Co Inc	5	3	1	1	2.6
Tresco Concrete Products	5	3	1	1	2.6
Cooper Trading Inc	5	3	1	1	2.6
Cemex	1	3	3	5	2.6
Essroc	1	3	3	5	2.6
Hanson Aggregates-Economy	3	1	2	5	2.4
IA Construction-Lafayette	3	1	2	5	2.4
Lindy Paving-Neville Island	3	1	2	5	2.4
Lindy Paving-Neville Terminal	3	1	2	5	2.4

Tallmadge Asphalt & Concrete	4	1	1	5	2.3
Derry Construction-Delmont	5	1	1	1	2.2
Cemex	1	3	2	5	2.2
Cemex	1	3	2	5	2.2
Essroc	1	3	2	5	2.2
Essroc	1	3	2	5	2.2
Lafarge North America	1	3	2	5	2.2
Lafarge Ready Mix Concrete	1	3	2	5	2.2
HRI-Brookville	2	1	2	5	2.1
Suit-Kote Corporation	2	1	2	5	2.1
Hanson Aggregates-#1 Asphalt Lane	3	1	1	5	2.0
Hanson Aggregates-Eighty Four	3	1	1	5	2.0
IA Construction-Homer City	3	1	1	5	2.0
IA Construction-New Kensington	3	1	1	5	2.0
Lane Construction Corporation	1	1	2	5	1.8
Lane Construction Corporation	1	1	2	5	1.8
Rinker	1	3	1	5	1.8
Essroc	1	3	1	5	1.8
Lafarge North America Inc	1	3	1	5	1.8
Glenn O Hawbaker-Turtlepoint	1	1	1	5	1.4
Glenn O Hawbaker-DuBois	1	1	1	5	1.4
Lane Construction-Bridgeville	1	1	1	5	1.4

3.2. Financial Returns

Table 7 Net savings for Advanced Cast Products when selling spent foundry sand at different prices and in different quantities

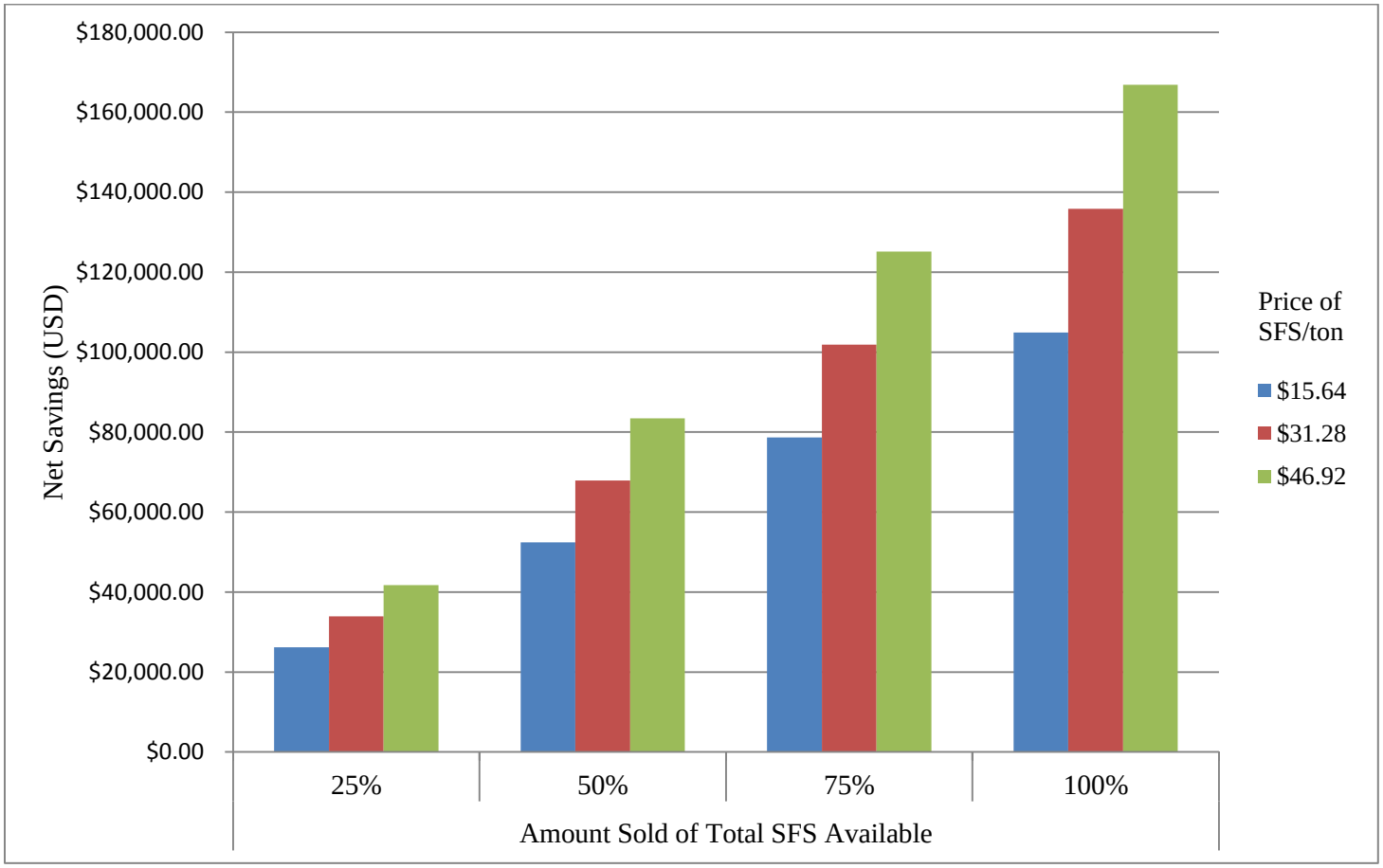

Table 7 shows the net savings for Advanced Cast Products under different quantities sold and at different prices. Under the worst scenario modeled, where only 25% of all spent foundry sand was sold and it was sold for $15.64/ton, the company would have a net savings of $26,220. Under the best scenario in this model, where 100% of spent foundry sand was sold at $46.92/ton the net savings for Advanced Cast Products is $166,811.

4. Conclusions

4.1. Company Suitability

As mentioned, 65% of the companies examined in this study fit the criteria to be deemed suitable for spent foundry sand reuse as they received a score of 3.0 or above. This suggests that it is feasible for Advanced Cast Products to find a company willing to establish a partnership within the determined 115 mile radius, making it closer than the current disposal site. The limiting factor for the success in implementing this project will be the interest level of the firms Advanced Cast Products reaches out to. Only if the firms have an interest in, or are open to, switching to SFS use in their products will this project be feasible. This study was originally going to measure the interest levels of the firms identified as suitable for SFS, however I found it nearly impossible to get anyone from the firms identified as suitable to talk to me given that I have no official standing within Advanced Cast Products.

4.2. Economic Feasibility

In every scenario ran by the model, Advanced Cast Products had a positive net savings by selling at least some of its spent foundry sand. This is mainly due to the discrepancy of how costly it is dispose of SFS with Allegheny Recovery Corporation compared to the cost of trucking SFS to another firm. Where it would cost just over $180 per trip of 19 tons to truck SFS 115 miles (the distance of the current disposal site) using an outside trucking firm, it costs over $820 to truck and dispose of 19 tons of SFS the same distance. This led to the examination as to how little the price of SFS and the quantity sold would have to be in order to have selling be the more expensive option, or have the net savings be negative. It was found that the SFS could be given away for free with Advanced Cast Products paying the shipping cost of $1.57/mile and it

would still result in a net savings of over $18,400 for the company. This justifies Advanced Cast Products selling the SFS at any price, and it still being better for the company's bottom line when compared to disposing of the SFS with Allegheny Recovery Corporation.

However, left out of this analysis is Advanced Cast Products switching costs, or how much money the firm would have to make to warrant the change of status quo in regards to handling its spent foundry sand. Advanced Cast Products may be unwilling to dedicate the man-hours to find a firm to sell its SFS to if there was only $2,000 to be made, but may be more willing if there would be a net savings of $100,000 or more. This price point is something the company will have to decide on and that will help determine whether the switch to selling SFS is made.

5. Recommendations

Given the feasibility and cost analysis model run, it would make economic sense for Advanced Cast Products to sell its spent foundry sand. There are 106 companies within a 115 mile radius which are suitable to utilize SFS, and even giving the SFS away for free results in a positive net savings over current methods of disposal. However, the company's switching cost must be taken into account when deciding whether to make the switch to selling its SFS. Only if the price set and quantity sold equal above the switching cost threshold should Advanced Cast Products sell its spent foundry sand. If the company decides it wants to sell its SFS, it should first reach out to the top 25 ranking firms in order to gauge interest and ability. This should be done with both a written letter and phone call as all too often emails to these companies are ignored.

If nothing comes from talks with the first 25 companies, Advanced Cast Products should move down the list until finding a willing firm.

To set a market price for spent foundry sand I suggest an initial price of 50% the cost of virgin sand, or $31.28/ton. At this rate, any amount over 4 tons sold will cover the cost of trucking the SFS to a firm. This will allow firms to buy a few tons of SFS to see if it works in their process before fully committing to buying regularly from Advanced Cast Products, while ensure Advanced Cast Products does not lose money for firms to try SFS in their products. Additionally it provides a good middle ground to see how much firms are willing to buy. If there is low tonnage sales that are still over the 4 ton threshold, Advanced Cast Products could easily drop the price have higher net savings. Implementing this project relies on finding one of the identified companies that is willing to accept the spent foundry sand and whether Advanced Cast Products sees enough value in doing so to change its status quo.

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7. Appendix

7.1. Ranked List of Company Suitability

Company	Address	Weighted Score
Joe Klapec & Son Inc	218 PA-428, Oil City, PA 16301	5.0
McClymonds - Wallace	6250 Sterrettania Rd, Fairview, PA 16415	5.0
Northwest Gravel Co	10746 Ridge Rd, Girard, PA 16417	5.0
Franklin Concrete Products	970 Mercer Rd, Franklin, PA 16323	4.6
Frye Sand & Gravel	3049 S Denmark Rd, Dorset, OH 44032	4.6
WDC Concrete Inc	5000 OH-193, Dorset, OH 44032	4.6
Meadville Redi-Mix Concrete	19824 Cochranton Rd, Meadville, PA 16335	4.6
Seelinger Topsoil Service	9887 Jones Rd, Erie, PA 16510	4.6
Nelson Sand & Gravel Inc	5720 OH-193, Kingsville, OH 44048	4.6
Conneaut Lake Sand & Gravel	11203 Ellion Rd, Conneaut Lake, PA 16316	4.2
Edinboro Redi-Mix Concrete Co	26269 Blystone Rd, Edinboro, PA 16412	4.2
Titusville Supply Co	12225 Gresham Rd, Titusville, PA 16354	4.2
Austin Concrete Co	1919 Reed St # 2, Erie, PA 16503	4.2
Baycrete Redi-Mix Inc	1816 Greengarden Blvd, Erie, PA 16502	4.2
Castle Builders Supply	1409 Moravia St, New Castle, PA 16101	4.2
Castle Builders Supply Inc	305 Steel St, Aliquippa, PA 15001	4.2
King Brothers Feed & Ready Mix	1306 OH-88, Bristolville, OH 44402	4.2
T C Redi-Mix Inc	203 W Washington St, New Castle, PA 16101	4.2
Slab City Organics	8777 Kidder Rd, Sherman, NY 14781	4.2
Topsoil Inc	193 Top Soil Dr, Worthington, PA 16262	4.2
MRLM	6011 Heisley Rd, Mentor, OH 44060	4.2
S & S Processing	478 Beaver Rd, West Pittsburg, PA 16160	4.2
The Sagamore Companies	16781 Hilltop Park Pl, Chagrin Falls, OH 44023	4.2
J J Kennedy Inc	19929 Paint Blvd, Shippenville, PA 16254	3.9
Dunbar Asphalt-Conneaut Lake	11203 Ellion Rd, Conneaut Lake, PA 16316	3.8
A. Anthony & Sons, Inc.	1450 W 21st St, Erie, PA 16502	3.8
Akerly Concrete Inc	5201 Iroquois Ave, Erie, PA 16511	3.8
Ashtabula Concrete Inc	3440 N Ridge Rd W, Ashtabula, OH 44004	3.8

Corry Concrete Inc	1244 N Center St, Corry, PA 16407	3.8
North Girard Concrete Works	100 Richardson Dr, Lake City, PA 16423	3.8
Elk Creek Ready Mix	3000 Blair Rd, Fairview, PA 16415	3.8
M & B Services LLC	15303 US-322, Clarion, PA 16214	3.8
Montgomery Block & Ready Mix	4275 William Flynn Hwy, Harrisville, PA 16038	3.8
Slippery Rock Materials Inc	704 Golf Course Rd, Volant, PA 16156	3.8
Cashen Ready Mix	1225 Dock Rd, Madison, OH 44057	3.8
Erie Strayer Co	1851 Rudolph Ave, Erie, PA 16502	3.8
FORTA Corporation	100 Forta Dr, Grove City, PA 16127	3.8
Warren Concrete & Supply Co	1113 Parkman Rd NW, Warren, OH 44485	3.8
Bessemer Concrete LLC	13501 Pittsburgh Rd, Petersburg, OH 44454	3.8
Crystal Concrete Supply	238 T585, Saxonburg, PA 16056	3.8
T C Redi-Mix Inc	2400 Poland Ave, Youngstown, OH 44502	3.8
Bonsal American	97 Main St, Fredonia, PA 16124	3.7
IA Construction-2 Mile Run	Gibb Rd, Franklin, PA 16323	3.6
Russell Standard-Wheelertown	8124 PA-97, Union City, PA 16438	3.6
Joseph McCormick Construction Company	3340 Pearl Ave, Erie, PA 16510	3.5
J J Kennedy Inc	10373 PA-85, Kittanning, PA 16201	3.5
Commercial Asphalt	161 Plain Grove Road, Slippery Rock, PA 16057	3.4
Maybro Asphalt Co	1255 W 18th St, Erie, PA 16502	3.4
Vincent Cross Paving Inc	11620 Lake Pleasant Rd, Union City, PA 16438	3.4
Koski Construction Co	1149 E 5th St, Ashtabula, OH 44004	3.4
Dunbar Asphalt Products	3766 New Castle Rd, West Middlesex, PA 16159	3.4
Alfred D Swartzlander Plant	399 Keck Rd, Butler, PA 16002	3.4
Blank Concrete & Supply	804 Factory Ave, Ellwood City, PA 16117	3.4
Geauga Concrete Inc	10509 Kinsman Rd, Newbury Township, OH 44065	3.4
Heade's Ready Mix	615 Dinnerbell Rd, Saxonburg, PA 16056	3.4
Integraspec of Western Pa	690 Glenwood Way, Butler, PA 16001	3.4
Oesterling's Concrete Inc	690 Glenwood Way, Butler, PA 16001	3.4

Semper Concrete Products	858 New Castle Rd, Butler, PA 16001	3.4
M & B Services LLC	236 Waterford Pike, Brookville, PA 15825	3.4
M & B Services LLC	88 Glenn Redi Mix Ln, Clarion, PA 16214	3.4
DuBrook Inc	303 Bantam Ave, Butler, PA 16001	3.4
DuBrook Inc	600 S Washington St, Evans City, PA 16033	3.4
Avelli Construction Corporation	300 Ohio River Blvd, Ambridge, PA 15003	3.4
Frank Bryan Inc	100 S 3rd St, Pittsburgh, PA 15219	3.4
Frank Bryan Inc	1263 Chartiers Ave, McKees Rocks, PA 15136	3.4
Jamestown Macadam Inc	1946 New York Ave, Falconer, NY 14733	3.4
Jamestown Macadam Inc	75 Walden Ave, Jamestown, NY 14701	3.4
Pittsburgh Mobile Concrete	1933 Babcock Blvd, Pittsburgh, PA	3.4
T & J Hopper Building Supplies Inc	5975 Station Hill Rd, Gibsonia, PA 15044	3.4
Beaver Concrete & Supply Inc.	10 Industrial Park Rd, Monaca, PA 15061	3.4
Chappell & Zimmerman Inc	641 Olive St, Salem, OH 44460	3.4
Concrete Concepts Inc	1095 Thompson Ave, McKees Rocks, PA 15136	3.4
Paul R. Lipp & Son, Inc.	47563 Pancake-Clarkson Rd, Rogers, OH 44455	3.4
Carr Brothers Inc	7177 Northfield Rd, Cleveland, OH 44146	3.4
Castle Builders Supply Inc	1325 Broadway Rd, Hermitage, PA 16148	3.4
Riverside Builders Supply	889 Pennsylvania Ave, Coraopolis, PA 15108	3.4
Wine Concrete Inc	1000 Big Sewickley Creek Rd, Sewickley, PA 15143	3.4
R W Sidley Inc	715 New Castle Rd, Slippery Rock, PA 16057	3.3
R W Sidley Inc	3401 New Castle Rd, West Middlesex, PA 16159	3.3
R W Sidley Inc	1550 Furnace Rd, Sharon, PA 16146	3.3
IA Construction-Paint	19000 Paint Blvd, Shippenville, PA 16254	3.2
IA Construction-Starbrick	66 Star Brick, Warren, PA 16365	3.2
Lindy Paving Inc	809 Sampson St, New Castle, PA 16101	3.2
Russell Standard-Erie	2002 Pittsburgh Ave, Erie, PA 16502	3.2
Mack Industries-Pennsylvania	2207 Sodom Hutchings Rd NE, Vienna, OH 44473	3.1

Wiest Asphalt Products & Paving	310 Mitchell Hill Rd, Butler, PA 16002	3.0
Dunbar Asphalt-Hillsville	4877 W State St, Edinburg, PA 16116	3.0
Hei Way	290 N Pike Rd, Sarver, PA 16055	3.0
Jamestown Macadam Inc	75 Walden Ave, Jamestown, NY 14701	3.0
Cable Enterprises Ready Co	185 Washington Ave, Vandergrift, PA 15690	3.0
DCI	1 Lane Rd, Carnegie, PA 15106	3.0
Quality Concrete Inc.	1051 McCartney St, Pittsburgh, PA 15220	3.0
Fawn Developers Inc	5391 Bull Creek Rd, Tarentum, PA 15084	3.0
43rd St Concrete Co	1 43rd St, Pittsburgh, PA 15201	3.0
Cooper Trading Inc	149 Nichol Ave, McKees Rocks, PA 15136	3.0
Durasteel Abrasive Co	105 26th St, Pittsburgh, PA 15222	3.0
John W Thrower Inc	409 Saxonburg Blvd, Saxonburg, PA 16056	3.0
Cti & Coordinators	2876 PA-286, Saltsburg, PA 15681	3.0
JJI Concrete Contractors	1917 Nash Ave, Pittsburgh, PA 15235	3.0
Irwin Concrete Co	1 E Penn Ave, Irwin, PA 15642	3.0
J. Bazella Concrete Construction Co	543 Dusty Ln, Saltsburg, PA 15681	3.0
Marion Center Supply	10680 US-422, Shelocta, PA 15774	3.0
Marion Center Supply	2431 PA-286, Indiana, PA 15701	3.0
West End Builders Supply Co	1102 E Gaskill Ave, Jeannette, PA 15644	3.0
Shelly Materials	2000 Beeson St, Alliance, OH 44601	3.0
Silhol Builders Supply Co	100 Union St, Bridgeville, PA 15017	3.0
R W Sidley Inc	3424 Oregon Ave, Youngstown, OH 44509	2.9
IA Construction-West Pittsburgh	167 Sandbank Rd, Wampum, PA 16157	2.8
Lindy Paving	1755 Pennsylvania Ave Monaca, PA 15061	2.8
Lindy Paving-2nd Avenue	1807 Shenango Rd, New Galilee, PA 16141	2.8
Lindy Paving-Big Beaver	1735 Shenango Rd Big Beaver PA 18466	2.8
Lindy Paving-Koppel	1811 Shenango Road New Galilee, PA 16141	2.8
Russell Standard Corporation	171 7th Ave, Valencia, PA 16059	2.8
DW Dickey & Son	700 River Rd, East Liverpool, OH 43920	2.7
Dw Dickey & Son Inc	1080 Elmwood St # 1, East Liverpool, OH 43920	2.7
J J Kennedy Inc	3740 Johnsonburg Rd, Ridgway, PA 15853	2.7

J J Kennedy Inc	1790 PA-588, Fombell, PA 16123	2.7
Stone & Co	20 Commerce Dr, Pittsburgh, PA 15239	2.7
Stone & Co	4136 Old William Penn Hwy, Monroeville, PA 15146	2.7
Stone & Co	1 Harrison St, Glassport, PA 15045	2.7
Pittsburgh Asphalt Company	4993 Old Clairton Rd, Pittsburgh, PA 15236	2.6
Perrin Asphalt-Perrin Concrete	525 Dan St, Akron, OH 44310	2.6
Tresco Paving Corporation	415 Unity Center Rd, Pittsburgh, PA 15239	2.6
Glenn O Hawbaker-Barkeyville	1041 Stevenson Rd, Harrisville, PA 16038	2.6
3 Dogs Concrete, LLC	260 Millers Run Rd, Bridgeville, PA 15017	2.6
D & C Supply Co	335 Washington Ave, Bridgeville, PA 15017	2.6
Htne Hydro Demolition Svc LLC	632 Hunt Valley Cir, New Kensington, PA 15068	2.6
Metered Concrete	417 Grey Wolf Ln, New Kensington, PA 15068	2.6
Modified Concrete Suppliers	632 Hunt Valley Cir, New Kensington, PA 15068	2.6
Pasquini Nicholas	2002 Mohawk Rd, Pittsburgh, PA 15241	2.6
South Hills Cement Contracting	1286 Girard Rd, Pittsburgh, PA 15227	2.6
Eles Bros Ready Mix Concrete	1000 Thompson Run Rd, Monroeville, PA 15146	2.6
Hosmer Supply Co Inc	384 Old Curry Hollow Rd, Pittsburgh, PA 15236	2.6
Tresco Concrete Products	155 Plant Rd # 1, Export, PA 15632	2.6
Cooper Trading Inc	1078 U.S. 30, Irwin, PA 15642	2.6
Cemex	200 Neville Rd, Pittsburgh, PA 15225	2.6
Essroc	2220 Second Avenue, Pittsburgh, PA 15219	2.6
Hanson Aggregates-Economy	1008 Big Sewickley Creek Rd, Sewickley, PA 15143	2.4
IA Construction-Lafayette	7024 PA-59, Lewis Run, PA 16738	2.4
Lindy Paving-Neville Island	4500 Neville Road, Pittsburgh, PA 15225	2.4
Lindy Paving-Neville Terminal	200 Neville Road Pittsburgh, PA 15225	2.4
Tallmadge Asphalt & Concrete	741 Tallmadge Rd, Kent, OH 44240	2.3
Derry Construction-Delmont	6762 US-22, Delmont, PA 15626	2.2
Cemex	2001 Portland Park, Wampum, PA 16157	2.2

Cemex	200 Neville Rd # 4, Pittsburgh, PA 15225	2.2
Essroc	1 7th St, Braddock, PA 15104	2.2
Essroc	500 W Park Rd, Leetsdale, PA 15056	2.2
Lafarge North America	1529 Chartiers Ave, Pittsburgh, PA 15204	2.2
Lafarge Ready Mix Concrete	100 Beechnut Dr, Pittsburgh, PA 15205	2.2
HRI-Brookville	785 Route 830, Brookville, PA 15825	2.1
Suit-Kote Corporation	57 Lister St # 1, Jamestown, NY 14701	2.1
Hanson Aggregates-#1 Asphalt Lane	1 Asphalt Lane, Adamsburg, PA 15611	2.0
Hanson Aggregates-Eighty Four	339 Somerset Dr, Eighty Four, PA 15330	2.0
IA Construction-Homer City	1981 Old US 119 Hwy S, Homer City, PA 15748	2.0
IA Construction-New Kensington	450 Stevenson Blvd, New Kensington, PA 15068	2.0
Lane Construction Corporation	Robb Street (Foot of), McKees Rocks, PA 15136	1.8
Lane Construction Corporation	300 Bilmar Dr Suite 200, Pittsburgh, PA 15205	1.8
Rinker	2000 Gregg Station Rd, Oakdale, PA 15071	1.8
Essroc	E Poland Ave, Bessemer, PA 16112	1.8
Lafarge North America Inc	4810 Buttermilk Hollow Rd, West Mifflin, PA 15122	1.8
Glenn O Hawbaker-Turtlepoint	Champlin Hill Rd, Turtlepoint, PA 16750	1.4
Glenn O Hawbaker-DuBois	627 Rich Hwy, DuBois, PA 15801	1.4
Lane Construction-Bridgeville	2 Prestley Rd, Bridgeville, PA 15017	1.4

7.2. Further Background on Spent Foundry Sand

Introduction

Recently, Advanced Cast Products—a ductile iron foundry in Meadville, Pennsylvania—approached Allegheny College seeking assistance in finding a way to reduce its landfill waste in order to save costs. To understand this project the topics of industrial ecology, metal forges, natural aggregate mining, spent foundry sand reuse, and an understanding of Advanced Cast Products must also be established.

Industrial Ecology

Deemed the "science of sustainability", industrial ecology has become a focus for both environmentalists and economists in the last few decades (Isenmann, 2003; von Hauff & Wilderer 2008). However from the 1950s to the late 1980s, most initiatives to generate interest and implementation of what became known as industrial ecology failed. It was not until an article by Robert Frosch and Nicholas Gallopoulos was published in *Scientific American* that international interest in industrial ecology was generated (Erkman, 1997). This article, titled "Strategies for Manufacturing" after the original title 'Manufacturing-The Industrial Ecosystem View' was rejected, has since come to be seen as one of the founding documents of industrial ecology (Erkman, 1997; von Hauff & Wilderer 2008).

So what was so pivotal about Frosch and Galloupoulos's "Strategies for Manufacturing"? Quite frankly, not much. It combined ideas that had been floating around academic circles for years, however both authors and the publication had enough clout to pique the interest of fellow scientists and make the concept stick (Erkman, 1997). "Strategies for Manufacturing" begins with an examination of ancient Greek tales that show the unintended and devastating consequences that accompany new inventions, and then shows how relatable that is to the present day. These unintended consequences of today are due to the open loop system industry

partakes in where virgin material is excavated, used, and then thrown away. It leads to excessive waste which can no longer in be dumped haphazardly given the interconnectedness of the modern world. The authors then go on to suggest that perhaps it need not be this way, and use the analogy of biological systems to back up the statement. They explain how in a biological system, there is nearly no waste and nutrients are cycled through the system—it is a closed loop. Acknowledging that this ideal will most likely never be accomplished, Frosch and Galloupoulos argue that changing the current industrial system to one more like a biological system it would do infinite good for the world by reducing emissions, waste, the mining of virgin material, and overall becoming more efficient (Frosch, & Gallopoulos, 1989). Later this process was compared to how early life forms changed and evolved into the efficient ecosystems that can be seen today which further suggested that this movement of 'industrial ecology' was a natural progression that should occur (Erkman, 1997).

Since Frosch and Galloupoulos's article, firms have adopted some industrial ecology practices with varying degrees of urgency and success. Research into the implementation of industrial ecology and green business practices has shown that the process can help businesses as well as hinder them (Esty & Porter, 1998; Sarkis et. al, 2011; Wu & Pagell, 2010). The switching costs associated with implementing the new processes were found to be the biggest challenge to businesses implementing industrial ecology practices. To begin, research by Wu and Pagell found that "…proactive investment in green technology may not pay off for decades" (2010). This means that even if a company has the desire to implement green technology, they put more money into it than they get out for years. Up fronting expenses that take a long time to be profitable is a financial hardship on businesses and affects decisions in both the short and long term (Wu and Pagell, 2010). Additionally Esty and Porter's paper points out that there are cases

where the cost of 'closing the loop' actually outweighs the benefits of making the system more sustainable (1998). With no financial gains to be had in making the company more sustainable, it would be hard to sell the idea to the company and its shareholders. These are issues a business must keep in mind when considering industrial ecology practices.

Additionally, adopting a more 'closed loop' system has the potential of benefiting the company who adopts it, as well as industry as a whole. Sarkis et al., found that a company could *save* money by using the waste products of another company rather than extracting new resources (2011). An example of this would be a company that makes concrete buying waste aggregate material from a company that performs housing demolition. This saves the concrete company from having to buy virgin material, and keeps the waste aggregate from being dumped in a landfill. A good example of this is Kalundborg, an industrial town in Denmark where the companies share waste and byproducts with other companies who can use them. This has saved all the companies money, which benefits the overall industry (Ehrenfeld & Gertler, 1997). Furthermore, research by Esty and Porter argues that this increase in resource productivity makes a company more competitive (1998). Resource productivity, which is defined as the sum of both direct and indirect value of a resource minus the direct and indirect costs of said resource. The higher this number (more value than cost), the more use the resource theoretically holds before being used up and 'worthless'.

Metal Forges

Traces of humans manipulating metal can be traced back to 9,000 B.C., with first indications of heat being utilized in the process around 5,000 B.C. (ASM, 2011). These early metalsmiths sought to make tools that aided in defense, farming, and hunting as well as decorative ornaments (ASM, 2011; Kren, 2013). It was not until 2,500 B.C. that blacksmiths

were able to develop methods that ensured both the repeatability and the desired characteristics of the metal being forged (Kren, 2013). From 2,500 B.C. to 1856 A.D. iron was the metal of choice given the comparatively low temperature it took to melt it, and that the relative cost was low (Kren, 2013; Spoerl, n.d.). It was found that by melting metals and then pouring it into molds a consistent shape would be created. The consistency of finished products made it possible for inventions such as the cotton gin, sewing machines to be produced quickly helping to spawn the Industrial Revolution (Kren, 2013). However, the 'cast' iron used was brittle and prone to cracking, so in 1856 new methodology called the Bessemer process was developed which decreased the cost of steel. Steel could be cast just like iron, but was much more flexible and durable which opened up new markets of use further revolutionizing human life Even today metal forges play a part in many of the items utilized in day to day life: from silverware, to refrigerators, to car parts, to nails, to clocks, to elevators, to canned food (Spoerl, n.d.). This industry has remarkably shaped, and continues to transform, the human experience.

The metal forging industry historically has had a large environmental impact. From the extraction of virgin materials, to air pollutants released during melting, to toxic chemicals used throughout the process, to the massive amounts of energy required, and the reliance on nonrenewable resources, the negative environmental impacts are apparent throughout the process (Durgesh, Yashwant, & Ravi, 2011; Energy, n.d.; Sustainability, 2012). Though the industry has taken steps to limit negative impacts and made plans on how to further reduce impacts, legislation is forcing the industry to reduce impact both further and faster than companies would on their own (Norgate, Jahanshahi, & Rankin, 2007, Sustainability, 2012). The Forging Industry Association proactively has committed to "reduce total per-piece energy input/content by 75%" as well as reducing total energy consumption by 20% (Energy, n.d.). However, an often

overlooked environmental impact of the casting process is the sand used to make the molds. This sand is rarely, if ever, recycled and makes up a huge portion of a foundry's waste (Foundry, 2004; Sustainability, 2012). It appears that this may be one of the simplest, and cheapest, ways a foundry can reduce its environmental footprint.

Natural Aggregate Mining

Sand mining falls under the umbrella category of 'natural aggregate' which includes sand, gravel, and rocks. This multibillion dollar industry has been referred to as "…the most valuable nonfuel mineral commodity in the world" (Drew et al., 2002). Every state within the United States has mining operations within it (Meador, & Layher, 1998). In 2013 alone, over 62.1 million metric tons (Mt) was mined from 182 mining operations within the 50 states. This was an increase of over 12Mt from 2012 (Dolley, 2015). These millions of metric tons of natural aggregate materials are used to make roads, parking lots, and construction materials such as glass and concrete (Anders Sandberg & Wallace, 2013; Dolley 2015). This means of all industrialized countries, people interact with the products of natural aggregate use each and every day. However few give thought to how this aggregate material is collected, and the environmental impacts production creates. Looking at sand specifically, the environmental effects vary between the two major methods of collection—stream dredging and coastal excavation—however both prove to be devastating to the ecosystems it occurs within.

As water is the main source of sand and gravel distribution, stream dredging for natural aggregate has occurred since before written history (Meador, & Layher, 1998). However, unlike the past most streams today are having more sand extracted from them than is being replenished, meaning it is an unsustainable yield (Sreebha, & Padmalal, 2011). Not only is the amount unsustainable, but the way in which current stream dredging occurs can causes environmental

issues such as habitat fragmentation, changing sediment loads of rivers, and changes in flow rates (Meador, & Layher, 1998). Salinity, hydrology, and overall water quality are also affected by stream dredging which in turn affects all living things which rely on that water source including humans, vegetation, and animals (Masalu, 2002). Most concerning is that without remediation efforts, it takes several decades before a stream that has been mined for natural aggregate recovers back to its 'natural' state (Meador, & Layher, 1998).

Coastal sand excavation and ocean dredging are some of the leading causes of coast line erosion and degradation. Some areas near mining operations experience erosion rates of 2m or more per year while others show a huge decrease in shoreline recovery rates after natural occurrences such as storms (Mensah, 1997; Hilton & Hesp, 1996). Furthermore, coastal sand mining disrupts the breeding grounds of threatened species and the habitats of commercial fish and fauna (Charlier, 2002; Masalu, 2002). Additionally marine dredging re-suspends pollutants and nutrients which can lead to lower oxygen content in the water and eutrophication respectively. However, natural aggregate mined from the coastline and sea floor is the least valuable commodity by volume in the ocean (Charlier, 2002). In other words, humans are destroying the coastal ecosystem to obtain sand despite it being of less value than the plants and animals in the ecosystem it is destroying.

With as environmentally impactful as natural aggregate mining is, it would be expected that recycling of natural aggregate to decrease the amount of virgin material needed would be implemented. However, this is not as prevalent as one would expect (Wilburn & Goonan, 1998). Often it is argued that recycling costs more and is less profitable than utilizing new materials, but research by Robinson Jr., Menzie, & Hyun suggests that this is not the case. Instead, their findings suggest that in densely populated areas with over 400 people/sq km and no natural

aggregate production sites nearby, recycling is actually much more cost effective (2004). Another critique of recycling natural aggregate is that it is 'unable' to be recycled, however it has been found that between 25-40% of all demolition materials has the potential to be recycled (Robinson Jr, Menzie, & Hyun, 2004). Other critics claim that using recycled natural aggregate changes the structural characteristics of what it is reused in, however nearly all of the literature either disagrees or suggests that it depends on what type of natural aggregate is being reused and how it is being reused (Sagoe-Crentsil, Brown, & Taylor, 2001; Sahmaran et. al, 2011; Siddique, 2009; Siddique et. al, 2015; Wilburn & Goonan, 1998).

SFS Reuse

Therefore, the potential reuse of foundry sand should be examined given its status of metal foundries' biggest percentage of waste material (Ji, Wan, & Fan, 2001). As mentioned previously, sand is used to make molds to cast in a foundry. Once this sand is no longer able to be used, it is called "spent foundry sand" or SFS. The Federal Highway Administration, the Recycled Materials Resource Center, and the U.S. Department of Agriculture have all pledged support to develop the resources needed to make spent foundry sand more feasible to recycle (Actions, 2009; Benson, & Bradshaw, 2011). However, not all SFS can be used; sand from bronze, brass, and copper foundries are unusable as the sands hold and subsequently leach heavy metals. Yet sand from iron, steel, and aluminum foundries do not leach and are safe for reuse (Foundry, 2004). Still many misconceptions about SFS and its environmental impacts linger on despite large bodies of evidence that exist proving it is safe (Regan, Heaney, & Dunkelberger, 1997). The most common ways spent foundry sand is reused is as a soil amendment, in building materials, and in road construction (Beneficial, 1996). There are both positives and negatives to

each reuse method, and a particular method may not be feasible for every business. Each method needs to be carefully examined before a reuse method is chosen for a specific company.

One way spent foundry sand is reused is as a soil amendment. This method of reuse is often met with the most resistance due to fears about sand leeching heavy metals. This prompted the Environmental Protection Agency to study the feasibility of iron, steel, and aluminum foundry sand reuse in soil and found that risks involving leachability were minimal as the trace metals in SFS were not bioavailable (Risk, 2014). Other research showed that the overall leachability of As, Ba, Cd, Cr, Pb, Hg, Se, Ag, Cu and Zn were very low across SFS soil samples suggesting that the sand is not contaminated by metal (Ji, Wan, & Fan 2001; Dayton et. al, 2010). Researchers from Pennsylvania State University found that plants grown on a mix of compost and spent foundry sand grew bigger than on natural soil (Stehouwer, Hindman, & MacDonald, 2010). Additionally, Dugan et. al found that spent foundry sand use in soil does not affect bacteria colonies in the soil (Dugan et. al, 2009). More to the benefit of SFS reuse in soil, the EPA found that it saved the annual energy equivalent of 800 homes and the annual CO2 emission equivalent of 800 cars (2014).

Another reuse method of spent foundry sand is as an aggregate for building materials such as bricks and concrete. Currently over 25,000,000,000 tons of concrete are used annually, providing huge economic and environmental incentive to find a more sustainable way of making concrete (Long, Gao, & Xie, 2015). This has led to research into how SFS can be used to make building materials. Research by Alonso-Santurde et. al found that SFS can be substituted in a concrete mix for virgin sand with no effects on the concrete's performance (2011). A later study by Siddique et. al showed that by using a partial replacement method where SFS is blended with virgin material the strength properties of the concrete increase by up to 15% (2015). Portland

cement has shown no characteristically differences when SFS is used in the mix instead of virgin materials (Benson, & Bradshaw, 2011).

The final common reuse method of spent foundry sand is in road construction. SFS can be used both as an additive in the asphalt or as an additive in the substrate layer which is laid under the road (Carpenter, & Gardner, 2009; Using, 2009). As an additive in asphalt, it was found that using SFS decreased how much water could permeate the asphalt, thus decreasing how the asphalt was affected by the freeze-thaw cycle (Guney, Aydilek, & Demirkan, 2006). Furthermore, like in concrete adding SFS to asphalt increased the strength of the asphalt. This could lead to road layers not having to be as thick, which further decreases environmental impact (Hill, Dawson, & Mundy, 2001). Yet, in instances where SFS made up more than 10% of the aggregate used, it decreased the stability of the asphalt (Bakis, Koyuncu, & Demirbas, 2006). As a road base, SFS as an aggregate was shown to fit both mechanical and environmental regulations (Yazoghli-Marzouk, et. al, 2014). It saves 17,800,000 megajoules of energy from being spent and saves 1,500 metric tons of carbon from being released into the atmosphere (EPA, 2014). Given the potential economic and environmental benefits, this method of SFS reuse should be examined by foundries looking to decrease the amount material sent to landfills.

Advanced Cast Products' Problem

Advance Cast Products is a ductile iron foundry located in Meadville, Pennsylvania employing nearly 200 people with annual sales of $50 million (Bodnar, 2015). Now owned by the company Neenah Enterprises, the foundry site was built in 1900 and has been in continuous operation ever since. Its product lineup includes heavy truck, railroad, and mining parts as well as construction equipment (Advanced, n.d.) Currently, Advanced Cast Products sends nearly 2,000 tons of spent foundry sand to Allegheny Recovery Corporation for disposal per year. The

average cost per ton is $43.34, and equates almost half of all disposal costs for the foundry (Bodnar, 2015). As Pennsylvania is one of the top 10 foundry states in the country, and is the third biggest consumer of industrial sand using 1.55 million tons annually, it has taken steps to increase reuse of spent foundry sand (Foundry, 2004; Dolley, 2015). As of 2008 it has a SFS reuse rate of nearly 50% which is well over the national average of 14% reuse (Eckelman & Chertow, 2009; EPA, 2014). Given the systems Pennsylvania already has in place, it is hypothesized that Advanced Cast Products can capitalize on these programs and thus reduce both the environmental impact and economic costs of the foundry's spent sand (Pennsylvania, 2010; Eckelman & Chertow, 2009).