Conveyor Transport of Coal Combustion Byproducts: A Financial, Technical, and Environmental Analysis

A Major Qualifying Project
Submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE
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Degree of Bachelor of Science

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Abstract

In order to determine whether or not conveying coal combustion byproducts (CCBs) was cost competitive with trucking, we developed a preliminary design and cost estimate for three overland conveyor systems. We found that conveyors were cost competitive with trucking. Given their minimal environmental and social impacts and cost efficacy, we recommended that conveyors be used for CCB transport.

Acknowledgments

We would like to thank our advisors Professor Hart and Professor Suzanne LePage for their support and feedback over the course of the last two terms. We would also like to thank the staff at Stantec, especially Mark Willis, for the hospitality while we have been in Lexington, Kentucky. We have enjoyed our work here and are sure it will support us in our future endeavors.

Capstone Design Statement

In order to complete an undergraduate engineering degree, the Accreditation Board of Engineering and Technology (ABET) requires that all students complete a capstone project using the technical, non-technical, and problem solving skills they have developed in the course of their studies. The capstone design project should talk the following factors into consideration as applicable: economic, environmental, sustainability, manufacturability/constructability, ethical, health and safety, social, and political constraints: For this project, it was necessary to consider constructability, economic, environmental, health and safety, social, and political factors.

The constructability of a conveyor system is affected by the terrain, the material to be conveyed and the cost constraints. Since the purpose of this project was to determine whether or not a conveyor system would be cost-competitive with trucking, the costs associated with conveying were not factored in until a reasonable design was made. Google Earth's terrain feature was used in determining the type and location of the conveyor system.

After constructability, the economic analysis was the second largest component of the project. The economic analysis was conducted using a basic pricing methodology for conveyor systems and was considered for the expected operational lifetime of the conveyor. These costs were then compared with the trucking costs estimated by Stantec to determine whether or not a conveyor system would be cost competitive with trucking.

Waste generated from a coal-fired plant must be disposed of in a way that causes minimal harm to the public and the environment. The focus of this project is to design system of transporting CCP's to a landfill site. This project was completed in accordance with the ASCE Code of Ethics, thus safety and impact to the environment was considered throughout the design.

Health and safety, the environment, and social and political factors were considered. A final transportation design will be subject to public scrutiny and should incorporate public feedback. Health and safety of transportation methods were also considered noting that trucking may pose more public safety hazards simply due to increased traffic. The biggest environmental issues related to choosing a transportation method were noise pollution and air pollution from dust, which can also raise health concerns.

In the course of the design process the team met regularly with Stantec engineers, made calls to professionals in the conveyor design industry, and utilized reference material to create a design and complete the cost estimate. They utilized online resources as well as a site visit to develop a list of social and environmental effects. They also researched current regulatory issues related to the classification of CCPs as well as air quality standards that could affect the choice of transportation method. Finally, the student team summed up their recommendations and presented them to the Stantec team.

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1. Introduction

When coal is burned it creates many byproducts which must be stored. Over time, storage facilities reach capacity and new ones must be built. Space must be found for the new facility, which usually takes the form of a landfill or impoundment.

Undergraduate engineering students at Worcester Polytechnic Institute are required to complete a capstone project in their major field called the Major Qualifying Project. This is one such project. In this MQP, two students, Nick Bloksberg and Linnea M. Palmer Paton, were recruited to develop and design a project with Stantec, an engineering services company, at their office in Lexington Kentucky. After several conference-call meetings Stantec and the students had identified a project that would meet the students' educational goals while providing the company with a valuable product.

2. Project Summary

The student team was recruited to determine whether or not another means of transportation would be cost-competitive with trucking. The student team then decided to focus on transportation by an overland bulk material conveyor system. By the conclusion of the project, the team had developed a preliminary conveyor design and price estimate that enabled them to make recommendations about the cost-competitiveness of conveying. In addition to documenting their methodology and decision-making processes, the team researched and considered the social and environmental impacts of the project as well as the regulatory climate affecting the industry at this time.

3. Background

3.1. Cumberland Fossil Plant

3.2. Coal Combustion Byproducts

Coal is made of fossilized plant matter. There are three major types of coal: lignite, bituminous, and anthracite. Lignite and bituminous coals are the most common. They are softer, sedimentary rocks. When bituminous coals are subjected to heat and pressure, they form anthracite, a hard, black, metamorphic rock (Tarbuck & Lutgens, 2008). "In addition to the major elements of carbon, oxygen, hydrogen, nitrogen, and sulfur, coal also contains varying levels of trace elements such as sodium, mercury, chlorine, etc. Coal occurs in association with various types of inorganic minerals such as alumino-silicates (clay minerals), carbonates (calcite and dolomite), sulfides (pyrite), chlorides and silica (quartz). Some elements such as sulfur occur in both the organic and inorganic coal fractions. The inorganic minerals, deposited along with the plant material, are inherent and make up 5 to 10% of the coal (Tishmack, 1996)."

When coal is combusted, often to make electricity, it releases several gasses including carbon dioxide, sulfur oxides, nitrous oxides, and trace amounts of mercury. Not all of the components of coal are able to combust completely. This leads to coal combustion wastes including ashes, gypsum and boiler slags (Kalyoncu). Coal combustion wastes also called coal combustion products or byproducts (CCPs or CCBs) are a significant concern because they are produced in large quantities and must either be stored properly or put to use.

There are two types of ash: fly ash and bottom ash. Both are made up of "silicon, calcium, aluminum, iron, magnesium, and sulfur oxides, along with carbon and various trace elements. These elements are found in the ash because of their high melting points and the short time the ash particles actually remain in the furnace during combustion. The mineral quartz (SiO2) survives the combustion process and remains as quartz in the coal ash. Other minerals decompose, depending on the temperature, and form new minerals. The clay minerals lose water and may melt, forming alumino-silicate crystalline and noncrystalline (glassy) materials (Tishmack, 1996)." In a furnace where coal is being burned, "approximately one fifth of the ash particles fall to the bottom of the furnace and are collected as bottom ash." The rest of the matter is transported out of the furnace with the flue gas. This matter is called pulverized coal fly ash or simply "fly ash (Tishmack, 1996)." The main difference between fly ash and bottom ash are the sizes. Fly ash is a fine powdery material, whereas bottom as is a coarse granular material.

Almost all fly ash is captured by dust collecting systems, such as electrostatic precipitators. Bottom ash is defined as the large ash particles that accumulate at the bottom of the boiler. Boiler slag is the molten inorganic material that is collected at the bottom of the boilers and discharged into a water-filled pit where it is quenched and removed as glassy particles resembling sand (Kalyoncu).

The synthetic gypsum is created by removing the sulfur from the coal combustion emissions. It is also known as Flue Gas Desulfurization (FGD) gypsum. "Scrubber sludge" is also produced in this process. The term scrubbing is used to describe the removal of the sulfur from the air by an aqueous solution of lime or limestone. When the scrubber sludge is oxidized it creates the synthetic gypsum. It is also possibly to do this process using dry limestone and collect the precipitates (Walker, Punawat, Singh Butalia, Wolfe, & Dick, 2002).

Table 1 summarizes and engineering properties of fly ash, bottom ash, boiler slag, and FGD material. Many of these values are important because they affect the design of systems that work with these materials (Walker, Punawat, Singh Butalia, Wolfe, & Dick, 2002).

Table 1. Physical and Engineering Properties of CCBs

Physical Characteristics	Fly Ash	Bottom Ash/ Boiler Slag	Wet FGD Material	Dry FGD Material
Particle Size (mm)	0.001-0.1	0.1-10.0	0.001-0.05	0.002-0.074
Compressibility (%)	1.8	1.4	-	-
Dry Density (lb/ft^3)	40-90	40-100	56-106	64-87
Permeability (cm/s)	10^{-6}-10^{-4}	10^{-3}-10^{-1}	10^{-6}-10^{-4}	10^{-7}-10^{-6}

3.3. Reuse Potential

The preferred method for managing coal combustion products is to reuse them as construction products. Fly ash has several practical applications, and is most commonly used as a high-performance substitute for Portland cement. Cements blended with fly ash are widely accepted in almost all applications. Fly ash has multiple other building material applications that range from grouts and masonry products to cellular concrete and asphalt pavements. Fly ash also can be utilized in geotechnical applications including soil stabilization, road base, structural fill, embankments and mine reclamation (Hohne, 2009). More recently, fly ash has been used to manufacture geopolymers and zeolites (Telone).

FGD Gypsum is currently used in about 30 percent of the gypsum panel products manufactured in the U.S. Gypsum is also used in agricultural applications to treat undesirable soil conditions and improve crop production. Often times, wallboard plants will build their facilities adjacent to such coal-powered electric utilities; in order to have easy access to the FGD gypsum as is the case with the Cumberland Fossil Plant. FGD issues affect, directly or indirectly, coal, gypsum, lime, limestone, and soda ash producers. Increased commercial use of FGD products represents an economic opportunity for high-sulfur coal producers and the sorbent industry (especially lime and limestone). As restrictions on plant emissions increase, more and more FGD gypsum is produced. Today, synthetic gypsum competes directly with natural mined gypsum as raw material for wallboard manufacture (Kalyoncu). “The value of CCPs is well established by research and commercial practice in the United States and abroad. As engineering materials, these products can add value while helping conserve the Nation's natural resources (Kalyoncu)."

Of the fly ash that is produced each year, 70 percent is marketed into the concrete industry while the remaining 30 percent must be stored. For gypsum, 50 percent of the product is marketed to a nearby wallboard company while the remaining 50 percent is stored (Stantec). Reusing CCPs as construction materials is important for several reasons. First and foremost reusing CCPs keeps them out of landfills and other storage facilities, which is beneficial to their environment. Additionally, the plant can make some money from construction companies who will pay for the products.

3.4. Environmental Concerns

When land filling CCBs, it is important to consider the interactions between the landfill and the surrounding environment as well as potential routes of hazardous exposure during their transport such as dust. Several concerns arise when water carrying dissolved organic matter (DOM) intrudes into the landfill. "Dissolved organic matter and sulfate-reducing bacteria can promote the transformation of elemental or oxidized mercury into methyl mercury (Withum, Locke, & Tseng, 2005)." Methyl mercury bioaccumulates in the environment and has harmful impacts on human health. Therefore, Withum, Lock and Tseng warn that "the landfill should be properly designed and capped with clays or similar materials to minimize the wet-dry cycles that promote the release of methyl mercury. (Withum, Locke, & Tseng, 2005)" Fly ashes contain trace amounts of toxic constituents including "arsenic, beryllium, boron, cadmium, chromium, chromium IV, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with dioxins and PAH [polyaromatic hydrocarbons] compounds (Telone)."

3.5. Regulatory Climate

There are numerous regulations related to coal combustion emission and waste materials. Emissions from coal plants are regulated under the U.S. Clean Air Act, originally written in 1967 and amended in 1970. The Clean Air Act has been used to enforce a decrease in sulfur and nitrous oxides as well as mercury from coal combustion emissions.

In 1980, the Bevill Amendment exempted special wastes such as coal combustion byproducts from being regulated under the Resource Conservation and Recovery Act's (RCRA) Subtitle C regulation. Currently, CCBs are regulated under subtitle D of the RCRA, which pertains to nonhazardous solid wastes. This means that the use and/or disposal of CCBs are regulated at the state level. In this case, the regulations are overseen by the Tennessee Department of Environment and Conservation. The U.S. Environmental Protection Agency (EPA) has issued two reports to Congress both concluding that CCBs are nonhazardous and nontoxic materials (URS Corporation, 2010).

The EPA has proposed several new coal ash regulations. The one that is chosen in the end could have a significant impact on CCB reuse, transport, and disposal and is therefore an important consideration in this report. The EPA's proposals fall into two categories: regulate their disposal under RCRA Subtitle C by creating a new category of waste called "Special Waste" or regulate them under RCRA Subtitle D. Regulation under Subtitle C would allow the EPA to enforce and permit activities related to their disposal. Regulations under Subtitle D would allow the EPA to set performance standards, which would be enforced by states who adopt their own CCB management programs (URS Corporation, 2010).

Both approaches would require groundwater monitoring and the use of liner systems and leachate collection and removal systems for environmental protection. Both approaches encourage beneficial reuse of CCBs. Either way CCBs are regulated the beneficial use of CCBs should remain unchanged, except for normal market fluctuations (URS Corporation, 2010).

However, the Subtitle C approach would treat CCBs as hazardous waste whereas under Subtitle D they wound not be. The EPA is considering regulating them under Section C because there has been continued evidence that CCBs in landfills and surface impoundments have been mismanaged. In addition events such as the impoundment failure in Kingston, TN have caused concern. Furthermore, the EPA risk assessment identified human health risks from cancer due to cancer risk thresholds being exceeded. CCBs may also be subject to CERCLA regulations requiring notification to be given of the amounts disposed or the amounts that spill in the case where a spill or release occurs. "The Subtitle C approach allows for direct federal enforcement and CCRs generators, transporters, treaters, storers, or disposers would be subject to the existing Subtitle C cradle-to-grave waste management requirements…The proposed rule includes provisions for siting, liner requirements, run-on and run-off controls, groundwater monitoring, fugitive dust controls, financial assurance, corrective action (including facility-wide corrective action), unit closure, and post-closure care (URS Corporation, 2010)."

While the Subtitle D regulations would not be enforceable by the federal government as management would be under the state's jurisdiction, there could still be incentives for the states to comply since citizen suits or state actions could be filed. Interaction with federal regulatory officials would not be required unless deemed necessary by the state management program. "EPA believes that the use of the Subtitle D program provides a balance between protecting human health and the environment from the risks of CCRs and provides each facility the ability to implement the criteria (URS Corporation, 2010)."

Another regulatory issue that may affect CCBs is greenhouse gas regulation. In 2007, the U.S. Supreme Court ruled that the EPA had the authority to regulate greenhouse gas emissions because they harm human health and welfare by contributing to climate change (Environmental Defense Fund). While the EPA has not acted upon this authority, there is potential for it to do so in future. By making greenhouse gas producing fuel sources and consequently their wastes more expensive to produce, the price of transporting and reusing CCBs could increase. However, further analysis into a carbon tax's effect on the cost of transportation was not researched further because it is unclear which price would be affected more, coal or petroleum based fuels, and whether or not alternatives would be readily available.

4. Social and Environmental Impacts

In any problem solution that impacts the environment it is important to consider the impact on the natural, political, and cultural environment. The Tennessee Department of Environment and Conservation has numerous resources regarding the local habitats in Tennessee and the regulations protecting them, which will be useful for understanding the ecological implications. Newspapers, blogs, and congressional proceedings can give insight into the political and cultural implications of any proposed solution.

4.1. Demographics and Economy

In 1994, President Clinton enacted Executive Order 12898 to ensure that minority and low income populations were not disproportionately bearing adverse health or environmental impacts of federal programs, policies and activities (US Army Corps of Engineers, 2011). Based on the demographics living in the area, none of the sites should have a particularly adverse effect on a low-income or minority groups. Furthermore, the transportation of the wastes to the landfill should not have a disproportionate effect on a low-income or minority groups.

4.2. Political Climate

4.3. Geography

5. Landfill Sites

When faced with the challenge of designing a landfill, arguably the most important and time consuming process is the selection of an appropriate site. The first thing that one must do when undertaking a site selection process is set the parameters. In this case, the original limiting parameter was a 15-mile radius. Stantec determined that it would be too expensive to transport the materials to any site outside of that area. Within this radius, Stantec also considered the size of the sites, the number of owners, and environmental access. With those parameters in mind, Stantec narrowed their choice to 14 sites.

The initial site selection considered trucking as the only means of transportation, and given the volume of byproducts that were expected to be produced; these 14 sites were narrowed down, with site access identified as the crucial factor.

Once these sites were chosen, conceptual designs were performed and estimates of costs and environmental impacts were generated. In order to make a confident and informed site recommendation, Stantec expanded their analysis of the 5 remaining sites and developed a site selection matrix, as shown in Table 3. Within this matrix there were 7 categories, each weighted according to importance, and each with multiple subcategories.

Table 2. Site Selection Matrix for Five Landfill Sites

Metric	Relative Weighting		Site Identification				
			Site 7	Site 8	Site 9	Site 11	Site 12
Site Location	25%						
		Average	8.83	9.67	9.17	8.83	9.17
	0.25	Weighted Average	2.21	2.42	2.29	2.21	2.29
Geotechnical and Geologic Considerations	15%						
		Average	10	9.75	10	9.63	10
	0.15	Weighted Average	1.5	1.46	1.50	1.44	1.50
Regulatory Considerations	20%						
		Average	9.4	8	9.2	8.4	7.8
	0.2	Weighted Average	1.88	1.6	1.84	1.68	1.56
Design / Construction Considerations	10%						
		Average	8.25	10	8	8.75	9
	0.1	Weighted Average	0.83	1.00	0.80	0.88	0.90
Non-Monetary Considerations	10%						
		Average	8.25	10	8.75	8.75	7.75
	0.1	Weighted Average	0.83	1.00	0.88	0.88	0.78
Economic Evaluation (Costs)	10%						
		Average	8.29	9.43	8.29	7.86	9.29
	0.1	Weighted Average	0.83	0.94	0.83	0.79	0.93
Environmental Justice	10%						
		Average	10	10	10	10	10
	0.1	Weighted Average	1.0	1.0	1.0	1.0	1.0
Total	**100%**	**Composite Score**	9.1	9.4	9.1	8.9	9.0
		Rank	**3**	**1**	**2**	**5**	**4**

The first category considered was site location. Site location was considered the most important of the seven factors as it was weighted at 25 percent of the matrix. Within the site location category were multiple subcategories, one being the area and volume constraints of the site. It is crucial that the site that is chosen be able to adequately hold the required volume of byproducts, while also having enough space to effectively complete construction and operation. Proximity and accessibility of the site are directly related to the transportation and infrastructure costs. The site should be as close to the plant as possible to simplify the transportation issues. In terms of accessibility, it is important to understand what roads will be used, and what new roadways, or improvements to current roadways will be necessary. Additionally, stream crossings, intersections, railroad crossings, etc. can lead to increased costs and problems.

The physical properties of the site also make a difference. The location of homes, businesses, utilities, cultural centers, historical and archaeological sites, and ecological sites all impact the viability of the site. One needs to consider the number of property owners on the sites in order to attempt to estimate the land acquisition costs, and the deconstruction costs of any homes of businesses that are currently on the site. On-site utilities can be a major factor as they can hold up and complicate construction as well as create problems in operation when they require maintenance. Cultural centers include schools, churches, cemeteries etc. and can not only be costly to relocate but they can stir up a lot of public opposition. For this reason, the presence of historic sites and landmarks can halt construction very quickly. Often times there is much public and private opposition to moving or removing these sites, so much so that it is best to avoid sites with a large number of culturally significant areas.

Ecological areas can be an issue as well. There may be protected habitats within a site that cannot be altered or damaged, effectively making the project unviable. Finally, the last two factors associated with site location are local zoning regulations, and the compatibility with the surrounding land uses.

Geotechnical and geographic considerations were weighted as 15 percent of the overall matrix. These considerations relate more to problems that may occur during the construction and operation of the landfill. It is important to know the geology of the area, such as the sub-surface and foundation characteristics to have an idea of the strength and/or volatility of the underlying rock. Soil types must be considered in terms of constructability and surface concerns. Related to geology and soil types, is the hydrogeology of the area. Hydrogeology refers to the flows and patterns of groundwater in the area. Karst topography, which refers to the presence of soluble bedrock, must be considered as sinkholes can occur in karst regions. The presence of active or inactive mines, oil and gas wells, or water wells can also present problems in landfill construction and operation. The potential for earthquake activity should be considered in this section as well. The last factor within the geotechnical and geological considerations is the presence of non-standard (non-engineered) fills such as ash ponds.

The second most important category, based on weight, in the site selection process is regulatory considerations. Within this category, several things must be considered, starting with the presence of streams or wetlands on the site that may be impacted. Any streams or wetlands in the area must be mitigated in order to continue with site construction. Another important consideration is flood hazards. It is necessary to estimate the potential for site flooding in the area, and at all costs avoid building on floodplain areas. The general rule is to look at floodplains for a 100-year, 24-hr storm, meaning a storm intensity that has a 1% probability of occurring based on historical precipitation patterns for that particular area. The presence of archaeological and historic sites is an issue within regulatory considerations just as it was in the site location category. The presence of endangered and/or protected plant or animal species must be known as we do not want to hurt these animals and as environmental groups will fight to protect these habitats. The final factor involved is the solid waste siting criteria; in other words the perceived difficulty to obtain the landfill construction and operation permits. This is influenced by whether or not coal combustion products are regulated as hazardous waste. Currently, they are not, but the U.S. Environmental Protection Agency is considering reclassifying them as is discussed further in section 3.1.5 of this report.

The next category in the site selection matrix is design and construction considerations. This category focuses on the anticipated constraints that may be involved within the lifetime of the plant including its design, construction, and operation. One possible factor that could make site design more difficult would be the topography of the site. Landfills are best designed in valleys, in order to maximize the amount of fill that can be stored in a given area. As far as construction constraints, some of the major constraints are the possible difficulty of establishing access roads on the site. Additionally, if much work is needed in clearing the site of trees and buildings, then landfill construction will take longer. Problems that may occur during landfill operation such as phased construction and interim closure constraints must also be considered. Lastly, the design must ensure that the landfill is able to be constructed within practical property limits.

Non-monetary considerations account for 10 percent of the matrix evaluation. One factor within non-monetary considerations is the potential opposition from the site property owner(s). The property owners may object to having to sell their land and homes, while owners of neighboring properties may object to potential aesthetic, noise and pollution disturbances related to the sites. The general public is given the opportunity to voice their opinions when this type of project is undertaken. The public may object to the landfill based on the location or operation of the landfill, as well as any negative environmental impacts. The local government also has the capacity to make complaints about the site which may hold up construction. The client wants to be perceived by the public in the most positive way possible in order to avoid any delays related to opposition.

The economic evaluation for each site was weighted as 10 percent of the matrix. The cost must be evaluated for the entire life of the landfill from design and construction to the closure of the landfill 20 years later. The first costs are associated with the purchasing of the site land. Once the land is purchased, there are costs associated with utility relocation. Design and regulatory cost prior to building can be significant also. Estimations need to be made for the costs associated with obtaining permit compliance and maintaining permits. The construction costs then need to be estimated, which include not only building the landfill, but also the building of access roads. Operations and maintenance costs for the 20-year lifetime of the landfill also need to be estimated. Finally, the cost of the long-term closure of the site needs to be approximated.

The final factor that was included in the matrix was environmental justice. Environmental justice, as described in 4.1 is concerned with the presence of low income households and minority populations in the area. Environmental justice should be considered when undergoing any construction project to make sure that the citizens in the area are not being treated unjustly. In this case, each site scored the same in this category, implying that no one group was expected to be disproportionately affected. Thus the presence of environmental justice neighborhoods was not a major factor in the Stantec analysis.

Based on the site selection matrix factors, and the individual site characteristics, Stantec was able to narrow down to Sites 8 and 9 as the preferred locations. Shortly after, site 12 was reinserted as a site of interest mainly due to its close proximity to the Site. The three site finalists are discussed in more detail in the following section.

Figure 1. Aerial View of Landfill Sites

5.1. Site 8

The total property area of the Site is approximately 1,418 acres. The size is more than adequate to handle the amount of CCBs that are expected to be transported. Two separate hollow fills have been identified in the preliminary design, with the larger of the two fills envisioned to provide 18 million tons capacity for CCB storage. Along with the additional hollow fill, the Site layout shows that the Site can easily accommodate over 25 million tons. The area for the 18 million ton fill is 110 acres. The designed fill is 170 feet tall at its face. Due to the size of the Site, it could be utilized for much greater volumes of fill than are currently expected; potentially extending its useful life beyond the 20 year lifetime that was used during design.

Site 8 is efficient to design, operate and maintain. Because of this, it is possible that the entire 1,418 acre area will not need to be purchased. The land area between the plant and Site 8 is not appropriate to build on as it is part of the 100-year floodplain for Lake Barkley. The majority of Site 8 consists of tree-covered ridges and valleys. The physical relief of the property, or the change in elevation over the property, is about 220 feet with the highest point being just over 600 feet above sea level. There are several farms and residences present on the property that would need to be purchased and most likely demolished. Currently a bridge does exist over Wells Creek on the west side of the plant, though some renovation may be necessary. It may be appropriate additionally, to build a private bridge across the Creek to simplify travel and reduce public visibility. There is one historic site present on the property, the Hollister Furnace, which is on the national register of historic places. The possible costs and impacts of mitigation of the furnace are currently unknown. Three small streams are present on the property as shown on the USGS quadrangle map. There may be approximately 6,000 feet of stream impacted by landfill construction.

One positive factor is that Site 8 is not adjacent to any schools, churches or densely populated areas. There are densely populated residential units along the nearby roads; however, public opposition can be minimized with the use of conveyors instead of trucks.

Site 9

The Site is composed of three parcels with a total area of approximately 1,002 acres. Like Site 8, the full area of the property is not needed and could be partitioned off during the purchase. The Physical relief of the property is on the order of 240 feet with the highest elevation just over 600 feet. The terrain is hilly with a network of numerous narrow ridges and valleys. Several residences and farms are present on the parcels which must be purchased and deconstructed in order to build the landfill. Approximately 5,000 feet of streams may be impacted by construction. The Site is not adjacent to any schools, churches or densely populated areas. Forest clearing and demolition of residential and farm structures would be required. The parcels are owned by 2 individuals and a non-profit foundation. Combined 69 kV and 161 kV transmission lines, owned by, bisect the site and run approximately north-south. Three double-pole structures would need to be raised in order to increase vertical clearance for the safe operation of construction machinery. Based on the topography of the Site, two hollow fills are envisioned to provide over 18 million tons capacity for CCBs. The combined area of the footprint of the fills is 151 acres. The fills are 100 to 190 feet in height at their faces, as measured from the foot of the hollows. Significant earthwork will be required to utilize this Site as a landfill.

5.2. Site 12

Site 12 is the smallest of the three sites by far; however it is also the closest to the plant. The Site is adjacent to the east side of the plant and is only separated from the property by a railroad spur track. The Site is located just 0.75 miles to the east of the plant from the center of the Site. Site 12 is composed of 3 parcels, owned by 2 individuals and an industrial park and contains 256 acres. A 20-acre portion of the industrial park parcel is not needed and could be partitioned off during the land purchase. The land is fallow pasture with minor wooded areas, gently rolling and with a total relief of about 100 feet.

The main parcel of 140 acres is occupied by at least 2 residences and some farm buildings and ponds. Several archeological sites exist on the property. A wetland is indicated where a pond once was. Several streams are indicated on mapping emanating from ponds that are shown on mapping, but no longer exist or are only seasonally wet and therefore do not show up in aerial photography. Two small ponds remain. About 2,000 feet of stream may be impacted by fill construction. Few trees stand on the property, eliminating clearing costs. Demolition of houses and farm buildings would be required. About 3,000 feet of 500 kV transmission lines traverse the mid-section of the property.

Since the topography of Site 12 is more level than the other sites, a stack-type fill as opposed to a hollow fill is envisioned for this site. The fill could accommodate at least 18 million tons of CCBs. The area of the footprint of the fill is 144 acres. The total height of the fill would be about 270 feet. It would extend to about 200 feet of adjacent Old Highway 149. The Site is, in essence, hillside. Excavated soil could be reserved for use as temporary and final landfill cover.

6. Stantec Economic Analysis

Costs were estimated for each site including land acquisition, landfill capital construction, closure and post closure maintenance, transportation infrastructure, and operations and maintenance. The transportation infrastructure and operations and maintenance costs were estimated with trucking being considered as the only means of transportation. As this study is concerning the use of conveyors as the transportation technique, only the land acquisition, landfill capital construction, and closure and post closure maintenance costs will be provided for consideration of sites, however the transportation and operation costs of trucking will be used for comparison purposes. The costs for each of the five sites are shown in Table 4.

Table 3. Five Site Economic Overview (Stantec)

Estimated Net Present Worth (2010 $)	Site 7	Site 8	Site 9	Site 11	Site 12
Land Acquisition Costs	$1,957,465	$7,401,829	$5,230,347	$4,243,785	$1,336,296
Landfill Capital Construction Costs	$36,341,742	$36,340,202	$47,406,892	$61,646,055	$43,430,522
Transportation Infrastructure Capital Construction Costs	$1,126,227	$438,910	$1,856,204	$210,677	$157,084
Operation and Maintenance Costs	$77,450,379	$50,016,888	$63,611,548	$70,691,015	$50,435,626
Closure Costs and Post Closure Maintenance	$4,028,206	$2,438,137	$32,869,900	$4,760,196	$3,187,158
Total Costs	**$120,904,021**	**$96,635,965**	**$121,391,891**	**$141,551,727**	**$98,546,686**

Based on this analysis, Stantec wanted to pursue sites 8 and 9 for further study (drill tests etc.) However, after discussion, they decided to include site 12 in the next phase of the study based on its close proximity to the plant. Sites 7 and 11 were eliminated because they were the furthest away of the five and had other issues (political i.e. too many landowners, environmental considerations etc.)

7. Site Selection Summaries

This is the summary of the three sites that Stantec selected as desirable that were described previously in Section 1.6. Each landfill site is designed to fill a hollow. Although no rare or endangered species have been found on those sites it well be necessary to mitigate damage to wetlands. Any species living in the hollow will have to move elsewhere if possible. These sites were selected from a previous list of five sites, but these sites performed the best in their initial economic analysis. Each of the three sites is being given equal consideration for the site of the landfill.

Table 4. Cost of Land Acquisition, Landfill Capital Construction, Closure and Maintenance for each Landfill Site

Costs (2010 $)	Site 8	Site 9	Site 12
Land Acquisition	7,401,829	5,230,347	1,336,296
Landfill Capital Construction	36,340,202	47,406,892	43,430,522
Closure and Post Closure Maintenance	2,438,137	3,286,900	3,187,158
Total	46,180,168	52,637,239	47,953,976

Table 5. Landfill Site Advantages and Disadvantages

Site 8

Advantages	**Disadvantages**
Largest site	Historical site present
Not all of the site is needed for the landfill	Separated from plant by creek and floodplain
Less visibility due to trees and hollow fill	Significant tree clearing required
Closer to the plant than Site 9	

Site 9

Advantages	**Disadvantages**
Large enough so that not whole site is required.	Furthest site from the plant
No historical or archaeological sites present	Separated from plant by creek and floodplain
Less visibility due to trees and hollow fill	

Site 12

Advantages	**Disadvantages**
Adjacent to the site	Landfill design is very visible to the public
Very little tree clearing necessary	Smallest site
Least land acquisition costs	

8. Transportation Systems

The coal combustion products destined for the new landfill can be transported several ways depending on a few factors. The main ways that the dry CCB cake could be transferred are by trucking, conveying, barging, rail transport, or hydraulic transport. The optimal transportation method depends on the distance to the landfill, environmental factors, and most importantly, cost. In this case, shipping by barge and transporting by rail will not be considered because those options were either not feasible or not desirable according to Stantec.

8.1. Trucking

Currently, Stantec plans on trucking the CCBs from the plant to the landfill. Trucking the material requires little infrastructure investment in comparison with conveyor systems. Because of this, trucking is generally considered more cost effective. Trucking also has several disadvantages. The increased truck trips on local roads may be considered a noise nuisance and a safety hazard. Dust from trucking operations can also be considered a nuisance. The cost of trucking is also subject to the volatility of the price of fuel, which has been increasing due to recent political instability in the Middle East (Krauss & Mouawad, 2011). The various advantages and disadvantages of each system are discussed further in the final recommendations section.

8.2. Conveyor Systems

The two main types of conveyors systems that are in use today to transport ash pneumatic conveyors and belt conveyors. Each of these systems has certain advantages and disadvantages that must be identified when choosing the most feasible system for a given site.

Compared to trucking, conveyors have several advantages. They do not require extensive support systems like haul roads. They also have greater operational safety because they reduce traffic and material hazards. Furthermore, conveyors are designed with overload and malfunction protection to protect people from electrical and mechanical failures. One of the disadvantages of conveyor systems is that when a failure occurs, it can prevent the plant from operating whereas, with trucking, new trucks can be brought in. However, it is possible that trucking could be impacted by severe weather or road failure, but such events are generally unlikely. It is possible that trucks could be used to transport the waste in the event of conveyor failure as long as the system is designed to accommodate them. A comparison of the advantages and disadvantages associated with conveyors versus trucking on roads is shown in Table 7.

Table 6. Comparison of Conveyor Systems to Trucking Systems (MSHA Engineering and Design Manual)

Roads	Conveyors
+ Lower initial investment	- Higher initial investment
- Higher O & M costs	+ Lower O & M costs
+ Route Flexibility	+ Less visibility
+ Can handle larger loads	- Difficult to handle increased loads
- Air quality issues	+ Less air quality issues
+ Less material handling?	- May not always run at full capacity
- Need outside contractors	- Corrosion and wear
+ More standard costs and variables	- More variables/difficult calculations

8.2.1. Pneumatic Conveyors

Pneumatic conveying refers to transporting ash through a pressurized pipe system along a stream of air. The basic system requirements of pneumatic conveying are; a source of compressed gas (usually air), a feed device, a conveying pipeline, and a receiver at the end of the system to disengage the material and gas. A pneumatic system is totally enclosed, and can effectively operate without the conveyed material coming into contact with any moving parts. In order for pneumatic conveying to be effective, the ash must be completely dry (Tennessee Valley Authority and U.S. Environmental Protection Agency, 1981).

There is a good amount of system flexibility within pneumatic conveying in that multiple feeding points can be built into a common line, and a single line can be discharged into a number of receiving hoppers. Additionally, the system can easily sustain horizontal and vertical travel as well as bends in the pipeline. Most of these systems can conveniently be designed for completely automatic operation. Because it is an entirely closed system, there are no issues with dust except at the loading and unloading areas. Pneumatic systems can be designed to operate continuously (24/7) or to handle periodic batches. The majority of systems are conventional, continuously operating, open systems, in a fixed location; however, variations to these factors can occur. When designing the pipeline, several factors must be considered in order to achieve efficiency and sustainability including the pipe material, wall thickness, surface finish and bends in the pipeline. Essentially any amount of dry material can be conveyed pneumatically over very long distances, however there are practical limitations. The main limiting factors for a pneumatic conveyor are economic considerations, factors of scale, and power requirements.

The actual design of the transfer method may be either dense phase or dilute phase, referring to the concentration of ash particles within the air stream. Upon reaching the disposal area, the air velocity is reduced and the ash settles into a storage silo prior to placement in the landfill. Specific transport distance capabilities are based on the type of phase transport, temperature of the air and/or ash, piping system resistance, and altitude. If long transfer distances are required, a transfer or booster station may be necessary. Advantages of pneumatic transport include unattended operation, use of an existing technology relative to ash handling, and ability to conform to existing topography. Disadvantages include high capital cost and potential doubling of ash handling costs at the disposal area.

8.2.2. Belt Conveyors

Belt conveyors are the most common type of conveyor used to transport bulk materials within nearly all fields. Conceptually, the purpose of a belt conveyor is to transport the material on an endless belt spanned between pulleys. Nowadays, belt conveyors are driven by motorized pulleys and can take many configurations.

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The Conveyor Equipment Manufacturers Association (CEMA) is the premier reference entity for conveyor design. One of the textbooks they produced, Belt Conveyors for Bulk Materials (5th ed.) describes the methodology for designing a belt conveyor as well as some of the advantages of using belt conveyors. The methodology was used in this report and is summarized in the following sections. CEMA notes that there are some limitations to the design methodology described in the book. For instance, it says that high energy, high tension conveyors that are longer than 3,000 feet, horizontally curved, head and tail driven, high lifting, on large decline and require braking, or undulating geometrically require advanced technical design methods beyond the scope of the book. However, since the purpose of this project was to create an estimate and since dynamic computer models were not readily available for analysis, the design methodology presented in the book was utilized for creating basic conveyor designs.

There are several advantages to using belt conveyors in comparison to other forms of transportation. First off, belt conveyors are economical. The price of operation is stable; it will be minimally impacted by fluctuations in the price of oil. Furthermore, the labor required to operate and maintain the conveyor is minimal, which results in conveyors having low lifetime labor costs. Aside from the initial capital costs, most of the costs associated with operating the conveyor will be for power, inspection, and lubrication.

Conveyors are reliable. Depending on the design, the impact of weather on operation is minimal. (For example, completely enclosed conveyors do not experience any weather effects.) Repairs and replacements can be anticipated and planned for in order to avoid disruptions in operation. Compared with trucking, repairs are also less costly. Spare parts can be cost-effectively inventoried and stored in a relatively small storage space. For very large volumes of material, conveyors usually have lower costs per ton of material transported than other transportation methods.

Conveyors also are good for meeting environmental requirements. Their design flexibility allows them to fit in with the landscape. They can follow existing terrains up to 35% grade and can even be curve horizontally (Conveyor Equipment Manufacturers Association). They can minimize air pollution from dust and produce fewer operational emissions. Even when the material is transferred from one belt to another or is loaded or unloaded from the belt, dust can be minimized using transfer chutes. Lastly, conveyors operate silently and therefore do not contribute to noise pollution as roadways do.

8.2.3. Horizontal Curves

In the past it was difficult to get conveyor systems to curve horizontally. This drove up costs for large, turning conveyor systems because expensive transfer stations had to be installed and more pulleys, motors, and other infrastructures were needed. The biggest concern when creating horizontally curved conveyor systems is belt slippage in the turn as shown below. The belt, shown in black, is supposed to be centered on the idlers, striped in gray. In Figure 5, the belt has slipped to the left making material spillage more likely. Proper conveyor design can ensure that belt slippage is unlikely.

Figure 2. Belt Slippage on Idlers (Alspaugh M. , 2004)

Figures 6 and 7 show real world examples of curved belt conveyors.

Figure 3. Curved Conveyor (Alspaugh M. , 2004)

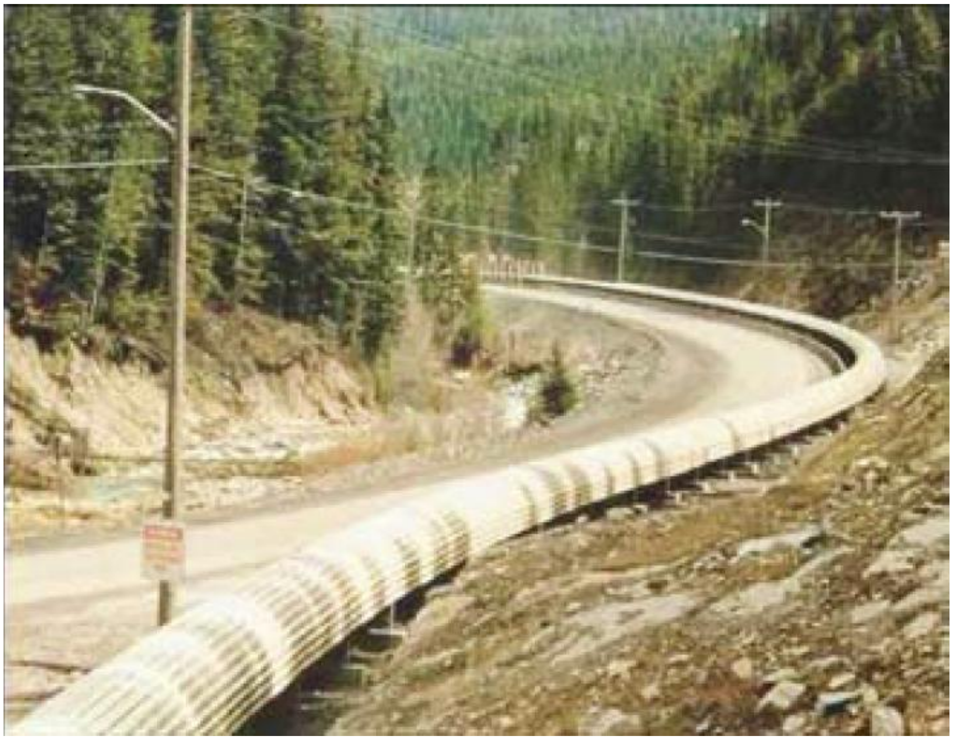


Figure 4. Curved, Covered Conveyor on Rocky Terrain (Unmacht, May 2009)

8.2.4. Characteristics and Conveyability of Bulk Materials

When designing belt conveyors it is important to consider the characteristics of the materials being conveyed. The material characteristics that must be taken into account are listed below (Conveyor Equipment Manufacturers Association):

1. Angle of repose: the “acute angle which the surface of a normal, freely formed pile makes to the horizontal…”
2. Angle of surcharge: “the angle to the horizontal which the surface of the material assumes while the material is at rest on a moving conveyor belt. This angle is usually is 5 degrees to 15 degrees less than the angle of repose…”
3. Flowability of a material, as measured by its angle of repose and angle of surcharge, determines the cross-section of the material load which safely can be carried on a belt. It also is an index of the safe angle of incline of the belt conveyor. Flowability is determined by material characteristics such as the size and shape of the particles,

abrasiveness of the particles, proportion of fine particles to lumps, and moisture content.

4. Weight per cubic foot
5. Dustiness
6. Moisture content
7. Stickiness
8. Abrasiveness
9. Corrosive ability
10. Temperature

The material characteristics affect how the material behaves on the belt. The material behavior will also vary based on the slope and speed of the conveyor belt. When the material is loaded onto the belt, the acceleration of material causes agitation in the material (assuming forward velocity of the material and the velocity of the belt are different). Agitation causes the finer particles to move to the bottom of conveyor belt which can affect the stability of the material. Furthermore, such separation may not be desired.

Belt Tension, Power, and Drive Engineering Estimates

Estimating the belt tension is important because the operating maximum belt tensions play a significant role in wear on the belt. Furthermore, the belt tensions when the belt starts may be many times more than the calculated operating tension if motors are not designed correctly. Belt tensions usually are highest at the discharge end of the conveyor; however, if the conveyor has steep slopes or other inflection points the maximum tension may occur elsewhere. It is recommended that software be used for final design calculations as the tension calculations can be quite complex. For the purposes of this study, several general calculations were used to estimate the power required to run the conveyor. The development and results of these calculations are described in section 10.2.1.

8.2.5. Conveyor Covers

Belt covers come in many shapes and sizes. Some are simply loops over the conveyor ever 15 feet or so that serve as wind breaks. These prevent large lifting forces from being exerted on the conveyor by the wind and decrease the need for large foundations. Conveyors can also be partially covered to minimize dust and protect the materials. A fully enclosed conveyor system offers the most protection to the material as well as to the maintenance personnel who may be exposed to the elements while servicing the conveyor if the service walkway is exposed.

9. Conveyor Design and Methodology

When choosing a proper conveyor system, there are multiple factors that must be identified to choose the most efficient and cost effective system. Important factors that need to be considered are the distance, the type of material(s) and the amount of materials that need to be transported. For this project, there were three sites being considered, and there were three types of by-products to be conveyed, thus it is quite possible that different conveyor types and/or multiple conveyors may be required for each site. Beyond these major factors, there are many other variables including plant arrangement and expected landfill characteristics that affected the preliminary design, and will play a significant role in any future design iterations.

9.1. Distance to Landfill

The distance to the landfill is an important piece of the design that has several complicating factors. When finding out the distance from a plant to a landfill it is crucial to attempt to map out a feasible route based on the topography of the land, the location of roads, utilities and bodies of water, and sometimes the land on which the conveyor is to be built.

The land on which a conveyor is to be built can be a right-of-way, meaning that it is government owned land. In that case, if the land owners need to do work on the area where your conveyor is located, it must be moved at the expense of the conveyor operator. Alternately, the conveyor can be built on private land with the purchase of an easement where that property is purchased and owned, thus if some complications arise, the conveyor can only be moved or altered at the expense of the outside contractor.

When mapping out a route there must be an understanding of the location of recreational and residential areas to avoid public nuisance and costly detours. Additionally, it is important to know the location of public utilities so that they can be avoided as complications may arise during the construction or operation of the system. The utilities can be moved if necessary, but at a cost. Also, attempting to cross roads and bodies of water will increase costs in permitting and construction.

Finally, it is helpful to know the changes in elevations on a route. Mountains and valleys can lead to increased construction costs and pumping up a hill requires more power from the conveyor (although power can sometimes be retrieved by generating electricity from a loaded, downward sloping conveyor). Once these factors are taken into account and one or more routes are designed, then an accurate conveyor distance can be determined. The distance of the route is important for a conveyor system as the capital construction costs and operations costs increase with more distance conveyed. The distances from the plant for sites 8, 9 and 12 are 1.5, 2.5, and 0.75 miles respectively, as estimated by Stantec Engineers.

9.2. Type of Materials

The type of materials that are being conveyed is very important when choosing a conveyor. The materials in this case include fly ash, bottom ash, and synthetic gypsum. Some physical properties that are important to know for each material are particle size, density, and moisture content. The physical properties of fly ash are shown in Table 8 which was adapted from Table 3-2 and 3-3 in the Belt Conveyors for Bulk Materials textbook. The properties of fly ash were determined to be the most limiting on design and therefore are the only ones included in the table.

Table 7. Fly Ash Characteristics (Conveyor Equipment Manufacturers Association)

Fly Ash	
Density (lb/ft^3)	90
Avg. Weight lb/cu ft	40-45
Angle of Repose (degrees)	42
Recommended maximum inclination (degrees)	20-25
Size	Very fine – 100 mesh and under
Flowability (degrees)	30 to 39
Abrasiveness	Very abrasive

In order to transport ash by belt conveyor, the ash must be dry, although partial wetting can be allowed to minimize dust. Dust minimization can also be achieved by fully covering the conveyor system.

In addition to the physical characteristics, there are several chemical characteristics that come into play. It is not efficient to attempt to convey the different types of byproducts together all at once, as they are extracted differently from the boilers. In addition, it is appropriate to keep them separated in the landfills as they all have potential for reuse in various areas of construction and these materials can potentially be re-mined and sold at a later time. That being said, it is still plausible to design for all of the materials to be transferred on one belt, during separate time intervals. The plant also generates other wastes such as calcium silicate thermal insulation, boiler sandblasting residue, spent resin and activated alumina. The amounts of these in comparison to the gypsum and ash are minor and do not affect site selection.

9.3. Amount of Materials

The daily mass and volumetric loads are shown in Table 9.

Table 8. Amount of Materials Produced Per Year

	Total Mass (ton/year)	Landfill Mass (ton/year)	Mass (ton/day)	Density (lb/ft^3)	Volume (ft^3/day)	20 year Volume (ft^3)
Fly Ash	480,000	180,000	500	90	11,000	80,000,700
Bottom Ash	120,000	120,000	330	100	7,000	47,997,500
Gypsum	1,100,000	600,000	1,650	90	37,000	266,669,000
Total	1,700,000	900,000	2,480		55,000	394,667,200

These are the provided loads, nevertheless it is important to leave room in the design for increased loads in this case, where the full output of the plant (1,700,000) may need to be landfilled. This may occur if the plant, for some reason, is no longer able to sell the same amount of byproducts as construction materials as they currently do. This factor needs to be accounted for especially with a conveyor system as it is very difficult to increase the capacity of a conveyor that has already been built. Increased capacity may also be necessary in the situation where the conveyor malfunctions or breaks down. There are several ways to prepare for this scenario and they are as follows:

1. Design conveyors that don’t need to run for 24 hours a day at normal capacity.
2. Design conveyors that can handle the full output at normal running capacity.
3. Design multiple conveyors, each with a capacity of at least the current output.

A conveyor that does not run continuously has its advantages and disadvantages. Whenever a backup of byproducts or an increased output is experienced, the operator can easily choose to operate the conveyors for an increased amount of time. It is less energy efficient however, to have to start up and stop the conveyor system multiple times as opposed to allowing it to run continuously.

By designing the conveyors so that they are able to handle the full amount of output at their normal capacity then they would be able to easily handle any increased loads. This scenario can prove to be costly however, as the conveyor will often be operating at less than its full capacity which is not efficient.

Having multiple conveyors can be a reasonable solution; however it would obviously lead to increased capital construction costs. Alternatively, the conveyors that are built would not need to be as large or powerful as a conveyor designed for full plant output.

9.4. Plant Arrangement

When designing the conveyor route, there are several structures on site that need to be built around. The layout of the plant provides several design challenges. The ash and gypsum stacks as well as the wallboard plant are in the way of a direct line of travel from the plant to the landfills, as can be seen in Figure 1. Wells Creek surrounds the stack providing further design challenges. The gypsum byproducts are sluiced in pipes to the gypsum stacking area where they are dewatered. There are several existing conveyors on the site of the plant, several that transport coal from barges to the plant itself, and several conveyors that send gypsum to the adjacent wallboard plant. Based on their current use and location, it is unlikely that these conveyors could be implemented into the new conveyor system.

When conveying to site 12, a conveyor needs to be built around the wallboard plant on the east side of the plant as it is not feasible to build an elevated conveyor over the plant. When considering conveyance to sites 8 and 9, care must be taken when building over the ash stacks on the southwest side of the plant. It is ideal to avoid these stacks as they do not necessarily provide a stable base on which to build the conveyor supports. Additionally, vehicles travel over the stacks multiple times daily. It is important that the conveyor does not interfere with the closing of the existing stacks that will take place over the next several years.

9.5. Landfill Characteristics

The landfill is to be designed for a 20-year lifetime. The conveyor will be built to the nearest corner of the site, and extend into the site about 100 feet. Significant transport by construction vehicles is necessary at the end of the conveyor to spread the ash over the entirety of the site. Ideally, the materials should be placed in designated areas separate from each other in order to maximize their potential for reuse. The accessibility of the landfill is important in terms of being able to get construction vehicles onto the site, and the ability to clear the site effectively.

9.6. Design Considerations Summary

With the amount of materials, material characteristics and conveying distances known, textbooks and several outside firms were consulted in an attempt to obtain recommendations for the conveyor design. For long overland systems, belt conveyors were the most widely used and were recommended above pneumatic systems. Based on these findings, it was determined that a covered belt conveyor would be the most effective conveyor system to use.

10. Conveyor Design

10.1. Belt Material Selection

The belt is a significant part of the initial capital costs for conveyor construction. Therefore it is desirable to ensure that the belt has a long useful life by ensure that a proper belt is selected for the type of materials and load being carried. The belt itself actually is composed of three elements: the top cover, the carcass in the middle, and the bottom cover. The three elements together form a sort of belt sandwich, which sit on the idlers and hold the material. The belt carcass in the middle is the part of the belt that carries the tension forces when the belt starts and moves. It also absorbs the most impact energy during material loading. Furthermore, it provides stability for alignment and load support. It is very important the covers protect this piece of the belt.

There are different kinds of general purpose belting. Belts serve a range of industrial applications including mining, ore processing, lumber, paper/pulp and agriculture. Usually covers are made of natural rubber, SBR (styrene-butadiene rubber), polybutadiene, and acrylonitrile or associated blends. In this case, the belts will be used to transport CCBs. Two of the main classes of belt covers are described in Table 10.

Table 9. Conveyor Belt Cover Qualities

Cover Grade	**Major Advantages**			**General Applications**
	Cut and Tear Resistance	Abrasion Resistance	Oil Resistance	
Grade I	Excellent	Excellent	Not recommended	Large size ore, sharp cutting materials. For extremely rugged service.
Grade II	Good	Good to Excellent	Not recommended	Sized materials with limited cutting action —primarily abrasion. For heavy duty service.

Adapted from Table 7-3 in Belt Conveyors for Bulk Materials

Table 10. Suggested Minimum Carry Thickness for Normal Conditions: RMA—Grade II Belting

Class of Material	Examples	Thickness (inches)
Light or fine, nonabrasive	Wood chips, pulp, grain, bituminous coal, potash ore	1/16 to 1/8
Fine and abrasive	Sharp sand, clinker	1/8 to 3/16
Heavy, crushed to 3”	Sand and gravel, crushed stone	1/8 to 3/16

Adapted from Table 7-4 in Belt Conveyors for Bulk Materials

10.2. Belt Width and Cross-Sectional Area

In the design of the conveyor system, it was necessary to determine the relationships between the amount of materials being conveyed and the necessary size of the system. In order to do this, a relationship first needs to be established between belt width and the cross-sectional area of the material laying on the belt.

10.2.1. Belt Widths, Speeds, and Capacities

10.2.1.1. Belt Widths and Speeds

Belt widths usually come in the following standard sizes in inches: 18, 24, 30, 36, 42, 48, 54, 60, 72, 84, and 96 (Conveyor Equipment Manufacturers Association). Belt speeds depend on many factors including material characteristics, desired capacity, belt tensions, and design of the discharge and loading areas. The ash and gypsum would be a dry, powdery, and very abrasive material. This means that extra measures would need to be taken to prevent dusting at the loading and discharge sites. It will also be important to design the belt with a low enough velocity so as to minimize the wear of the abrasive materials on the discharge and transfer chutes (Conveyor Equipment Manufacturers Association).

10.2.1.2. Belt Conveyor Capacities

It is important to design a belt that has a large enough capacity to handle all the material that must be transported. It may be tempting to build large conveyor systems to provide flexibility in the amount of materials carried. However, it is not efficient to run belts below their capacity. Therefore it is desirable to design the conveyor system to run at full capacity.

There are several general principles that are useful in determining and designing belt capacity. First off, for a given speed, belt conveyor capacities increase as the belt width increases. This is because larger belts can carry more materials. Furthermore, the capacity depends on the surcharge angle of the material and the inclination of the side rolls of the three-roll troughing idlers. This is because the surcharge angle and the angle of the idlers all have a direct effect on the total cross-sectional area of the material on the belt, which dictates the amount of material that belt can carry for a given speed. For most conveyors the effect of an incline or decline on the cross-sectional belt capacity is very small.

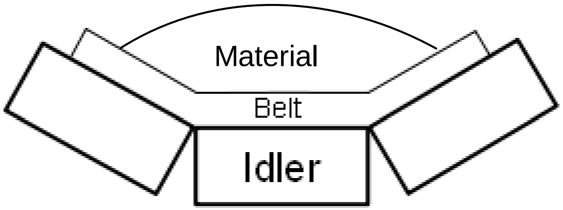
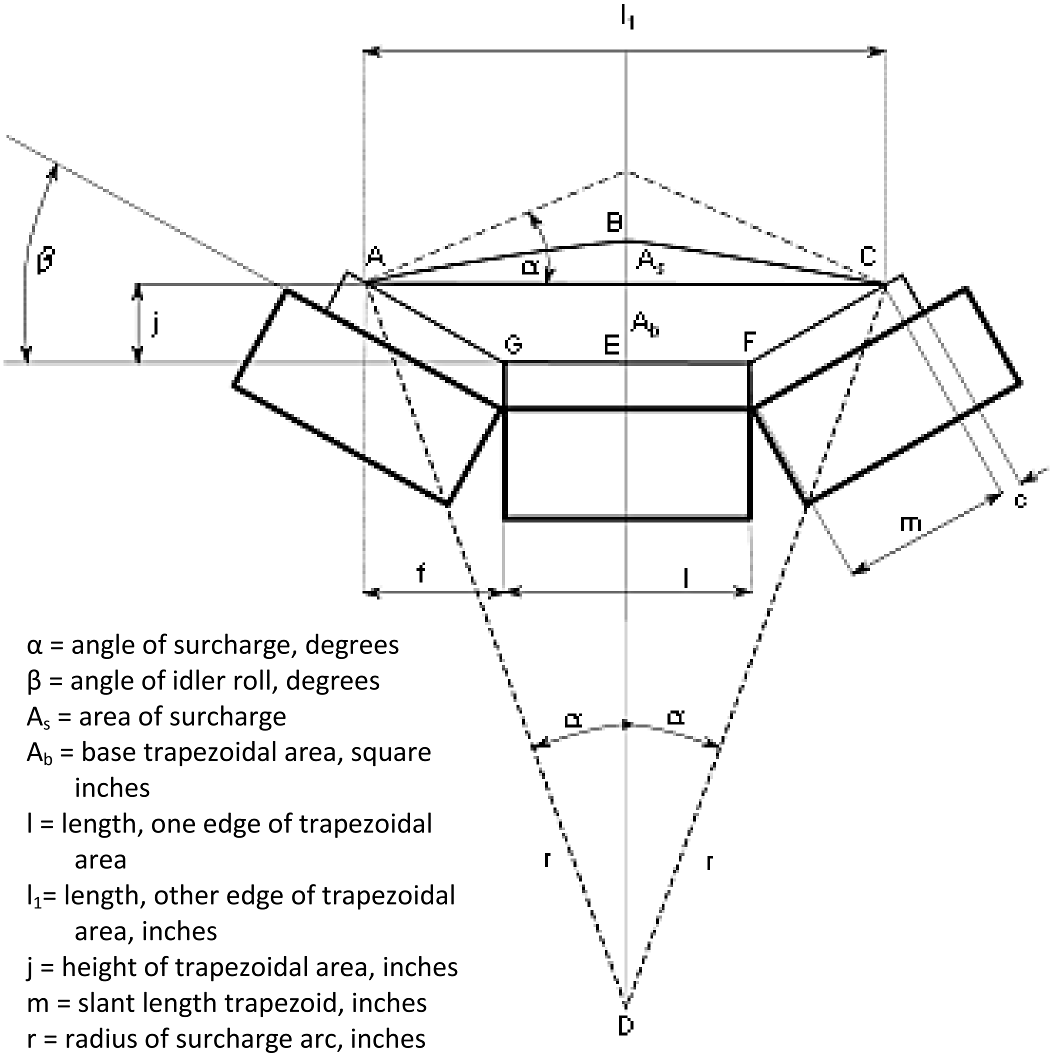


Figure 5. Cross-Section of a Troughed Idler Conveyor System

When material is loaded on a troughed belt there are several design factors that should be followed. The material load on the belt should not extend past the belt edges or it will fall and damage the idlers. The distance from the edge of material to edge of belt should be set at the "standard edge distance," which is defined to be 0.055b+0.9 inch, where b is the width of the belt in inches. A more detailed drawing of the cross sectional area, complete with descriptions of how to find the cross-sectional area of the material, is shown in Figure 9.



α = angle of surcharge, degrees
β = angle of idler roll, degrees
A_s = area of surcharge
A_b = base trapezoidal area, square inches
l = length, one edge of trapezoidal area
l_1= length, other edge of trapezoidal area, inches
j = height of trapezoidal area, inches
m = slant length trapezoid, inches
r = radius of surcharge arc, inches
f = horizontal projection of slant side of trapezoid, inches
c = edge distance, edge of material to edge of belt, inches
b = width of belt, inches
c = standard edge distance = 0.055b+0.9 inches

Figure 6. Area of Load Cross Section of a Troughed Belt Conveyor

Adapted from Figure 4.2 in Belt Conveyors for Bulk Materials 5th Ed.

Figure 9 can be used to find the cross sectional area of the material on a troughed-idler belt system. “Based on an analysis of the three-equal-roll troughing idlers of eight manufacturers, the length of the flat surface of the center roll averages 0.371b, where b is the belt width in inches (Conveyor Equipment Manufacturers Association).” The list below describes the equations for calculating each variable in more detail.

Equation 1. Area of trapezoid ($AECFG$)

$$\boldsymbol{A_b = \left(\frac{l+l_1}{2}\right) * j}$$

Equation 2. Belt width

$$\boldsymbol{b = 1 + 2m + 2c}$$

Equation 3.

$$\boldsymbol{l_1 = l + 2f} \text{ and } \boldsymbol{l_1 = 0.317b + 0.25 + 2(0.2595b - 1.025)\cos(B)}$$

Equation 4.

$$\boldsymbol{l = 0.371b + 0.25}$$

Equation 5.

$$\boldsymbol{c = 0.055b = 0.9}$$

Equation 6.

$$\boldsymbol{b = 0.317b + 0.25 + 2m + 2(0.055b + 0.9)}$$

Equation 7.

$$\boldsymbol{2m = b - 0.418b - 2.05}$$

Equation 8.

$$\boldsymbol{m = 0.2595b - 1.025}$$

Equation 9.

$$\boldsymbol{f = m(\cos(\beta)) = (0.2595b - 1.025)\cos(\beta)}$$

Equation 10.

$$\boldsymbol{2f = 2(0.2595b - 1.025)(\cos(B))}$$

Equation 11.

$$\boldsymbol{j = m * \sin(\beta)}$$

Equation 12. Circular segment (surcharge) area

$$\boldsymbol{A_s = r^2\left(\frac{\pi\alpha}{180} - \frac{\sin(2\alpha)}{2}\right)}$$

Equation 13. Total Area

$$\boldsymbol{A_t(ft^2) = \frac{(A_b + A_s)}{144}}$$

10.2.1.3. Process for Determining Belt Conveyor Capacity

Selecting the belt conveyor is important step in the design process because determines the load a conveyor will be able to carry and the run times necessary to convey the materials. In order to find the capacity, it is necessary to make several decisions about the design of the conveyor. When choosing a belt width it is also important to decide whether the conveyor will be flat or troughed. Troughed conveyors have the advantage of having much larger cross-sectional areas and thus are able to transport much more material per foot than flat belt conveyors. Standard angles for trough conveyors are 20, 35, and 45 degrees. The angle that is picked will depend on the characteristics of the material to be transported. It will be necessary to choose a design based on the surcharge angle of the material and the belt speed (which is primarily determined by the abrasiveness of the material.) The following list for determining conveyor capacity has been adapted from Belt Conveyors for Bulk Materials (Conveyor Equipment Manufacturers Association).

1. Determine the surcharge angle of the material. The surcharge angle, on average, will be 5 degrees to 15 degrees less than the angle of repose

2. Determine the density of the material in lb/ft^3

3. Choose the idler shape suited to the material and to the conveying problem

4. Select a suitable conveyor belt speed using Table 12.

Table 11. Recommended Maximum Belt Speeds

Material Being Conveyed	Belt Speeds (fpm)	Belt Width (inches)
Grain or other free-flowing, nonabrasive material	500-1000	18-96
Coal, damp clay, soft ores, overburden and earth, fine-crushed stone	400-1000	18-95
Heavy, hard, sharp-edged ore, coarse crushed stone	350-600	18-36+
Foundry sand, prepared or damp; shake-out sand with small cores, with or without small castings (not hot enough to harm belting)	350	Any width
Prepared foundry sand and similar damp (or dry abrasive) materials discharged from belt by rubber-edged plows	200	Any width
Nonabrasive materials discharged from belt by means of plows	200, except for wood pulp, where 300 to 400 is preferable	Any width
Feeder belts, flat or troughed, for feeding fine, nonabrasive, or medley abrasive materials from hoppers and bins	50-100	Any width

Adapted from Belt Conveyors for Bulk Materials 5th Ed. CEMA

5. Convert the desired tonnage per hour (tph) to be conveyed to the equivalent in cubic feet per hour (ft^3/hr).

Equation 14.

$$\frac{ft^3}{hr} = \frac{tph \times 2000}{material\ density}$$

6. Convert the desired capacity in cubic feet per hour to the equivalent capacity at a belt speed of 100fpm.

Equation 15.

$$Capacity\ (equivalent) = \left(\frac{ft^3}{hr}\right) \times \left(\frac{100}{actual\ belt\ speed\ (fpm)}\right)$$

7. Using this equivalent capacity, find an appropriate belt width. See Table 13.

Table 12. Conveyor Belt Capacities for 35-degree Troughed Belt with Three Equal Idler Rolls and Standard Edge Distance

Belt Width (inches)	A_t Cross Section of Load (ft^2)				Capacity at 100 FPM			
	Surcharge Angle				Surcharge Angle			
	15°	20°	25°	30°	15°	20°	25°	30°
18	.194	.212	.230	.248	1169	1274	1381	1492
24	.373	.406	.440	.474	2241	2438	2640	2847
30	.609	.662	.716	.772	3658	3875	4300	4636
36	.903	.980	1.060	1.142	5419	5886	6364	6857

Adapted from Table 4-3 in Belt Conveyors for Bulk Materials 5th Ed.

When designing a conveyor it is helpful to develop a relationship between the cross-sectional area of the conveyor and the corresponding belt width. Graphing this relationship makes it easier to determine either variable given the other. The process used for graphing and analyzing the relationship between the cross-sectional area and the belt width is included below.

In order to calculate belt width and cross sectional area, several design parameters must be identified, as specified in the "Area of Load Cross Section of a Troughed Belt Conveyor" figure. The type of conveyor chosen for this study was a conveyor with three equal sized idlers as shown in Figure 8. With this configuration, two additional parameters were identified; trough angle, and refuse angle. A trough angle of 35 degrees and a refuse angle of 25 degrees were chosen based on Table 3-1 in the Belt Conveyors for Bulk Materials textbook. The table lists the angle of surcharge and angle of repose for materials based on their flowabilitiy. The cross-sectional area of a conveyor is actually the cross-sectional area of the materials as they lay on the conveyor. To find this area, it is necessary to find the area of two separate sections: the lower trapezoidal section, and the upper arc section. The calculations and procedure to find the area of the trapezoidal section are shown in Section 10.2.1.2 and Figure 9.

The results of calculating the cross sectional area of the trough based on the width of the belt for 6 belts ranging in width from 10 inches to 60 inches (a range that we thought was reasonable), in increments of ten inches, are shown below in Table 14 and Figure 10.

Table 13. Belt Width vs. Cross-Sectional Area

Belt Width (in)	Cross-Sectional Area (ft^2)
0	0
10	0.055
20	0.293
30	0.717
40	1.327
50	2.124
60	3.107

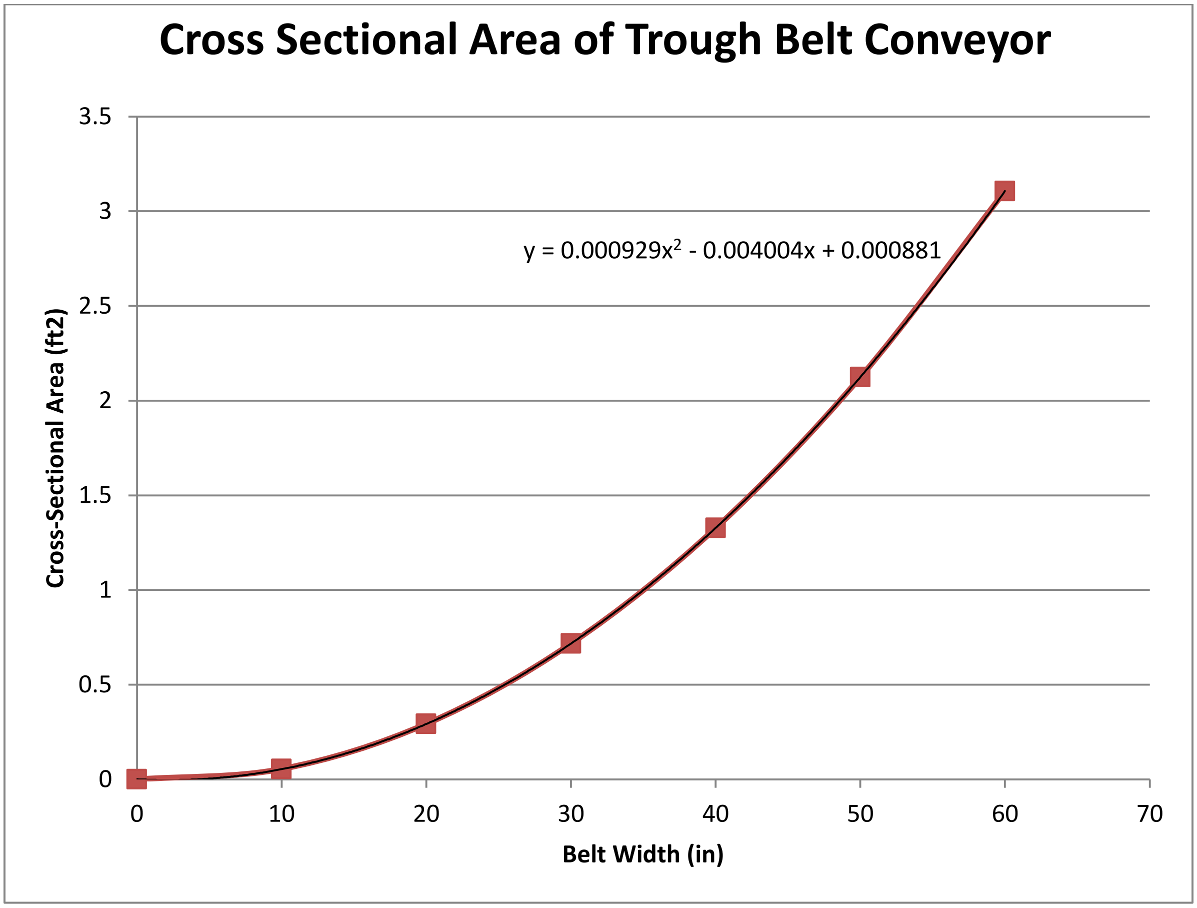


Figure 7. Graph of Belt Width vs. Cross Sectional Area

10.2.2. Balancing Conveyor Size and Run Times

The equation that governs the design of a conveyor belt is:

Equation 16.

$$\boldsymbol{Q = \rho A v}$$

Where Q = throughput (lb/min), ρ = material density (lb/ft^3), A = conveyor cross-sectional area (ft^2), and v = belt velocity (ft/min) (Alspaugh M. , 2008).

Two separate analyses were performed using this equation, one for gypsum, and one for combined fly and bottom ash. It is expected that only one conveyor will be economically feasible and that gypsum and combined ash can be conveyed to the landfill separately at different times. With the annual throughput (Q, mass flow rate) as well as the densities of the ash types known from previous sections, we completed an analysis to determine the volumetric flow rate (Av) as a function of the cross-sectional area (A) and belt velocity (v).

The first analysis was performed to get a better understanding of how the relationship worked. This analysis assumed an 8-hr run time per day for both gypsum and combined ash. The analysis was performed first for gypsum, assuming the plant output is 600,000 tons/year. The calculations are as follows:

Equation 17.

$$\boldsymbol{600,000\frac{ton}{year} \times 2000\frac{ton}{year} \times \frac{1\ yr}{365\ days} \times \frac{1\ day}{8\ hours} \times \frac{1\ hr}{60\ min} = 6,849\ \frac{lb}{min}}$$

With the density of gypsum known to be 90 lb/ft^3:

Equation 18.

$$\boldsymbol{6,849\frac{lb}{min} = \left(90\frac{lb}{ft^3}\right) \times Av}$$

$$\boldsymbol{Av = 76.1\frac{ft^3}{min}}$$

With the value of Av known, a plot of A versus v was completed for a range of areas as shown in the figure below. It shows a general inverse relationship between belt velocity (v) and the cross-sectional area. In short, as the belt velocity increases the cross sectional area required to move an amount of material decreases.

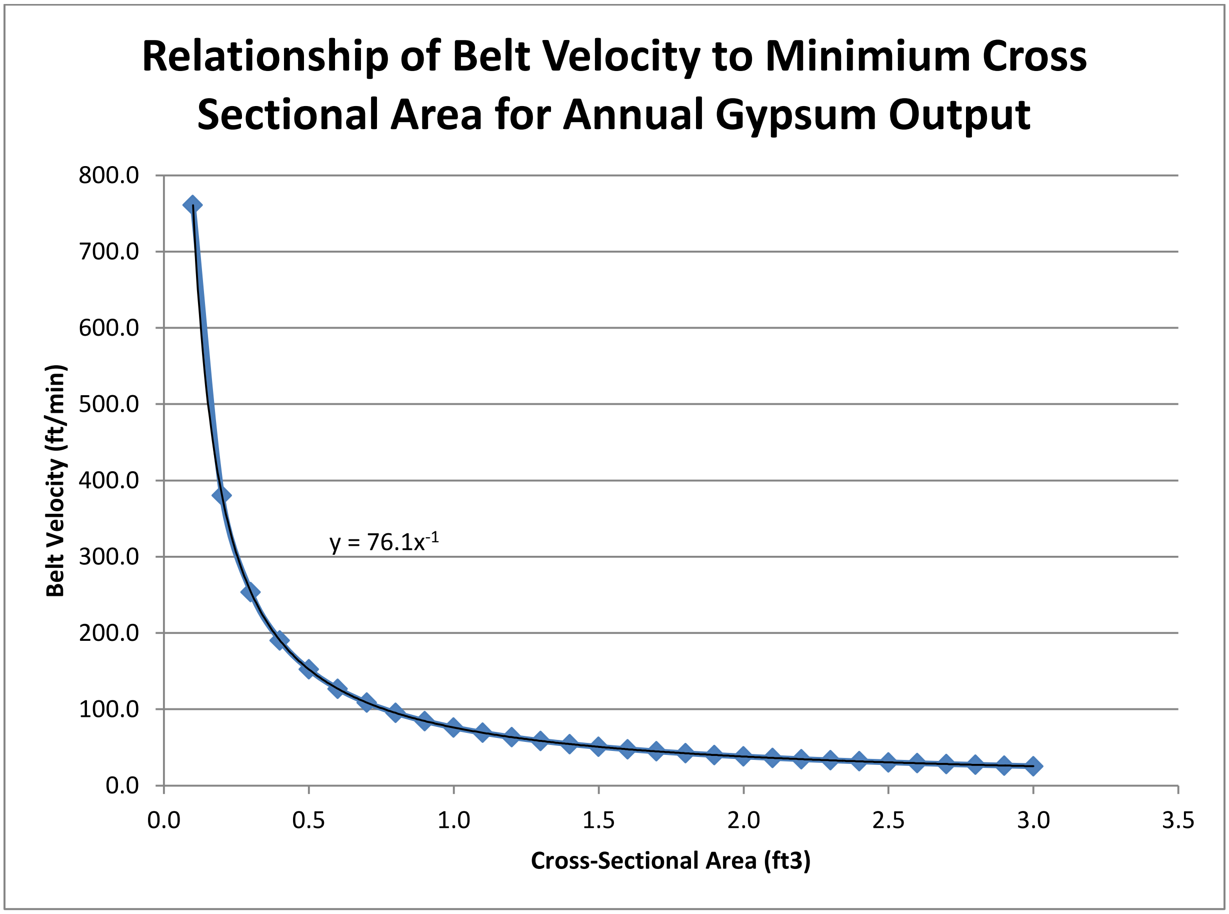


Figure 8. Belt Velocity vs. Cross-Sectional Area for Annual Gypsum Output

A similar analysis was done for combined fly and bottom ash to yield the following figure.

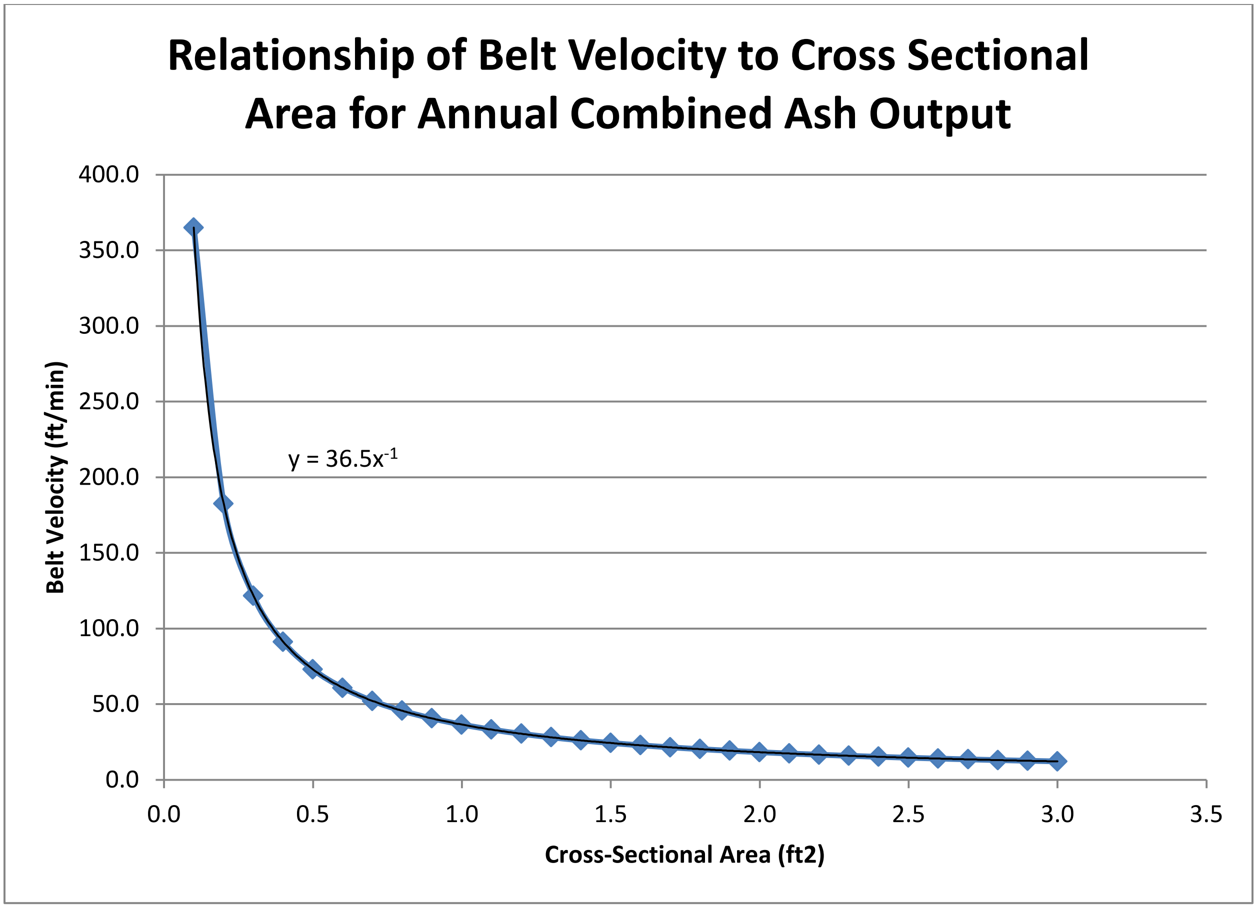


Figure 9. Belt Velocity vs. Cross-Sectional Area for Annual Combined Ash Output

The purpose of creating Figures 11 and 12 was to attempt to understand the basic relationship between cross-sectional area and belt velocity with 8-hour run times for each as an arbitrary factor. It was determined from that the optimal belt speed for our type of material was 200 ft/min (Conveyor Equipment Manufacturers Association). With this value in mind, a cross-sectional area was determined for both gypsum and combined ash from the following procedure:

Ex. Gypsum, where v = 200 fpm

Equation 19.

$$\boldsymbol{Av = A(200\,fpm)\;A = 76.1\,\frac{ft^3}{min}}$$

$$\boldsymbol{A = 0.38\,ft^2}$$

These area values were 0.38 ft^2 and 0.18 ft^2 for gypsum and ash respectively. Assuming that the belt was designed to carry gypsum given a 0.38 ft^2 cross sectional area, assigning each material the same run time would result in the ash being run inefficiently because it would barely fill half of the cross-sectional capacity. Thus, it was determined that the conveyor runs times for each material should be altered in order to arrive at the same material cross-sectional area on the conveyor in order to achieve maximum efficiency. A relationship was determined between run time, in hours, and the cross-sectional area at a belt velocity of 200 feet/min. First we needed to determine the volumetric flow rate per day, with the assumption that the system will run 365 days per year:

Daily volumetric flow rate of gypsum:

Equation 20.

$$600{,}000\ ton/year * 2{,}000\ lb/ton * 1\ \mathrm{yr}/365\ days = 3{,}287{,}671\ lb/day$$

Equation 21.

$$3{,}287{,}671\ lb/day = (90\ lb/ft^3)Av$$

$$\boldsymbol{Av = 36{,}530\ ft^3/day}$$

Based on the above volumetric flow rate (Av), the flow rate of gypsum to the landfill is expected to be 36,530 ft^3/day. Dividing by the number of hours of run time, and a conversion factor of 60 min/hr, we can determine Av (volumetric flow) in ft^3/min. Dividing this value by the known belt velocity of 200 ft/min yields a cross-sectional area value for the given run time. The values of this analysis for gypsum and combined ash are given in Tables 15 and 16.

Table 14. Required Material Cross-Sectional Area by Run Time based on Annual Gypsum Output to be Landfilled for Gypsum

Run Time (hr)	Av (ft3/min)	A (ft2)
1	608.83	3.04
2	304.41	1.52
3	202.94	1.01
4	152.21	0.76
5	121.77	0.61
6	101.47	0.51
7	86.98	0.43
8	76.10	0.38
9	67.65	0.34
10	60.88	0.30
11	55.35	0.28
12	50.74	0.25

Table 15. Required Material Cross-Sectional Area by Run Time based on Annual Gypsum Output to be Landfilled for Combined Ash

Run Time (hr)	Av (ft3/min)	A (ft2)
1	292.24	1.46
2	146.12	0.73
3	97.41	0.49
4	73.06	0.37
5	58.45	0.29
6	48.71	0.24
7	41.75	0.21
8	36.53	0.18
9	32.47	0.16
10	29.22	0.15
11	26.57	0.13
12	24.35	0.12

Figure 13 is a graph of the run time vs. cross-sectional area results for both material types. After determining the ideal cross-sectional area, that value can be inserted into the equations of the two curves to yield the ideal run times for each material. For instance a cross sectional area of 0.75 ft^2 would require run times of 2 hours and 4 hours for combined ash and gypsum respectively.

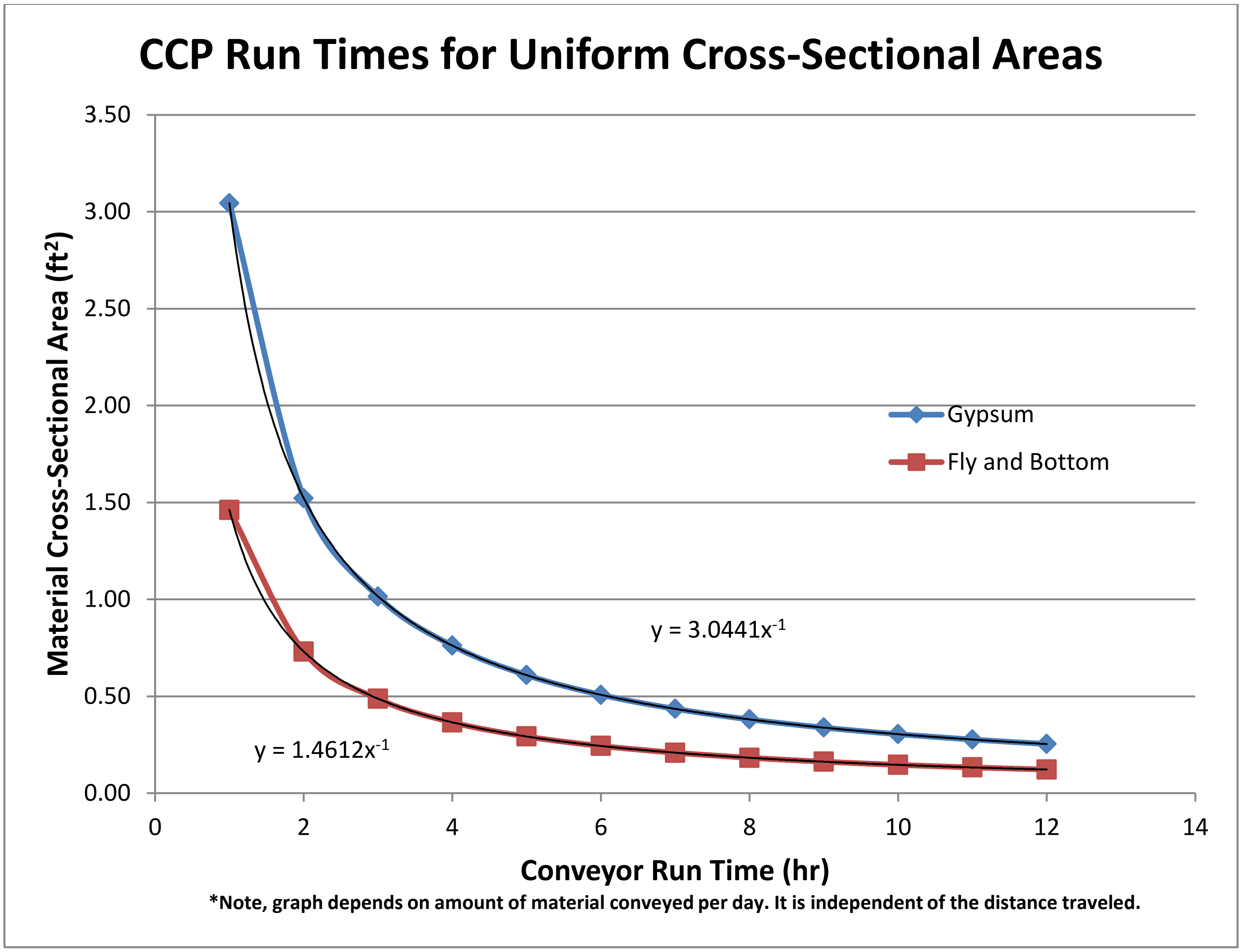


Figure 10. CCP run times for Uniform Cross-Sectional Areas

Note, the times listed above indicate the amount of time necessary to load all the material onto the belt given a specific cross section and run time. It does not take into account the length of belt. In other words, it does not take into account the time necessary to travel to the landfill site. It is necessary to adjust the time it takes to get to each landfill site based on its distance from the plant. This is calculated later in this report after the distance to each site was determined.

At this point in our design, we have determined the relationships between conveyor run time and material cross-sectional area, as well as a relationship between cross-sectional area and belt width. We know from the Belt Conveyors for Bulk Materials textbook that 200 fpm is the ideal speed for the type of material we are studying. The next step in the design is to choose a belt width. Based on recommendations from the aforementioned text, we learned that standard belt widths for bulk materials were 18, 24, 30, 36, 42, 48, 54, 60, 72, 84, and 96 inches.

Given these belt widths, we calculated run times starting with the smallest belt width. The material cross-sectional area was calculated by plugging in a belt width value into the equation from Figure 13. Where y = cross-sectional area and x = belt width:

Equation 22.

$$y = 0.000929x^2 - 0.004004x + 0.000881$$

Once cross-sectional area is known, it can be plugged into the equations

Equation 23. Gypsum

$$y = 3.0441x^{-1}$$

Equation 24. Ash

$$y = 1.4612x^{-1}$$

Where y = cross-sectional area and x = run time, to find the corresponding run times for each material based on the area. The results are shown below for the three smallest standard belts widths, 18, 24 and 30 inches.

Table 16. Belt Width and Run Times

Belt Width (in)	Cross-Sectional Area (ft^2)	Gypsum Run Time (hr)	Ash Run Time (hr)	Total Run Time (hr)
18	0.23	13.25	6.36	19.61
24	0.44	6.92	3.32	10.24
30	0.72	4.25	2.04	6.29

Any larger belt widths would not be cost effective as the run times would be too small and the construction costs would be higher than necessary. With these values in mind, it was determined that a belt width of 24 inches would provide the best material transport with adequate flexibility in terms of handling increased loads as well as providing an efficient runtime.

In summary, the conveyor will have a 24” belt and run for approximately 10 hours a day (7 hour gypsum run, 3 hour combined ash run). At this point, the major design parameters were identified and were then doubled checked using tables in the Belt Conveyors for Bulk Materials text in order to ensure that they were feasible.

10.2.3. Idler Spacing

Idlers are the rollers on which the belt sits on the conveyor system. For our system, we chose a design with 3 equal sized idlers. The spacing of the idler was determined based on the belt width that we chose from the Table 18.

Table 17. Troughing Idler Spacing

Belt Width (inches)	Troughing Idler Spacing						Return Idlers
	Weight of Material Handled, lbs/cu ft						
	30	50	75	100	150	200	
18	5.5	5.0	5.0	5.0	4.5	4.5	10
24	5.0	4.5	4.5	4.0	4.0	4.0	10
30	5.0	4.5	4.5	4.0	4.0	4.0	10
36	5.0	4.5	4.0	4.0	3.5	3.5	10
42	4.5	4.5	4.0	3.5	3.0	3.0	10
48	4.5	4.0	4.0	3.5	3.0	3.0	10
54	4.5	4.0	3.5	3.5	3.0	3.0	10
60	4.0	4.0	3.5	3.0	3.0	3.0	10
72	4.0	3.5	3.5	3.0	2.5	2.5	8

Suggested normal spacing of belt idlers, S_i (ft), Note, “spacing may be limited by load rating of idler.) (Adapted from Table 5-2 in Belt Conveyors for Bulk Materials 5th Ed.)

10.2.4. Conveyor Routes

Feasible conveyor routes for each site were determined using Google Earth. Before we could attempt to map out a route, we first needed to determine the loading point(s) for gypsum and ash. With assistance from Stantec, we were able to estimate two loading points, one for gypsum and one for combined ash, based on the plant characteristics and existing infrastructure, as shown in Figure 14.

Figure 11. Conveyor Loading Points

With the loading points determined, several conveyor options were drawn for each site. After an ideal route was developed for each site, we measured the total horizontal and vertical distance of the conveyor in order to price the system as well as calculate the power requirements. The program Google Earth was used to the conveyor system lengths. The program provides allows one to draw a route and then view a profile of the route's elevation. With this profile view, a measure of the total length of the route is provided. Additionally, by looking at the profile, one can determine the necessary height of the conveyor. In our design, we elevated the system at least 20 feet off of the ground in most cases in order to allow for vehicles to be able to travel under the system without any disturbances.

10.2.4.1. Site 12

Our first route analysis was performed for site 12 since it would be the shortest. A conveyor to site 12, must start at the ash loading point, and travel in a straight line to the gypsum loading point. Beyond the gypsum loading point, the first route that was mapped was a straight path continuing from the existing conveyor section as it would provide the shortest distance and would not require any horizontal shifts. It was determined that this route was not feasible as the conveyor would need to be built over the wall board plant that is located to the southwest of the plant. Thus, horizontal turns must be built in order to send the conveyor either to the north or south of the plant. The conveyor route to the north of the wallboard plant is of a shorter distance and it requires two horizontal turns, the same amount of turns for the route traveling south of the plant. In the end, the route that travels north of the plant was chosen as the ideal route because it was the shortest distance and also due to the fact that it provides a delivery point on the site that allows for easy access by construction vehicles. The final route selection is X miles long, with a minimum, maximum and average elevation of 377, 442, and 399 ft respectively. The three routes are shown in the Figure 15 with the preferred route in yellow.

Figure 12. Aerial View of Site 12 Conveyor

The initial land elevation at the starting point of the site 12 conveyor was 394 ft, and for the entire length of the system on the plant grounds, the land elevation did not exceed 410 ft. Based on these factors, we chose to design a level system for the first 3,485 feet of the system at an elevation of 425 ft. This height was chosen in order to allow a 25' clearance when the conveyor crosses the railroad (23' clearance was required).This would require a (silo) system at the beginning of the conveyor that releases the materials onto the conveyor 31 ft. above ground. Towards the end of the route, after leaving the plant area and arriving on the northwest corner of the site, the ground elevation increases to 442 ft. at the end of the proposed route. Because of this, we planned for the conveyor to increase at an 8 percent slope over the remaining 370 ft of horizontal distance to a final elevation of 455 ft. An 8 percent slope is consistent with an incline angle of less than 5 degrees thus that slope is very feasible. At this final height, the conveyor is able to discharge at a comfortable distance above ground directly into a silo or a large truck. The total distance factors for this conveyor, which are necessary in determining power requirements, are 3,856 feet of total conveyor length, 3,855 feet of horizontal distance, and 30 feet of vertical distance. A simplified diagram of the profile view is shown below in Figure 16.

(X-axis = Horizontal Distance, Starting from Plant. Y-axis = Elevation of Ground Level Surface)

Figure 13. Elevation Profile under Site 12 Conveyor

10.2.4.2. Plant Section Conveyor

For sites 8 and 9, a straight route from the loading points to the site was not feasible because it is best to avoid building over ash ponds, ash stacks and the gypsum complex whenever possible. An ideal starting route for the conveyors to sites 8 and 9 was developed that attempted to travel on existing plant roads and disrupt plant and stack operations as little as possible. This route is shown in Figure 17, starting from the gypsum loading point on the right side of the figure.

Figure 14. Aerial View of Plant Section Conveyor

Because sites 8 and 9 both required that the conveyor be sent over the south west side of the plant, special care was taken in not building the conveyor on top of the existing ash ponds and stacks. Because of that, one efficient route was developed for the conveyor system to travel by the haul road on the ash stack that could be utilized for both sites. The ground elevation at the start of this route was 398 feet, with a maximum elevation over the duration of the route at 404 ft. In order to leave enough room for a vehicle to travel under the system, the conveyor was designed to be level at an elevation of 420 ft. There must be a (silo) developed to put the materials on the conveyor belt 22 ft. above ground at the start of the system. The total length of this system is 5,174 ft. This distance must be included when considering the total distance from the plant to each site.

The starting route for a site 8 and 9 is 0.98 miles long and contains 3 horizontal turns and a minimum, maximum and average elevation 359, 404, 375 ft respectively. From the end point of the starting conveyor route, multiple routes were developed to bring the materials the remaining distances to the sites.

(X-axis = Horizontal Distance, Starting from Plant. Y-axis = Elevation of Ground Level Surface)

Figure 15. Elevation Profile under Plant Section Conveyor

10.2.4.3. Site 8

For site 8, two routes were designed, one continuing on the same path from the starting conveyer and turning southwest towards the landfill area, and the other, shifting to the southwest at the junction and heading straight to the site as shown below in Figure 19.

Figure 16. Aerial View of Site 8 Conveyor

Both routes contain one horizontal turn, and while the route in red is of a shorter distance, the route in yellow is preferred as it avoids a large elevation increase in the northeast corner of the site.

For the conveyor to site 8, the initial elevation of the system is 420 ft. (continuing from the starting conveyor). The conveyor can be continued in the same direction as the previous conveyor section for a distance of 1,500 ft., with the elevation of the system being reduced from 420 ft. to 380 ft., or a downward slope of negative 2.7 percent. After traveling that distance, the ground elevation gradually increases to the end elevation of 399 ft. The ending conveyor elevation should be 430 ft. in order to leave adequate room underneath the system for the materials to dump directly into a silo or other storage area. This 2,196 foot distance with an increase in elevation of 50 ft, has a slope of 2.3 percent. The total distance factors for this conveyor, which are necessary in determining power requirements, are 8,871 feet of total conveyor length, 8,870 feet of horizontal distance, and a net vertical change of 10 feet. A simplified diagram of the profile view for the conveyor to site 8 is shown below in Figure 20.

(X-axis = Horizontal Distance, Starting from Plant. Y-axis = Elevation of Ground Level Surface)

Figure 17. Elevation Profile under Site 8 Conveyor

10.2.4.4. Site 9

For site 9, two routes were mapped, the first a straight path from the end of the starting conveyor to the site, and a second that involves two horizontal turns but avoids several complications. The routes are shown below in Figure 21.

Figure 18. Aerial View of Site 9 Conveyor

The path in yellow is preferred nevertheless because it avoids the wetlands that can be costly to build upon, and it goes around a large elevation increase directly to the north of the site.

The conveyor to site 9 can be continued at the elevation of 420 ft. from the previous conveyor section for a distance of 9,768 ft. After this point, an increase in elevation is experienced, with the elevation at the end of the system reaching just over 400 ft, and the portion of land several feet before the end section reaching a maximum elevation of 428 ft. Because of this, the conveyor should be increased to an elevation of 450 ft. over the final 1,056 feet of length, a 2.8 percent slope. The total distance factors for this conveyor, which are necessary in determining power requirements, are 15,999 feet of total conveyor length, 15,998 feet of horizontal distance, and 30 feet of vertical increase. A simplified diagram of the profile view for the conveyor to site 9 is shown below in Figure 22.

(X-axis = Horizontal Distance, Starting from Plant. Y-axis = Elevation of Ground Level Surface)

Figure 19. Elevation Profile under Site 9 Conveyor

10.2.4.5. Routes Summary

Table 18. Summary of Conveyor Route Design Parameters

	Plant Section	Site 8	Site 9	Site 12
Horizontal Distance (mi)	0.98	0.71	2.05	0.73
Number of Horizontal Shifts	3	1	3	2
Minimum Elevation (ft)	359	362	356	377

Maximum Elevation (ft)	404	418	428	442
Average Elevation (ft)	375	385	381	399

Maximum slopes were not analyzed for this table because it requires a level of detail that is beyond the scope of this project.

10.2.5. Horizontal Curves Check

It is well known that that shortest distance between two points is a straight line. When designing a long overland conveyor system however, building the conveyor straight from the loading point to the end point can create unnecessary complications. Over the past several years, there has been significant progress in the ability of engineers to build conveyor systems that contain horizontal curves (Latest Developments). A horizontal curve may be necessary to avoid a wide array of natural and man-made obstacles such as bodies of water, hills or buildings. A horizontal curve allows obstacles and the construction of a costly transfer point to be avoided, which also increases the efficiency of the overall system. When designing a horizontal curve, the general rule is that the largest possible radius should be used, with the minimum allowable radius being:

Equation 25.

$$\textit{Minimum Turning Radius} = 900 * \textit{Belt Width}\ \text{(Conveyor Handbook, June 2009)}$$

$$\mathbf{900 * 24\ \boldsymbol{in} * 1\ \boldsymbol{ft}/12\ \boldsymbol{in} = 1{,}800\ \boldsymbol{ft}.}$$

For the conveyor designed in this report, the belt width is plugged into Equation 25 to get a minimum required turning radius of 1,800 ft. This means that for a given degree of turn desired the arc length would have be adjusted as recommended in Table 20.

Table 19. Minimum Arc Length Based on Turning Angle

Turning Angle (Degrees)	Minimum Arc Length (ft)
10	5341
20	5027
30	4712
40	4398

50	4084
60	3770
70	3456
80	3142
90	2827
100	2513
110	2199
120	1885
130	1571
140	1257
150	943
160	628
170	314
180	0

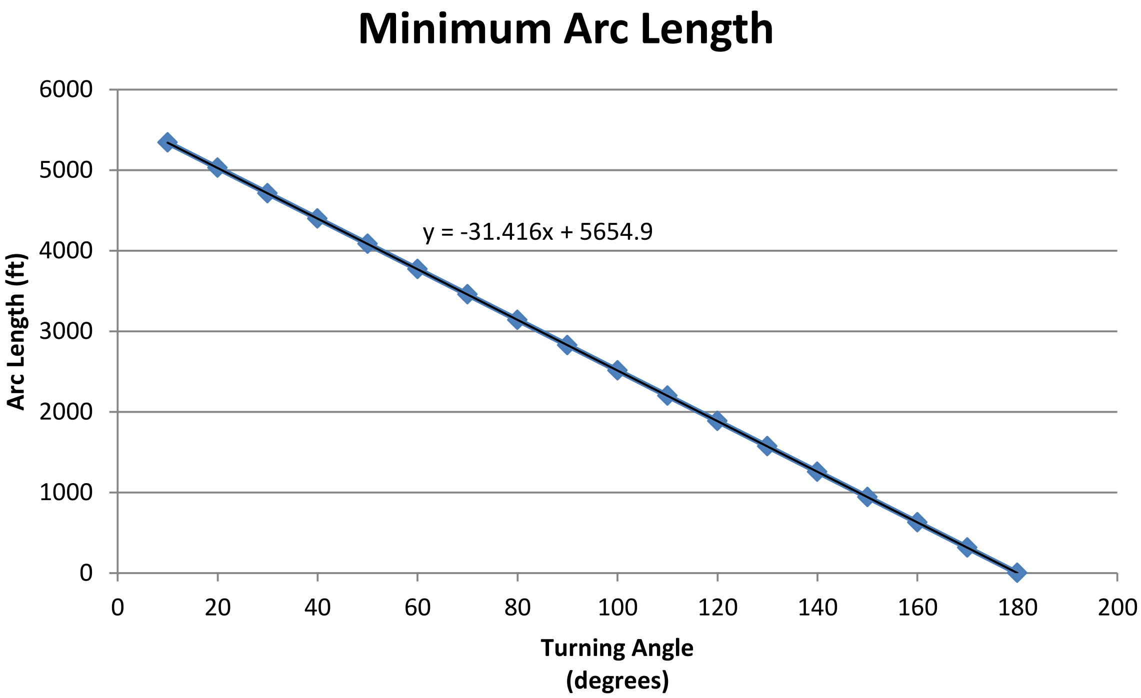


Figure 20. Graph of Minimum Arc Length Based on Turning Angle

The design of horizontally curving conveyors differs from that of straight conveyors because there is increased tension in the belt. Additionally, the location of the belt differs in that the material and the belt cling to the outside edge of the curve when turning as shown in the diagram below (Conveyor Handbook, June 2009)

There are multiple other design parameters that need to be considered for a horizontally turning conveyor that are beyond the scope of this analysis. For this project, the important issue is making sure that the proposed turns in our site routes can meet the minimum turning radius requirements.

Each of the three conveyors designed contain multiple horizontal changes in direction. The angles of these curves need to be measured in order to determine if it is possible to build a conveyor section of the necessary arc length in that particular area. The arc length (L) is found from Equation 26:

Equation 26.

$$L = (2\pi r)(180-\alpha)/360$$

Where r = radius of the curve, and α = turning angle

With a minimum radius of 1,800 ft, the minimum arc length for a given angle can be found from Equation 27:

Equation 27.

$$L = (2\pi*1{,}800)(180-\alpha)/360 = (10\ \pi)(180-\ \alpha) = 5654.9 - (31.416*\alpha)$$

$$\boldsymbol{L = 5654.9 - (31.416*\alpha)}$$

The relationship is such that the necessary minimum arc length increases with a tighter (smaller) turning angle. In order to determine if each of the proposed turns were possible, the angle of each turn was found using a protractor.

Table 20. Arc Length Check

Site	Turn	Angle (Degrees)	Arc Length (ft)	Feasible
Plant Section	1	160	628	Y
Plant Section	2	168	377	Y
Plant Section	3	162	566	Y
8	1	142	1194	Y

9	1	120	1885	Y
9	2	162	566	Y
9	3	128	1634	Y
12	1	155	785	Y
12	2	112	2136	N

Of the turns, only one was determined to be impossible based on the length of conveyor available and the surrounding area. This was the turn at the tail end of the conveyor system for site 12. This is not overly troublesome as it could very well be more effective to install a movable conveyor section at the tail end of the system in order to distribute the materials to various locations on the landfill. It would be helpful for the conveyor section to be able to flex 100-500 feet in either direction. If this flexible portion is found to be feasible, a similar section should also be considered at the end of the site 8 and 9 conveyor systems to allow for a wide range of dumping areas.

10.2.6. Conveyor-Landfill Run Time Adjustments

As mentioned in the "Balancing Conveyor Size and Speed Section," it is necessary to adjust the total runtimes based on the length of the conveyor, assuming that the conveyor is run at the end of each day until all materials are off of the belt. Since each landfill requires a different distance, it was necessary to calculate three different additional times to find the adjusted total run time. This was done using the equation 28 that we developed:

Equation 28.

$$\boldsymbol{Run\ time\ adjustment\ (hrs)} = \frac{\boldsymbol{Conveyor\ length\ (ft)}}{\boldsymbol{200\ FPM * 60}}$$

A summary of the resulting adjustment times is in Table 22.

Table 21. Adjusted Conveyor Runtimes

		Gypsum	Combined Ash	
Original Runtime (hrs)		6.92	3.32	
	Adjusted Runtimes (hrs)			
Site	Additional Time	Total Gypsum Runtime	Total Ash Runtime	New Total Runtime
8 (8,871 ft)	0.74	7.66	4.06	11.72

9 (15,999 ft)	1.33	8.25	4.65	12.90
12 (3,856 ft)	0.32	7.24	3.64	10.88

The new total run time is the amount of time that the system is required to run for both gypsum and combined ash so that all materials produced that day are transported to the landfill and so that the belt is emptied at the end of the day.

10.2.7. Power Requirements

In order to find the total amount of power that is required to transport materials with a conveyor belt, three factors must be considered: the horsepower required to drive the conveyor empty, the horsepower required to elevate the material, and the horsepower required to convey the materials horizontally. The power requirements were estimated using several generalized equations as well as by developing several equations from graphs that resulted in an equation capable of estimating the power requirements per directional foot.

The first factor that needs to be determined is the weight per linear foot of the belt and revolving idler parts. The horsepower (hp) at the drive of a belt conveyor is derived from the pounds of effective tension, T_e required at the drive pulley to propel or restrain the loaded conveyor at the design velocity of the belt V, in fpm. This can be found by using Equation 29:

Equation 29.

$$\boldsymbol{hp = \frac{T_e + V}{33{,}000}}$$

To find T_e “it is necessary to identify and evaluate each of the individual forces acting on the conveyor belt and contributing to the tension required to drive the belt at the driving pulley. There is a detailed analytical method of determining T_e. However, it can also be solved graphically based on the belt velocity and estimated horsepower requirements. This was the preferred method for this report. The textbook notes that graphical methods of estimating horsepower are useful even when conditions exist that would make graphical estimates of horsepower inaccurate for final calculations.

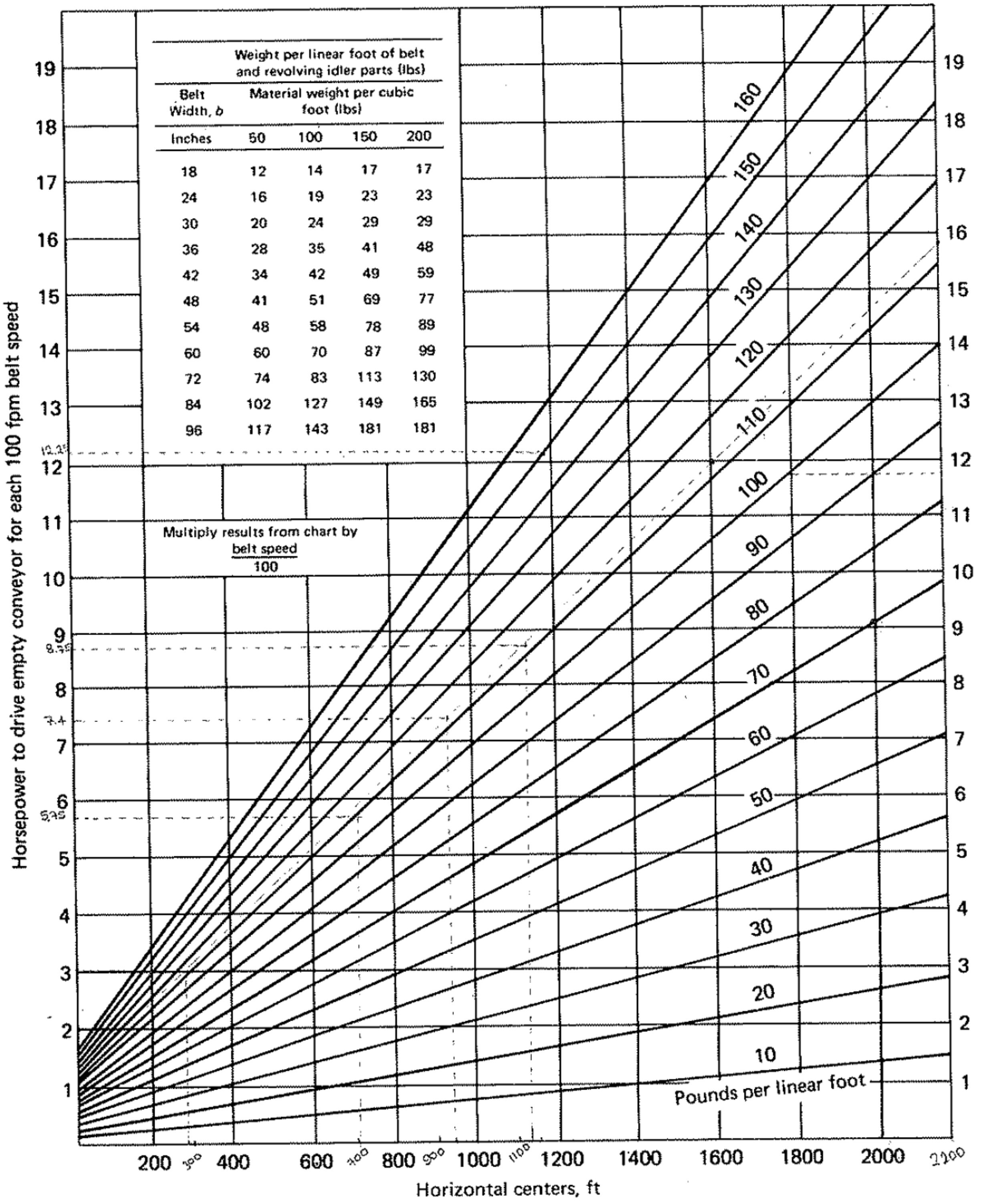
In order to estimate the required horsepower it is necessary to find the average weight of the belt.

Table 22. Estimated Average Belt Weight, Multiple and Reduced Ply Belts, lbs/ft

Belt Width inches (b)	**Material carried, lbs/ft^3**		
	30-74	75-129	130-200
18	3.5	4.0	4.5
24	4.5	5.5	6.0
30	6.0	7.0	8.0
36	9.0	10.0	12.0
42	11.0	12.0	14.0
48	14.0	15.0	17.0
54	16.0	17.0	19.0
60	18.0	20.0	22.0
72	21.0	24.0	26.0

Notes: 1. Steel-cable belts —increase above value by 50 percent. 2. Above values are estimates, actual values will vary. (Conveyor Equipment Manufacturers Association)

Once the average belt weight is determined, Figures 24, 25 and 26 can be used to estimate the required horsepower for the conveyor belt.



	Weight per linear foot of belt and revolving idler parts (lbs)			
Belt Width, *b*	Material weight per cubic foot (lbs)			
Inches	50	100	150	200
18	12	14	17	17
24	16	19	23	23
30	20	24	29	29
36	28	35	41	48
42	34	42	49	59
48	41	51	69	77
54	48	58	78	89
60	60	70	87	99
72	74	83	113	130
84	102	127	149	165
96	117	143	181	181

Multiply results from chart by $\frac{\text{belt speed}}{100}$

Figure 21. Horsepower Required to Drive an Empty Conveyor (Conveyor Equipment Manufacturers Association)

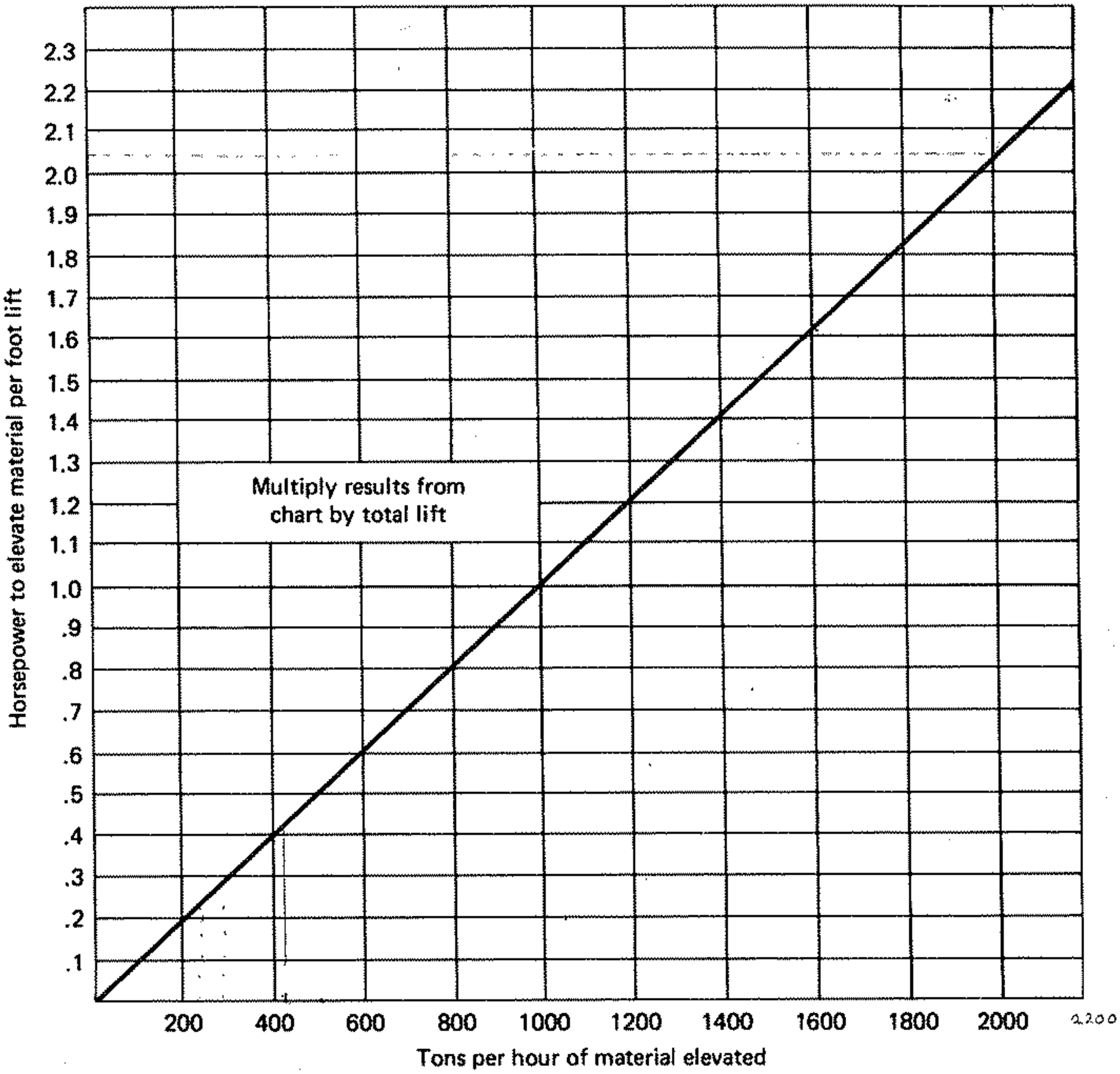


Figure 22. Horsepower Required to Elevate Material (Conveyor Equipment Manufacturers Association)

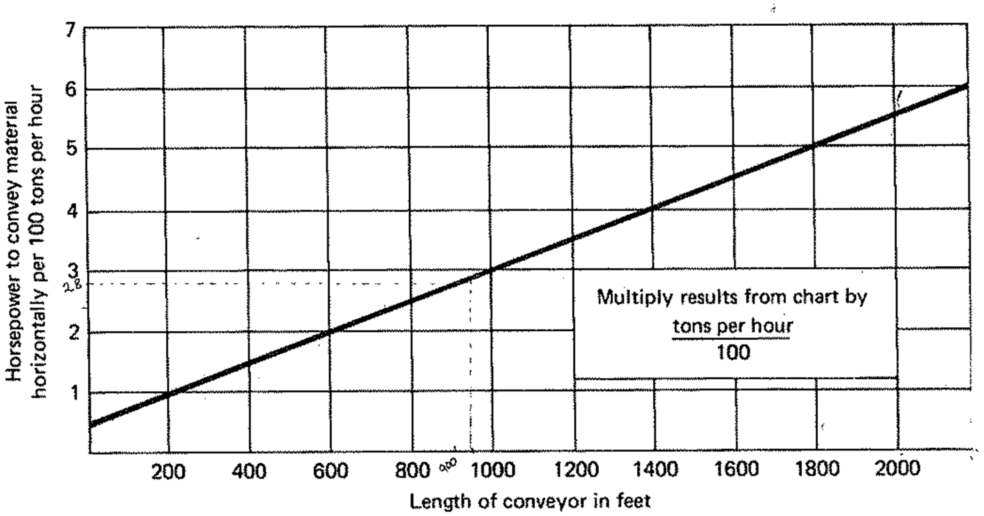


Figure 23. Horsepower Required to Convey Material Horizontally (Conveyor Equipment Manufacturers Association)

Horsepower was determined using figures 24, 25 and 26 by plugging in the known factors of a 24 inch belt width, and an approximate material weight of 100 lbs per cubic foot. Based on those variables, the weight per linear foot of the belt and revolving idler parts was found to be 19 lbs per linear foot. Using the 20 lbs per linear foot line for comparison, a relationship between the horsepower to drive the conveyor per each 100 fpm belt speed and horizontal distance was developed as follows, by finding the slope between two data points on the graph of horizontal horsepower requirements.

Point 1 (1500 ft, 2 hp) Point 2 (650 ft, 1 hp)

Because the belt speed is 200 fpm, the values were adjusted to (1500 ft, 4 hp) and (650 ft, 2 hp) respectively. The slope was found from the equation slope = $(y_2-y_1)/(x_2-x_1)$

The slope was found to be 2 hp/850 ft, or 0.00235 hp/ft.

The value of 0.00235 hp/ft means that 0.00235 hp are required for every foot of conveyor travel.

Next, the horsepower required to elevate the material needed to be calculated. The graphs in Section 2.7.2.2.7.1 provided a relationship between the tons per hour of material elevated and the horsepower required to elevate the material per foot of lift. The slope of the graph was found to be 0.001 hp/(ton/hour) using the data points (200 ton/hour, 0.2 hp) and (400 ton/hour, 0.4 hp).Based on the value of 240.80 tons per hour of materials based on the plant output and runtime of the conveyor, a value of 0.241 hp/ft of lift was calculated.

Equation 30.

$$900{,}000\ ton/year * 1\ year/365\ days * 1\ day/10.24\ hr = 240.80\ tons/hr$$

Next, the horsepower required to move the material horizontally was calculated. The graphs in Section 3.2.6 provided a linear relationship between the length of the conveyor and the horsepower required to conveyor the material horizontally per 100 tons/hr of material. The slope of the graph was found using the points (200 ft, 1 hp/(100 ton/hr)) and (600 ft, 2 hp/(100 ton/hr)) to yield a slope of 0.0025 [hp/(100 ton/hr)]/ft. Since the system is designed to transport 240.80 tons/hour, the horsepower requirement must be multiplied by 240.80/100 or 2.41 to get a value of 0.006025 hp/horizontal ft.

To find the overall horsepower required, the horsepower requirements for the empty conveyor, horizontal travel and vertical travel must all be calculated and combined. Equation 31 can be employed to find total power requirements:

Equation 31.

$$0.00235z + 0.241y + 0.00603x = total\ hp$$

Where z is the total conveyor length in ft, y is the total conveyor vertical distance in ft, and x is the total horizontal distance of the conveyor in ft. From Equation 33, the horsepower requirements were calculated for the conveyors of the three sites based of the conveyor distances. Additionally, the horsepower required to life the materials to the conveyor starting height was calculated. The horsepower results are shown in Tables 24 and 25.

Table 23. Horsepower Requirements for Each Landfill Site

	Site 8	Site 9	Site 12
Total Length	8,871	15,999	3,856
Vertical Distance	10	30	30
Horizontal Distance	8,870	15,998	3,855
Total Horsepower	76.74	141.30	39.54

Table 24. Power Required to Elevate Materials from Ground Level to Conveyor Height

	Site 8 and 9	Site 12
Lift Height (ft)	22	31
Horsepower	5.30	7.47

11. Economic Analysis

11.1. Pricing Factors

Stantec originally priced multiple factors during their site selection process. The cost of land acquisition, landfill capital construction, closure and post closure maintenance, transportation infrastructure, and operations and maintenance were calculated for each of the three sites. The transportation infrastructure and operations and maintenance costs were estimated with trucking being considered as the means of transportation. As this study is concerning the use of conveyors as the transportation technique, only the land acquisition, landfill capital construction, and closure and post closure maintenance costs will be constant throughout the cost comparison process. The transportation and operation costs of trucking will be used for comparison purposes, while transportation infrastructure and operations and maintenance costs for conveyors are independently developed.

Table 26 lists the constants for each site. All dollar values are provided in terms of their 2010 net present worth. The net present worth of an income stream is the sum of the present values of the individual amounts in the income stream. "When the net present worth is being calculated, each future income amount in the stream is discounted, meaning that it is divided by a number representing the opportunity cost of holding capital from now until the year when income is received or the outgo is spent." The net present worth of an investment tells allows you see understand more easily how the investment compares with an alternative investment (Baker, 2000) An 8% rate of return was assumed for all net present worth calculations throughout this report.

Table 25. Landfill Costs for Sites 8, 9 and 12

(2010 Net Present Worth)	Site 8	Site 9	Site 12
Land Acquisition	7,401,829	5,230,347	1,336,296
Landfill Capital Construction	36,340,202	47,406,892	43,430,522
Closure and Post Closure Maintenance	2,438,137	3,286,900	3,187,158
Total $	46,180,168	52,637,239	47,953,976

A brief overview the factors involved in the trucking price and of how Stantec obtained their estimates is provided in Section 3.3.2.

11.2. Cost of Trucking

The costs of operating the landfill with trucking as the means of transportation were developed by Stantec to estimate the lifetime cost of the landfill. Stantec's estimates of the 2010 net present worth of each landfill site are included in Table 27.

Table 26. Trucking Costs for Sites 8, 9 and 12

(2010 $ Net Present Worth)	Site 8	Site 9	Site 12
Transportation Infrastructure	438,910	1,856,204	157,084
Operations and Maintenance	50,016,888	63,611,548	50,435,626
Total	50,455,798	65,467,752	50,592,710

11.3. Transportation Infrastructure

The transportation infrastructure costs contain several subcategories that varied by site including railroad relocation, access road construction, stream crossing culverts, bridge upgrading, and county road improvement. As shown in the previous table, the transportation infrastructure costs are equal to only a fraction of the operations and maintenance costs. The transportation infrastructure costs of trucking are generally lower than those of conveyor systems however often times the operations and maintenance costs for trucking will exceed those of conveyor thus making the means of transportation competitive with each other.

11.4. Landfill Operations and Maintenance

The operation and maintenance costs for the landfill also are made up of multiple subcategories, some of which will remain constant for the conveying scenario. The subsections that make up the operations and maintenance costs are:

1. Waste Disposal
2. Maintenance
   a. Mowing
   b. Access Road
   c. Security
3. Surface Water and Ground Water Monitoring
4. Annual Operating Fee

5. Landfill Cover, Seeding and Mulching

Of the above costs, waste disposal contributes the largest amount cost, and is concerned mainly with the operations of the trucks in transporting the materials. The costs other than waste disposal are associated with the operation and maintenance of the landfill itself, thus they are applicable to the cost analysis for the conveyor scenario as well. In terms of the maintenance costs, mowing and security are factored in while access road maintenance is not included, as access roads were not considered for the conveying scenario. The remaining costs that were developed by Stantec for the 20-yr lifetime of the landfill are shown in Table 28 and can be considered miscellaneous costs in the final conveyor cost analysis in the operations and maintenance category:

Table 27. Miscellaneous Costs for Sites 8, 9 and 12

(2010 Net Present Worth)	Site 8	Site 9	Site 12
Mowing and Security	1,730,784	2,205,354	2,149,523
Surface and Ground Water Monitoring	186,106	372,212	186,106
Annual Operating Fee	93,053	93,053	93,053
Landfill Cover, Seeding and Mulching	1,116,635	1,116,635	1,116,635
Total $	3,126,578	3,787,254	3,545,317

11.5. Cost of Conveying

When considering the transportation infrastructure of a conveyor system, what are really being considered are the capital construction costs needed to build the system. Within the capital construction costs are the cost of the conveyor materials, the labor required to build the conveyor, and mobilization/demobilization costs. Mobilization and demobilization costs refer to the costs that are associated with pre and post construction work. An example of some mobilization and demobilization costs that can occur are the movement of equipment and supplies to and from the site, the establishment of offices and buildings at the site, any temporary utilities or temporary access roads, temporary site protection and periodic and final cleanup (Choi, 2005). For the conveyor system construction, mobilization/demobilization costs are assumed to be equal to five percent of the conveying system construction costs based on recommendations from Stantec.

11.5.1. Materials

The materials that are required for the conveyor system are shown in Table 29:

Table 28. Structural Conveyor Parts

Item	Description
Belt Structure (24" Structure on 5' Centers w/ Return on 15' Centers)	The belt structure refers to the base structure of the system including the idlers.
Metal Hood (without side panels)	The metal hood over the conveyor is an important part of the conveyor system, especially when dealing with CCPs. The metal hood keeps moisture from getting into the materials and also reduces the dust formation from wind.
Belt (24"; 3 ply 440, Goodyear or Scandura)	A 24" wide belt was chosen for this system. Additionally, a 3 ply belt was used for this analysis based on Stantec recommendation as it provides adequate strength and durability. The 440 value refers to a tension rating that is appropriate for a system of this size, while Goodyear and Scandura are the companies from which the unit costs were developed.
Drives (150 HP)	The drives are the components that power the belt. 150 HP drives were chosen based on Stantec recommendations and pricing availability factors. Although the power requirements for the sites were generally below 150 HP, there are added power requirements in starting and stopping the system that sometimes require additional power. Also, systems run more efficiently with distributed drive systems, thus for longer systems more than one drive may be ideal.
Radial Stacker	One radial stacker is required for each conveyor system. The radial stacker stockpiles discrete CCP streams as shown in Figure 27. The radial stacker allows storage of the materials onsite and can rotate to separate materials and deliver to various areas.
Scrapers	Scrapers are arms that extend over the return belt to clean excess materials off of the belt in order to prevent unnecessary corrosion.
Pole Lines (to Drives and Stacker)	One pole line is necessary to connect each of the drives in addition to the stacker. The pole line is used for the transmission of electricity.

Figure 24. Radial Stacker

11.5.1.1. Material Costs

The unit costs of the materials were provided by the (Stantec Report). The units LF refer to linear feet, while EA refers to the cost of each item. The belt structure and metal hood lengths were based on the total length of the system. The belt length was calculated as twice the length of the system, because the belt is continuous and has a top side as well as a return side. The number of drives was estimated based on the minimum horsepower requirements that were calculated in section 3.2.6 with the assumption of at least one 150 HP drive necessary per mile of conveyor travel based on recommendations from Stantec and from texts. For each system, 4 scrapers were assumed based on recommendations from Stantec. One radial stacker is needed for each system. The number of pole lines is directly related to the number of drives, as each drive requires a pole line in addition to the radial stacker.

Table 29. Material Unit Costs and Total Costs

Cost (2007$)		**Site 8**		**Site 9**		**Site 12**	
	Unit Costs	Quantity	Price	Quantity	Price	Quantity	Price
Belt Structure	37.50/LF	8,871	332,663	15,999	599,963	3,856	144,600
Metal Hood	14.00/LF	8,871	124,194	15,999	223,986	3,856	53,984
Belt	11.50/LF	17,742	204,033	31,998	367,977	7,712	88,688
Drives	36,250/EA	2	72,500	3	108,750	1	36,250
Scrapers	1,500/EA	4	6,000	4	6,000	4	6,000
Radial Stacker	125,000/EA	1	125,000	1	125,000	1	125,000
Pole Lines	40,000/EA	3	120,000	4	160,000	2	80,000
Total $			984,390		1,591,676		534,522

11.5.1.2. Additional Materials

The unit prices that were used for the previous section came from a 2007 report done by Stantec to price a conveyor system. In that report, support structures were not considered as part of the price. For the system that was designed for this project, foundation support structures are an important factor and need to be relatively large considering that the systems are designed to be about 20 feet off of the ground. Based on other conveyor systems that we have observed, 250 feet of spacing between the support structures is appropriate. From Stantec we obtained an estimate of $20,000 per support structure in 2010 dollars. In 2007 dollars, to maintain consistency with the other materials prices, the unit costs for the foundation structures are as follows:

Equation 32.

$$20{,}000 / (1.025^3) = 18{,}572$$

Based on the system lengths for each site, the number of foundations necessary for each site was found as shown below:

Site 8:

Equation 33.

$$8{,}871/250 = 35.5 = 36 \text{ foundations}$$

Site 9:

Equation 34.

$$15{,}999/250 = 64 \text{ foundations}$$

Site 12:

Equation 35.

$$3{,}856/250 = 15.4 = 16 \text{ foundations}$$

Structure costs are shown in Table 31:

Table 30. Foundation Costs for Sites 8, 9 and 12

Cost (2007$)		Site 8		Site 9		Site 12	
	Unit Costs	Quantity	Price	Quantity	Price	Quantity	Price
Foundations	18,572/EA	36	668,592	64	1,188,608	16	297,152

11.5.2. Labor

To find the labor costs, the labor required to build the system is broken down into the 3 sections.

a. Belt Structure (5-Person Crew, 2 10-ton Cranes, 1 Dozer)

b. Hood (5-Person Crew, 2 10-ton Cranes)

c. Belt (2-Person Crew)

The unit costs of labor are given on a per hour basis and include the cost of the crew and the machine rental costs. To find the number of hours that are required to build each section, the production rates must be known. In all three cases, the production rate is 1,000 linear feet per 8-hour day. With that in mind, the hourly construction times for site 8 are as follows:

Equation 36.

8,871 ft of belt structure/ 1,000 feet per day = 8.871 days * 8 hrs/day = 71 hrs

Equation 37.

8,871 ft of hood/ 1,000 feet per day = 8.871 days * 8 hrs/day = 71 hrs

Equation 38.

$$17{,}742\ \mathit{ft\ of\ belt}/\ 1{,}000\ \mathit{feet\ per\ day} = 17.742\ \mathit{days} * 8\ \mathit{hrs/day} = 142\ \mathit{hrs}$$

The times for Sites 9 and 12 were found using the same process.

Table 31. Belt Replacement Costs for Sites 8, 9 and 12

(2007 Dollars)		Site 8		Site 9		Site 12	
	Unit Price	Hours	Cost	Hours	Cost	Hours	Cost
Belt Structure	645/hr	71	45,795	128	82,560	31	19,995
Hood	550/hr	71	39,050	128	70,400	31	17,050
Belt	250/hr	142	35,500	256	64,000	62	15,500
Total Cost			**120,345**		**216,960**		**52,545**

Because the trucking costs for comparison were made with the landfill planned to operate from 2016 to 2035, the construction is assumed to take place in the year 2016. Therefore the capital costs for construction should be calculated in 2016 dollars. In other words, the material and labor costs must be estimated for 9 years (2016-2007) of inflation. Assuming an annual inflation rate of 2.5%, the inflated costs are found from Equation 39:

Equation 39.

$$2016\ \mathit{Cost} = 2007\ \mathit{Cost} * (1.025^{\wedge}9)$$

Table 32. Materials and Labor Costs for Sites 8, 9 and 12

Year	Item	Site 8	Site 9	Site 12
2007	Materials	984,390	1,591,676	534,522
2007	Labor	120,345	216,960	52,545
2007	Foundations	668,592	1,188,608	297,152
2007	Total1	1,773,327	2,997,244	884,219
2016	Total2	2,214,642	3,743,146	1,104,268

11.5.3. Mobilization/Demobilization

Mobilization/Demobilization costs are found by adding the materials and labor costs of the conveyor, and multiplying by 0.05, because the mobilization/demobilization costs are equal to 5 percent of the conveyor construction costs (before contingency).

Example for Site 8: Mobilization/Demobilization = 2,214,642 * 0.05 = 110,732

The materials and labor costs were also estimated with a 25% contingency. Contingency refers to the approximate accuracy of an estimate so that the percent contingency can effectively account for any unforeseen costs elements that were missed, misestimated, or that change between the time of design and implementation. Contingency can account for unpredictable conditions or uncertainties with a project scope. A 25% percent contingency is appropriate for an analysis that is in the early stages of development. Ideally, as a project progresses and more factors are discovered and understood, the contingency should be reduced (Department of Energy, March, 28, 1997).The equation to calculate a 25% contingency is shown below:

Example for Site 8:

Equation 40.

$$\mathit{Construction\ Costs} + 25\%\ \mathit{Contingency} = 2{,}214{,}642 * 1.25 = 2{,}768{,}302$$

Table 33. Total Transportation Infrastructure Costs

(2016 Dollars)	Site 8	Site 9	Site 12
Materials and Labor + 25 %	2,768,302	4,678,933	1,380,335
Mobilization/Demobilization	110,732	187,157	55,213
Total Transport Costs	2,879,034	4,866,090	1,435,549

The above costs are in 2016 dollars, and in order to make an accurate comparison to the trucking estimates, they need to be found in 2010 net present worth units. The net present worth costs are found from the equation below. Note, the equation assumes and 8 percent return on investment.

Equation 41.

$$\textit{Total Capital Cost} * (1.08\text{^}(2010\text{-}2016)) = \textit{Total Capital Cost} * (1.08\text{^-}6)$$

Table 34. Transportation Infrastructure Summary

(2010 Net Present Worth)	Site 8	Site 9	Site 12
Transportation Infrastructure	1,814,280	3,066,462	904,639

11.5.4. Conveyor Operations and Maintenance

Within operations and maintenance, there are the costs of loading the materials onto the belt at the plant, the costs of unloading and spreading the materials at the landfill, the costs to operate (power) the system, maintenance costs, including a onetime belt replacement cost.

11.5.4.1. Maintenance

The maintenance costs are broken down into the per year system maintenance costs and the per year cost of the maintenance personnel, in addition to the one time belt replacement cost. To find the one time belt replacement cost, the costs need to be found for mobilization/demobilization, which is equal to 5 percent of the belt replacement cost (before contingency), the cost of the belt, and the cost of a 2-person labor crew producing

1,000 linear feet of belt per 8-hour day. The cost of the belt and labor will be the same costs that were found in the capital construction section. The belt replacement costs contain a 25% contingency. Since the belt replacement is expected to take place after ten years, the prices must be inflated for the year 2025, keeping with the assumption of a 2.5% annual inflation rate (assuming that the life of the landfill is from 2016 to 2035). Belt replacement cost are shown in Table 36.

For 18 years of inflation (2025-2007), the equation is:

Equation 42.

$$2025\ Cost = 2007\ Cost * (1.025\string^18)$$

Table 35. Belt Replacement Costs

Item	Site 8	Site 9	Site 12
Belt	204,033	367,977	88,688
Labor	35,500	64,000	15,500
Mobilization/Demobilization	11,977	21,599	5,209
Total (2007)	251,510	453,576	109,397
Total with 25% Contingency	314,387	566,970	136,746
Inflated Total (2025)	490,337	884,279	213,278

Based on estimates from the Stantec Alcoa project, the system maintenance costs for the first year of the landfill (2016) are estimated to be equal to 2 percent of the conveyor system construction costs (just the materials and labor, before contingency).

Table 36. 2016 System Maintenance Costs

(2016 Dollars)	Site 8	Site 9	Site 12
System Maintenance (per year)	44,292	74,863	22,085

For this analysis, it was assumed that there would be 2 persons on the maintenance crew, working 12 hours per day for 365 days in the year for all of the three sites. With a pay rate of 40 dollars per hour, the 2007 yearly salary for the personnel is equal to:

Equation 43.

$$2 * 40 * 12 * 365 = \$350{,}400$$

In 2016 dollars, that salary would be equal to:

Equation 44.

$$350{,}400 * (1.025^9) = \$437{,}602$$

The total 2016 maintenance costs for each site are shown in Table 38.

Table 37. 2016 Total Maintenance Costs

(2016 Dollars)	Site 8	Site 9	Site 12
System Maintenance	44,292	74,863	22,085
Maintenance Personnel	437,602	437,602	437,602
Total	481,894	512,465	459,687

In order to get the total maintenance costs for the 20-year lifetime of the landfill, the maintenance costs need to be found for each successive year, factoring in inflation as shown in Table 39.

Table 38. 20-year Maintenance Costs

Year	Site 8	NPW 2010	Site 9	NPW 2010	Site 12	NPW 2010
2016	481,894	303,675	512,465	322,940	459,687	289,681
2017	493,942	288,210	525,276	306,494	471,179	274,929
2018	506,290	273,533	538,408	290,885	482,959	260,928
2019	518,948	259,603	551,868	276,072	495,033	247,640
2020	531,921	246,382	565,665	262,012	507,408	235,028
2021	545,219	233,835	579,807	248,669	520,094	223,059
2022	558,850	221,927	594,302	236,005	533,096	211,700
2023	572,821	210,625	609,159	223,987	546,423	200,919
2024	587,142	199,899	624,388	212,580	560,084	190,687
2025	1,092,157	344,293	1,524,277	480,516	787,364	248,210
2026	616,866	180,057	655,998	191,480	588,438	171,760
2027	632,287	170,888	672,398	181,728	603,149	163,012
2028	648,094	162,185	689,208	172,474	618,228	154,711
2029	664,297	153,926	706,438	163,690	633,684	146,832
2030	680,904	146,087	724,099	155,354	649,526	139,355
2031	697,927	138,647	742,201	147,443	665,764	132,258
2032	715,375	131,586	760,756	139,934	682,408	125,522
2033	733,259	124,885	779,775	132,808	699,468	119,130
2034	751,591	118,525	799,270	126,044	716,955	113,063
2035	770,381	112,489	819,251	119,625	734,879	107,305
Total	12,800,165	4,021,259	13,975,009	4,390,738	11,955,825	3,755,728

Notice that in the year 2025, the maintenance cost experience a large increase which is due to the belt replacement costs that were calculated in the previous section.

11.5.4.2. Operations

Operations costs are broken down into two areas, the cost of electricity to run the system, and the cost to employ an operations staff.

11.5.4.2.1. Electricity

The costs of electricity are based on the amount of power that is required to run the drives for the given amount of time every day. The parameters for each site are shown in Table 40.

Table 39. Run Times and Drive Requirements for Sites 8, 9 and 12

	Site 8	Site 9	Site 12
Run Times (hr)	12	13	11
Drives (150 HP)	2	3	1

To calculate the costs of operating the drives for a year, the following equation must be used:

Equation 45.

$$\text{Cost/year} = ((\text{Number of Drives} * 150\ \text{HP})*1.25) * 746\ \text{Watts}/1\ \text{HP} * 1\ \text{KW}/1000\ \text{Watts} * \text{Number of hours/day} * 365\ \text{days/year} * \$/\text{KWh}$$

There is a 25% extra horsepower value that is added to the normal horsepower of the drives to account for expected losses in transmission and added power necessary for starting and stopping the system. That factor was based on estimates and recommendations from Stantec. The other numbers are conversion factors. The cost of electricity was obtained from the EIA website (U.S. Energy Information Administration, 2011), with the electricity costs for industrial use in Tennessee, in Nov. 2010, being utilized.

A cost of 6.72 cents/KWh for 2010 was obtained from the website. This value was deflated for the year 2016 to be:

Equation 46.

$$6.72 * (1.025^6) = 7.79\ cents/KWh = 0.0779\$/KWh$$

For site 8:

Equation 47.

$$(2 * 150 + 75) HP * 746\ Watts/1\ HP * 1\ KW/1000\ Watts * 12\ hr/day * 365\ days * 0.0779\$/KWh = \$95{,}451$$

Site 9:

Equation 48.

$$(3 * 150 + 112.5) HP * 746\ Watts/1\ HP * 1\ KW/1000\ Watts * 13\ hr/day * 365\ days * 0.0779\$/KWh = \$155{,}166$$

Site 12:

Equation 49.

$$(1 * 150 + 37.5) HP * 746\ Watts/1\ HP * 1\ KW/1000\ Watts * 11\ hr/day * 365\ days * 0.0779\$/KWh = \$43{,}765$$

11.5.4.2.2. Operators

From previous Stantec reports and system parameters, it was determined that 2 operators were needed, working 365 days per year for 12 hours per day. With a 2007 pay rate of 50 dollars per hour, the yearly cost of the operators is equal to:

Equation 50.

$$2 * 50 * 12 * 365 = 438{,}000$$

Cost in 2016 dollars is equal to:

Equation 51.

$$438{,}000 * (1.025^9) = 547{,}002$$

The total 2016 operating costs for each site are shown in Table 41.

Table 40. Operations Costs for Sites 8, 9 and 12

(2016 Dollars)	Site 8	Site 9	Site 12
Electricity	95,487	155,166	43,765
Operators	547,002	547,002	547,002
Total	642,489	702,168	590,767

In order to get the total operations costs for the 20-year lifetime of the landfill, the costs need to be found for each successive year, factoring in 2.5% annual inflation as shown in Table 42.

Table 41. 20-year Operating Costs

Year	Site 8	NPW 2010	Site 9	NPW 2010	Site 12	NPW 2010
2016	642,489	404,877	702,168	442,485	590,767	372,283
2017	658,551	384,258	719,722	419,951	605,536	353,324
2018	675,015	364,689	737,715	398,565	620,674	335,331
2019	691,890	346,117	756,158	378,267	636,191	318,254
2020	709,187	328,491	775,062	359,004	652,096	302,047
2021	726,917	311,762	794,439	340,721	668,398	286,665
2022	745,090	295,886	814,300	323,370	685,108	272,066
2023	763,717	280,817	834,657	306,902	702,236	258,211
2024	782,810	266,516	855,524	291,272	719,792	245,061
2025	802,380	252,944	876,912	276,439	737,787	232,581
2026	822,440	240,062	898,835	262,361	756,231	220,737
2027	843,001	227,837	921,305	249,000	775,137	209,496
2028	864,076	216,234	944,338	236,320	794,516	198,827
2029	885,678	205,222	967,946	224,285	814,379	188,701
2030	907,820	194,771	992,145	212,863	834,738	179,092
2031	930,515	184,852	1,016,949	202,023	855,606	169,971
2032	953,778	175,438	1,042,372	191,735	876,997	161,315
2033	977,623	166,504	1,068,432	181,970	898,922	153,100
2034	1,002,063	158,025	1,095,143	172,703	921,395	145,303
2035	1,027,115	149,977	1,122,521	163,908	944,429	137,904
Total	16,412,156	5,155,282	17,936,644	5,634,144	15,090,936	4,740,268

11.5.5. Loading

To get the loading costs, the Alcoa report was used. The amount of CCPs and the number of hours per year of operation were altered and the same unit costs were utilized to find the loadout costs at plant as well as loadout and transportation at the landfill. The report is included as a separate attachment to this document.

Loadout at Plant: 569,400 (2007$)

Loadout at Landfill: 569,400 (2007$)

Transportation at Landfill: 757,440 (2007$)

Total Loading Costs = 1,896,240 (2007$)

Inflated Loading Costs (2016$) = 1,896,240 * (1.025^9) = 2,368,144

Table 42. 20-year Loading Costs

	Cost	NPW 2010
2016	2,368,144	1,492,332
2017	2,427,348	1,416,334
2018	2,488,031	1,344,206
2019	2,550,232	1,275,751
2020	2,613,988	1,210,782
2021	2,679,338	1,149,122
2022	2,746,321	1,090,602
2023	2,814,979	1,035,062
2024	2,885,354	982,350
2025	2,957,487	932,323
2026	3,031,425	884,844
2027	3,107,210	839,782
2028	3,184,890	797,016
2029	3,264,513	756,427
2030	3,346,125	717,905
2031	3,429,779	681,345
2032	3,515,523	646,647
2033	3,603,411	613,716
2034	3,693,496	582,462
2035	3,785,834	552,800
Total	60,493,428	**19,001,809**

Table 43. 20-year Operations and Maintenance Summary

(2010 Net Present Worth)	Site 8	Site 9	Site 12
Maintenance	4,021,259	4,390,738	3,755,728
Loading	19,001,808	19,001,808	19,001,808
Operation	5,155,282	5,634,144	4,740,268
Misc.	3,126,578	3,787,254	3,545,317
Total	**31,304,927**	**32,813,944**	**31,042,988**

12. Results and Conclusions

The results show that, on average, conveying the CCBs is approximately 40 percent more cost effective than trucking. The results for conveying versus trucking were consistent for all three sites. The costs analyses showed that conveyor systems required more capital construction costs, and less operations and maintenance costs over the lifetime of the landfill. A summary of the costs as well as the potential savings are included in Tables 45, 46 and 47.

Table 44. Comparison of Total Costs of Conveying and Trucking

2010 Net Present Worth	Site 8		Site 9		Site 12	
	Trucking	Conveying	Trucking	Conveying	Trucking	Conveying
Transportation Infrastructure	438,910	1,814,280	1,856,204	3,066,462	157,084	904,639
Operations and Maintenance	50,016,888	31,304,927	63,611,548	32,813,944	50,592,710	31,042,988
Total	**50,455,798**	**33,119,207**	**65,467,752**	**35,880,406**	**50,749,794**	**31,947,627**

Table 45. Summary Total Costs of Conveying and Trucking

Site 8		Site 9		Site 12	
Trucking	Conveying	Trucking	Conveying	Trucking	Conveying
50,460,000	33,120,000	65,470,000	35,880,000	50,750,000	31,950,000

Table 46. Total Savings for Conveyors

Site 8		Site 9		Site 12	
2010 NPW	Percent	2010 NPW	Percent	2010 NPW	Percent
17,340,000	34.4	29,590,000	45.2	18,800,000	37.0

For Site 8, in terms of 2010 net present worth, transportation infrastructure costs for conveying were more than 410% greater than those of trucking. This was not a very significant factor in the overall costs however, as the transportation infrastructure for trucking for site 8 was equal to 0.87% of the combined infrastructure and operations and maintenance costs. The operations and maintenance costs for conveying were only 62.6% percent of the same costs for trucking. Because operations and maintenance made up the majority of the total costs for both trucking and conveying, the total cost to convey was equal to 65.6% of the overall trucking costs. Based on the analysis, using conveyors over trucking for site 8 could potentially save the client approximately 17,340,000 dollars.

For Site 9, in terms of 2010 net present worth, transportation infrastructure costs for conveying were about 165% greater than those of trucking. Despite this discrepancy, conveying was less expensive overall because the transportation infrastructure for trucking for site 9 was equal to 2.8% of the combined infrastructure and operations and maintenance costs. The operations and maintenance costs for conveying were equal to 51.6% percent of the same costs for trucking. Because operations and maintenance made up the majority of the total costs for both trucking and conveying, the total cost to convey was equal to 54.8% of the overall trucking costs, or just more than half as much. Based on the analysis, using conveyors over trucking for site 9 could potentially save the client approximately 29,590,000 dollars.

For Site 12, in terms of 2010 net present worth, transportation infrastructure costs for conveying were about 576% greater than those of trucking. This was not a very significant factor in the overall costs however, as the transportation infrastructure for trucking for Site 12 was equal to 0.31% of the combined infrastructure and operations and maintenance costs. The operations and maintenance costs for conveying were only 61.4% percent of the same costs for trucking. Because operations and maintenance made up the majority of the total costs for both trucking and conveying, the total cost to convey was equal to 63.0% of the overall trucking costs.

Based on the analysis, using conveyors over trucking for Site 8 could potentially save the client approximately 18,800,000 dollars. From the cost analysis, it can be said that the capital costs for conveyor infrastructure are increased in relation to trucking costs for sites that are closer to the starting area. Therefore, transportation infrastructure costs for conveyors become more competitive with those of trucking the further a site is from the starting point.

From our analysis, operations and maintenance costs in relation to those of trucking do not seem to follow a certain pattern based on distance; instead there are more complicated factors involved. Based on the operation and maintenance results, conveying is more efficient than trucking irrespective of distance. For all of the sites, the factor that contributed most to the overall cost of the conveyor system was loading. Loading refers to the machinery that transports the materials from the plant output, onto the conveyor, and transports the materials off of the conveyor. Additionally, it refers to the costs of the machinery that place and spread the materials at the landfill. Based on that fact, it is most cost efficient to reduce or eliminate all unnecessary handling of the materials at the plant or on site.

13. Discussion

Throughout the process of our analysis, there were multiple factors that constrained the design and analysis. These included time, available information, determining the scope of work, and the complexity of design and calculations. With that in mind, there are several factors that were not analyzed in depth that should be considered when making a final decision.

One of the first challenges encountered was insufficient information. For instance, there was no average number of supports per foot of conveyor mentioned in the textbooks examined or in the historical project that was used as a references for the cost estimates. It is likely that a conveyor will require many more supports than estimated in this analysis, which was one large support per 250 feet assuming smaller, less expensive supports, could be placed in between. It was also difficult to estimate the some of the costs of the materials such as a fully enclosed hood. Both of these factors could increase the initial infrastructural costs. However, it is unlikely that they would increase the total costs of the project by more than 40 percent. Therefore, despite these additional costs, conveyors are still likely to be cost competitive with trucking.

Another factor that should be considered is plant output flexibility. Theoretically it can run more often, however this would increase the labor costs. Since conveyors are usually designed to operate at maximum capacity for maximum efficiency, it would not be feasible to simply add more material to the conveyor. There are several other infrastructural considerations that should be taken into account. With conveyor systems, there is limited unloading area which means that more spreading of the materials would be necessary at the landfill, which may increase the costs. The construction of storage silos at the plant or at the landfill site may also be required to accommodate material loading and spreading schedules. In any project, the costs associated with managing the infrastructure after its estimated useful life should, also be considered. For safety and aesthetic reasons, it may be necessary to remove the conveyor.

There are also several assumptions in the design and cost estimate that could make conveyors more affordable than predicted in this study. Since the conveyor system is serving a power plant, it can most likely get electricity at a wholesale price, which is lower than the 7.79 cents/KWh that was used in the electricity cost estimate. There will also be limited costs for the transmission of electricity.

For trucking there are several factors that could affect the overall costs. Trucking could be made more expensive by volatility in gas prices, which have been rising as political revolutions have sprung up in many Middle Eastern countries. Trucks also create a lot of dust, which may be expensive to mitigate or may make the permitting process more difficult. There may also be public opposition to the increase wear on road infrastructure as well as increased truck traffic. Trucking may also be more affordable if more CCBs are sold consequently reducing the number of truck trips to the landfill. There is also the possibility that fuel prices remain cheap or that cheaper alternative fuels become available.

A tax on carbon emissions as has been advocated for by environmental and some industrial groups would increase the costs of both trucking and conveying. Trucking would become more expensive because of the carbon tax on petroleum products, while conveying would become more expensive due to tax on carbon emissions from coal. At this point, it would be very speculative to estimate which price would increase the most. However, since most of trucking's costs are in operations and a relatively small proportion of conveyor's costs are dependent on the price of fuel, it is still likely that conveyors would out-compete trucking. In theory, it would also be possible to produce electricity from the conveyor from renewable sources.

14. Final Recommendations

Based on the cost analysis, our outcome is that conveying is a cost effective alternative to trucking. The analysis that was performed for conveying attempted to include all relevant factors; however, it must be understood that the results obtained are consistent with preliminary design estimates. In other words they are more of an estimate than an exact price and take contingency into account. In order to make an educated decision about the best interest of the client, a more comprehensive analysis of conveyor systems would be required along with a CAD development of the system and its components, which was beyond the scope of our work. Nevertheless, with the costs estimates considered, in addition to the environmental benefits of conveying, it is our recommendation that Stantec perform a thorough analysis of conveying as an alternative to trucking for the transport of CCBs for all of the sites being considered as our analysis shows that it would be competitive with trucking.

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