TETRA TECH

FINAL MEMO

To:	Patty Daley, Michele White, Kari Parcell Barnstable County/Cape Cod Commission
Cc:	----
From:	Debra Darby, Doug Allen, Wilbert Yang Tetra Tech
Date:	October 25, 2021, Revised
Subject:	Barnstable County MSW Diversion Options for Recyclables, Reusable and Hard to Dispose Waste Materials Task 5: Identify Market and Estimate Program Costs

1.0 INTRODUCTION

Tetra Tech conducted research to look historically and plan forward to determine markets for beneficial end-products to be identified. The assessment includes estimated costs to bring materials to end-markets and perform a high-level review of annual operating costs, including transportation via truck haul.

Objectives:

- Identify current beneficial use (BU) end-product market prices and estimated futures.
- Where appropriate, identify when and how acquiring feedstocks from off-Cape communities could improve unit processing cost and examine potential adverse fiscal impacts on anticipated municipal operations and investments.
- Identify recycling options relative to quantity coming into the Cape and Islands town transfer stations, including facilities in other jurisdictions, potential capacity analysis for local processing and local markets.

2.0 WASTE STREAM MATERIALS FOR REUSE AND RECYCLING

This technical memo provides an overview of potential recycling processes and end markets for material streams that are collected at the Cape and Islands town transfer stations. This is only for the drop-off materials collected at the municipal transfer stations, and does not consider other collection solid waste streams, such as private or municipally administered collection programs.

2.1 ORGANICS

Residential food waste collection at Cape Cod and Islands town transfer stations is relatively new with nine Barnstable County municipalities providing a drop-off location for collection within the County. These towns are Barnstable, Brewster, Chatham, Dennis, Falmouth, Mashpee, Truro, Wellfleet, and Yarmouth.

On Martha's Vineyard, residential food waste is collected at five of the six town transfer stations including Chilmark, Edgartown, Oaks Bluff, Tisbury, and West Tisbury. Island Grown Initiative (IGI) provides toters for residents to bring their food waste to these town transfer stations, and at two drop-off locations (the IGI farm gate or on Chappaquiddick).

The organics stream includes all food waste, leaf and yard waste, and food-soiled compostable papers. Approximately 19,376 tons of yard waste and 205 tons of food waste were collected at the municipal transfer stations in 2019, for a total of 19,581 tons of organics collected across the Cape. The Islands manage their own organics through composting. There are several viable options that the County could pursue for processing the collected organics, including composting and anaerobic digestion.

2.1.1 Composting Methods

Composting is an aerobic biological decomposition process that reduces organic material to produce a peat-like humus, typically used as a soil amendment. Composting processes can range from simple pile systems to process yard and garden waste to more complex self-contained systems that are capable of processing putrescible organics such as food waste.

Composting is utilized in many jurisdictions for processing yard and garden waste, food scraps, food-soiled paper, animal by-products, manure, and biosolids. Composting generates heat that is used to deactivate pathogens within the compost pile (i.e., heat is generated and then used to reduce pathogen levels in the compost) if a certain duration and temperature is maintained. This process to reduce pathogen levels is referred to as Processes to Further Reduce Pathogens (PFRPs). Composting is also often used after anaerobic digestion (wet and dry methods) to produce a more stable and marketable nutrient rich compost and biogas for renewable energy. The benefits and considerations for composting are summarized in **Table 2-1** below. **Figures 2-1** and **2-2** are photos of the simplest forms of the composting processes.

Table 2-1: Benefits and Considerations for Composting

Benefits	Considerations
▪ Simplicity – minimal skills required by operator. ▪ Low capital cost and operating cost. ▪ Applicable to small volumes of leaf and yard waste.	▪ Requires adequate temperatures and duration to ensure pathogen reduction is achieved. ▪ Extended time to produce compost product. ▪ Exposure to rain, wind, and cold requires additional design requirements to control leachate and maintain temperatures in the pile.

Figure 2-1: Static Pile Composting

Figure 2-2: Windrow Composting

2.1.1.1 Windrow (Aerated Turned)

Turned composting consists of placing the mixture of organic materials into piles, or windrows, which are turned on a regular basis. Turned windrows is the most common method of composting in North America. Typically, windrows are formed for this application, that are up to 8 feet high for dense or tightly packed materials such as manures, and 10 to 12 feet high for porous or less dense materials such as yard waste (leaves and branches). In colder climates such as the Cape and Islands, windrows can be built taller and wider to reduce heat loss in the pile. The equipment used for turning these windrows determines the size, shape, and spacing of the windrows. Front-end bucket loaders or telescopic handlers with a long reach can build higher and wider windrows. Windrows formed with turning machines are sized based on the equipment design. Small pull-type turners form smaller windrows, while large self-propelled machines form 10- or 12-feet piles with a base width of 20 feet or more.

Windrows aerate primarily by natural or passive air movement (convection and gaseous diffusion). The rate of air exchange depends on the porosity of the windrow. Turning the rows mixes the materials, rebuilds the porosity of the windrow, and releases trapped heat, water vapor and gases. This type of compost technology is best suited to composting yard and garden waste. Windrow systems have been used for composting food waste if it is incorporated and covered with non-food substrates as it is received. Composting times can be expected to be six months or longer depending on feedstocks, climate and turning frequency. During the winter months such as in Barnstable County, Massachusetts, the composting time could increase by up to 2 months depending on the size of the pile and frequency of pile turning. **Figures 2-3, 2-4 and 2-5** show examples of windrow turner equipment that are available as both self-propelled and as a pulled system.

Figure 2-3: Self-Powered Windrow Turner

Figure 2-4: Self-Powered Windrow Turner

Figure 2-5: Tractor-pulled Windrow Turner

Table 2-2: Windrow Composting Benefits and Considerations[1]

Benefits	Considerations
▪ Can handle feedstocks with lower Carbon to Nitrogen (C: N) ratios. ▪ Relatively low capital costs and low technology requirements (windrow turners, front-end loaders, or farm equipment will suffice). ▪ Can achieve pathogen reduction temperatures with careful management and monitoring of the pile. ▪ Relatively low operating costs. ▪ No electric power needed. ▪ Large amount of industry practical experience.	▪ Large land area required. ▪ More labor intensive that aerated static pile, particularly for feedstock with low C:N ratio or porosity. ▪ Can be odorous, which may require larger buffer area between operation and neighbors. ▪ More challenges to overcome if food waste or biosolids are included due to increased odors and attraction of food waste to pests and wildlife. ▪ Exposure to rain, wind, and cold can be problematic unless in a covered environment.

[1] Sourced from http://aep.alberta.ca/waste/reports-data/documents/LeafYardWasteDiversionStrategy-Aug2010.pdf

2.1.1.2 Aerated Static Pile (ASP)

Below are variations of aerated static pile composting systems.

2.1.1.2.1 Passive Aeration System

A method of augmenting a passive composting system is by introducing aeration systems at the base of the compost pile. Perforated pipes are laid on the ground, as shown on **Figure 2-6,** where air flows into the pipe and then percolates upwards through the compost by convection. This aids in achieving aerobic conditions in the pile, as it reduces the likelihood of anaerobic pockets of material occurring throughout the pile. Passive aerated piles can still benefit from turning the piles to re-build porosity. However, these systems can still require significant composting periods (up to two years) and are not well-suited to process feedstocks with food waste or low C:N ratios.

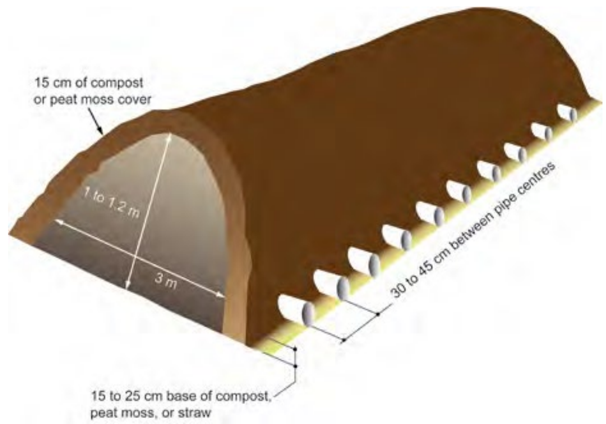

Figure 2-6: Example of Passive Aeration

Table 2-3: Passive Aeration Systems Benefits and Considerations

Benefits	Considerations
▪ Low capital and operating costs. ▪ Well-suited to small quantities of material. ▪ No electric power needed. ▪ Large amount of industry practical experience.	▪ Not suitable for food waste. ▪ Odors can be problematic. ▪ Pathogen reduction temperatures may not be well controlled. ▪ Not suitable for large quantities of material. ▪ Constructing piles overtop aeration systems can be complex. ▪ Exposure to rain, wind, and cold can be problematic unless under cover.

2.1.1.2.2 Active Aeration System

Active aeration differs from the above-described technologies in that air is forced through the composting pile using fans or blowers. This composting approach should have the composting area built on an impermeable surface such as a concrete or asphalt pad with a 2% grade to allow for leachate collection. Each pile can be equipped with a concrete floor with imbedded aeration channels or piping, or perforated pipe can be placed on the compost pad, and compost piles are built over top. The aeration pipes are connected to a blower equipped with a control system to moderate temperature and oxygen content in the pile. The control system tracks operating conditions to determine aeration rates, usually based on temperature feedback. Condensate and leachate are collected in the trench with drainage to a sump. Odor is managed by maintaining aerobic conditions in the pile and placing a cover of finished compost over the pile surface with positive air systems. With negative aeration systems, exhaust air is treated through a biofilter consisting of a wood chip and compost based medium. The composting time for this type of system is typically three months with a curing stage of 3 to 6 months, depending on feedstocks and climate.

The Cape and Islands have potentially cold winters and winter storm events. Composting facilities in colder climates will generally need to increase the composting time.

Figure 2-7 shows an example of an aerated static pile (ASP). The aeration pipes are the visible lines located below the composting pile. **Table 2-4** describes the ASP composting benefits and considerations, and discusses composting during the active aeration process.

Figure 2-7: Aerated Static Pile Inside Bunker Walls

Table 2-4: Aerated Static Pile Composting Benefits and Considerations[1]

Benefits	Considerations
▪ Can be suitable for composting food waste and biosolids. ▪ Forced aeration reduces land requirements and mixing. ▪ Can result in more rapid stabilization in the high-rate compost stage. ▪ Use of negative aeration with a biofilter can help control odors. ▪ Smaller surface area relative to windrows. ▪ Can have lower operating equipment requirements with less mixing/turning. ▪ Can achieve pathogen reduction temperatures.	▪ Slightly higher capital cost for forced aeration equipment. ▪ Moisture addition may be required if piles dry from over aeration. ▪ Feedstock pre-processing requires a higher degree of care; feedstocks must be well mixed and properly sized and moistened. ▪ More operator skill required to manage aeration systems. ▪ Aeration systems generally require three phase electrical supply. ▪ Exposure to rain can be problematic if pile becomes over saturated unless it is under cover.

[1] *Source*: http://aep.alberta.ca/waste/reports-data/documents/LeafYardWasteDiversionStrategy-Aug2010.pdf

2.1.1.3 Membrane Covered Aeration System

A membrane covered aerated static pile (CASP) composting system is typically constructed on an impermeable surface such as concrete or asphalt with an aeration system that adds oxygen to the pile. The membrane cover contains odors and sheds precipitation away from the composting pile to minimize leachate generations.

The system shown in **Figure 2-8** is the GORE Cover System that operates using positive aeration and in **Table 2-5**: Membrane Covered Aerated Static Pile Composting Benefits and Considerations. The cover is made of a microporous membrane (PTFE) sandwiched between a bottom and top fabric. The cover is placed over the pile and secured to the ground or to support walls on the side of the pile.

As air is injected into the pile, the breathable membrane expands like a balloon to create an in-vessel like environment. The sealed edges create a fully enclosed system. This membrane allows for the management and retention of moisture, temperature, and odor. Odors are reduced with efficient aeration, and with odor molecules being absorbed into the moisture film forming inside the cover. The control system monitors oxygen content and pile temperature. The control system uses oxygen feedback to activate the blowers to maintain oxygen levels.

The composting process consists of the main active phase (4 weeks under GORE cover), second active phase (2 weeks under GORE cover) and curing phase (2 weeks without GORE cover). The residence time for this type of system is approximately 56 days. Further curing of the compost can be expected with a market ready compost produced in about 6 months, depending on feedstocks and climate. During winter months the processing time could be extended an additional 1-2 months. Recent systems are being constructed inside a sheltered structure for the first stage. This enhances odor controls in sensitive areas.

Figure 2-8: Membrane Covered Aerated Static Pile

Table 2-5: Membrane Covered Aerated Static Pile Composting Benefits and Considerations[1]

Benefits	Considerations
▪ System uses low volume blowers and has reduced energy consumption over other static pile systems. ▪ Lower space requirements than windrow systems. ▪ Contained system reduces potential for odor emissions and leachate from composting. ▪ Pathogen reduction temperatures are exceeded. ▪ Moisture loss due to aeration is minimal compared to uncovered aerated piles.	▪ Potential steam or dust issues inside if inside a building enclosure. ▪ Indoor air must be managed in odor control system prior to release (possibly biofilter). ▪ Requires advanced operating skills. ▪ Moderate to high capital and operating costs.

[1] Sourced from http://aep.alberta.ca/waste/reports-data/documents/LeafYardWasteDiversionStrategy-Aug2010.pdf

2.1.1.4 In-Vessel Systems

In the in-vessel composting process, the compost is aerated continuously (with a combination of positive and negative air flow) in a contained vessel as shown in **Figure 2-9**. Systems typically include automatic control systems for aeration and moisture adjustments. Composting is typically contained within a rigid structure. In-vessel systems are commonly proprietary with numerous variations.

2.1.1.4.1 Enclosed Composting Systems

Permanent facilities may be made of concrete, with gasketed and insulated stainless steel doors. These offer significant advantages for corrosion resistance and odor containment. The residence time for these types of systems is in the order of 28 days to stabilize and with 6 to 9 months for curing. The vessel is equipped with an aeration floor and condensate/leachate collection system. The control system tracks operating conditions to optimize aeration rates. Exhaust gases are treated with wet scrubbers and biofilters to control odors.

Figure 2-9: In-Vessel Composting Bunker

Table 2-6: Enclosed Aerated Static Pile (Tunnel) Composting Advantages and Disadvantages[1]

Advantages	Disadvantages
▪ High degree of odor control except for receiving area and when doors are opened ▪ Controlled aeration and moisture ▪ Lower space requirements ▪ Enclosed facility is not impacted by weather ▪ Reduced structural corrosion, as composting is contained within concrete tunnel ▪ Suitable for food waste and biosolids	▪ A high degree of operating and maintenance expertise required to manage more complex aeration and control systems ▪ High capital and operating costs. ▪ Shorter residence time claims by some vendors can result in unstable compost and requires an additional composting stage. ▪ Requires additional operations to cure compost (e.g. turned windrows, static pile)

[1] Sourced from http://aep.alberta.ca/waste/reports-data/documents/LeafYardWasteDiversionStrategy-Aug2010.pdf

2.1.1.4.2 Static or Agitated Container

More temporary or modular in-vessel facilities may involve sealed metal containers similar to 40 yd^3 roll-off bins (static container) or a smaller version of the agitated mass bed (agitated container) as shown in **Figures 2-10, 2-11 and 2-12**. These containers offer modularity and flexibility compared to a fixed concrete structure, as more containers can be added if feedstocks increase, and site layout can be readily modified to changing conditions.

Static containers often involve modular metal bins that can be filled with material, sealed from the front or side, moved around site, and connected to an active aeration system. These systems are typically batch systems with low quantities of material per container (up to 900 tons per year) but can easily be scaled with acquisition of more containers. The active composting period of materials is typically quite short (2 to 3 weeks), which results in higher odor content of material entering the curing and maturing phase, than in systems with longer composting periods.

Agitated containers differ in processing flow, as material continuously flows through the system. Input organics undergo active composting while slowly travelling through the system. Compost exiting the system after the 2- to 4-week processing time still requires curing and maturing. Agitated containers are generally used for smaller quantities of material (660 lbs to 10 tons per day), but are highly modular, as they can be run in parallel. These systems also typically involve more sophisticated control systems that automatically adjust temperature, water input, and other control parameters.

An important consideration for these types of systems is operation and maintenance. Moving parts assist in processing the organic materials but generally result in higher wear and tear of the processing equipment. Over time the operator should also expect more replacement parts and component cleaning.

Figure 2-10: Static Container System

Figure 2-11: Agitated Container System (Wright Digestor)

Figure 2-12: Hot Rot Compost System (Continuous Process)

Table 2-6: Static and Agitated Container Benefits and Considerations

Benefits	Considerations
▪ High degree of odor control except for when material is removed. ▪ Lower space requirements, static and agitated containers are relatively mobile, so site layouts can be modified. ▪ May allow for modular expansion if feedstocks grow or are larger than expected. ▪ Agitated containers are highly automated.	▪ Operating and maintenance expertise required to manage more complex aeration and control systems. ▪ Higher capital and operating costs (vary with technologies). ▪ May require skilled maintenance staff. ▪ Some vendors claim shorter residence time (one to four weeks) and are used in combination with another composting method/technology. ▪ Longer curing time for processed materials.

2.1.2 Anaerobic Digestion

Anaerobic digestion (AD) is the biological decomposition of organic materials in the absence of oxygen. The process is carried out by anaerobic micro-organisms that convert carbon-containing compounds to biogas, which consists primarily of methane (CH_4) and carbon dioxide (CO_2), with trace amounts of other gases. This methane-rich biogas can be used to generate electricity or can be cleaned and upgraded to be sold and transported as renewable natural gas (RNG).

Figure 2-15: Anaerobic Digestion Facility

AD can occur in a dry state called "Dry AD" (also known as high solids AD) or in a wet state called "Wet AD". Dry AD technologies require the organic material to be 40% to 50% solid by mass, whereas Wet AD technologies require organic material to be less than 15% total solids by mass. Wet AD facilities are more appropriate for waste generators that produce source separated food waste (source separated organics) and biosolids for facility feedstocks, as those materials typically contain high water content and high methanogenic production potential.

Wet AD Systems have been in operation for over 20 years at municipal wastewater treatment plants. Some of these plants are co-digesting source separated food waste with wastewater treatment residuals (biosolids).

2.1.3 Barnstable County Considerations for Organic Waste

Table 2-8 presents some organic waste processing facilities in Massachusetts that are in close proximity to the County. Included is the distance to each facility from the centroid of the County as well as the estimated per ton hauling cost based on the 2019 organic waste feedstocks (~19,000 tons). It is estimated that each truckload would hold approximately 30 tons of organic waste material per trip. The hauling costs account for travel to and from each composting facility and the U.S. average cost of trucking per mile ($2.11[1]). The hauling cost does not include the tipping fee. In addition to the listed facilities, there are over 150 municipality-run and over 30 private compost facilities across the state. Not all of these facilities accept food waste.

Table 2-8: Nearby Organic Waste Processing Facilities

Facility	Location	Roundtrip from the Facility to the County (miles)	Hauling Cost/Ton (USD)	Process
Blacksmith Shop Farms Inc.	Falmouth, MA	15 miles	$2 per ton	Static Pile
Watts Family Farm	Sandwich, MA	15 miles	$2 per ton	Turned Windrow
Black Earth Composting (Compost With Me)	Falmouth, MA	20 miles	$3 per ton	Turned Windrow
Sam White & Sons Inc.	Middleborough, MA	90 miles	$6 per ton	Turned Windrow

[1] Henry, C. (2020). What is Total Cost Per Mile for Truckload Carriers? *Freightwaves.* Retrieved from https://www.freightwaves.com/news/understanding-total-operating-cost-per-mile

Save That Stuff Composting	Brockton, MA	108 miles	$8 per ton	Turned Windrow
Vanguard Renewables	Agawam, MA	306 miles	$22 per ton	Depackaging Facility

Based on current County organic waste feedstocks that are collected at the Cape and Islands town transfer stations, it is estimated that the capital cost of a facility would range from $15 M to $50 M dependent on the selected processing technology. This is a high-level cost estimate for an approximate 20,000 tons per year organics processing facility. The lower cost range is typically for composting technologies and the higher-end cost range for anaerobic digestion. In actuality, the cost could be much higher and that depends on so many factors. This cost is not inclusive of any costs related to land procurement or facility operations.

2.2 ASPHALT, BRICK & CONCRETE AND CONSTRUCTION & DEMOLITION WASTE

Construction and demolition (C&D) materials are inclusive of waste from the construction and demolition of buildings or structures. This includes wood waste (clean and treated), steel, gypsum, plaster, cardboard, papers, plastic, and metal[2]. C&D also includes inert materials such as asphalt, brick and concrete (ABC) products. There is no singular system that recycles all C&D or ABC waste as the waste is typically heterogeneous. Thus, the diversion options vary, and depend on the type of waste. Some potential diversion options include:

- Deconstructing structures to salvage materials for reuse, as an alternative to demolition. The EcoBuilding Bargains at the Center For EcoTechnology in Springfield Massachusetts is an example for the resale of salvage materials for reuse in the building trades. ecobuildingbargains.org
- Processing clean wood similar to organic waste described in **Section 2.1** above. For example, New England Recycling (NER) in Taunton Massachusetts processes clean wood for reuse as landscape mulches. www.nercans.com
- De-papering and crushing clean gypsum for use as a soil amendment.
- Recycling ABC materials through crushing, grinding and screening of the materials into aggregate or fill material. ABC materials can be transported to a place where it will be recycled, such as an asphalt batching plant where asphalt pavement is crushed and made into new asphalt or a crushing operation where ABC rubble is crushed to a size that makes it useful as a substitute for stone or aggregate in construction projects.
- Salvaging metals and other materials for re-introduction into the commodities market.
- Producing refuse derived fuel (RDF) from plastics, treated wood and clean wood. RDF facilities generally produce pellets to be co-fired in industrial boilers (cement kilns, lumber mills, etc.) with wood or coal.

2.2.1 Barnstable County Considerations for Recycling ABC and C&D

In 2019, the fifteen municipal transfer stations collected approximately 30,000 tons of C&D materials. **Table 2-10** presents some C&D recycling facilities that are in Massachusetts. The table includes the roundtrip distance from each facility to the County, and the estimated per ton hauling cost based on the 2019 C&D feedstocks. It is estimated that each truckload would hold up to 20 tons of C&D material. The costs account for travel to and from each facility based on the average U.S. hauling cost per mile ($2.11).

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[2] State of Connecticut Department of Energy and Environmental Protection. (2020). What is Construction and Demolition Waste? Retrieved from https://portal.ct.gov/DEEP/Waste-Management-and-Disposal/Construction-and-Demolition-Waste/What-is-CD-Waste

Table 2-10: Nearby C&D Recycling Facilities

Facility	Location	Roundtrip from the Facility to the County (miles)	Hauling Cost/Ton (USD)	Process
Costello Dismantling Corp.	West Wareham, MA	64 miles	$8 per ton	▪ Material Salvaging
New Bedford Waste Services, LLC	New Bedford, MA	92 miles	$10 per ton	▪ Material Salvaging
Trojan Recycling, Inc.	Brockton, MA	100 miles	$11 per ton	▪ Material Salvaging
All State Waste, LLC	Bridgewater, MA	100 miles	$11 per ton	▪ Material Salvaging
New England Recycling	Taunton, MA	120 miles	$13 per ton	▪ Material Salvaging ▪ Composting ▪ Aggregate Production
Dorrance Recycling	Norton, MA	120 miles	$13 per ton	▪ Aggregate Production
E.L. Harvey & Sons, Inc.[1]	Westborough, MA	186 miles	$21 per ton	▪ Material Salvaging
Agretech Corp.	Dracut, MA	208 miles	$22 per ton	▪ Aggregate Production
United Material Management of Millbury, LLC	Millbury, MA	206 miles	$22 per ton	▪ Material Salvaging ▪ Aggregate Production
Graniteville Materials	Westford, MA	230 miles	$24 per ton	▪ Aggregate Production
Ondrick Materials and Recycling, LLC	Chicopee, MA	296 miles	$32 per ton	▪ Aggregate Production

1) *EL Harvey was recently acquired by Waste Connections, Inc. in 2021.*

There is no “typical” conceptual design for a pre-processing platform since this is either undertaken within a large industrial recycling facility that manages many types of C&D materials or a smaller facility that manages a small number or specific C&D material types. The capital cost is dependent on the throughput capacity and location of a respective processing unit. Based on current County C&D feedstocks, the capital cost of a C&D facility could range from $23 M for an RDF production facility that manufactures pellets from the waste to be used as fuel to $30 M for a C&D materials recycling facility. This is high-level cost estimate to provide some context to building such a facility as there are many factors that affect the price.

It should be noted that this capital cost is not inclusive of any costs related to land procurement or facility operations. However, if C&D processing occurs at a facility that recovers other streams of materials, the capital costs associated with C&D processing would decrease due to economies of scale. It should also be noted that New England Recycling, a large C&D handling facility located near the Cape currently handles C&D processing for some of the towns.

2.3 TEXTILES AND CARPETS

Textiles include fabrics, clothing, rags and carpet. Textile manufacturers use extensive resources to produce textiles, including oil to produce synthetic fibers (nylon), fertilizers to grow cotton, and chemicals to produce, dye, and finish fibers and textiles. It can be difficult to recycle textiles because the material is not homogenous and difficult to separate.

Textiles are collected for reuse at organizations such as The Salvation Army, an international charitable organization. Otherwise, textiles that are not dropped off at a charitable service or a used clothing resale business often end up in landfill or incineration.

There are many options that the County could pursue for diverting textiles from landfill or incineration. Additionally, the MassDEP will add textiles to the list of banned materials for disposal starting in November 2022.

Most textile recycling operations are open-looped, meaning that the end-product is lower quality than the original fabrics. For example, clothing and carpets may be recycled into mop heads or furniture padding. Some potential diversion options are discussed in the sub-sections below.

2.3.1 Cotton Recycling

Virgin cotton is produced from the natural fibers of cotton plants. It is possible to recycle textiles made from cotton; but the current technologies available are labor-intensive and costly compared to producing virgin cotton. Ensuring a homogenous feedstock of materials is important to consider with cotton recycling as textiles are produced from a wide variety of materials.

The recycling process begins by shredding the cotton fabrics into yarn and then further shredding into raw cotton fibers. This shredding process is very harsh, putting strain on the fibers. It is common for cotton fibers to break and entangle during this process. The degraded cotton fibers can then be spun back into yarns for reuse in other products[3].

Recycled cotton is known as regenerated cotton and has reduced quality when compared to its original form. As such, regenerated cotton generally is used for lower-grade products such as insulation, mop heads and stuffing. Further, regenerated cotton generally requires the addition of other fibers in order to make a new yarn that is durable.

2.3.2 Nylon Recycling

Virgin nylon is a plastic produced from petroleum. Similar to recycling cotton, recycling nylon is an expensive process compared to producing new nylon products. Globally, there is one nylon recycling technology that dominates the marketplace, called ECONYL[4].

ECONYL is a depolymerization process that uses nylon fibers from textiles and carpet to create new nylon. Nylon is a synthetic fiber and does not degrade in quality as much when recycled. According to ECONYL, the purity of recycled nylon yarn exceeds 95%, though pre-sorting is required to ensure a homogenous feedstock.

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[3] Cottonworks. (2021). Sustainability & Recycled Cotton. Retrieved from https://www.cottonworks.com/topics/sustainability/cotton-sustainability/recycled-cotton/

[4] Papen, J. (2019). Nylon Recycling Company Announces US Acquisition. *Plastics Recycling Update.* Retrieved from https://resource-recycling.com/plastics/2019/06/12/nylon-recycling-company-announces-us-acquisition/

2.3.3 Textile Donation

Some organizations, including the Salvation Army and Baystate Textiles, collect donated clothing and footwear that have some usable life remaining. These textiles are either re-sold in second-hand stores in North America or shipped to developing countries. There is a high demand for quality clothing and footwear in developing countries.

2.3.4 Retail Take-back Programs

Some clothing and footwear manufacturers have programs for taking back their products at the end of usable life. Those brands have taken it upon themselves to operate a more sustainable brand by avoiding disposal as well as reducing the need for virgin resources. **Table 2-11** lists some brands that have take-back recycling programs for their respective products. Some stores offer customers an incentive such as discounts on new clothing purchases when bringing back used clothes for recycling.

Table 2-11: Retail Brand Take-Back Programs

Retail Brand	Take-Back Programs
Columbia Sportswear	Rethreads Program is for consumers to bring in their used clothing and shoes in clean and dry condition to participating retail stores
H&M	The Garment Collection Program is for consumers to drop a bag of unwanted clothing in the recycling box at a local participating store. The textiles are sent to the nearest recycling facility to be sorted by hand. Incentive is offered for each bag of textiles dropped off; consumers receive a 15% discount on in-store purchases.
Levi Strauss	Partners with Cotton's Blue Jeans Go Green, focused on recycling denim.
Patagonia	Worn Wear program encourages consumers to trade-in their used Patagonia clothing that is in good condition to receive credit at retail and online stores.
Uniqlo	Re.Uniqlo collects and recycles used garments worldwide for reuse in the form of emergency clothing aid for refugee camps and disaster areas, partnering with non-government organizations (NGOs).
Zappos	Zappos For Good Program is a community-focused effort, programs include donations of clothing and books, textile recycling, and an education program.
Zara	Clothing Collection Program in collaboration with local non-profit organizations, clothing is collected for reuse. Consumers can bring gentled used clothing to local retail stores.

2.3.5 Barnstable County Considerations for Recycling Textiles

In 2019, public drop-off facilities across the County collected approximately 736 tons of textiles. **Table 2-12** presents some textile recycling and transfer facilities that are in close proximity to the County. Included is the roundtrip distance from each facility to the County and the estimated cost of hauling per ton based on 2019 textile feedstocks. It is estimated that each truckload would hold up to 30 tons of textiles. The costs account for travel to and from each facility based on the average U.S. hauling cost per mile ($2.11).

Table 2-12: Nearby Textile Recycling and Transfer Facilities

Facility	Location	Roundtrip from the Facility to the County (miles)	Hauling Cost/Ton (USD)	Process
Baystate Textiles	Kingston, MA	70 miles	$5 per ton	Exports ~50% of donated clothing to developing countries
CHaRM Facility	Saugus, MA	160 miles	$12 per ton	Textiles Recycling
Conigliaro Industries	Framingham, MA	180 miles	$13 per ton	Carpet Recycling
Millbury Textile Recycling	Worcester, MA	210 miles	$15 per ton	Conversion of non-woven textiles into low-grade products.
Aquafil O'Mara	Rutherford College, NC	1,780 miles	$127 per ton	ECONYL Nylon Recycling
Aquafil USA	Cartersville, GA	2,258 miles	$158 per ton	ECONYL Nylon Recycling

The capital and operating costs of developing and operating a textile recycling facility to process the feedstocks from the Cape and Islands exclusively (736 tons in 2019) is cost prohibitive. As an example, the capital cost of Aquifil's Phoenix facility for carpet recovery amounted to over $10 M with 17,500 tons of annual processing capacity (over $550 per ton based on one year's feedstock)[5]. Economies of scale would suggest that a small textile processing facility would likely be more expensive on a per ton basis.

2.4 MATTRESSES

The mattress recycling stream includes all mattresses (futons and foam) and box springs. An estimated 12,518 mattresses (approximately 630 tons) were collected from fourteen Cape town transfer stations in 2019.

The Town of Bourne reported the total volume of mattresses collected at the transfer station was 137 tons in 2019. Nantucket reported mattress collected at the transfer station was 36 tons in 2019. Martha's Vineyard did not provide information. Based on the reported data, a total estimate of mattresses collected from the Cape town transfer stations and Nantucket Island was 803 tons in 2019.

Mattress recycling typically involves cutting, dismantling and separation of the individual components. Foam padding can be shredded and recycled into low-grade textiles such as pet bedding, insulation or furniture padding. The mattress springs can be salvaged for scrap metal. The wooden frames of the mattresses can be shredded and reduced to chips.

California, Connecticut, and Rhode Island have passed regulations that ban the disposal of mattresses in landfill. In these states, mattress recycling is supervised by the Mattress Recycling Council[6]. Massachusetts will implement a similar regulation in November 2022.

2.4.1 Barnstable County Considerations for Mattress Recycling

Table 2-13 presents some mattress recycling facilities that are in close proximity to Barnstable County. Included is the roundtrip distance from each recycling facility to the County as well as the estimated annual cost of hauling

[5] Aquifil. (2017). How facility will recover nylon 6 from carpet. Retrieved from https://www.aquafil.com/newsmedia/how-facility-will-recover-nylon-6-from-carpet/

[6] Mattress Recycling Council. (n.d.). Who we are? Retrieved from https://mattressrecyclingcouncil.org/who-we-are/

based on 2019 mattress feedstocks. It is estimated that each truckload can hold approximately 83 mattresses. The costs account for travel to and from each facility based on the average U.S. hauling cost per mile ($2.11) and based on the following assumptions:

- Mattresses are queen sized (60" x 80" x 24") as a margin of safety
- Trailer dimensions are 53' x 8.5' x 13.5'
- There is extra room in each dimension as an additional safety factor (length 3', width 0.5', height 0.5')

Table 2-13: Nearby Mattress Recycling Facilities

Facility	Location	Roundtrip from the Facility to the County (miles)	Hauling Cost/Mattress (USD)
Daniels Recycling	Orleans, MA	40 miles	$1
UTEC Mattress Recycling	Lawrence, MA	200 miles	$5
Ace Mattresses Enterprises LLC	West Warwick, RI	200 miles	$5
Superior Waste and Recycling	Worcester, MA	220 miles	$6
Gold Circuit E-Cycling	Palmer, MA	280 miles	$7
Valley Recycling	Northampton, MA	350 miles	$9

The capital cost of developing a mattress recycling facility to process the feedstocks from the Barnstable County fourteen town transfer stations exclusively (12,518 mattresses in 2019) is difficult to estimate. Mattress recycling is largely a manual process that does not require complex machinery. Thus, there is a potential opportunity to scale mattress recycling operations down to accommodate the current County mattress feedstocks. Metals, wood, fabric, and foam components are generally separated by hand and distributed to their respective end markets[7].

2.5 BULKY ITEMS

Bulky items as a waste stream includes a variety of materials, including couches, chairs, tables, large rigid plastics (including lawn furniture) and tool cases. In 2019, 1,562 bulky item units were collected at the Barnstable County fifteen town transfer stations. The 2019 reported bulky item units did not include the Island transfer stations.

As the bulky item category is very broad, there is no one way to recycle it all. Furniture, such as couches or chairs can be deconstructed in a similar fashion to mattresses. Foam, wood, and fabric can all be separated out and recycled separately. As for large rigid plastics, such as lawn furniture, these can potentially be melted or shredded to be recycled into lower grade plastic pellets for reuse.

2.5.1 Barnstable County Considerations for Recycling Bulky Items

Assuming that the average bulky item weighed 100 lbs[8], approximately 78.1 tons of bulky items were collected at transfer stations in Barnstable County. (There was no data on bulky items reported from the Islands.) This assumption is based on the approximate weight of a 2-cushion couch. The average bulky item will likely weigh less than 100 lbs, so this number was used as a safety factor.

Table 2-14 presents some bulky item recycling facilities that are in close proximity to the County. The table also includes the roundtrip distance from each facility to the County as well as the estimated annual cost of hauling based

[7] The Canadian Coalition for Green Health Care. (n.d). Mattresses. Retrieved from https://greenhealthcare.ca/waste/mattresses/
[8] What things weigh. (n.d.). Weight of a couch. Retrieved from https://whatthingsweigh.com/how-much-does-a-couch-weigh/

on the average U.S. trucking cost per mile ($2.11) and 2019 bulky item feedstocks. It is assumed that each truckload could hold up to 15 tons of bulky items. The costs account for roundtrip transportation from each recycling facility.

Table 2-14: Nearby Bulky Item Recycling Facilities

Facility	Location	Roundtrip from the Facility to the County (miles)	Hauling Cost/Ton (USD)
CHaRM Facility	Saugus, MA	180 miles	$25
Gold Circuit E-Cycling	Palmer, MA	264 miles	$37
Valley Recycling	Northampton, MA	324 miles	$46

2.6 ELECTRONIC WASTE

Electronic waste includes items such as computers, TVs and printers. In 2019, 10,006 electronic units were collected at the fifteen municipal transfer stations across the County. Nantucket reported 36 tons of electronic waste recycled at the town transfer station in 2019.

The recycling of electronics involves breaking the units down into their individual components. Some components may require manual separation from the electronic waste unit, such as with circuit boards and cords. Other components are generally broken down and separated via mechanical processes.

2.6.1 Barnstable County Considerations for Recycling Electronic Waste

Table 2-15 presents some electronic waste recycling facilities that are in close proximity to the County. The table includes the roundtrip distance from each facility to the County as well as the estimated annual cost of hauling based on the average U.S. trucking cost per mile ($2.11) and 2019 electronic waste feedstocks. It is assumed that the average electronic waste unit weighs 20 lbs and that each truckload can hold 15 tons of electronic waste. The costs account for travel to and from each facility.

Table 2-15: Nearby Electronic Waste Facilities

Facility	Location	Roundtrip from the Facility to the County (miles)	Hauling Cost/Ton (USD)
Electronic Recycling International	Holliston, MA	160 miles	$23 per ton
CHaRM Facility	Saugus, MA	180 miles	$25 per ton
Gold Circuit E-Cycling	Palmer, MA	264 miles	$37 per ton
Zeep	South Hadley, MA	300 miles	$45 per ton
Valley Recycling	Northampton, MA	324 miles	$48 per ton

Eco-Cycle/CHaRM in Boulder, Colorado recycles electronic waste onsite through a program with Blue Star Recyclers[9], a company that employs people with autism and other disabilities in Colorado. Employees are trained as recycling technicians to disassemble electronics inside a retrofitted warehouse located at the CHaRM. With

[9] http://bluestarrecyclers.org/

electronics recycled onsite, the CHaRM can provide a chain of custody and is certified to the e-Stewards standard. The e-Stewards Standard[10] is a North American initiative aimed to make progress in establishing and ensuring e-waste recycling best practices.

2.7 WHITE GOODS

White goods, or large appliances, is inclusive of stoves, refrigerators, ovens, dishwashers, washing machines and dryers. In 2019, 5,578 white good units were collected at transfer stations across the County. White goods are predominantly made of metals that can be salvaged and sold back into the commodities market. White goods that contained compressed gases *(e.g., refrigerators, air conditioners, etc*.) require purging before the metal can be salvaged.

2.7.1 Barnstable County Considerations For Recycling White Goods

Table 2-16 presents some white goods recycling facilities that are in close proximity to the County. The table includes the roundtrip distance from each facility to the County as well as the estimated annual cost of hauling based on the average U.S. trucking cost per mile ($2.11) and 2019 white goods feedstocks. It is estimated that each white good unit weighs 100 lbs and each truckload could hold 15 tons of white goods. The costs account for travel to and from each facility.

Table 2-16: Nearby White Goods Recycling Facilities

Facility	Location	Roundtrip from the Facility to the County (miles)	Hauling Cost/Ton (USD)
Electronic Recycling International	Holliston, MA	160 miles	$23 per ton
Gold Circuit E-Cycling	Palmer, MA	264 miles	$39 per ton

As an example, the capital cost for the Athens, Georgia CHaRM Facility was estimated at $187,000 in 2015. This does not include the costs for site improvement capital costs, land improvement and operations. Athens-Clarke County

The Athens-Clarke County operation could be used as a potential baseline cost estimate for the County should it consider a white goods recycling facility.

2.8 TIRES

The tire waste stream consists of tires from cars, bikes, motorcycles, trucks and heavy machinery. In 2019, the fifteen town transfer stations across the County collected 10,933 tires *(approximately 164 tons).*

End-of-life tires are collected from points of generation *(e.g., retailers, etc.)* and transferred to designated collection sites such as transfer stations and drop-off centers. The tires are then hauled to tire recycling facilities. Typically, up to 90% of the tires are recycled into mulch, rubber crumb, and construction aggregate which are recycled into molded rubber goods or rubber flooring. The residual components of the process are textiles (also known as tire fluff), and small amounts of metal. Alternatively, tires can be recycled into tire derived fuel (TDF). TDF has a high

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[10] https://e-stewards.org/

BTU value and can often be used as fuel in industrial boilers (pulp mills, cement kilns, etc.) with adequate environmental controls.

2.8.1 Barnstable County Considerations for Recycling Tires

Table 2-17 presents some tire recycling facilities that are in close proximity to the County. Included is the roundtrip distance from each facility to the County as well as the estimated annual cost of hauling based on the average U.S. trucking cost per mile ($2.11) and the 2019 tire feedstocks. It is estimated that each truckload would hold 15 tons of tires (assuming 30 lbs per average tire). Presented costs account for travel to and from each facility.

Table 2-17: Nearby Tire Recycling Facilities

Facility	Location	Roundtrip from the Facility to the County (miles)	Hauling Cost/Ton (USD)
Bob's Tire Co.	New Bedford, MA	100 miles	$14 per ton
FBS Tire Recycling	Ayer, MA	229 miles	$31 per ton
Valley Recycling	Northampton, MA	324 miles	$48 per ton

According to Environmental Waste International, the capital cost to construct a tire processing facility typically ranges from $8 M to $20 M depending on location and feedstock quantities[11]. The number of tires dropped off at the fifteen municipal Town Transfer Stations (10,933 in 2019) is likely too low to be economically practical without significant additional feedstocks.

2.9 UNIVERSAL WASTE

Universal waste as a waste stream inclusive of household batteries, electric vehicle (EV) batteries, propane tanks, fire extinguishers, compact fluorescent lamps (CFLs) and aerosol cans. In 2019, the fifteen municipal transfer stations collected 143 tons of universal waste.

2.9.1 Propane Containers and Fire Extinguishers

Some types of fire extinguishers can be recharged as an alternative to recycling. At their end of life, some stores or manufacturers will accept fire extinguishers for a fee. In some instances, fire stations will also accept fire extinguishers for safe recycling.

Propane containers and fire extinguishers are generally made of recyclable metal. However, many metal recyclers typically accept these materials when their pressurized contents have been removed. So, propane containers and fire extinguishers are depressurized prior to their recycling as scrap metals.

[11] Environmental Waste International. (n.d.). EWI Systems. Retrieved from https://www.ewi.ca/tires-process.html

2.9.2 Batteries

Batteries are inclusive of lead acid batteries, lithium-ion batteries, alkaline batteries and nickel metal hydride batteries. Batteries can be dropped off at over 400 retailers across Massachusetts, in addition to most municipal transfer stations[12].

While the components across the battery types may vary, most components have value and can be recovered. Most battery recycling processes include a mechanical process (shredding, cutting, etc.) and a pyrometallurgical process (smelting, pyrolysis, etc.). Materials such as nickel, manganese and cobalt can be precipitated out and introduced back into the commodities market.

2.9.3 Compact Fluorescent Lamps

Massachusetts Department of Environmental Protection (MassDEP) prohibits mercury-containing lamps from being discarded in landfills. *(Chapter 190 of the Acts of 2006 as amended by Chapter 196 of the Acts of 2014 and 310 CMR 75.00 – Collection and Recycling of Mercury-Added Products.)*

EPA recommends for consumers to consider local options for recycling Compact Fluorescent Lamps (CFLs), and not dispose CFLs in the waste stream or curbside recycling bins. Local recycling programs include the Home Depot Stores or with qualified recyclers. CFLs typically contain 4 milligrams (mg) of mercury, a household hazardous waste. As long as the CFL bulb is intact, the mercury is safely contained inside the bulb or tube for proper recycling. Mercury (Hg) is a naturally occurring metallic element toxic to people and wildlife.

CFLs can be shredded and separated into its individual components. The glass can be converted to aggregate materials, the metals can be salvaged, and the mercury can be distilled back into its elemental form[13].

2.9.4 Mercury Containing Products

Mercury containing products include thermostats, manometers (analog or digital instrument to measure pressure), switches, water meters, thermometers, and gauges. Massachusetts has a collection program for mercury containing thermostats paid for by Covanta and Wheelabrator (now WIN Solutions). This collection program is part of the Mass Save energy efficiency installation and weatherization program, funded by a coalition of utility companies. The Mass Save energy efficiency program has the potential to extract substantial mercury thermostats for recycling, allowing Massachusetts to capture one of the last reservoirs of mercury still in service. For more information regarding state regulations on the disposal of mercury-containing thermostats, visit Thermostat Recycling.

Mercury containing products are highly recyclable, as it can be distilled back into its elemental form and directed back into the commodities market. Other components, namely plastic and metal, can also be recycled.

2.9.5 Barnstable County Considerations for Recycling Universal Waste

Table 2-18 presents some universal waste recycling facilities that are in close proximity to the County. Included is the roundtrip distance from each facility to the County based on the average U.S. trucking cost per mile ($2.11) cost of hauling and in 2019 universal waste feedstocks. It is estimated that each truckload can hold 30 tons of universal wastes. The presented costs account for travel to and from each facility.

[12] Commonwealth of Massachusetts Executive Office of Energy & Environmental Affairs – Department of Environmental Protection. (n.d.). Guide to Safely Managing Hazardous Household Products. Retrieved from https://www.mass.gov/doc/guide-to-safely-managing-hazardous-household-products/download

[13] Product Care Recycling. (n.d.). Light Recycling. Retrieved from https://www.productcare.org/products/lights/?utm_campaign=efc

Table 2-18: Nearby Universal Waste Recycling Facilities

Facility	Location	Roundtrip from the Facility to the County (miles)	Hauling Cost/Ton (USD)	Accepted Materials
Tradebe Stoughton	Stoughton, MA	130 miles	$10 per ton	Batteries Electronics Mercury-Containing Products
Electronic Recycling International	Holliston, MA	164 miles	$12 per ton	CFLs
Battery Resourcers	Worcester, MA	210 miles	$16 per ton	Batteries
Gold Circuit E-Cycling	Palmer, MA	280 miles	$21 per ton	CFLs Batteries
Valley Recycling	Northampton, MA	324 miles	$25 per ton	Propane Tanks
Bethlehem Apparatus	Hellertown, PA	680 miles	$50 per ton	Mercury Products
Inmetco	Ellwood City, PA	1300 miles	$96 per ton	Batteries
Battery Solutions	Wixom, MI	1620 miles	$119 per ton	Batteries

As universal waste encompasses a wide variety of materials, there are several different processing options and techniques that could be utilized. In most cases, universal waste processing only makes up a portion of a much larger processing facility. Battery recycling facilities use very specialized and expensive equipment. Unless additional battery feedstocks are secured, it likely does not make economic sense to process Barnstable County's battery feedstocks.

3.0 CONCLUSIONS

The solid waste and recycling industry is dynamic. Individual towns will see cost for managing recyclable and hard to dispose materials increase. However working together as a Diversion Collaborative or a collective approach, the participating municipalities would be in a better position for markets.

To advance toward resiliency and longer-term waste diversion options, the County could work with Cape and Islands towns to identify options to collaborate on MSW aggregation, processing and diversion.

As stated in Task 1 and Task 3, the two areas of greatest opportunity for the County are to increase recycling and reuse with C&D materials and organics (food materials and yard waste) because they represent the highest quantity by weight as material categories in the waste stream.

With C&D materials, there is no "typical" conceptual design for a pre-processing platform since this is either undertaken within a large industrial recycling facility that manages many types of C&D materials or a smaller facility that manages a small number of C&D material types.

Capital costs are dependent on the throughput capacity and location of a respective processing unit. Based on current County C&D feedstocks, the capital cost of a C&D facility could range from $23 M (RDF production facility) to $30 M (C&D materials recycling facility). It should be noted that this capital cost is not inclusive of any costs related to land procurement or facility operations. However, if C&D processing occurs at a facility that recovers other streams of materials, the capital costs associated with C&D processing would decrease due to economies of scale.

There is potential for a regional C&D recycling facility that could be sited within the County, for example at the JBCC. However, since New England Recycling (NER) is located in Taunton, a recommendation is to further develop the County's relationship with NER due to their close proximity and the large volume they can manage. In addition, based on our interviews with NER, they seem to be open to beneficial reuse and recycling BU end-markets that could go beyond the typical and align with the County's beneficial use definition. For example, processing C&D residuals for use as fuel for cement kilns as opposed to sending the residuals to landfill.

Based on current County organic waste feedstocks (yard waste, food material and compostable papers) that are collected at the fifteen town transfer stations, it is estimated that the capital cost of an organics management facility would range from $15 M to $50 M dependent on the processing technology. This cost is not inclusive of any costs related to land procurement or facility operations. There is potential for developing a County-wide organics management facility that could be sited within the County, for example at the JBCC.

The County and its member towns should seek ways to reduce the transportation of organic materials and finished compost by managing these materials locally. A recommendation for the County is to consider a County-wide organics management program that would encourage both residents and businesses to source separate organics, including all food materials and yard debris, to be managed locally on the Cape. The County-wide approach to organics management would also encourage residents, businesses, and seasonal individuals to buy locally produced compost for use on gardens, lawns, and landscaping. This could be a Cape-wide opportunity to develop a closed loop system for organics material management.

The paradigm for materials management continues to evolve as markets shift and new technologies become available, allowing local and regional entities to realize a larger fraction of value from resources that are discarded, bringing municipalities toward a more circular infrastructure and economy.