Evaluation of Effectiveness and Cost-Benefits of Woolen Roadside Reclamation Products: Cost Analysis

Task 5 Report

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Glossary

Batt	a piece of felted or carded wool material in rolls or sheets, such as wool
Carding	a mechanical process to disentangle unorganized clumps of wool fiber and align them to be parallel with one another
Felt	a textile that is produced by matting, condensing and pressing fibers, such as wool, together
Greasy wool	raw, uncleaned wool that contains lanolin
Needle felt	"barbed" needles in machines enter wool and grab top layers and intertwine them with interior layers of fibers in a continuous repeated process to make wool fabric
Noil	short fiber removed by the combing of wool
Roving	a slightly twisted roll or strand of unspun wool fiber
Scour	the removal of wool wax (lanolin), suint (perspiration), dirt, excrement, dust and other matter from the fleece in water.
Wet felt	warm soapy water is applied to layers of wool and it is repeatedly agitated and compressed to make a single piece of fabric
Worsted	wool or yarns that have a long staple length (4 inch fibers and longer only), are carded *and* combed, are stronger, finer, smoother and harder than woolen yarns/wool

1. INTRODUCTION

This document is the Task 5 Report for the Montana Department of Transportation (MDT) project that is developing and evaluating the effectiveness of woolen roadside reclamation products. The overall objective of the project is to develop and evaluate prototype wool products that can be used for reclamation and erosion control projects. The project seeks to develop and test potential wool products that can be easily produced as complementary or replacement products to existing traditional roadside products. Previous project tasks identified wool products with potential for roadside applications (Ament et al. 2016a). The project conducted laboratory tests for promising wool products to determine whether they meet various performance specifications, as required by MDT and the Federal Highway Administration (FHWA; Ament et al. 2016b). Another part of the project developed experimental plots to field test the woolen reclamation products and evaluate their relative effectiveness compared to standard products (Ament et al. 2016c).

The primary objective of Task 5 is to report on the costs and benefits of the most promising lab and field tested wool products.

2. BACKGROUND

Highway right-of-way management following construction on MDT lands requires creating conditions conducive to the establishment and survival of reclamation seeding while controlling soil erosion and surface runoff. Woolen reclamation best management practices (BMP) products have many attributes that may make them superior to existing standard materials. This project seeks to develop and test the effectiveness of wool-based products for erosion control, soil retention and vegetation establishment. Wool products will be compared to standard industry erosion control products that often use imported coconut fiber (coir) or synthetic non-biodegradable geotextile materials.

Erosion control fabrics generally meet the requirements established by the Erosion Control Technology Council and the U.S. Department of Transportation, Federal Highway Administration's standard specifications for construction of roads and bridges on federal highway projects [FP-03 2003 Section 713.17, Type 3.B]. There are several types of erosion control blankets (ECB): temporary, extended, and semi-permanent. One of the most commonly used erosion control blankets produced is comprised of 2 layers of jute netting filled with straw and coconut fibers (coir) and stitched together. According to several manufacturer's product specifications, erosion control blankets have a functional longevity up to eighteen months. These ECB products are intended to reduce soil erosion, water run-off and improve the environment for revegetation.

During the conceptual phase of this project, it was surmised that roadside reclamation products containing wool may perform similarly or better than traditional straw/coconut ECBs. Scoured weed-seed free wool can store up to 400% of its weight in water (Upton 2003). Wool becomes saturated at 33% of its weight of moisture-free fibers (D'Arcy 1990). That is, when scoured wool absorbs water greater than 33% of its weight, the moisture is readily available for plant growth. This characteristic could make woolen erosion control blanket more advantageous in drier climates and especially in areas with sandy soil. In addition, sheep wool contains up to 17% nitrogen and can act as a slow release fertilizer for plant growth (Herfort 2010). Research from Europe testing the use of woolen fabrics for establishing vegetation on green roofs resulted in over three times more plant canopy cover when wool was used in mats compared to traditional coconut fibers mats (Herfort 2010). Waste wool pellets are also marketed as fertilizer in both the U.S. and Germany (Bohme et al. 2010). In addition to providing fertility, the wool pellets hold 20 times their weight in water (Wild Valley Farms 2016).

In Task 3, a variety of laboratory tests were conducted of various wool and conventional (used as controls) products to determine whether they meet specifications for MDT and Federal Highway Administration (FHWA) deployment (Ament et al. 2016b). In the Task 4 Report, woolen products developed for the project were evaluated in several field experiments along highways in Montana as well as on a test slope built and maintained by the Western Transportation Institute (WTI) at the Transcend Research Facility near Lewistown, MT.

In this Task 5 Report, we assess the costs and benefits of the most promising lab and field tested wool reclamation products.

3. METHODS

The project gathered and analyzed three different sources of information to develop reasonable cost estimates associated with producing the wool reclamation materials: wool market news, interviews, and price lists. All three sources of information were used to form the basis for the cost benefit analysis.

1. US Wool Market News: Information on the U.S. wool market is publicly available and produced by the U.S. Department of Agriculture (USDA) or state agricultural departments.
2. Interviews: This cost-benefit analysis was based on information gathered by interviews with wool mill owners and geotextile manufacturers. Since the project developed new wool reclamation materials and there has been no manufacturing of wool reclamation materials in North America, the research team interviewed wool mills and geotextile manufacturers for their cost of production.
3. Price lists: Price lists were used for commercially available products such as the standard ECB and compost used as controls in the field trials. Information on standard product costs was available by reviewing the literature and company sales information such as price sheets.

In addition, the following assumptions were used to develop this cost analysis:

- The wool reclamation products' manufacturing costs are projected, and based on future manufacturing and production reaching a scale that maximizes cost effectiveness. For example, this project required approximately 800 pounds of scoured, cut wool at $4.00/pound for the wool ECB products developed for use in lab and field tests. To decrease the cost of scoured, cut wool for wool ECB production, at least 2,000 pounds of wool would need to be bought and processed at once. If 2,000 pounds of wool were requested, then the cost of wool for ECB production could potentially be reduced to approximately $2.20/pound (Mackey 2017) if markets are similar in the future as they were when the wool was ordered for this project.
- The final wool product costs the same to ship from the manufacturer to the reclamation site as the standard product; therefore, manufacturer shipping costs are not included since they would vary widely depending on the shipping distance and quantity ordered.
- Projects costs are estimated based on future large scale wool processing, not small batches of wool batts that were developed for the project.
- If manufacturers provided a range of costs for a particular stage of production, then the middle of the range was used in the calculations.
- The wholesale prices are used for the analysis because retail prices were more variable depending on producer, quantity purchased, and the vagaries of supply and demand.

4. RESULTS

4.1 Background: Wool Markets and Processing Costs

Since wool is integral to the development of the innovative products developed for this project, a brief understanding of wool production and costs is essential to understanding its viability as a component of these roadside reclamation products. The wool industry has witnessed a gradual decline in total numbers of sheep and lambs in the U.S. over the past decade (Table 1). In 2014, the U.S. had an inventory of 5.2 million sheep and lambs. According to the United States Department of Agriculture (USDA), Montana ranked eighth in the nation for sheep production with 220,000 head of sheep and lambs in 2014 (USDA, NASS. 2014).

Table 1. Sheep and lamb inventory (USDA, NASS 2014).

Sheep and Lamb Inventory	
Year	**1,000 Head**
2005	6,135
2006	6,200
2007	6,120
2008	5,950
2009	5,747
2010	5,620
2011	5,480
2012	5,365
2013	5,335
2014	5,210

As sheep inventory has shrunk in the U.S., so has wool production. In 2004, greasy wool (raw, uncleaned wool) production was approximately 37 million pounds. By 2012, greasy wool production had decreased to 27 million pounds across the nation (USDA, NASS. 2014). The latest data in the agricultural census indicates that Montana produced 1.8 million pounds of greasy wool in 2012. Scouring renders greasy wool weed seed free and hypoallergenic and is an important step in wool production. However, greasy wool is reduced to approximately half its weight in the scouring process as feces, oils, dirt and other impurities are removed (personal communication, Thayne Mackey, Brookside Woolen Mill, 2016).

It has been estimated that for every three pounds of greasy wool produced, one pound is unmarketable and stays on American farms and ranches (personal communication, Thayne Mackey, Brookside Woolen Mill, 2016). Qualities that make wool unmarketable, include short fibers, the presence of hair, and inconsistent color. Therefore, of 27 million pounds of greasy wool produced in the U.S., approximately 9 million pounds of greasy wool (equating to 4.5 million pounds scoured wool) generates no income for wool producers. This ‘waste wool’ could be used for wool reclamation product production while having no effect on existing U.S. wool markets. In fact, use of the unmarketable greasy wool would benefit producers by generating additional income. Unmarketable greasy wool has been bought in Montana for $0.10-$0.20 per pound (personal communication, Thayne Mackey, Brookside Wool Mill, 2016). The 9 million pounds of waste wool in the U.S. would have a value of $900,000 - $1.8 million. In comparison, the national posted price (30-day weighted average) for the lowest grade of marketable greasy wool was $0.56 per pound in October 2016 (USDA, FSA 2016). The 27 million pounds of marketable wool in the U.S. has a value of $15.1 million. Thus, the unmarketable wool would have a value of 6 – 12% of the marketable greasy wool being sold today in the U.S. Other costs such as the amount purchased, transportation costs, and relative cleanliness (i.e. scouring needs) of waste wool should also to be considered in the total cost of using either unmarketable or market-based wool for erosion control products.

4.2 100% Wool and wool-straw blend erosion control blankets

There were two types of wool ECB products developed by the project and tested in the field. One type manufactured by Montana wool mills was deployed only along U.S. Highway 287 (US Hwy 287) near Three Forks, Montana. The second type was manufactured by a rolled ECB manufacturer in Minnesota and were field tested along US Hwy 287 and at WTI's test slope at Transcend experimental station in Lewistown, Montana (See Task 4 Report, Ament et al. 2016c).

4.2.1 Pure Wool ECB Batts produced by Montana wool mills

Descriptions of four pure wool ECB batts

Four wool ECB products that were developed and field tested by this project were produced by Montana wool mills. Two weights of carded pure wool batts and two types of needle punched pure wool batts were ultimately selected for field tests (see Task 2 and Task 3 Reports). Each batt was approximately one square meter in size and were deployed for field testing along US Hwy 287. For the results of vegetation establishment by each of the four treatments, see the Task 4 Report (Ament et al. 2016c).

The project field tested the carded wool batts, at two different weights, 73 grams/meter^2 ((g/m^2) (2 ounce/yard^2 (oz/yd^2)) and 44 g/m^2 (1 oz/yd^2). The wool batts were made by Thirteen Mile Wool and Lamb Company of Belgrade, MT. Eleven replications of both types of carded batts were deployed by covering them with a jute netting and using sod staples adhere them to the ground. The netting was needed to give them strength and durability to the carded wool prototype since, by itself, the batts are quite frail, such as having a low tensile strength, as an ECB.

The two types of needle punched batts field tested along US Hwy 287 were either processed through a needle punch machine once in one direction or four times in two opposing directions. Each of these wool ECBs used approximately 73 grams/meter^2 (g/m^2) (2 oz/ yd^2) of wool. Needle punched batts were produced by Brookside Wool Mill of Malta, MT. Eleven replications of both types of needle punched batts were deployed by covering them with netting and using sod staples to adhere them to the ground. The netting was not necessary for the needle punched batts because they were a more durable material. However, we used the netting on all plots to maintain installation consistency for all applications along US Hwy 287.

None of the four wool batts were considered a commercially viable product since Montana wool mills do not have equipment to produce large scale batt production (size and quantity) at the time of their production to produce rolls similar to the standard straw-coconut Type III ECB. Rather, they were developed and tested as prototypes to determine if relatively small amounts of wool could protect slopes from soil erosion and support the establishment of vegetation. Utilizing small amounts of wool was crucial in keeping wool ECBs cost competitive with coconut-straw ECBs.

Costs associated with pure wool ECB batts

Using wool by itself for ECB batts is cost effective if using greasy non-marketable wool ($0.10 to $0.20 per pound) or wool bought at the low end of the market value ($0.56 per pound, USDA FSA 2016). Shipping of greasy wool to a wool mill with a scouring train and batt producing machinery would be additional costs to consider in the production of these pure wool ECB batt products. Scouring of greasy wool costs about $1.00 per pound, and only half the weight of the original wool remains after the cleaning process (i.e. $1 to scour for each ½ pound produced). If the wool source was located near the scouring and ECB production facility, shipping costs would be lower (Table 2).

Scoured wool for these products, if bought in quantity (at least 2,000 pounds) would cost approximately $1.10 to $1.20 per pound. The four wool ECBs each used 44 to 73 grams of clean weed seed free wool per square meter. Therefore, the wool used in production of wool ECBs by the Montana woolen mills would be $0.11 - $0.12 per square meter. Another cost is the woolen mills' time for batt production. Thirteen Mile Wool produces and Brookside Woolen Mill sells wool batts for $9 per pound. Therefore, the cost for pure wool ECB batt production is $0.90 - $1.44 per square meter (Tables 2 and 3).

Further research and development of the wool ECBs

After the field tests, several factors were considered to determine the economic feasibility to further develop these four wool ECBs. First, carded pure wool is not strong enough to act as an ECB by itself. Thus, more materials and manufacturing processes would be required to make the "proof of concept" product viable commercially. This suggests that there will be more expenses of additional materials and additional manufacturing process(es) increasing the overall costs for pure wool ECBs. Machines that roll, stitch, or insert mesh netting to strengthen the wool batts are not typically found at a wool mill. Therefore, a mill would have to invest significant dollars to go into commercial wool ECB batting production. To adhere to typical dimensions of other commercial ECBs available on today's market and used by the transportation sector, the woolen mills' machines would have to be large enough to make rolls of wool ECB that are 2.5 m (8 ft) wide and at least 30 m (100 ft) long. Currently batt size production is about 1.2 m (4 ft) wide with variable lengths.

Second, each of the pure wool ECBs developed by the project shrunk in the field experiments, often to such an extent that after two years they provided minimal ground coverage (Figure 2). The shrinkage reduced their protection of the soil and vegetation (compare the two wool batts at the feet of the three workers in Figure 1 and the plot coverage of a wool batt in Figure 2). Encasing the batting within a non-shrinking netting and threads may alleviate the tendency of the batting to shrink, but that was not tested in the field.

Figure 1. Replications of erosion control products along US Hwy 287, Three Forks, Montana, October 2014. Plot dimension is one meter square and all treatments are covered with mesh netting stapled in place.

Figure 2: June 2016 field monitoring found shrinkage of a pure wool needle punched batt along US Hwy 287 near Three Forks, MT. The product initially covered the entire one square meter within the PVC frame.

Table 2: Estimated costs of materials and processes for manufacturing erosion control materials.

Product or Manufacture Process	Unit	Unit Cost (dollars)	Comments
Unmarketable Wool	pound	0.10 - 0.20	from individual producer ranches and farms
Greasy Wool	pound	0.50 - 0.80	from wholesale markets
Scouring Wool	pound	1.00 - 3.00	based on 1000-2000 pounds
Scoured Unmarketable Wool	pound	1.10 - 3.20	
Scoured Marketable Wool	pound	1.50 - 3.80	
Cut and shredded Wool	pound	1.00	
Scoured, Cut, Shredded Unmarketable Wool	pound	2.10 - 4.20	Used for rolled ECB production, cost scaled for 2,000 pound purchase
Scoured, Cut, Shredded Marketable Wool	pound	2.50 - 4.80	Used for rolled ECB production, cost scaled for 2,000 pound purchase
Straw	pound	0.06	from local farmers
Coconut Fiber (coir)	pound	0.30	imported in bales
Burlap	square meter	1.20	
Jute Netting + Manufacturing	square meter	0.49	

Table 3: Costs of various wool and standard non-wool ECB products, excludes production shipping costs.

Final Product[1]	Unit	Unit Cost (dollars)	Comments
Pure wool batting (no netting)	square meter	1.39 - 1.93	manufacturer cost – Thirteen Mile Wool and Brookside Woolen Mill[2]
100% Straw ECB[3]	square meter	0.52	manufacturer cost (includes shipping for production) – Ero-Guard[4]
70% Straw / 30% Coconut ECB	square meter	0.62	manufacturer cost (includes shipping for production) – Ero-Guard
100% Wool ECB[5]	square meter	2.69	manufacturer cost with scaling projection
50% Wool / 50% Straw ECB	square meter	1.18	manufacturer cost with scaling projection
25% Wool / 75% Straw ECB	square meter	0.84	manufacturer cost with scaling projection

[1] All ECBs have two layers of biodegradable jute netting and approximately 8 oz (0.5 lb) fill (straw, coir and/or wool) between the netting. The unit cost was determined by using the weight of wool and straw in each product, the known cost of straw, and the scaled cost of wool

[2] Personal communication, Brookside Woolen Mill, Malta, MT, and Thirteen Mile Wool and Lamb website.

[3] All rolled ECB products include double layer of jute netting.

[4] Personal communication, Ero-Guard, Mapleton, MN.

[5] Based on scoured, cut and shredded unmarketable wool costing $3.15 per pound (mean value scaled for production; see Table 2). Does not include the shipping cost to get wool to the ECB manufacturer.

4.2.2 Wool / Straw rolled ECB

Descriptions of the four wool / straw rolled ECB products

Four wool / straw rolled ECB products that were developed and field tested by this project were produced by Ero-Gaurd of Mapleton, MN. The four products vary in the percent composition of wool and straw fill but all were stitched with the same double layer jute netting (Figure 3). The four field tested wool / straw rolled ECB products were:

- 100% Wool
- 55% Wool / 45% Straw
- 40% Wool / 60% Straw
- 25% Wool / 75% Straw

The project field tested the two rolled ECB products (100% Wool, 55% Wool / 45% Straw) at the US Hwy 287 site, and all four wool / straw ECB at WTI's Transcend Research Facility. The rolled ECB products were 2.5 m (8 ft) wide and 30 m (100 ft) long. At the US Hwy 287site, the ECB was cut into one meter squares for testing (Figure 1). At the Transcend site, the ECB was cut into 1.5 m wide by 5 m long plots to cover the height of the slope. Eleven replications were tested at US Hwy 287 and ten replications were tested at Transcend. In addition, each site tested the standard 70% straw / 30% coconut ECB product and broadcast seed only as control plots were tested (see Task 4 Report, Ament et al. 2016c).

The four wool / straw ECB are considered commercially viable products. The Minnesota-based ECB manufacturer (Ero-Guard) was able to substitute wool for coconut in the production of their products. The wool / straw ECB is constructed using the same machinery as the standard ECB (Figures 4 and 5).

Figure 3. Example of wool combined with straw as fill between two biodegradable net layers in a rolled ECB.

Costs associated with rolled wool ECBs

Mixing wool with straw helps control the cost of the ECB products. To develop the product, we bought small amounts (400 pounds) of low quality wool that was scoured, cut, and shredded for $4/pound. Then we shipped the processed wool to the ECB manufacturer in Minnesota at a cost of approximately $1 / pound. Ero-Guard volunteered their time and equipment for the development of the wool / straw ECB. The four wool ECBs ranged from 59 to 302 grams (0.1 – 0.7 lbs) of wool per square meter. Therefore, the wool used in production of wool / straw ECBs would cost $0.32 - $2.20 per square meter using the weight of wool in each product and the median cost when scaled for production. In addition, there is a straw component, jute netting and manufacturing cost. Overall, one square meter of a rolled wool / straw ECB cost $0.84 - $2.69 to produce, depending on the wool / straw composition (Table 3).

The highest costs were purchasing the wool, processing it at the woolen mill so it is ready for ECB production, and transportation to the ECB manufacturer, especially when purchasing and shipping relatively small quantities of wool (e.g., 400 lbs). Several factors could reduce the cost of this product in the future if scaled for production. These factors were incorporated in the costs listed in Tables 2 and 3. If scoured, cut and shredded wool for these products were bought and shipped in quantity (at least 2,000 pounds), then wool costs could be reduced to $2.10 to $4.80 per pound for wool (Table 2). For the research, shipping the wool from the wool mill to the ECB manufacturer cost $1/lb. If shipping in bulk, shipping could become more cost effective (shipping costs are not included in the wool ECB production costs in Tables 2 and 3). Furthermore, if ECB production could occur near the wool scouring mill, shipping costs would be even lower. Similar to the manufacturing of other products, the more product produced could maximize its cost efficiency of scale.

Further research and development of the rolled wool ECBs

In comparison to the standard ECB products currently developed, the wool / straw ECB is $0.32 - $2.17 more expensive per square meter (Table 3). The rolled wool / straw ECB products would benefit from additional research on the ratio of wool / straw needed to provide a benefit to the vegetation while keeping wool component low enough to control product cost. Our research found the 50% wool / 50% straw ECB preformed equally well at establishing vegetation as the 100% wool ECB in the US Hwy 287 field trial. Lab tests for the 50% wool / 50% straw ECB indicate it meets MDT’s short-term ECB requirements (Ament et al. 2016c). Therefore, the 50% wool / 50% straw ECB should be the product to further developed. The scaled cost for this wool ECB product is $1.18 per square meter, approximately double the cost of standard ECB. However, after two growing seasons at the US Hwy 287 site, the 50% wool / 50% straw ECB averaged 15% more seeded grass cover than the standard 70% straw / 30% coconut ECB product suggesting the added cost may have benefits with greater vegetation establishment. After one growing season at the Transcend site, there was no difference in the vegetation establishment of the wool verses standard ECB. An additional field season of data will be collected from the Transcend site to determine if the wool ECB had a cost benefit at both sites after two growing seasons. The Transcend site will also determine of a wool/straw blend (e.g. 25% wool / 75% straw) with lower proportions of wool could be beneficial to plant performance while lowering costs associated with the wool.

Figure 4: Equipment that manufactures rolled ECBs, Ero-Guard, Mapleton, MN.

Figure 5: Close up of a straw and jute net ECB manufacturing at Ero-Guard, Mapleton, MN.

4.3 Wool as an additive to compost

Pieces of cut wool were mixed with commercially available wood-based compost. The field tests comparing the compost with cut wool pieces to compost alone did not find any advantage of adding cut wool to compost. That is, adding wool to compost did not increase seeded species establishment (Ament et al. 2016c). Thus, conducting a cost benefit analysis for wool as an additive to compost is not necessary because the additional cost of adding wool had not vegetation establishment benefit.

4.4 Wool silt fences

Descriptions of the different wool silt fence products

There were three generations of wool silt fence product types developed for the project. The first generation of wool silt fence consisted of 100% biodegradable 244 g/m^2 (7 oz/yd^2) wet felted wool batts. The silt fence was manufactured by Sugar Loaf Wool Carding Mill. Each rectangular wool batt was approximately 106.7 cm (42 in) by 91.4 cm (36 in), and was subsequently sewed together by Custom Canvas Design of Bozeman, MT into a continuous roll of wool silt fence 106.7 cm (42 in) wide. The second generation silt fence used the same felted wool product and included stitching to increase strength and longevity of the product. Custom Canvas Design of Bozeman, MT stitched at 10 cm (4 in) intervals into two layers of 140 g/m^2 (4 oz/yd^2) felted wool silt fence (Figure 2b). A plastic mesh net was stitched between the two layers of felted wool to increase strength of the resultant fence. A third generation 100% biodegradable silt fence was designed that consisted of two burlap sheets stitched together with cut and shredded scoured wool in the center, between the two layers of burlap, this was produced by Ero-Guard using the same machinery as the wool ECBs (Figures 4 and 5) .

Of the three versions of wool silt fence, the burlap-wool silt fence could conceivably be used in existing silt fence installation machinery, thus making installation expenses approximately the same.

There were two expenses not calculated for this evaluation. First, burlap-wool silt fence is 100 percent biodegradable, thus it would not have to be removed at the conclusion of construction projects like plastic silt fence often is required, providing a cost savings in labor for de-installation, compared to woven plastic silt fence. Similarly there would be no plastic pollution of surface waters if the burlap-wool silt fence replaced woven plastic silt fence, thus the indirect costs for small bits of plastic potentially entering surface waters was also not evaluated.

Costs associated with wool silt fence

Costs associated with the development of the wool silt fence are provided in Table 4. The second generation wool silt fence had the greatest longevity in the field tests but it also had the greatest cost for production, especially compared to the standard plastic silt fence. At this time in the development of wool silt fencing, it appears the three versions produced are 10 to 25 times more expensive than plastic woven silt fence (Table 4). These make the products prohibitively expensive.

Further research and development of the wool silt fence

The third generation silt fence did not perform well in the field trials; however, the third generation wool / burlap silt fence was much easier and less costly to produce at larger scales than the previous generation felted wool silt fence (Figure 6.a and 6.b). This final version of silt fence could be produced on ECB machinery to keep costs lower than the felted wool silt fence developed for the project. Further research could investigate the amount of wool in the center of the burlap as a function of durability, filtration, and longevity. However, given the performance in the field, and the large cost differential between wool and standard products, further research may not be justified.

Table 4: Summary of wool silt fence costs.

Silt Fence Product & Description	Cost per linear foot of 30.5 cm-wide rolled material	Manufacturer	Fences tested by project
Standard woven plastic silt fence[1]	$0.26 - $0.37	Tenax®	Standard silt fence - control
Wool batts, wet felted, sewn together[2]	$5.93	Sugar Loaf Woolen Mill / Custom Canvas Design	1st Generation wool silt fence
2 layers of wool batts, wet felted, sewn together with strengthening stiches and plastic mesh in center[3]	$6.43	Sugar Loaf Woolen Mill / Custom Canvas Design	2nd Generation wool silt fence
2 layers of burlap with cut wool pieces in center layer	$3.75	Ero-Guard	3rd Generation wool silt fence

[1] Price determined by the wool, burlap, and labor costs provided by the manufacturer. Standard product cost provided by manufacturer.
[2] Actual costs for project, experimental, not mass produced to benefit from economy of scale
[3] Estimated, based on first version, experimental, not mass produced to benefit from economy of scale
[4] Estimated by manufacturer after making only one roll of fence, based on cut scoured, shredded unmarketable wool at $3.15.

Figure 6 (a): Rolled silt fence constructed of two burlap layers sewn together with cut wool pieces as filler. (b) Backlit burlap and wool silt fence shows the lack of consistency in the distribution of the wool pieces in the center layer of the fence.

5. CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION

The following are the conclusions of the cost analysis:

- Wool production has decreased in the U.S.. Using waste wool for reclamation products would contribute an additional $900,000 – $1.8 million (6 – 12%) to existing markets.
- The cost of a pure wool batt is $0.90 - $1.44 per square meter to produce (within two layers of reinforcement netting); however, they did not improve seeded grass establishment in the field trials, and the products shrunk in size over time due to weather.
- The 50% wool / 50% straw ECB should be the rolled wool ECB product to further develop. The scaled cost for this wool ECB product is $1.18 per square meter, approximately double the cost of standard ECB. However, after two growing seasons at the US Hwy 287 field site, the 50% wool / 50% straw ECB averaged over 5 times more seeded grass canopy cover than the standard 70% straw / 30% coconut ECB after two years, 24.99% cover versus 4.7% cover, respectively. This suggests the added cost for wool ECB may be a benefit due to greater seeded grass establishment and cover. The 2017 Final Report will also evaluate performance and costs of other wool/straw blends that may be more cost-effective.
- If you calculate the cost it took to generate each percent of seeded grass canopy cover per square meter of material at the US Hwy 287 site, then the 50% wool / 50% straw ECB is more cost effective than the 70% straw / 30% coir ECB:
  50% wool / 50% straw ECB: 25.0% canopy cover/$1.18/ m^2 = $0.05/percent cover/m^2
  70% straw / 30% coir ECB: 4.7% canopy cover/$0.62/ m^2 = $0.13/percent cover/m^2
  Restated, the calculations above indicated that it cost five cents to establish each percent of seeded grass canopy cover per square meter using the 50% wool / 50% straw ECB and it cost thirteen cents to establish each percent of seeded grass canopy cover per square meter using the 70% straw / 30% coir ECB. This makes it nearly three times more cost effective to use the wool ECB material than standard ECB if the goal is maximizing vegetative cover.
- After one growing season at the Transcend site, there was no difference in the vegetation establishment of the wool verses straw-coir ECB. An additional field season of data will be collected from the Transcend site to determine if the wool ECB had a cost benefit at both field sites after two growing seasons.
- The 2017 Final Report will incorporate observations on product longevity and any impacts on cost benefits.
- Adding cut wool pieces to compost had no vegetation establishment benefit in the field trials; therefore, a cost analysis was not completed.
- The second generation wool silt fence had the greatest longevity in the field tests but it also had the greatest cost for production ($6.43), especially compared to the standard plastic silt fence ($0.26 - $0.37).

The further development and production of rolled woolen reclamation products has merit, especially if they their noted improvement in vegetation establishment can continued to be demonstrated. The rolled products are the simplest to produce since they use existing ECB manufacturing equipment, and are the most cost effective of all the woolen reclamation products. Additional research could work on reducing the costs associated with scouring, shredding and shipping to make the product more cost competitive.

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