CONSTRUCTION AND DEMOLITION END MARKET DEVELOPMENT REPORT 2019

For the Pollution Prevention Advisory Board and the Colorado Department of Public Health & Environment

Prepared by Recycle Colorado

Table of Contents

Key Terms v

Executive Summary vi

Introduction 1

Purpose 1

PART I - OVERVIEW OF TASKS AND METHODOLOGY 3

1. Create a list of C&D materials 3

2. Rank materials by importance based on economic value of diversion and input received during C&D Council meetings 3

    3. Identify top five materials by rank 3

    4. Produce a materials summary for each of the top five materials 4

    4.1 Statewide volume calculation 4

    4.2 Summary of available processing or manufacturing options 5

5. Develop a plan to bring end markets to Colorado 5

6. Recommendations for the Recycling Resources Economic Opportunity grant program 6

7. Recommend next steps for the C&D Council 6

PART II – MATERIALS RESEARCH 7

SECTION 1 - Gypsum wallboard 7

1. Statewide material volume 7

    1.1 Diversion rate 8

2. Recovery process 8

    2.1 Special consideration: asbestos 9

    2.2 Collection 9

    2.3 Processing 9

3. Summary of available markets 11

    3.1 Reuse 11

    3.2 Recycling 11

    3.3 Land Application 14

    3.4 Other Known Applications 16

    3.5 Exploratory Solutions 17

4. Plan to bring end markets to Colorado 18

    4.1 Description of status of existing market including current and near-future capacity or demand 19

    4.2 Market trends 19

    4.3 Market development opportunities 19

4.4 Challenges and barriers 24
Additional Resources 26
SECTION 2 - Treated wood 27
1. Statewide material volume 28
1.1 Diversion rate 28
2. Recovery process 28
2.1 Collection 28
2.2 Processing 29
3. Summary of available markets and processing options 30
3.1 Reuse 30
3.2 Recycling 31
3.3 Energy recovery 32
3.4 Other strategies 33
4. Plan to bring end markets to Colorado 33
4.1 Description of status of existing market including current and near-future capacity or demand 34
4.2 Market trends 34
4.3 Market development opportunities 34
Additional Resources 39
SECTION 3 - Reclaimed asphalt shingles (RAS) 40
1. Statewide material volume 40
1.1 Diversion rate 41
2. Recovery process 41
2.1 Collection 41
2.2 Processing 41
2.3 Asbestos 43
3. Summary of available manufacturing or processing options 43
3.1 Recycling 43
3.3 Exploratory solutions 47
3.4 History of RAS use in CO 47
4. Plan to bring end markets to Colorado 48
4.1 Description of status of existing market including current and near-future capacity or demand. 49
4.2 Market trends 49
4.3 End market development opportunities 49
4.4 Surveying attitudes of RAS use in the Colorado paving industry 53

SECTION 4 - Carpet tiles 55
1. Statewide material volume 55
1.1 Diversion rate 55
2. Recovery process 56
2.1 Collection & sorting infrastructure 56
2.2 Carpet America Recovery Effort (CARE) 57
2. Summary of available processing or manufacturing options 59
3.1 Reuse 59
3.2 Chemical recycling 59
3.3 Mechanical Recycling 60
3.4 Waste to energy 61
3.5 Other end markets 61
4. Plan to bring end markets to Colorado 61
4.1 Description of status of existing market including current and near-future capacity or demand 61
4.2 Market trends 61
4.3 Market development opportunities 62
Additional Resources 66
SECTION 5 - Plastics 67
1. Statewide material volume 67
1.1 Diversion rate 68
2. Recovery process 68
2.1 Collection 68
2.2 Processing 69
3. Summary of available processing or manufacturing options 69
3.1 PVC 69
3.2 HDPE/LDPE 71
3.3 Expanded Polystyrene (EPS) 72
3.4 Characterizing Colorado's potential end users 72
4. Plan to bring end markets to Colorado 72
4.1 Description of status of existing market including current and near-future capacity or demand. 73
4.2 Market trends 74
4.3 Market development opportunities 74
Additional Resources 78

PART III – RECOMMENDATIONS FOR THE RECYCLING RESOURCES ECONOMIC OPPORTUNITY GRANT PROGRAM 79
1. Market development for specific materials 79
2. Strategic outreach for C&D infrastructure and market development 79
3. Leverage grant dollars for C&D research and development 79
4. C&D-specific end market and infrastructure grant funding 80
5. Regional study grants 80
6. Potential actions to support C&D for other agencies 80
6.1 C&D recycling market directory 80
6.2 Partnership development 81
6.3 C&D market development coordinator 81
PART IV – NEXT STEPS FOR THE C&D COUNCIL 82
Appendix 84
Appendix A: Names, professional title and affiliation of everyone participating on the C&D Council 84
Appendix B: Sources contacted in researching this study 86
Appendix C: C&D materials ranked by value 88
End Notes 89

List of Tables and Figures

Table A: Total C&D waste generation estimates by region 2016 – 2036 (Colorado ISWMMP Appendix G, 2016) 4
Table B: Clean wallboard as a percentage of total C&D (Colorado ISWMMP Appendix G, 2016) 4
Table C: Example clean drywall generation estimates by region in 2016, 2019, 2021, 2026 and 2036 (extrapolated from Colorado ISWMP Appendix G, 2016) 5
Table 1: Clean and contaminated wallboard as a percent of total C&D 7
Table 2: Clean wallboard generation estimates by region in 2016, 2019, 2021, 2026 and 2036 7
Table 3: Painted wallboard generation estimates by region in 2016, 2019, 2021, 2026 and 2036 8
Figure 1: Flow Diagram for a Typical Wallboard Recovery Facility that Receives Segregated Wallboard and Produces Gypsum Powder 10
Table 4: Market specifications for recycled gypsum wallboard 10
Figure 2: GreenZip technology diagram 18
Table 5: Wallboard processing equipment needs 22
Table 6: Representative preserved wood products 27
Table 7: Treated wood as a percent of total C&D 28
Table 8: Treated wood generation estimates by region in 2016, 2019, 2021, 2026 and 2036 28
Figure 2: Products manufactured using CCA treated wood 30
Table 9: Tangible products from reused CCA-treated wood 31

Figure 3: Example of a mixed wood sorting facility accepting vegetative wood, source separated C&D wood, and wood waste commingled with other C&D materials 35
Table 10: Treated wood processing equipment costs 36
Table 11: Treated wood sorting cost calculation with updated input costs 36
Table 12: Asphalt shingle generation estimates by region in 2016, 2019, 2021, 2026 and 2036 40
Figure 4: Typical asphalt shingle recovery facility process 42
Figure 5: What limits RAS use in your state survey 44
Table 13: Shingle processing equipment needs 51
Table 14: Carpet as a percent of total C&D 55
Table 15: Carpet generation estimates by region in 2016, 2019, 2021, 2026 and 2036 (extrapolated from Colorado ISWMMP Appendix G, 2016 and Gracestone, Inc. et al., 2009) ... 55
Table 16: Carpet processing equipment needs 63
Table 17: Plastic applications in construction 67
Table 18: Plastic as a percent of total C&D 67
Table 19: Plastic generation estimates by region in 2016, 2019, 2021, 2026 and 2036 68
Figure 7: Recycling flows for PVC products 70
Table 19: Equipment used by existing processors 75

Key Terms

BTU – British Thermal Unit, a standard measurement of heat content of fuels or energy sources

C&D – Construction and demolition

C&D Council – Recycle Colorado's C&D subject matter council

CDPHE – the Colorado Department of Public Health & Environment

HDPE – High density polyethylene

HMA – Hot mix asphalt

LDPE – Low density polyethylene

LEED – Leadership in Energy and Environmental Design

PCR – Post-consumer recycled

PP – Polypropylene

PPAB – Pollution Prevention Advisory Board

PRF – Plastic recycling facility

RAP – Reclaimed asphalt pavement

RAS – Reclaimed asphalt shingles

RREO – Recycling Resources Economic Opportunity grant program

Executive Summary

Recycle Colorado (formerly Colorado Association for Recycling) is a registered 501(c)(3) nonprofit organization. It is an action-oriented and member-driven organization that works on projects that are tangible, actionable and measurable related to infrastructure and end markets for material recovery, reuse and manufacturing. Recycle Colorado also works to advance both local and state policy that supports keeping valuable material resources out of our landfills. Recycle Colorado received grant funding through the Recycling Resources Economic Opportunity program in 2019 to produce the Construction and Demolition End Market Development Report.

I. Purpose

The purpose of this report is to identify and rank by economic value all of the major materials moving through construction and demolition (C&D) projects and identify potential end markets that can be established in Colorado for the top five materials that do not already have a Colorado market. It builds on previous research conducted by the CDPHE and other entities in Colorado that analyzed market challenges for C&D materials. It is intended for use as a decision-making support tool for Colorado's Pollution Prevention Advisory Board ("PPAB") and Front Range Waste Diversion ("FRWD") Enterprise Fund Board of Directors to aid in allocating funds through the Recycling Resources Economic Opportunity ("RREO") Grant Fund and FRWD Enterprise Fund. Contents of the report may also be valuable for local, regional and state waste managers to better understand conditions for improving recovery of C&D materials in Colorado.

It is the first step towards a more strategic market development initiative at the state level to expand access to Colorado-based markets for recyclable C&D debris generated in the state. It provides research that helps identify opportunities to increase waste diversion and will lead to additional diversion infrastructure and attract end-markets and other businesses to Colorado.

II. Research components

In partnership with Recycle Colorado, a research design and outline was developed by the CDPHE to guide the research.

The project consisted of five major components:

1. Compile a list of C&D materials by communicating with C&D Council members, landfill operators, contractors, material haulers and other states
2. Rank materials by importance based on
    a. Economic value of diversion
    b. Input received from C&D Council
3. Identify end market opportunities for the top five materials by rank identified in C&D Council meetings and by researching:
    a. Statewide material volume
    b. Available processing or manufacturing options
    c. Site criteria necessary for a processor or manufacturer to locate in Colorado
    d. Plan to bring end markets to Colorado
4. Develop recommendations for the Recycling Resources Economic Opportunity grant program.
5. Recommend next steps for Recycle Colorado's C&D Council

III. Materials research findings

The five materials selected for developing end market recommendations in the report are gypsum wallboard, treated wood, asphalt shingles, plastics and carpet tile. Each numbered item under the bolded headings summarize the main findings for each material and the potential steps Colorado can take to develop local end markets or utilize existing markets in other states. The full findings are found under PART II – Materials Research.

Gypsum wallboard

The wallboard recycling recommendations described here focus on clean scrap material generated on construction sites and not post-consumer material removed during renovations or demolitions. For current end markets, wallboard that is contaminated in any way poses challenges for recycling and diminishes the quality of the final recycled product. Until end markets emerge that can handle post-consumer wallboard, it is recommended that Colorado focus on clean scrap material.

The primary markets for this material are:

- Agricultural – Gypsum soil amendment and gypsum/paper as a compost additive
- Industrial – Gypsum use in new wallboard or Portland cement

The potential market development opportunities based on available processes and what would work best for Colorado are:

1. **Further research needed on agricultural markets**

Learnings from the various soil experts described in Gypsum Wallboard Section 3.3.2 suggests there would be validity to further exploring land application of gypsum as a direct soil amendment and/or as a compost additive for end market development.

Option 1 - Wallboard as a compost additive

Two of three commercial composting facilities contacted during this project accept small amounts of clean scrap wallboard as a compost additive and bulking agent. A1 Organics accepts material because the current quantity accepted doesn't impact the aesthetic look or chemical composition of their end product and Renewable Fiber, Inc. uses the gypsum to neutralize pH and also contended that some of their agricultural customers in Weld County commonly use gypsum. The proposed solution for this market would be to conduct further research into the potential benefits of adding wallboard to compost.

Option 2 - Gypsum as a soil amendment

Research is needed to identify agricultural areas with the right conditions where the addition of gypsum would provide soil benefit and determine if growers use it in practice to define the potential customer base. A recommended strategy is to coordinate with the CSU College of Agricultural Sciences as well as CSU Extension offices located in each county. Extension offices are said to work more closely with local growers and have better knowledge of their practices. Hemp growers were specifically cited as a group that uses gypsum so targeted outreach may be done to see if that is a potential market. A study could be done in partnership with researchers before any investments in equipment are made to determine if market development activities should continue.

2. **Wallboard collection and processing for gypsum use in new products**

A minimum level of processing will be required to prepare material for end markets, especially if targeting industrial applications.

While the economic viability is questionable considering low landfill tipping fees in the state, relatively low prices for virgin gypsum, and potentially insufficient volumes of collected material due to Colorado's population size, a wallboard recycling operation could theoretically produce gypsum powder of high enough purity to be used in industrial applications like new wallboard and cement production. First, a reliable market for the material should be confirmed before recycling infrastructure is developed.

Under one scenario, researchers in a previous study found that it was possible to process drywall at a landfill using a front loader and trommel screen to prepare the material for market applications in agriculture, Portland cement and new wallboard. Their calculated processing capacity was just over 20 tons/hour which equated to over 40,000 tons of diverted material per year.

3. **Alternative building materials**

Due to the difficulties with end of life management of wallboard, Colorado could look to promote the development and application of alternative building materials.

Option 1 – Support development and use of alternative building materials

One alternative building product developed in the EU and commercialized in the US is ReWall, a type of wallboard made of post-consumer recycled carton. The company was awarded an RREO grant in 2018 to help fund the construction of a facility but the project was dropped and grant rescinded. In addition, GreenZip wallboard tape allows for deinstallation and reuse of wallboard panels. While these are not technically "end markets," state agencies could potentially begin promoting the use of alternative materials through environmentally preferable purchasing standards.

Option 2 – Create gypsum bricks/blocks out of wallboard waste

Various gypsum blocks and bricks have been developed from wallboard waste that use different binders worldwide. Through conversations with Washington State University researchers, ASTM and building code testing take a significant length of time for materials that will be used for structural purposes. As such, developing applications for gypsum blocks that are non-structural would potentially be a more viable market and one that can be applied in the more immediate future.

Treated wood

There is limited diversion of treated wood from construction applications taking place today. When diverted, the primary method is through energy recovery at biomass facilities.

1. **Characterizing the wood waste stream**

A first step towards developing end markets is acquiring better data about which types of treated wood are present in the C&D waste stream in Colorado. Better information will help in form appropriate end market development since some materials are more appropriate for diversion than others. For example, the states that allow combustion of treated wood typically require as part of regulatory permit conditions that CCA-treated wood be separated and managed distinctly from other mixed woods.

2. Mixed wood waste sorting feasibility

It is uneconomical for generators to source separate treated wood so it would be of interest to evaluate whether the material can be sorted from mixed wood waste loads. According to one study, it was technically feasible for laborers to separate treated wood from mixed wood waste through visual means and aided by testing equipment, although the most reliable method for identifying treated wood required 9 laborer hours per ton of material.

3. R&D in new technologies

New energy recovery technologies like pyrolysis and gasification could convert treated wood into usable secondary products as long as pollution controls are followed and research is also being done into processes to extract chemical preservatives from treated wood to allow for other diversion methods for the wood fraction.

4. Promote case-by-case reuse

The potential for upcycling into value added products like art or furniture pieces from treated wood (a material with no present value) should not be overlooked. As cited previously, contractors pursuing aggressive waste diversion efforts in construction projects in Colorado have successfully identified outlets for donating treated wood. Since the economics of establishing new infrastructure or markets specifically for treated wood other than for energy recovery are challenging, one option could be to promote and support case-by-case uses of reusable treated wood from construction and renovation activities.

Reclaimed asphalt shingles (RAS)

The greatest market opportunity remains using reclaimed asphalt shingles (RAS) in paving applications as evidenced by numerous other states. Due to problematic market development in the past, The CDPHE determined asphalt shingles are not “recyclable” in the state of Colorado. A total of 7.8 million tons of HMA/WMA was estimated to be produced in Colorado in 2018. If 5% RAS was used in all projects, the theoretical demand for RAS would be 390,000 tons. Paving activities ebb and flow based on macroeconomic trends so this potential demand would change year to year, however this could be a significant market if initiative is taken to resurrect RAS recycling in the state.

1. Establish best practices and market demand for RAS use in HMA

Pilot testing done by various actors in Colorado found mixed results for pavement quality when the market first began to emerge. It was suggested that if mixes are prepared according to proper specifications using RAS they will perform as well or better than traditional mixes and at reduced cost. A potential phased approach to market development would consist of cultivating buy-in from key partners like generators, a disposal site and end users, creating a pilot project, marketing correct specifications for RAS use, creating safeguards for and slow rollout of additional projects. The core of this recommendation revolves around educating private, municipal, county and state users on correct implementation.

1a. Survey attitudes of RAS use in CO paving industry

A general takeaway from the research is the lack of consensus in the industry in Colorado on the quality of using RAS in paving applications. RAS is used heavily in hot mix asphalt applications in other parts of the country, but conflicting opinions and conflicting scientific evidence were raised on its appropriateness in Colorado. It would be beneficial to understand where our industry stands as a whole to assess whether it would be worthwhile to put more energy into RAS end market development. As the state-level affiliate of the National Asphalt

Pavement Association, the Colorado Asphalt Pavement Association could be a valuable partner to help carry out this initiative.

2. Explore asphalt shingle processing capability

Scalability of this activity is conditional on whether RAS can be produced economically and if markets are developed first. A processing pilot would have to begin at an existing permitted solid waste facility and demand for the material must already be secured to make it worthwhile to process RAS. In 2009, Asphalt Specialties Company, Inc reported diverting over 50,000 tons of manufacturer scrap asphalt shingles from landfill. They started by partnering with Owens Corning to process their manufacturing scrap, eventually transitioning to accept tear-off materials as well. They utilized a space at the Denver Arapaho Disposal Site (DADS) to perform the grinding operation and a representative said the partnership worked well.

According to a CDRA guidance document, the necessary equipment for processing is a grinder and loader or excavator to feed it and cites a range of 40 to 100 tons per hour processing capacity.

Carpet tile

Carpet tile made of Nylon face fiber and PVC backing material are virtually the only demanded carpet for recycling activities, while other materials are typically destined for energy recovery if diverted. Colorado has three companies that deal in carpet tiles but do not take in large quantities. At least one company recycles material through Carpet America Recovery Effort's (CARE) Voluntary Product Stewardship Program.

1. Carpet collection and sorting

It may not be realistic to locate actual end markets (mechanical or chemical recycling processing described above) for recovered carpet in the state of Colorado because the vast majority of recycling takes place in large facilities owned and operated by carpet manufacturers in more densely populated parts of the country. As such, the most viable opportunity and first step for Colorado may be to establish a carpet collection and sorting facility that brings in all types of carpet materials. The core process for such an operation would be to:

- Partner with CARE to access transportation network, VPS program funding, and other resources
- Secure incoming feedstock by partnering with and marketing to carpet installers
- Develop processing and diversion strategy

2. Extended producer responsibility (EPR)

Carpet collection and sorting in the absence of regulation and incentives is economically challenging and provides only small marginal profits. California mandated EPR with CARE as the lead administrator but has had challenges achieving results. At the time of writing, other states Minnesota, Illinois and New York are discussing the feasibility of their own EPR legislation for carpet materials. Policymakers in Colorado may be prioritizing EPR and other policies materials management goals, however learnings from other states could be looked to as models in the future. EPR legislation of any kind is of course contentious but in the case of carpet, the economics do not appear to favor purely market-driven recovery efforts.

Plastics

Plastics are a diverse category of materials whose applications and end of life management practices can vary significantly, but the major plastic types observed in construction are rigid polyvinyl chloride (PVC), high density polyethylene (HDPE) film, low-density polyethylene (LDPE) stretch plastic film and expanded polystyrene (EPS). It is estimated that just over 19000 tons of plastic material will be generated by C&D activities in Colorado this year.

1. **Collect better data about C&D plastic waste stream**

There is a lack of specific data about the type, volume, quality and other characteristics of plastics in the C&D waste stream. In order to write the materials summary in previous sections, assumptions were made about the composition of C&D plastics in Colorado based primarily on visual observations from other research and data from the EU. More specific data could be gathered about Colorado's generation and may be the first step towards exploring C&D plastic recovery and whether or not investing in equipment would be financially viable. Better data about levels of contamination, characterization of the materials and their grade and quality is necessary to evaluate what processing equipment is needed since equipment is highly specialized and calibrated to specific plastics.

This could be achieved by promoting a C&D plastics waste sort at an existing or planned facility. A mixed C&D sorting facility such as 5280 Waste & Recycling Solutions's proposed site in Adams County could be a possible location to perform this work.

2. **Increased processing infrastructure**

Colorado's current processing infrastructure consists of two primary facilities in the Denver metro area. They do not possess sorting capabilities at this time so materials must come pre-sorted and baled or bundled and they also focus on post-industrial scrap rather than post-consumer materials. Investments are needed in equipment such as optical and robotic sorting and other automated systems to better sort and clean plastics that are desirable for recovery. Plastic recovery facilities that focus on sorting mixed loads of plastic or a mixed C&D sorting could aid recovery efforts. However, this equipment is expensive and new infrastructure will have a long payback period.

3. **End market development**

Based on the highly variable, specialized and technical nature of plastics recycling and manufacturing, it is clear that an individual with plastics industry expertise is needed to conduct further research on potential opportunities for plastic manufacturers in Colorado to utilize recycled feedstock to increase demand. This effort could begin by compiling a list of plastic manufacturers in the state that utilize plastics common in C&D waste (e.g. HDPE, LDPE, PVC) and doing outreach to qualify what gaps are missing that would allow them to use some percent of recycled feedstock. Some of those activities could include determining what percent of recycled materials could be used, what upgrades to production lines could be made, if there is potential for pilot projects and outlining other market challenges and opportunities.

The PPAB could fund a position or project designed for a technical expert in plastics to conduct further exploration into plastics end market development. This work is already done in the private sector to some so a new position could be housed in a non-profit or public agency.

General findings

An overarching need for conducting better research is better data availability for quantities of C&D materials generated, donated, reused, diverted and landfilled. It is challenging to track progress and make the case for alternative methods of diversion without this information. This report relied heavily on assumptions and estimates that have arguably limited reliability.

IV. Recommendations for RREO Program

These recommendations address the Recycling Resources Economic Opportunity (RREO) program's existing grants and that offer other general ideas for supporting C&D end market development in Colorado. The recommendations were developed based on the materials research, information from other end market development reports and feedback from the C&D Council, RREO grant administrators and other CDPHE staff. It is recommended to:

1. Conduct targeted outreach for C&D infrastructure and market development

RREO grants are currently not industry specific and a range of different proposals are received each year. The state could consider allocating RREO funds to market the program to specific industries such as C&D to increase the number of incoming proposals from targeted audiences. The RREO program previously allocated funding to pay a third-party firm to develop a marketing toolkit for grant recipients and the PPAB/RREO program could consider similar actions to conduct targeted outreach to different industries perhaps on a rotating basis.

2. Allocate grant funding for C&D-specific end market and infrastructure development

In support of the previous recommendation, the state could model RFPs for C&D-specific ideas on King County, Washington's C&D Grant program that supports proposals based on:

- Innovation in approach to increasing waste prevention and/or reuse
- Identification of new recycling streams for specified materials to prevent combustion-based uses
- Increase collection of specified materials through improved infrastructure, equipment, and processes
- Applied research of emerging recycling technologies and/or recycling techniques
- Market development and/or development of new products made from C&D materials
- Improvement of existing recycling infrastructures or processes for construction and demolition recycling
- Piloting new processing technologies for specified materials
- Promote manufacturing of new materials from C&D materials

3. Leverage grant dollars for research and development of alternative building materials and new recycling technology

A now defunct grant used to be available to fund R&D efforts in new recycling technologies in Colorado through RREO. The challenges presented by C&D material end markets indicate that further research is needed to develop recycling technologies and even alternative products that are more recyclable than what are currently used in construction. Greater coordination and support of academic and professional researchers from the state's waste policymakers could more rapidly aid our diversion efforts.

4. Provide regional study grants for C&D materials

Because markets for C&D materials are inherently more local and regional than other waste streams due to high weights and transportation costs, it is suggested that regional study grants provided to local governments through RREO could be used to investigate C&D materials. The traditional regional studies approach the waste system at a high level, but it is possible policymakers and other actors would likely benefit from having more detailed information about materials present in the local C&D waste stream and gaps in C&D-specific infrastructure.

5. Specific projects and activities

Knowledge of available material end markets was cited as a barrier to C&D waste diversion in CDPHEs 2017 C&D survey. Building on information collected through a related Recycle Colorado project, the state could support a web-based C&D recycling markets directory for Colorado. A partner organization could host and periodically update the platform to serve as a resource for material generators.

In general, Colorado's waste diversion efforts could be amplified through additional coordination between statewide and regional actors. Over the long term, we could look to cultivate partnerships and programming with the Office of Economic Development and International Trade, Regional Councils of Governments, and others.

V. Next steps for C&D Council

In 2019, the C&D Council was formed around two pre-planned, grant-funded projects and had a full-time staff person to organize the group and carry out the projects. Because of this, the traditional structure with Council leadership and project committee was not necessary. In 2020 the Council will revert to a traditional subject-matter council structure and will select a new project to work on. This section provides ideas and guidance for what the C&D Council may work on in the future drawing from the research findings and external events related to C&D that took place in Colorado in 2019.

1. Pilot an end market recommendation described in the report

In order to continue the progress made by this report, the C&D Council may select an Action Project that pilots an end market idea for one of the focus materials. Several potentially workable ideas presented themselves through the research, for example:

- HMA paving with RAS
- Promoting carpet collection pilot program

2. Deconstruction Network

EPA Region 8, CDPHE, Recycle Colorado and 5280 Waste & Recycling Solutions co-sponsored a "deconstruction workshop" in August 2019 that brought together industry stakeholders to advance the practice of deconstruction in Colorado. Multiple members of the C&D Council attended the event and have a vested interest in deconstruction, so it may be a logical focus area in the future especially when considering deconstruction as a pathway to improve C&D materials diversion since roughly 90% of C&D waste comes from demolitions. As of the end of 2019, the group had stalled due to lack of available resources for an entity or individual to take leadership, so the C&D Council may consider this initiative as a natural evolution in 2020.

Introduction

Construction and demolition ("C&D") materials comprise approximately 25% of the solid waste generated by weight in the State of Colorado while contributing anywhere from 25-60% of material going to landfill depending on the region.[1] C&D-related materials can be generated by large individual entities and also from diffuse sources including homeowners, commercial businesses, institutions, governments, and even industries in addition to contractors, roofers, landscapers, and C&D roll-off and hauling service providers. For Colorado to reach its statewide waste diversion goals of 28% by 2021, 35% by 2026 and 45% by 2036, finding solutions to divert heavy C&D materials will contribute significantly to the State's efforts.

In 2018, the Colorado Department of Public Health & Environment's ("CDPHE") Hazardous Materials & Waste Management Division conducted a survey of a diverse group of stakeholders to assess the generation, disposal and diversion of construction and demolition ("C&D") materials.[i] A major theme that emerged from the survey was the importance of end markets, where survey responses indicated that the materials considered easiest to divert resulted from readily available end use options supported materials considered easiest to divert, whereas the most problematic materials to divert resulted from a lack of end use options. When asked what information would help respondents further diversion efforts in the future, 31.8% wanted a report on end market development.

This provided scope to the CDPHE for a C&D study, and the agency provided grant funding to Recycle Colorado to support the development of an end market report by its C&D Council. The goal of the Council is to bring together businesses, organizations and government units that impact or have input on a closed loop system for C&D waste materials. In 2019, the Council was tasked with identifying and ranking by economic value all of the major materials moving through C&D projects in Colorado and identifying potential end markets that can be established in the state for the top five materials that do not already have a Colorado market. The following report is the culmination of the work plan.

Purpose

The purpose of this project was to identify and rank by economic value all of the major materials moving through C&D projects and identify potential end markets that can be established in Colorado for the top five materials that do not already have a Colorado market. It builds on previous research conducted by the CDPHE and other entities in Colorado. It is the first step towards a more strategic market development initiative at the state level to expand access to Colorado-based markets for recyclable C&D debris generated in the state. It provides research that helps identify opportunities to increase waste diversion and will lead to additional diversion infrastructure and attract end-markets and other businesses to Colorado.

The CDPHE's Pollution Prevention Advisory Board ("PPAB") commissioned the report to provide specific guidance and a decision-making support tool for the group to improve C&D waste diversion in the state. The report is ultimately intended for use by the PPAB to aid in allocating funds through the Recycling Resources Economic Opportunity ("RREO") Grant Fund, but it may support funding allocation for the Front Range Waste Diversion ("FRWD") Enterprise

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[1] Based on reporting from City and County of Denver, Larimer County, Pitkin County and other anecdotal reports.

Fund as well. Contents of the report may also be valuable for local, regional and state waste managers to better understand conditions for improving recovery of C&D materials in Colorado.

PART I - OVERVIEW OF TASKS AND METHODOLOGY

A general guiding framework was developed for the project by Recycle Colorado and the CDPHE to carry out the research. Sections 1.1 – 1.7 summarize the major steps provided in the project outline and the methodology used to address each step.

1. Create a list of C&D materials

The list of C&D materials was compiled through conversations with C&D Council members, landfill operators, contractors, material haulers and other states and based on research already completed by the CDPHE.

2. Rank materials by importance based on economic value of diversion and input received during C&D Council meetings

Values for C&D materials were gathered through web research, interviews and industry publications in order to rank materials by average US and CO value. The materials were organized into two categories: 1) materials with a positive economic value, and; 2) materials with negative economic value. The ranked materials list was submitted to the CDPHE as its own deliverable in March 2019 (*See Appendix C*).

1. All materials with negative or zero economic value were placed at the bottom of the list.
2. Positive values were ranked by most value to least value.
3. When there is a discrepancy in the Colorado value versus the US value, the Colorado value was used for ranking.
4. To the extent possible, economic values were converted from their original units (e.g., pounds) to a common unit (e.g., tons). Cubic yards were converted using 3.333 cy/ton.[1] Square feet and wood board foot used the conversion factors found in a conversion table for the City of Napa.[2]
5. Because of odd units, some positive value materials were ranked based on anecdotal evidence.

3. Identify top five materials by rank

Council Members voted on the materials that should be considered for this end market study during the Q1 C&D Council meeting in February 2019.

During the Q2 meeting in May 2019, Council Members were surveyed about their specific knowledge of existing end market solutions for these materials and feedback was collected. Based on that feedback and with additional research, the following materials were selected as the focus of this study.

- Gypsum wallboard
- Reclaimed asphalt shingles
- Treated wood

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[1] From CDPHE 6 CCR 1007-2 Section 1.7.4.a.4, provided by Emily Kaps at CDPHE

[2] Retrieved from City of Napa: https://www.cityofnapa.org/DocumentCenter/View/1942/Materials-Volume-to-Weight-Conversion-Worksheet-PDF?bidId="

- Carpet tile
- Plastics

4. Produce a materials summary for each of the top five materials

This section provides an overview of the methodology used to generate a summary for each of the top five materials selected for this report found in PART II – Materials Research.

4.1 Statewide volume calculation

Statewide material volumes were generated using the waste characterization data completed for the Colorado Integrated Solid Waste & Materials Management Plan Appendix G. The report provides estimates for total tonnages of materials and their corresponding composition as a percent of total waste generated in four state regions (Front Range, Mountains, Western Slope, Eastern/Southeastern) in 2016. Estimations of total waste generation during future years 2021, 2026 and 2036 are also given.

The 2016 and future estimates of total C&D waste generation for each of the four regions were extracted and compiled into the table below to help estimate tonnages of materials specific to this report in 2016, 2019, 2021, 2026 and 2036.

Table A: Total C&D waste generation estimates by region 2016 – 2036 (Colorado ISWMMP Appendix G, 2016)

Region	C&D total in 2016	C&D total in 2019	C&D total in 2021	C&D total in 2026	C&D total in 2036
Front range	1605400	1679100	1752800	1901600	2192600
Mountains	70400	73550	76700	84900	100800
Eastern/Southeastern	41400	43300	45200	49000	55300
Western slope	109800	115450	121100	133800	159400
Total	1827000	1911400	1995800	2169300	2508100

Appendix G contains estimates for the composition of drywall (Clean = 5.1%, Painted = 10.3%), asphalt shingles (18%), and dimensional wood (10%) as a percent of total C&D waste but does not include estimates for plastics or carpeting.

Using the method described above, the following is an example of how material volumes were calculated for clean drywall. The present (2019) volumes were calculated by averaging the 2016 and 2021 volumes.

Table B: Clean wallboard as a percentage of total C&D (Colorado ISWMMP Appendix G, 2016)

	Percent of total C&D
Clean	5.1%

Table C: Example clean drywall generation estimates by region in 2016, 2019, 2021, 2026 and 2036 (extrapolated from Colorado ISWMP Appendix G, 2016)

Region	2016 clean tonnage	2019 clean tonnage	2021 clean tonnage	2026 clean tonnage	2036 clean tonnage
Front range	81900	85700	89400	97000	111800
Mountains	3600	3750	3900	4300	5100
Eastern/Southeastern	2100	2200	2300	2500	2800
Western slope	5600	5900	6200	6800	8100
Total	93200	97500	101800	110600	127800

Table 2 figures were generated by multiplying Table 1 figures by the 5.1% composition rate for each region and each year.

4.2 Summary of available processing or manufacturing options

Information used to produce each section was collected from multiple primary and secondary sources including:

- Interviews with subject matter experts within C&D Council and external individuals and organizations
- Web research including industry publications, white papers, grey literature

The processing or manufacturing summaries include information such as processing steps, equipment and personnel needs, regulatory requirements, environmental impacts and whether they are currently being done or have been tested in Colorado.

5. Develop a plan to bring end markets to Colorado

The plan and strategy for bringing end markets to Colorado is informed by the materials research, learnings from other end market development studies conducted and guidance from the C&D Council and other interested parties. For some materials, it was found that full end market processing could be done, whereas for others it was more appropriate to set up intermediate collection and processing of material before being sent to out-of-state end markets.

Criteria used to outline the recommendations were developed based on feedback from the C&D Council and on the information found during the research.

- Diversion potential – How much material can potentially be diverted and can it be scaled?
- Feasibility of implementing – What is the state baseline and what gaps need to be addressed?
- Site criteria for locating in Colorado
    - Site location
    - Capital costs
        - Equipment
        - Personnel

- Processing costs
- Necessary material volumes
- Environmental regulations

This content is included for each material section in PART II – Materials Research.

6. Recommendations for the Recycling Resources Economic Opportunity grant program

Recommendations were developed based on the materials research, information from other end market development reports, and feedback from the C&D Council and other interested parties. This information is found in PART III.

7. Recommend next steps for the C&D Council

Recommendations were developed based on the materials research, information from other end market development reports, and feedback from the C&D Council and other interested parties. This information is found in PART IV.

PART II – MATERIALS RESEARCH

SECTION 1 - Gypsum wallboard

Gypsum wallboard is a construction material used to create walls, ceilings and design features including eaves, arches and other architectural specialties. It consists of about 90% gypsum[1] and 10% paper face and paperboard backing by weight and is a favorite building material in residential and commercial applications for its fire-resistant properties and ease of installation.[ii] When used in new construction, the wallboard, manufactured in standardized panel sizes, must be cut to fit various wall and roof dimensions. As a result, the National Association of Homebuilders estimated that the construction of an average size American home (2000 ft^2) produces about one ton of unused scrap wallboard.[iii] Even larger volumes of material are generated through renovation and demolition activities, wherein the wallboard generated is typically mixed in with other building materials and may be contaminated with joint compound, fasteners like screws and nails, paint, glue and wallpaper.

There are several concerns regarding end of life management of gypsum wallboard products. Wallboard may be contaminated with asbestos, requiring special handling and testing protocols (*this is addressed in more detail in Section 2*). In addition, when gypsum wallboard is disposed of in landfills it can react with the typically moist and anaerobic environment to produce hydrogen sulfide gas. Hydrogen sulfide has a strong odor and is toxic in high concentrations. Due to Colorado's dry climate however, hydrogen sulfide gas generation has been found to be limited.[2]

1. Statewide material volume

Table 1: Clean and contaminated wallboard as a percent of total C&D[iv]

	Percent of total C&D
Clean	5.1%
Painted*	10.3%

*"Painted" is terminology used in the ISWMMP and it is assumed to denote material contaminated by multiple aspects, not just paint.

Table 2: Clean wallboard generation estimates by region in 2016, 2019, 2021, 2026 and 2036[v]

Region	2016 clean tonnage	2019 clean tonnage	2021 clean tonnage	2026 clean tonnage	2036 clean tonnage
Front range	81900	85700	89400	97000	111800
Mountains	3600	3750	3900	4300	5100
Eastern/Southeastern	2100	2200	2300	2500	2800
Western slope	5600	5900	6200	6800	8100
Total	93200	97500	101800	110600	127800

[1] Chemical composition of hydrogen sulfate (CaSO4) and water (H20)
[2] Information provided by CDPHE Materials Management staff.

Table 3: Painted wallboard generation estimates by region in 2016, 2019, 2021, 2026 and 2036[vi]

Region	2016 painted tonnage	2019 painted tonnage	2021 painted tonnage	2026 painted tonnage	2036 painted tonnage
Front range	165,400	172900	180500	195900	225800
Mountains	7300	7600	7900	8700	10400
Eastern/Southeastern	4300	4500	4700	5000	5700
Western slope	11300	11900	12500	13800	16400
Total	188,300	196900	205600	223400	258300

1.1 Diversion rate

A 2008 report synthesized findings of multiple statewide and national studies to estimate a national US diversion rate for wallboard, estimating that approximately 1% of post-consumer material was being diverted at that time.[vii] More recently, the Construction & Demolition Recycling Association (CDRA) reported that 5% of gypsum wallboard is recycled in the US overall.[viii]

The only known diversion of material taking place in Colorado at this time is at A1 Organics, where in 2018 they accepted 193 cubic yards of clean wallboard scrap to be used as a compost bulking agent. Based on this finding, it is assumed that the diversion rate for wallboard in Colorado as of 2019 is <1% and effectively zero.

2. Recovery process

Wallboard waste from new construction sites is freer of contaminants than demolition wallboard, and it is the most commonly recycled. During installation, wallboard must be cut to meet the dimensions and openings of a building, so a relatively large percentage is wasted at construction sites compared to other materials. Furthermore, wallboard is usually installed during one specific period in the construction process meaning the unused scraps most valuable for recycling can be collected and managed over a relatively short time.[ix]

In some cases, during demolition or renovation, wallboard is removed and managed as a distinct material. However, in most demolition projects, wallboard is not removed separately but is mixed with other debris as the structure is torn down.

According to CalRecycle, wallboard waste from demolition sites may be recyclable for nonagricultural markets and the following contaminants should be considered:[x]

- Nails should be removed before processing.
- Tape breaks down in compost or can be screened out.
- Asbestos may be found in joint compound if the structure was built before the mid-1970s.
- Paint usually covers demolition wallboard. Structures built before 1978 may contain lead-based paint. Lead can be detected with an inexpensive lead paint test kit. Wallboard with lead-based paint should be disposed of properly. Mercury may also be a concern.

2.1 Special consideration: asbestos[3]

Asbestos is the umbrella term for naturally occurring minerals that have been used in the manufacture of many different products for useful properties such as thermal insulation, high tensile strength and chemical and thermal stability. These materials pose a health risk when the microscopic fibers they are composed of are inhaled into the lungs which can result in long term health impacts like asbestosis, mesothelioma and lung cancer.

Asbestos containing materials (ACM) are not hazardous to health as long as they are in good condition, however if they become disturbed or damaged the fibers may become airborne. As a result, it is illegal in Colorado to recycle materials that are bonded or contaminated with asbestos containing materials (ACM) because the processing may make the ACM friable (i.e. an ACM that can be reduced to powder by hand pressure). Under State and Federal regulations, the presence of asbestos must be tested by a Colorado-certified asbestos building inspector before a renovation or demolition project and possibly during new construction if scrap material is planned for recycling.

A generator of clean scrap wallboard from new construction should use product information from the manufacturer to decide whether asbestos could potentially be present in the materials used. If the generator can prove the scraps do not contain asbestos based on manufacturer information, then testing is not required.

2.2 Collection

The economic advantages of recycling scrap wallboard from construction sites are significantly increased through source separation. Gypsum is difficult to recover once it has been mixed with other C&D materials because it disintegrates very easily during mixed waste processing. Gypsum wallboard retained in larger pieces is the most valuable for recycling.[xi]

C&D Council members explained that some builders in Colorado do source separate wallboard during construction projects primarily when earning waste diversion credits for green building certifications like Leadership in Energy and Environmental Design (LEED). Most builders find source separation cost prohibitive and an extraneous activity and there are presently no policies to specifically divert wallboard, as such mostly only larger companies with the ability to pay and with the incentive of LEED credits are found to segregate wallboard in practice.

2.3 Processing

The two major objectives of processing wallboard are separation of gypsum from the paper and the size reduction of the gypsum itself. Several vendors market self-contained wallboard processing equipment. Many of these operate using some type of grinder followed by a screening system; a dust collection system is typically included. Standard size reduction devices found (e.g. tub grinders, horizontal mills) at many waste processing sites can be used to process wallboard.[xii] Grinding equipment can range from a large plant to a small mobile chipper. A hammer mill is often used.

The following flow diagram below shows the typical process at a wallboard recycling facility:

[3] See Additional Resources at the end of this chapter for links to CDPHE documents on asbestos management.

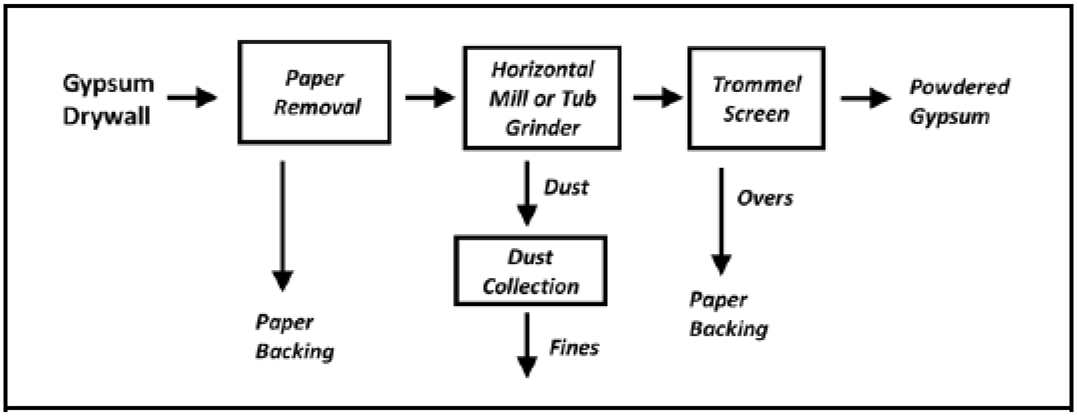

Figure 1: Flow Diagram for a Typical Wallboard Recovery Facility that Receives Segregated Wallboard and Produces Gypsum Powder[xiii]

A 2003 report outlines a wallboard recycling process for source separated material that was tested at landfill sites in Florida that is less equipment intensive than the diagram in Section 2 and requires one operator.[xiv] The necessary equipment in this process are a front-end loader and trommel screen. A front-end loader is used to break up wallboard into smaller pieces before being loaded into the trommel screen's hopper. By adjusting the trommel screen screen size, speed and tilt, an operator can control the degree of separation of the paper and gypsum for processing for different end markets. The report also provides guidance on specs for material size depending on the end market:

Table 4: Market specifications for recycled gypsum wallboard[xv]

Market	Specifications
Agriculture	Material size must be ¼"- but paper does not need to be removed
Portland Cement	Material can be of any size but must not be wet
Drywall	Material size is preferred to be ½"-

Finally, these activities were performed at a landfill which removed the need for further transport expenditure to dispose of the paper fraction. No newer research was found that studies wallboard recycling processes and processing rates, so this study from 2003 had to be used to help produce recommendations. A lack of current studies and gap in knowledge is a challenge for making more informed decisions, however the processing rate identified in the study was confirmed to be approximately correct, if not slightly conservative.[4]

Successful processing operations

Processing facilities like USA Gypsum in Pennsylvania can be looked to as a model. As one of the largest wallboard recyclers in the US, they handle over 30,000 tons annually from nine states in the northeast. Their two facilities successfully produce recycled gypsum that is used in the manufacture of new wallboard but their largest markets for gypsum are still in the agricultural sector.[xvi]

[4] Based on conversation with Power Screening, LLC.

Gypsum Recycling International (GRI), which operates in 10 countries including the US, has developed a recycling process that allows for the recovery of high purity gypsum powder as well as recovery of the paper fraction. Once the gypsum is separated from paper in the first stage of the recycling process, the paper is still too contaminated with gypsum and other residual wastes to be sent to fiber mills. They developed a second stage of the recycling process to remove contaminants and make the paper marketable to recycled paper markets. They previously sold the more contaminated paper as animal bedding.[xvii]

3. Summary of available markets

This section outlines known reuse and recycling solutions for recovered wallboard. The requirement for material generators to test for asbestos prior to any secondary use as discussed in Section 2.1 is implied for all available reuse, recycling and other markets described in Section 3.

3.1 Reuse

Information provided in Section 3.1 is taken from CalRecycle's wallboard recycling resources webpage, with Colorado-specific comments added to Section 3.1.3.[xviii]

3.1.1 Construction site reuse

Wallboard scraps can be placed in the interior wall cavities during new construction which eliminates the disposal and transportation costs. This solution of course does not actually provide a beneficial second use for the material and rather leaves the material for future builders to deal with. While this practice is technically possible, it is not encouraged.

3.1.2 Gunite Support

Gunite is concrete sprayed on at high pressure. Cutoff pieces of new construction wallboard have been used as forms to support gunite as it is being sprayed. A swimming pool construction company in California uses new cutoffs for this purpose, in sizes from 4 x 2 ft to 4 x10 ft, and thickness of 1/2 to 3/8 in. The pieces are then discarded.

3.1.3 Donate

Used building material supply stores and organizations like Habitat for Humanity have historically accepted whole sheets of unused wallboard (e.g. surplus material from a construction site), however based on conversations with some of these organizations in Colorado this is not a large market and many of them no longer accept the product due to limited demand and storage space. Clean wallboard scrap from new construction cannot be used in the place of new wallboard and painted and otherwise contaminated material cannot be reused due to quality and health concerns.

3.2 Recycling

As explained previously, wallboard recycling typically focuses on clean scrap leftover from new construction due to quality and concerns about contamination. If processed to high enough purity, gypsum extracted from clean scrap can be used in the same applications as virgin gypsum. It can be used to manufacture wallboard, cement, stucco, and other construction products. Application in these markets requires a low paper composition.[xix]

Both applications described in this section would rely on the services of a dedicated wallboard recycling operation with sufficient separation to produce high quality gypsum with little to no paper residue.

3.2.1 Wallboard manufacturing

This section is adapted from *Gypsum Wallboard Recycling and Reuse Opportunities in the State of Vermont*.[xx]

Collection options:

- Hauled by the contractor generating the wallboard scrap
- Hauled by the party accepting the discarded wallboard
- Hauled by a third party hired to transport the wallboard between sites

The wallboard waste may also be brought to a central transfer station by a local hauler or the contractor and then transported from there by the receiving organization.

Processing:

1. Source separate wallboard from other construction waste
    - Verify asbestos is not present in the material using manufacturer information
    - The wallboard must be kept dry and clean in order to guarantee meeting specifications.
2. Transport the wallboard to a transfer station or store until a large enough quantity has been generated to make transport to the recycling facility economical
3. Transport to the recycling facility

Once at the recycling facility, the load is then inspected by the loader/operator to determine load size and whether it meets specifications. The recycling facility will then reprocess the wallboard if it meets specifications. The processing varies significantly between different wallboard recyclers and is highly proprietary. However, the process generally involves the following steps:

1. Separate the gypsum from the paper
2. Run the scrap wallboard through a magnet to remove nails and other metal contaminants
3. Shred or chip gypsum
4. Combine with raw gypsum to form new gypsum wallboard

Costs:

Source Separation (including potential testing for asbestos, collection bin, employee training on procedures) + Transportation (site of generation to transfer station) + Storage + Transportation (transfer station to processor) + Tipping fee charged by processor.

Competing Products:

1. Synthetic gypsum – A class of gypsum by-products from different industrial processes. The most common synthetic gypsum is produced through the flue gas desulfurization process at coal-fired power plants.[xxi]

2. Virgin gypsum – There are two active gypsum quarries in Colorado.[xxii] American Gypsum in Gypsum, CO operates a quarry and a major US producer of gypsum wallboard products. The other quarry is located in Livermore, CO. Colorado is one of the leading U.S. producers of virgin gypsum.[xxiii]

Case Study: Building Product Ecosystems, Closed Loop Wallboard Collaborative[5]
Based in New York, Building Product Ecosystems's Closed Loop Wallboard Collaborative brings together builders, haulers, processors and manufacturers to focus on:

- Source separation of unused wallboard scraps during new construction
- Wallboard scrap processing
- Using processed scraps to manufacture new gypsum wallboard

On the East coast, the collaborative relies on USA Gypsum in Pennsylvania to process clean wallboard scrap collected from construction sites and sell the recovered gypsum to regional manufacturers. The organization also operates a collaborative in Northern California in the absence of a processor. In that case, a local manufacturer National Gypsum accepts their own material back to recycle it in their manufacturing process. 1770 tons of material has been recycled out of the NYC area collaborative and data was not obtainable for the Northern California operation.[6]

BPE's Executive Director explained that the key to the program is starting a dialogue with the developer and/or project owner to specify that clean wallboard scrap will be a focus of the project waste diversion plan. With the budget for source separation and hauling pre-determined and written into the project plan, the closed loop process is ensured throughout the project phases.

Market opportunities in Colorado
Based on our research, American Gypsum (AG) has been approached on multiple occasions by various entities to see if they would accept clean wallboard scrap for recycling into their process and the idea hasn't been possible due to a number of challenges. Recycle Colorado contacted AG in December 2019 to confirm, and the company stated they have previously tested wallboard recycling but the material was incompatible with their processes because:

- Products from other manufacturers contain different additives than their own so they cannot accept those materials
- Paper residues from recycled wallboard produce detrimental impurities resulting in quality concerns and potentially failure to comply with industry standards
- Even with their production scrap they have to send most to landfill due to complications in reprocessing

It seems this end market may only be technically feasible if post-consumer gypsum is recovered at high purity levels from wallboard.

3.2.2 Cement Production

As gypsum is an ingredient in the manufacture of Portland cement, some cement plants have attempted to utilize recycled wallboard. This practice has been limited in the US because of the need for a large and constant supply of uniform material.[xxiv]The typical gypsum content of Portland cement ranges from 5 to 10%. Virgin gypsum rock is often used by the cement kilns, and the different physical form of processed wallboard may necessitate adjustment of the facility's materials handling system. The purity of gypsum in the wallboard is a major concern. Paper should be removed, and care should be taken during the collection of the wallboard to minimize the amount of impurities such as soil that are introduced.[xxv]

[5] Interview July 17, 2019. Organization website: https://www.buildingproductecosystems.org/closed-loop-wallboard
[6] Closed Loop Wallboard Collaborative Working Group call on September 10, 2019.

Collection, costs and competing products are virtually the same as wallboard remanufacturing except for differences in preferred sizes of granules.

Market opportunities in Colorado

According to the Portland Cement Association, Colorado's clinker capacity in 2018 was 2.9 million metric tons.[xxvi] Assuming a 5% gypsum content, cement manufacturers consumed 145,000 tons of the material to produce cement in the state last year.[7] It is unknown how much of the gypsum consumed is virgin vs. synthetic gypsum but post-consumer gypsum recovered from wallboard could potentially serve as an alternative.

In their own market development research, 5280 Waste and Recycling Solutions initiated conversation with Cemex – one of Colorado's large cement manufacturers – to investigate whether they would accept post-consumer gypsum. Cemex expressed concern that recycled gypsum is in powder form after the typical wallboard recycling process which makes the material incompatible with their needs. The gypsum Cemex normally uses is 3"- in size and converting gypsum powder into larger pieces was deemed currently not economically viable.[8]

While the example above indicates a roadblock with Cemex, there are other cement manufacturers present in Colorado that could be engaged to develop this end market.

3.3 Land Application

Agricultural land applications are the primary market for post-consumer gypsum in the US and are summarized in this section.

3.3.1 Onsite Land Application

In recent years, the concept of recycling gypsum wallboard at the construction site has been proposed. In this approach, scrap wallboard from new construction is separated and processed using a mobile grinder and then size-reduced material is land applied (prior to placement of sod) as a soil amendment or a plant nutrient. This approach may be feasible when the soils and grass species show a benefit from the application of gypsum. This recycling technique offers a potential economic benefit when the cost to process and land apply the ground wallboard at the construction site is less than the cost to store, haul and dispose of the wallboard.[xxvii]

3.3.2 Agricultural Land Application

Gypsum can provide a number of benefits to the right type of soils if directly applied in pellet or powder form, including improving water penetration and workability of alkaline soils, softening soil with high clay content, neutralizing soil acidity, and adding the plant nutrients calcium and sulfur.[xxviii] Processing for agricultural end markets is essentially the same process as recovering for new wallboard or Portland cement, except the material needs to be screened to a smaller particle size (1/4"-).

From early in the research, Council members provided anecdotal feedback that Colorado soils are incompatible with this end market due to high alkalinity (high pH) soil composition. Since this market is one of the largest opportunities for diversion in other parts of the country, multiple soil and agronomy researchers were contacted to further investigate this idea and confirm whether that is accurate.

[7] Author's own estimation.
[8] Email with 5280 Waste and Recycling Solutions July 1, 2019.

Is gypsum beneficial for Colorado soils?
CDPHE staff provided contact information for a Colorado State University College of Agricultural Sciences researcher who explained that gypsum is used as soil remediation to leach sodium:

"Some Colorado soils can be naturally high in salts, especially sodium salts. An increase in sodium results in sodic soils. A sodic soil does not drain well and becomes very compacted resulting in poor plant growth. The sodicity of a soil is measured by analyzing the soil for its sodium adsorption ratio (SAR). The SAR is a measure of sodium relative to calcium and magnesium. If the SAR is greater than or equal to 13, then the soil is considered to be sodic. To remediate a sodic soil, there needs to be gypsum or sulfur available in the soil to help reduce the sodium. If the SAR is 13 or more, then the amount of gypsum needs to be determined in the soil first. This will determine if more gypsum should be added. The lesson here is that gypsum can be used to correct sodic soils that are commonly found in Colorado."

The interviewee went on to say that when gypsum is used in agriculture it is usually either applied as powder or pellets, and powder is the most preferable form in Colorado soils. The general rule for reclaiming sodic soil with gypsum is to apply 7 tons per acre, but first to apply about 1/3 of the material to test whether it is having the intended effect. He is aware of growers presently using this tactic but was unable to comment on actual volumes of gypsum being used for this purpose in Colorado. His recommended strategy to further verify gypsum use is to communicate with CSU Extension offices in each county that will know more detail about local grower practices.

A representative from Renewable Fiber, an agricultural products supplier based in Ft. Lupton CO, explained that in his three decades of experience he has known growers in Eastern Colorado to use gypsum as a soil amendment. He claimed that the material does provide a beneficial use at least in that region for neutralizing soil pH.

3.3.3 Compost Additive/Bulking Agent
Clean gypsum wallboard scrap from new construction is being added to composting systems in a number of locations in the US. Many of these systems are located at waste processing sites that already have compost operations in progress. While the paper fraction of the wallboard can biodegrade as part of the compost, it is important to note that the gypsum itself will not biodegrade to any major extent and will instead be incorporated into the final compost product. This results in a calcium- and sulfur-rich compost, which may have a benefit for some crops. Gypsum also offers the potential to bind odors associated with ammonia if the compost is kept aerobic.[xxix]

A1 Organics, Vail Honeywagon and Renewable Fiber, Inc were contacted during this research to determine if this practice is used and A1 Organics and Renewable Fiber, Inc were found to currently accept small quantities of clean drywall scrap. The manager at Vail Honeywagon explained that wallboard isn't accepted at their site since gypsum doesn't benefit Colorado soils.

Collection[xxx]

- Hauled by the contractor generating the wallboard scrap directly to the composting facility
- The composting facility may agree to collect the wallboard scrap
- Hauled by a third party hired to transport the wallboard between sites

The wallboard waste may also be brought to a central transfer station by a local hauler or the contractor and then transported from there by the receiving organization or hired hauler.

Process [xxxi]

1. Separate wallboard from other forms of construction waste
2. Transport gypsum wallboard to the composting facility
3. Shred, chip or crush the wallboard
    a. According to the Clean Washington Center shredding is best done when mixed with yard debris to prevent dust
4. Add the shredded or chipped wallboard to other ingredients of the compost mixture
5. Monitor the compost's temperature, moisture, and oxygen levels

Competing products

- Wood Chips
- Saw Dust

Interview with A1 Organics:
A1 Organics, with four facilities located between Denver and Fort Collins, does accept small volumes of wallboard to be used as a compost additive/bulking agent. In 2018 they accepted 193 cubic yards (or about 366 tons) company-wide, so a relatively small amount compared to the scale of that waste stream. The material must be from new construction, US made, single stream and free of contaminants. Size reduction is achieved by crushing the material with a front-loader and the material is incorporated into the compost mix. Representatives explained they could accept more material if it was pre-processed before delivery to the facility since the crushing process is not cost-effective. One stated limitation to utilizing a large amount of gypsum in their product would be a change in aesthetics (I.e. compost with a lighter color) that is not desirable to customers.

3.4 Other Known Applications

3.4.1 Animal/Livestock Bedding

USA Gypsum markets pulverized, pelletized, and proprietary blends of gypsum products used for dairy bedding and barn dry, poultry litter amendment and horse bedding additives. Gypsum is stated to soak up moisture and ammonia produced by animal excrement which reduces the likelihood of bacteria growth and other animal health problems.[xxxii]

Market opportunities in Colorado

In 2018, Colorado's livestock inventory included nearly 800,000 beef cattle, 180,000 dairy cows and 750,000 hogs.[9] With the significant livestock production taking place in Colorado, it would be of interest to investigate the products currently used for similar applications and determine whether post-consumer gypsum could be a potential substitute. Weld County is the leading producer of cattle and dairy products, meaning the largest potential market would be 'relatively' close to where most wallboard waste is generated in the state – the Front Range.

Renewable Fiber, Inc, an agricultural products supplier, was initially contacted to research whether gypsum or other materials are currently used for this purpose. For the purpose of absorbing moisture, the manager said there is another product on the market made of lava rock that is cheaper and more effective than gypsum. It's possible that other agricultural product suppliers promote the use of gypsum but more research is needed.

[9] United States Department of Agriculture National Agricultural Statistics Service. 2018 State Agriculture Overview. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=COLORADO

3.4.2 Wastewater/Water Treatment

Gypsum can be used as a bulking and drying agent for sludge. Gypsum aids in settling dirt and clay particles in turbid water. A gypsum market exists as an absorbent for liquid spills and to aid in soil stabilization and binding.[xxxiii]

3.4.3 Remedy sodic roadside soils

Damage caused to soil next to roadsides by winter salt can be reduced by adding gypsum. The sodium reacts with the sulfur facilitating the leaching of the salt from the soils. For gypsum wallboard to be effective in removing salt from soils the soils must be well drained.[xxxiv] This is the same process that is used to leach sodium in agricultural soils.

3.4.4 Application to Recreational Land

Gypsum can be applied to recreational land for the same reasons it is used on agricultural lands.

3.4.5 Athletic Field Marker

Gypsum can be used instead of chalk for drawing lines on athletic fields.

3.4.6 Mushroom Cultivation

Gypsum is reportedly a good medium for growing mushrooms.

3.5 Exploratory Solutions

This section summarizes potential markets introduced through recommendations from the C&D Council and other subject matter experts.

3.5.1 Gypsum Floor Underlayment (“Gypcrete”)

During related work at Recycle Colorado, a source suggested investigating the application of recovered gypsum in gypsum floor underlayment products. Gypsum infused concrete is a building material used as a floor underlayment used in wood frame and concrete construction for fire ratings, sound reduction, radiant heating, and floor leveling. It is a mixture of gypsum plaster, Portland cement, and sand. US patent 4,444,925 lists the components of Gyp-Crete® as atmospheric calcined gypsum, sand, water, and small amounts of various additives with gypsum comprising 24% by weight of the mix according to one example.[10]

There were no manufacturing facilities found in Colorado using a web search but technical staff from two manufacturers located in other states[11] were interviewed. Both facilities utilize raw gypsum in their products due to quality control ability and relative abundance. One interviewee cited past experimentation done by USG to use post-industrial wallboard for gypcrete production that was ended due to the residual paper interfering with the manufacturing process and also diminishing the fire resistance of the end product. He noted that if impurities could be fully removed from the gypsum sourced from wallboard it would be feasible to use.

3.5.2 Gypsum bricks

Researchers at the University of Washington are capturing wallboard scrap and converting it into masonry brick-like building materials. The blocks are made from 80 percent wallboard waste and a binder made from industrial byproducts and are waterproof and lighter than earth

[10] Wikipedia

[11] ACG Materials (Corporate HQ in Norman, OK) and Hacker Industries (Newport Beach, CA)

blocks, bricks or concrete blocks according to the research team. The researchers are partnering with local contractors to get the waste, and architecture students are using a press to build the blocks, which look like masonry bricks. As of 2019, the prototype design is currently undergoing testing to meet building, seismic and fire codes.[xxxv][12]

The collection steps would be the same as previously described markets, however this solution is reputed to be able to utilize material from both new construction and demolition projects. The processing technology is proprietary, but the lead researcher explained that contaminants like fasteners and other mixed debris are removed manually before pressing the material. He could not comment on the throughput or efficiency of this process, especially considering this idea is still in a R&D phase.

3.5.3 GreenZip[13]

The Green Zip Method is a patented "demountable" wallboard joint tape, enabling disassembly and reuse of ordinary wallboard partitions, rather than demolition and disposal. The technology extends the lifespan of wallboard, and according to case study evidence can promote the reuse of 75%+ of wallboard during demolition/renovation projects.

According to a company representative, office spaces and hospitals turn over large quantities of wallboard. Applying the technology gives building owners flexibility and the ability to reuse wallboard onsite if they want to remodel wall configuration for alternative building uses. Utilization of GreenZip on a broad scale could improve reusability of the material and reduce wallboard disposal rates over time.

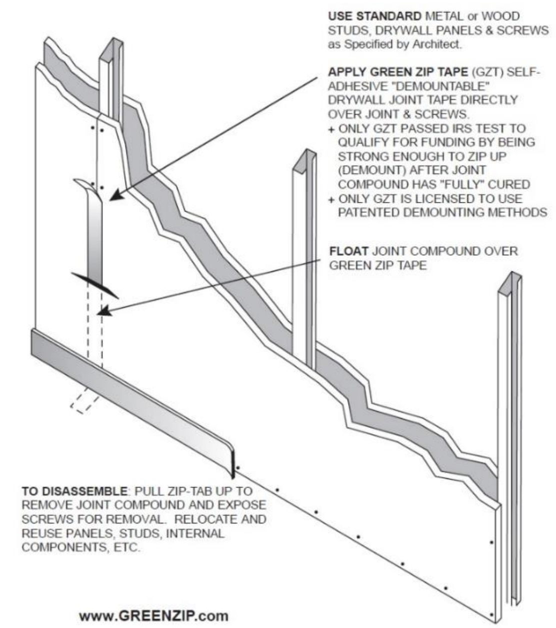

Figure 2: GreenZip technology diagram

4. Plan to bring end markets to Colorado

To complete this section, research performed by Recycle Colorado staff was presented to the C&D Council through multiple stages of in-person meetings, conference calls, and an online survey to collect feedback that ultimately guides the end market development recommendations.

Sections 4.1 and 4.2 establish the current situation and market forecast for gypsum wallboard. The end markets plan as outlined in Section 4.3 is not meant to be prescriptive; but rather the section is intended as a decision-making tool and lays out an analysis of different potential end market strategies based on their estimated ability to divert materials, the scalability of that process or end market, and costs to operate (when information could be found).

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12 Information confirmed through interview with lead researcher on July 8, 2019
13 Interview with GreenZip July 3, 2019

4.1 Description of status of existing market including current and near-future capacity or demand

The existing markets for gypsum in Colorado are agricultural, where it was determined that two composting facilities accept small quantities of clean wallboard scrap as an additive and bulking agent and some farmers are currently utilizing virgin gypsum as a soil amendment. This market has more room to grow as these activities are all taking place on a small scale relative to the whole of the waste stream.

Renewable Fiber, Inc. in Ft. Lupton has a composting operation that utilized 44 tons of material last year to neutralize pH levels. At A1 Organics the material is applied as a compost bulking agent. Of the nearly 600,000 cubic yards of material accepted at A1 Organics last year, only 193 cubic yards (roughly 366 tons) of wallboard was taken in. Indications are that the company will bring in more of the material during 2019 but still only a relatively small quantity compared to the size of their operation. It was determined through several conversations with CSU agronomists and soil scientists that under certain conditions gypsum is being used in the state of Colorado as a soil amendment on agricultural lands. So far, the size of this market has not been determined but interviewees suggested a path forward to further investigate.

4.2 Market trends

The estimated average value of post-consumer gypsum in the US is $30/ton.[14] There is currently no valuation of this material in Colorado markets, but we can speculate that those figures would range below the average US figure due to two natural gypsum mines in the state and limited market demand.

As noted previously, synthetic gypsum produced as a byproduct from coal power plants is a market competitor of post-consumer gypsum. As coal power plants are taken offline due to the growth of cleaner energy production then this material may become less abundant and potentially open the door to alternatives.

4.3 Market development opportunities

4.3.1 Wallboard as a compost additive

Two of three commercial composting facilities contacted during this project accept small amounts of clean scrap wallboard from new construction as a compost additive and bulking agent. A1 Organics accepts material because the current quantity accepted doesn't impact the aesthetic look or chemical composition of their end product and Renewable Fiber, Inc. uses the gypsum to neutralize pH. The proposed solution for this market would be to conduct further research into the potential benefits of adding wallboard to compost.

Site criteria:

Site criteria

Composting companies could continue using their own space to size reduce material or it could be pre-processed at a separate facility. A fair amount of space is would be needed for processing equipment whether using a front-end loader, grinder or other equipment.

[14] Interview with USA Gypsum in March 2019.

Equipment and personnel
A1 Organics uses an owned front-end loader to crush the material but stated more would be accepted if it was pre-processed. Various equipment is used in practice to size reduce wallboard depending on the target end market including horizontal grinders, tub grinders, chippers, hammer mills and trommel screens. For this end market, the literature indicates that only one phase of size reduction would be needed since a fine particle size is not required and the paper fraction does not need to be separated out.

Environmental regulations
If material is processed at a composting facility, then no further permitting would be needed. If processed at a separate site, then the facility would need to comply with solid waste, air quality and stormwater permitting described in Section 4.3.

Scalability:

Diversion potential
Currently limited but could increase as the market for compost grows and if material can be pre-processed before arriving at composting facility. Potential barriers that need to be addressed are marketability of compost containing gypsum (customers are not interested in compost with a white hue) and lack of consensus on the effects of gypsum in Colorado soil.

A bill concept was discussed during the 2019 interim legislative session to develop a statewide organics management plan over the coming years. While the focus of the current bill is on the carbon sequestration benefits of composting, if such legislation is passed, this would ideally give a boost to the organic waste composting industry in Colorado and develop a broader market for compost, thereby supporting greater capacity to accept wallboard.

4.3.2 Gypsum as a soil amendment
This end market is beyond the current recycling capacity for wallboard in Colorado and would be dependent on at least the availability of a front-end loader and trommel screen. Gypsum as a soil amendment requires smaller particle sizes and greater separation of paper and other residuals from the gypsum to prevent unintended consequences for soil health.

Gypsum is being used to treat sodic soils in Colorado, however the theoretical diversion potential is still an unknown due to a lack of information about the quantities of gypsum currently being used and where the practice is taking place. Learnings from the various soil experts described in Section 3.3.2 suggests there would be validity to further exploring land application of gypsum as a direct soil amendment and/or as a compost additive for end market development.

Research is needed to identify agricultural areas with the right conditions where the addition of gypsum would provide soil benefit and determine if growers use it in practice to define the potential customer base. A recommended strategy is to coordinate with the CSU College of Agricultural Sciences as well as CSU Extension offices located in each county. Extension offices are said to work more closely with local growers and have better knowledge of their practices. Hemp growers were specifically cited as a group that uses gypsum so targeted outreach may be done to see if that is a potential market. A study could be done in partnership with researchers before any investments in equipment are made to determine if market development activities should continue.

4.3.3 Wallboard collection and processing for gypsum use in new products

As explained previously, the wallboard and cement manufacturing industries use significant quantities of gypsum to manufacture their products. Promoting diversion through this recommendation would rely on incentivizing Colorado's sole wallboard manufacturer (American Gypsum) or cement manufacturers (e.g. Cemex and Martin Marietta) to start accepting post-consumer gypsum instead of virgin or synthetic gypsum that is more homogenous.[15]

While the economic viability is questionable considering low landfill rates in the state, relatively low prices for virgin gypsum, and potentially insufficient volumes of collected material due to Colorado's population size, a wallboard recycling operation could produce gypsum powder of high enough purity to be used in industrial applications like new wallboard and cement production. First, a reliable market for the material should be confirmed before recycling infrastructure is developed.

Site criteria:

Site criteria

The author chose not to calculate an estimate for a facility building cost because it is dependent on a number of different factors including building design and local real estate and construction costs. For reference on potential site size, Urban Gypsum in Portland, Oregon opened a 75,000 ft2 processing and recycling plant in 2019. USA Gypsum and Gypsum Recycling International are also fully enclosed buildings, whereas wallboard recycling has also been performed openly at landfills in Florida.

Equipment and personnel

Assuming the more simplified process elaborated by RW Beck & SCS Engineers (2003) in Section 2.3, a front-loader, trommel screen and one operator can be employed to perform the recycling process.

[15] It is noteworthy to mention that a member of the closed loop wallboard work group facilitated by Building Product Ecosystems said that CertainTeed, another wallboard manufacturer with US locations, uses 18-20% post-consumer gypsum in their products.

Table 5: Wallboard processing equipment needs

Equipment	Purchase Cost*	Rental Cost	Operating Cost	Avg. Life Span	FTEs to Operate
Front loader	$250000 - $350000	$11500[16]/month	$7,000 - $9,000/yr[xxxvi]	10-15 years	1
Trommel screen	$325000	$11000[17]/month	$50-$70/hr	10,000 hrs	1
Total	$575000-$675000	$22,500/month			

**Estimates based on interview with Power Screening, LLC, web research and research collected for Boulder County C&D Market Report (UHG Consulting, 2011).*

- Loader fuel and service = $12.50 (2003 value adjusted for inflation)
- Processing rate = 21.83 tons/hr (calculated in the reference study)

<u>*Processing cost*</u>
The cost analysis model below is adapted from RW Beck & SCS Engineers (2003) and uses some of the assumptions made in their study while adjusting costs for the 2019 market. In this model, full-time operators are paid at a rate of $25.00[18]/hr and the processing rate used is 21.83 tons/hr as calculated in the reference study.

Scenario 1 – Purchased equipment

$$\text{Cost per processed ton} = \frac{\text{Trommel screen hourly cost (O\&M)} + \text{loader hourly cost (O\&M)} + \text{operator}}{\text{Processing rate}}$$

Scenario 2 – Rented equipment

$$\text{Cost per processed ton} = \frac{\dfrac{\text{(Trommel screen rent + loader rent)}}{\text{Hours per month}} + \text{loader fuel \& service} + \text{operator}}{\text{Processing rate}}$$

Cost per processed ton = **$7.67**

[16] Value of $7925 in reference study. Trommel screen price was $7500 in reference study but increased to $11000 based on current rental website so increased loader rental by a similar amount.
[17] Rough estimate based on research of used equipment.
[18] Estimate based on heavy equipment operator Denver area Indeed job postings.

To calculate a full net profit/loss, we would also need to know the tipping fee, cost of disposal of the paper fraction, the value of material sales (the value of processed gypsum), and transportation costs.

Environmental regulations
The State-level regulations that may apply are:[19]

Solid Waste Act
If processing used/waste wallboard for recycling a facility would need to meet the requirements in Section 8 of the Solid Waste Regulations, Recycling and Beneficial Use. This type of operation (processing wallboard for recycling) would need to register as an industrial recycling facility. Depending on how the materials processed are used, CDPHE might also need a beneficial use of solid waste determination.

Clean Air Act
An air pollutant emissions notice (APEN) and permit would likely be required by the Air Pollution Control Division for emissions created at the site.

Clean Water Act
A storm water permit and industrial discharge permit may or may not be required depending on site operations- issued through the Water Quality Control Division.

Scalability:

Diversion capacity
Based on the calculation from the reference study, a facility utilizing a front loader and trommel screen can process 21.83 tons per hour and during a calendar year the facility could process:

21.83 tons/hour x 8 hours/day x 5 days/week x 50 weeks = **43,660 tons/year**

USA Gypsum's plant processes around 30,000 tons per year so the 43,660 may be a high estimate – however this does give an idea of the diversion potential.

Full scale wallboard recycling facilities sell material primarily into agricultural markets but also sell gypsum back to manufacturers for use in new products that use gypsum. It was not possible to quantify the market size of new wallboard production or gypsum use in agricultural markets. The market with the seemingly greatest diversion capacity in Colorado is cement manufacturing, where it was calculated in Section 3.2.2 that about 145000 tons of gypsum was used in 2018 process and because manufacturers are located in the Front Range.

4.3.4 Alternative building materials

Due to the difficulties with end of life management of wallboard, Colorado could look to promote the development and application of alternative building materials.

[19] Provided by Wolf Kray, Materials Management Unit Leader at CDPHE.

Option 1 – Support development and use of alternative building materials

One alternative building product developed in the EU and commercialized in the US is ReWall, a type of wallboard made of post-consumer recycled carton. The company has primarily sold its products to OEM manufacturers of roofing systems for commercial and industrial facilities. The company was awarded an RREO grant in 2018 to help fund the construction of a facility but the project was dropped and grant rescinded.

During the interview with GreenZip, the representative explained that the company has already worked on projects in Colorado. To further the use of the product in the state, he suggested the idea of doing a demonstration to show how it works. While this is not technically an "end market," state agencies could potentially begin promoting wallboard reuse through this technology and others through environmentally preferable purchasing standards.

Option 2 – Create gypsum bricks/blocks out of wallboard waste

Various gypsum blocks and bricks have been developed from wallboard waste that use different binders worldwide. Through conversations with the Washington State University researchers, ASTM and building code testing take a significant length of time for materials that will be used for structural purposes. As such, developing applications for gypsum blocks that are non-structural would potentially be a more viable market and one that can be applied in the more immediate future.

Market development activities

Both options are still in relative infancy so a range of support options could be applied:

- Revisit contract provisions for procurement and services and implement requirements that encourage use of post-consumer wallboard content materials in procurement and service contracts.
- Explore collaboration with universities to encourage or fund R&D of alternative building materials.
- Develop targeted grant funding state grant for development of alternative building materials and C&D-related solutions.

4.4 Challenges and barriers

There are a number of challenges and barriers for wallboard recovery, some of which are unique to this material but others that apply to C&D more generally. These include:

- Low tipping fees
- Transportation costs
- Low cost of virgin and synthetic gypsum

There are specific barriers related to the need to source separate material on job sites for most efficient recycling and output quality, including:[xxxvii]

- Requires system change – Job site employees are not accustomed to separating on-site
- Contamination resulting from improper disposal practices on site
- Adds to disposal costs associated with additional roll-offs or containers
- Space requirements of additional containers, bins or piles

Another consideration is the potential for sunk costs of investing in wallboard recycling infrastructure. Council members raised the point that the building industry may begin transitioning away from wallboard and substitute different products for building in the future.[20] While that is possibly true, due to the quantity of wallboard present in existing building stock, significant volumes of wallboard will still be disposed of through renovation and demolition activities for many decades to come so solutions for recovering this more contaminated material will be necessary.

[20] C&D Council meeting on September 12, 2019

Additional Resources

Asbestos Containing Materials (ACM) management in Colorado, CDPHE.

Asbestos Bans -
https://environmentalrecords.colorado.gov/HPRMWebDrawer/RecordView/1298241
Asbestos Guidelines for Renovation and Demolition -
https://environmentalrecords.colorado.gov/HPRMWebDrawer/RecordView/1298243
General Information on Asbestos -
https://environmentalrecords.colorado.gov/HPRMWebDrawer/RecordView/1298242

Chen, L., & Dick, W. (2011). *Gypsum as an Agricultural Amendment: General Use Guidelines* (p. 36). The Ohio State University.

RW Beck, & SCS Engineers. (2003). *Innovative Drywall Recycling Grant*. Retrieved from Orange County, Florida website:
https://cdrecycling.org/site/assets/files/1107/orangefinalrpt.pdf

Provides economic analysis model for different wallboard recycling operations.

Townsend, T. G. (2019). *Standard Specifications for the Production of Recycled Gypsum from Scrap Gypsum Wallboard*. Construction & Demolition Recycling Association.

The purpose of this specification is to aid wallboard processors in the selection, receipt, and handling of scrap gypsum wallboard to produce recycled gypsum for various markets. Additionally, regulators can use this specification to develop criteria for scrap wallboard recycling.

SECTION 2 - Treated wood

Wood exposed to the outdoors faces significant threats from predators such as mold, decay fungi and insects like termites and wood borers. These organisms seek to break down the wood fiber, reducing the structural soundness and serviceability of the wood. Preservative treating impregnates wood with a chemical barrier that protects it from these threats and provides long-lasting protection. As a result, the service life of wood is extended from just a few years to as much as 50 years or more.

The treating process utilizes pressure that forces the preservatives into the wood fiber. While there are a variety of preservatives used today, the manufacturing process is virtually the same for all.[xxxviii][1] The residential construction industry commonly used and sold chromated copper arsenate (CCA) treated wood until 2003, when the industry voluntarily discontinued manufacturing CCA treated wood products for home uses. Today products more frequently contain alkaline copper quaternary (ACQ), copper azole (CA) or micronized copper azole (MCA).[xxxix]

The following table provides examples of the different uses of preservative treated wood in construction applications.[2]

Table 6: Representative preserved wood products[xl]

Product	Wood	Preservative	Service
Decking	Sawn softwood lumber	Copper based including ACQ and CA	Exterior above ground exposed to weather
Sill plates and framing	Sawn softwood lumber	Borate or copper-based	Interior but potentially damp with insect damage or decay hazard
Fire retardant wood	Sawn softwood lumber and timber	Borate	Protected above ground location where protection from fire required

The chemicals present in treated wood shape the possible strategies that can be used for end of life management due to environmental and health concerns.

CCA-treated wood has received the most attention with regard to the C&D recovery industry because it may be difficult to distinguish from other types of commonly recovered C&D wood. Despite a voluntary decision by manufacturers to discontinue production in 2004, much material remains in service. CCA-treated wood contains arsenic, chromium, and copper. "Solo-Gabriele et al. (1998) reported average arsenic concentrations of 1,200 mg/kg and 33,000 mg/kg for unburned CCA-treated wood and ash produced from combusting CCA-treated wood, respectively"[xli].

[1] For more information on commonly used wood preservatives and their applications, visit PreservedWood.org
[2] More information on classifications and standards can be found at the American Wood Protection Association (https://awpa.com/images/standards/U1excerpt.pdf)

1. Statewide material volume

Table 7: Treated wood as a percent of total C&D[xlii]

Percent of total C&D
11.1%

Table 8: Treated wood generation estimates by region in 2016, 2019, 2021, 2026 and 2036[xliii]

Region	2016 tonnage	2019 tonnage	2021 tonnage	2026 tonnage	2036 tonnage
Front range	178200	186400	194600	211100	240400
Mountains	7800	8200	8500	9400	11200
Eastern/Southeastern	4600	4800	5000	5400	6100
Western slope	12200	12800	13400	14900	17700
Total	202,800	212200	221500	240800	278400

1.1 Diversion rate

No specific diversion rates were found for treated wood in the United States during this research. Due to a variety of factors including the impracticality of source separating the material, health and environmental concerns related to the various chemical treatments used, treated wood is largely disposed of in landfills and not suitable for processing into mulch, use in compost, or use as biomass fuel.

2. Recovery process

2.1 Collection

The recovery process will look different depending on the project phase. During a demolition the material will likely be mixed in with other C&D debris and difficult to recover. However, certain treated woods could be removed during a soft strip or deconstruction and source separated more easily. In new construction, the material would likely be off-cuts of wood in small quantities and potentially impractical to source separate.

"The best location to separate treated wood waste for proper management is at the generating source. Generators will be more knowledgeable of the type of wood being handled and source separation is more effective than trying to separate treated wood later at a disposal or processing facility. Ideally, dedicated, separate roll-offs should be used at job sites involving the construction or demolition of wooden decks, stairs, fences, playground equipment, landscaping materials, docks and for any other large-scale uses of treated wood. Generators should place all treated wood scraps in these roll-offs for later disposal at facilities permitted to receive treated wood".[xliv]

Another challenge with treated wood is discerning it from non-treated woods. The Western Wood Preservers Institute provides a list of methods one can use to evaluate if waste wood has been treated including[xlv]:

- "The wood may be identified by an ink stamp

- The location of the wood within a project and the project type may also suggest the presence of treated wood. If the wood was in contact with the ground or water, or exposed to the elements, and is not a decay resistant species such as redwood or cedar, it is likely treated material.
- If the material has not been stained or painted it may appear greenish in color. Materials used in industrial or transportation systems may be dark brown in color with a petroleum odor"

2.2 Processing

2.2.1 Sorting

"Preservative-treated wood in the waste stream greatly lowers the overall quality of waste wood, resulting in limitations to recycling wood waste in general." There are several options available for sorting material including visual sorting, chemical stains, laser spectroscopy, x-ray fluorescence (XRF) and near infrared spectroscopy (NIR).[xlvi]

Visual sorting
The most common method for identifying treated wood among lumber, timber and plywood is to look at the color of the wood. Untreated wood and borate-treated wood typically have a light-yellow color. Wood treated with copper, which includes CCA-, MCQ- and MCA-treated wood, varies in color from a very light green to an intense green color depending upon the amount of chemical impregnated into the wood.[xlvii]

Chemical stains
A chemical swab is applied to analyze for the presence of copper and arsenic in materials treated with waterborne preservatives.[xlviii]

Laser spectroscopy
Laser-induced breakdown spectroscopy (LIBS) uses a high-powered laser directed at a wood sample surface to vaporize a small portion of that surface. Chromium can be measured in the microplasma produced to characterize CCA-treated waste.[xlix]

X-ray fluorescence
XRF devices can be used in the field to screen arsenic, chromium, copper and other wood treatments. Users at various stages of the product lifecycle – such as landfill and recycling facilities – are able to distinguish what can be recycled and what must go into lined vs. unlined landfills.[l]

2.2.2 Handling precautions

If the material will be handled for any kind of waste diversion, certain handling precautions should be followed. Safety precautions include:[li]

- "Avoid contact with skin. Wear gloves and long-sleeved shirts. Wash exposed skin areas thoroughly with mild soap and water after working with treated wood.
- Wear a dust mask when machining any wood to reduce the inhalation of wood dust. Avoid frequent or prolonged inhalation of sawdust. Machining operations should be performed outdoors whenever possible to avoid indoor accumulations of airborne sawdust.
- Wear appropriate eye protection to reduce the potential for eye injury from wood particles and flying debris during machining.

- If preservative or sawdust accumulates on clothes, launder before reuse. Wash work clothes separately from other household clothing."

3. Summary of available markets and processing options

If treated wood in the waste stream is intended for diversion preserved wood products often include nails or heavy steel hardware, may be attached to other materials, such as sheetrock, and may be painted or stained. These products are generally large or randomly sized and awkward to handle. Use as fuel generally requires separation of steel and incombustible materials, grinding or chipping to acceptable fuel size, and transportation and use by facilities with the appropriate combustion and control equipment and permits".[lii]

3.1 Reuse

The reusability of treated wood depends on its original intended purpose. In a conversation with a researcher at the USDA's Forest Products Laboratory, the interviewee explained that treated wood should be reused in applications similar to the original application. For example, material taken from a backyard deck should ideally not be turned into a headboard for a bed since the initial product was not intended or risk assessed by regulators for indoor exposure.

Appearance is also a driver for reuse. "Materials with a high appearance value are readily reused, whereas recovery of wood for structural purposes is more challenging. This is certainly in part due to codes limiting the use of non-grade stamped material in structural use. Problems arise because much pre-1950 material was not grade stamped or that the stamps have degraded over time. Another problem can arise when only a portion of a member is removed and that portion is not marked with a grade stamp.[liii] Since not all cities have capabilities to grade structural wood for reuse, this need for grading can be a major challenge in its reuse."[liv]

There is mostly anecdotal case-by-case evidence that treated wood collected from commercial or residential applications has been used for small scale DIY-type projects where the material is remilled (i.e. resawing or shaving wood pieces into new shapes) to create a new product. In one study, researchers collected treated wood waste by partnering with local contractors and produced several different outdoor products that were relatively easy to assemble (See Figure 2). The researchers used CCA treated wood for the project but the same process could be applied to woods with other chemical treatment.

Product	Material (bd. ft.)	Total Board Feet	Hardware	Cost of Hardware	Worker Hours
Porch swing	2 × 4 (8.4), 5/4 × 6 (14.8)	23.2	3-1/2" & 2" screws, 3-1/2" lag screws. 3-1/2" lag bolts	$8.68	2.5
Chair	2 × 4 (6.7), 1 × 4 (4.4)	11.1	2-1/2" screws, 3-1/2" lag screws. 3-1/2" lag bolts	$8.71	3
Trash container	1 × 4 (5.1), 2 × 2 (1.8), Lattice (14 ft²)	6.9	1-3/4" screws, 1-1/4" nails	$2.00	4
Trellis	2 × 6 (22), 2 × 4 (7), 4 × 4 (81.7), 2 × 8 (15.4), 2 × 2 (7.5)	133.6	Corner bracket, 5-1/2" lag screws, 3-1/2 lag bolts, 3" & 2-1/2" screws	$28.70	27
Planter box	5/4 × 6 (4.5)	4.5	1-3/4" screws, 1-1/4" nails	$1.20	1.5
Planters	2 × 4 (12)	12	3-1/2" & 2-1/2" nails	$0.60	2
Patio tables	4 × 4 (18.4), 2 × 2 (3.8), 5/4 × 6 (12.4), 1 × 6 (5)	39.6	2" & 3" screws, 6" lag screws	$18.00	8
Picnic table	2 × 6 (65), 2 × 4 (6.2)	71.2	2-1/2" & 3"screws, 3-1/2" lag bolts	$18.31	8.5
Porch railing	2 × 2 (10), 2 × 4 (8.1), 4 × 4 (8.2)	26.3	All treated, 2-1/2" nails	$6.75	8.5
Deck	2 × 8 (108.8), 5/4 × 6 (100.8), 4 × 4 (36.8)	246.4	Joist hangers, 2-1/2" screws, 1-1/2" nails	$26.18	22
Sawhorse	2 × 6 (10.3), 1 × 6 (2.2)	12.5	3-1/2" & 2-1/2" nails	$0.35	1.25
Block pallets	1 × 4 (3.8), 1 × 6 (5), 5/4 × 6 (9.7), 4 × 4 (4.8)	23.3	2-1/4" and 1-5/8" spiral shank nails	$4.83	2.25
Stringer pallets	2 × 4 (5.3), 1 × 4 (5.1), 1 × 6 (4)	14.4	2-1/4" spiral shank nails	$2.52	1.75

Figure 2: Products manufactured using CCA treated wood[lv]

General contractors associated with the C&D Council provided examples of another type of reuse opportunity. Rather than providing material to a for-profit business, a contractor donated treated wood to a local artist collective in the Colorado Springs area.

3.2 Recycling

Due to environmental and human health concerns of some treated wood preservatives, this waste stream is not suitable for the same common secondary markets as clean wood (i.e. mulch or compost bulking). Recycling treated wood waste into other products is technically feasible and was studied at length during the 1990s. Clausen & Lebow (2011) cite multiple products that had been created from recovered CCA-treated wood (Table 6 below) and it is assumed that similar products could be manufactured from alternatively treated woods since CCA has fallen out of use.

Wood pieces treated with CCA were either remilled or comminuted (i.e. reduced into particles or flakes by grinding or pulverizing) to be able to manufacture the list of products below:

Table 9: Tangible products from reused CCA-treated wood[lvi]

Method[3]	Products
Size reduction	
Shaving, resawing, remilling	Decking, poles, posts
Reconstituted composites	
Wood/wood composites	Flakeboard, OSB, particleboard, MDF, glulam
Wood/cement composites	Sound barriers, structural forms
Thermoplastic composites	Specialty products
Remediation	
Chemical extraction, bioleaching, chelation	Composite products, paper products
Liquefaction	Polyurethane products

3.2 Challenges

Concerns about worker safety and potential environmental exposures of secondary products have been the main challenges in recovering treated wood.[lvii] Alderman et al. (2006) surveyed composite board manufacturers and found that they are "reluctant to consider spent CCA-treated lumber as a possible raw material source. The main reasons found were concerns over health and safety of mill workers, residual chemicals that the material may still have, and that products made from recycled treated wood may not have the same resistance to decay and insects as the original treated-wood product."[lviii] In interviews with representatives from composite board manufacturing associations conducted during this research, they added that quality of input material is of chief concern and there are higher quality recycled wood streams available that are more attractive than C&D wood.[4]

In addition, while remediation and recycling methods are all technically feasible at the pilot scale, most remain economically unfeasible, and there are low incentives to put them in practice.

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[3] For more detailed information see Clausen, C. A., & Lebow, S. T. (2011). Reuse and Disposal. In Managing Treated Wood in Aquatic Environments (p. 18).
[4] Composite Panel Association and APA – The Engineered Wood Association during July 2019

3.3 Energy recovery

Energy recovery is the primary end market for treated wood globally. The most preferable materials for recovery are those found in industrial applications – utility poles and railroad ties treated with oil-based preservatives – because they have high energy content.[5] However, due to low natural gas prices at the time of writing, it was reported by an interviewee that generators of those are stockpiling and not sending material for energy recovery.

Most of the available research on treated wood energy recovery from C&D applications focuses on CCA-treated materials. Energy recovery processes that have been evaluated using CCA as a fuel source include[lix]:

- Slow pyrolysis
- Flash pyrolysis
- Incineration
- Coincineration
- Gasification

Regulatory concerns

Due to the various chemical preservatives used, there are various emissions considerations that must be accounted for if using treated wood for energy recovery.

The presence of CCA-treated wood in a fuel product can dramatically alter the ash characteristics; Solo-Gabriele et al. (2002) observed that if mixed wood waste contains more than 5% of CCA-treated wood, the ash generated from its combustion would leach enough arsenic to be characterized as a hazardous waste based on the toxicity characteristic. Even in small amounts, the elevated metals concentrations in the ash resulting from CCA-treated wood could limit land disposal options."[lx]

Impurities like dirt and moisture content of input materials must be controlled to maintain performance levels of energy output and furthermore there are pollutants that could be emitted if the material is burned improperly including:[lxi]

- Creosote – Polycyclic aromatic hydrocarbons (PAHs)
- Pentachlorophenol – Hydrochloric acid (HCl), polychlorinated dibenzodioxins and dibenzofurans (PCDD/DF's)
- Waterborne preserved wood containing arsenic, chromium and/or copper – These metals are either released into the air or remain in the ash waste stream
- Waterborne preserved wood containing copper

Bolin & Smith (2010) cite studies that show emissions can be kept to acceptable levels through proper pollution control methods like scrubbers, baghouses, precipitators and burning at high temperatures in commercial and industrial applications. [lxii] For example, approved co-generation facilities can use certain types of treated wood as fuel in California.[lxiii]

3.3.1 Biochar

One company in Colorado was found to be Biochar Now, based in Berthoud, CO produces biochar through pyrolysis (high temperature combustion in the absence of oxygen). According to the company's website, Biochar Now works to:[lxiv]

[5] Interview with the Western Wood Preservers Institute October 29, 2019

- Understand biochar's beneficial properties and potential markets
- Understand how to consistently make high-quality biochar at very large scale
- Meet the EPA's emissions standards

A few of Biochar Now's major markets are bioremediation and hemp cultivation and the interviewee cited hemp yields are 2x-3x greater than normal when applying biochar. Other markets for biochar listed by another source include wastewater purification, filtration media, agricultural crop moisture retention and soil nutrient enhancement.[lxv]

The facility brings in beetle kill lumber, pallets, and woody biomass from other sources as its feedstock supply. Beginning in 2019, the facility also initiated work with the EPA and CDPHE to evaluate whether production of biochar using treated wood meets federal air emissions standards under the Clean Air Act. If burned at high enough temperatures, pyrolysis and other forms of combustion are reported to eliminate most pollutants that would be emitted. The kilns used onsite are reported to have emission control stacks that run at 1650° F.[6]

The site currently processing capacity is 66 tons of material per day but is planned to double according to conversations with the owner. Treated wood waste from C&D would supplement the incoming feedstock and could theoretically be managed as mixed wood waste.

3.4 Other strategies

3.4.1 Extraction of preservatives

Researchers have also evaluated the extraction of copper, chromium and arsenic from CCA-treated wood through chemical, biological and thermal processes. Copper and other preservatives have been successfully extracted through chemical processes in a laboratory environment, but these processes are not currently viable to perform economically on a large scale.[lxvi] [7]

3.4.2 Source reduction

An interviewee from the Western Wood Preservers Institute (WWPI) explained how source reduction of treated wood waste is a current focus area for their research. Treated wood is commonly used in building frames, if not required by building codes, and for residential back yard features like decks and fences. A trend exacerbating the challenge of managing these material streams cited by WWPI is the declining service lives of treated wood used in backyard applications. Rather than being replaced due to rot or structural problems that occur over long time periods, they are instead replaced mostly for aesthetic reasons. Keeping these products in service for longer is not technically end market development but this strategy is worth noting if there continues to be value in constructing with treated wood.

4. Plan to bring end markets to Colorado

To complete this section, research performed by Recycle Colorado staff was presented to the C&D Council through multiple stages of in-person meetings, conference calls, and an online survey to collect feedback that ultimately guides the end market development recommendations.

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[6] Interview with Biochar Now on August 6, 2019.
[7] Western Wood Preservers Institute interview October 29, 2019.

Sections 4.1 and 4.2 establish the current market and any noteworthy market trends related to treated wood in Colorado. The end markets plan is outlined in Section 4.3 and is not meant to be prescriptive; but rather the section lays out an analysis of different potential end market strategies based on their estimated ability to divert materials, the scalability of that process or end market, and costs to operate (when information could be found).

4.1 Description of status of existing market including current and near-future capacity or demand

4.1.1 Reuse

Anecdotal evidence was provided by C&D Council participants that artist collectives, schools, makerspaces or other nonprofit entities may accept donations of treated wood for art projects Colorado. Deconstruction contractors and construction projects with ambitious waste diversion goals are the main actors utilizing this 'market' and it is an otherwise uncommon practice. This is presently a small-scale diversion opportunity that lacks the ability to recover a significant amount of material, however creating art pieces or furniture out of the material would add considerable one that would fall outside of a typical end market development focus. The scale of this activity could not be quantified during the research

4.1.2 Recycling

There was no recycling of treated wood found to be taking place in Colorado at the time of this report.

4.1.3 Energy recovery

Testing is currently underway at Biochar Now to determine if treated wood burned in a pyrolysis process meets federal emissions standards.

4.2 Market trends

The primary trend affecting end markets for this material stream is the low price of natural gas which makes energy recovery of treated wood less attractive to potential users.

4.3 Market development opportunities

Market development opportunities are elaborated here including the feasibility of sorting treated wood from mixed C&D wood waste, promoting reuse and supporting R&D in new markets.

4.3.1 Characterizing the treated wood waste stream

A first step towards developing end markets is acquiring better data about which types of treated wood are being generated to determine diversion opportunities. Better information will help inform appropriate end market development since some materials are more appropriate for diversion than others. For example, the states that allow combustion of treated wood typically require as part of regulatory permit conditions that CCA-treated wood be separated and managed distinctly from other mixed woods.

4.3.2 Mixed wood waste sorting feasibility

Source separated loads of treated wood would be ideal to minimize processing requirements, but a potentially more appealing means of isolating treated wood (for contractors) for secondary uses would be to employ a mixed wood sorting facility. The theoretical feasibility and variables to consider for such an operation in Colorado are derived from Jacobi et al. (2007), who produced a cost analysis of sorting of treated wood at a mixed wood recovery facility using three methods: 1) visual sort only, 2) visual sort augmented with PAN stain indicator[8], and 3) visual sort augmented with an XRF unit.[lxvii]

The facility used for the study accepted three streams of material: 1) vegetative wood from land clearing activities, 2) C&D wood (treated and untreated), 3) and wood commingled with other C&D materials. The facility had an initial picking line where wood is sorted from commingled C&D waste and a secondary picking line

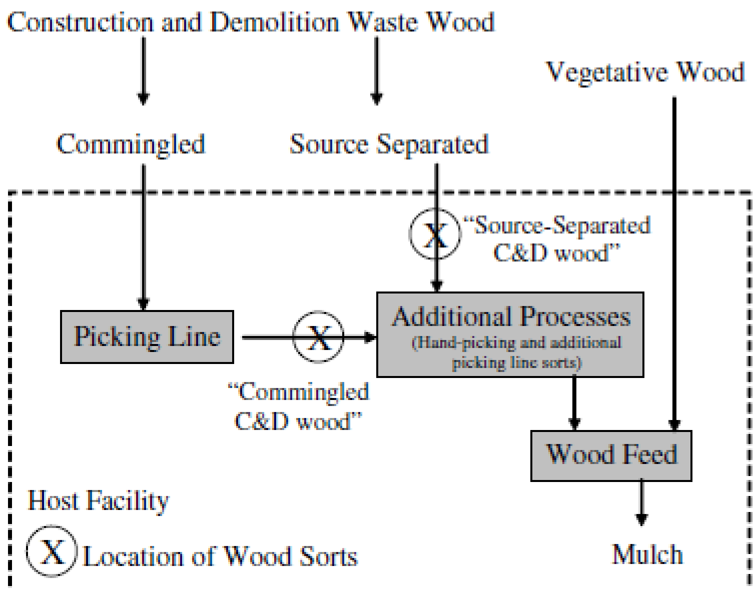


Figure 3: Example of a mixed wood sorting facility accepting vegetative wood, source separated C&D wood, and wood waste commingled with other C&D materials[lxviii]

The researchers calculated laborer hours spent to sort material per metric ton under the three treatments:

1. Laborer hours/ton for visual sort of mixed clean/treated wood (0.5% treated) = 2
    a. Additional labor hours including PAN stain = 2
2. Laborer hours/ton for visual sort mixed clean/treated wood (50% treated) = 2.2
    a. Additional labor hours including PAN stain = 4.2
3. Laborer hours/ton for visual sort plus XRF commingled wood (9% treated) = 9.3

Site criteria:

Site criteria
Based on the model referenced here, the work of separating treated wood from mixed wood waste would best be done at a mixed wood sorting facility. It was estimated in another study that facilities handling greater than 8000 tons of mixed wood waste per year can separate CCA-treated wood from the waste stream economically with laser and XRF systems.[lxix]

[8] A type of chemical test strip used to detect the presence of specific elements.

Equipment and personnel
The only special equipment used in this process is an XRF unit and the PAN stain solution. The cost of labor is assumed to be the 2019 minimum wage in Colorado of $11.10/hr. In the reference study, the researchers used 0.2L of stain per ton.

Table 10: Treated wood processing equipment costs

Equipment	Purchase Cost*	Maintenance Cost	Avg. Life Span	FTEs to Operate
XRF*	$22,000 - $30,000	$1500/year	5-8 years	0.5
PAN stain solution	$11/L	-	-	-
Total	$22,000-$30,000			

*Information provided by E&C Johnson Co.

Processing cost
Using the laborer hours calculation presented under *Diversion Capacity*, the costs per sorted ton are calculated for the present day in Colorado.

$$\text{Cost per sorted ton} = \frac{\dfrac{\text{XRF cost}}{\text{Hours per month}} + \text{operation \& maintenance cost} + \text{labor}}{\text{Processing rate}}$$

Table 11: Treated wood sorting cost calculation with updated input costs

Processing scenarios	**Costs**
Cost per sorted ton visual sort only	Labor ($11.10/hour)/0.5 ton/hour = **$22.20/ton**
Cost per sorted ton 0.5% treated visual plus PAN	Labor ($11.10/hr) + chemical stain ($2.40)] / 0.238 tons/hr (4.2 hrs/ton) = **$56.72/ton**
Cost per sorted ton 50% treated visual plus PAN	Labor ($11.10/hr) + chemical stain ($2.40)] / 0.159 tons/hr (6.3 hrs/ton) = **$84.91/ton**
Cost per sorted ton visual plus XRF	Labor ($11.10/hr) + XRF capital cost and maintenance[9] ($22.10/ton) / 0.108 tons/hr (9.3 hrs/ton) = **$307.41/ton**

The calculation using the model in the reference study and updated cost information for 2019 produced a range of $22.20/ton for the most basic sorting up to $307.41/ton for the most sophisticated sorting. While the visual sorting is cheaper and with greater processing capacity, it was also found to have the greatest inaccuracy compared to the processes using the stain or XRF device.

[9] 9.3 hours/ton processing speed so 4.3 tons per 40 hour work week, times 50 weeks per year equaling 215 tons/year. $4750 per year/215 tons per year = $22.10/ton to use XRF.

Environmental regulations
Appropriate occupational health & safety measures including wearing personal protective equipment should be followed to prevent worker exposure to harmful chemicals. Because some chemical treatments are not designed for direct exposure to the ground, it may be necessary for a proposed processing facility to be contained to control runoff and have impermeable paved surfaces for storing and processing material.

Scalability:

Diversion capacity
The most comprehensive sorting process that utilized an XRF was able to process one ton of material per 9.3 hours or 4.3 tons in a 40-hour work week. This equates to a sorting ability of 223.6 tons per year (52 weeks). For the second treatment that used a PAN stain in addition to visual sorting, they achieved a sorting rate of 4.2 hours per ton or 9.52 tons in a 40-hour work week. This equates to an annual processing capacity of 495.04 tons per year (52 weeks). Using this model, the diversion capacity is limited relative to the size of the treated wood material stream in Colorado.

4.3.3 Promote case-by-case reuse
The potential for upcycling into value added products like art or furniture pieces from treated wood (a material with no present value) should not be overlooked. As cited previously, contractors pursuing aggressive waste diversion efforts in construction projects in Colorado have successfully identified outlets for donating treated wood. Since the economics of establishing new infrastructure or markets specifically for treated wood other than for energy recovery are challenging, one option could be to promote and support case-by-case uses of reusable treated wood from construction and renovation activities.

Under this model, entities engaging in construction or renovation activities would source separate material on-site and self-haul or use a third party to haul material to the desired market. This would both reduce contamination of the treated wood stream and reduce contamination from treated wood of clean woods and mitigate challenges of identifying the type of treated wood after it has been collected.

Potential outlets could be artist collectives, ‘makerspaces’ or other nonprofits capable of converting material into new products. However, it is assumed that these organizations would not be able to consistently accept large volumes of material. One benefit is that the organizations may accept material as a donation rather than applying any kind of tipping fee or similar cost to the generator. A primary hurdle to overcome would be to establish demand with DIY-ers, existing entities that could remill material, or create new enterprises willing to do this work. How could Colorado C&D industry as a whole coordinate efforts to get material to these facilities?

Several challenges would need to be addressed to establish such a market.

- Lack of legitimized infrastructure for treated wood recovery

Strategies to promote this market include:[lxx]

- Lower tipping fees for sorted treated wood waste or raise fees on unsorted C&D wood waste.
- Create drop-off and purchase sites for reusable types of treated wood.

- Communicate benefits of recovery and reuse of treated wood to landfills, recyclers and potential users (individual citizens, parks and recreation, nonprofit organizations).

4.3.4 R&D in new technologies

Energy recovery

Energy recovery is the primary established market for handling this material worldwide. European countries like Germany and Sweden that have built waste management infrastructure around incineration have established stringent emissions standards and advanced technologies for mitigating the levels of pollutants released from these facilities. While there is debate around whether energy recovery infrastructure is a desirable investment, perhaps treated wood is one type of material that is best suited for that form of end of life management. There are concerns that processing the material in any way (for example through remilling) could expose workers to unhealthy levels of the chemical preservatives.

Testing is currently underway at Biochar Now to evaluate whether their pyrolysis process has sufficient emissions controls to process treated wood safely. If this is ultimately approved, this would be a new market for treated wood in Colorado and potentially set a precedent for future developments.

Extraction of chemical preservatives

As mentioned in Section 3.4, laboratory research has been done to find a practical and economical means of extracting chemical treatments from wood. This allows the chemicals to be recovered as well as freeing up the wood for a secondary purpose. While technically feasible and successful under pilot project conditions, no such technologies have been commercialized. Colorado may consider supporting R&D into these solutions.

Additional Resources

Solo-Gabriele, H., Jones, A., Marini, J., Sicilia, A., Townsend, T., & Robey, N. (2017). *Guidance for the Management and Disposal of CCA-Treated Wood*. The Hinkley Center for Solid and Hazardous Waste Management and Florida Department of Environmental Protection.

This document develops guidance for the regulated community and the Department in Florida on the management and disposal of wood treated with chromated copper arsenate (CCA). It contains recommendations, which are of an advisory nature, for the collecting and recycling of treated wood. It also contains specific Best Management Practices (BMPs) that are designed to reduce the amount of treated wood disposed of at unlined facilities and to minimize the processing of treated wood into mulch at processing facilities.

Howe, J., Bratkovich, S., Bowyer, J., Frank, M., & Fernholz, K. (2013). *The Current State of Wood Reuse and Recycling in North America and Recommendations for Improvements.* Retrieved from Dovetail Partners website: http://www.dovetailinc.org/report_pdfs/2013/wood_reuse_and_recycling/current_state_wood_reuse_recycling_namerica.pdf

Page 36-37 summarizes best practices for C&D wood reuse and recovery gathered from interviews with wood reuse and recycling experts.

SECTION 3 - Reclaimed asphalt shingles (RAS)

Asphalt shingles consist of an asphalt-impregnated mat, with the bottom coated with a fine mineral surface and the top coated with a coarser mineral fraction. The asphalt content of an asphalt shingle is 19% to 36% by weight.[lxxi] Organic shingles contain 30 to 36 percent asphalt whereas fiberglass shingles contain 19 to 22 percent asphalt. The other components by weight are[lxxii]:

- Mineral filler/stabilizer (limestone, silica, dolomite, etc.) – 8% to 40%
- Mineral granules (ceramic-coated natural rock, sand-sized) – 20% to 38%
- Felt backing (mat): 2% to 15%. There are two types of mats:
    - Organic felt, made with paper (cellulose)
    - Fiberglass felt

RAS challenges in Colorado

In 2015 the CDPHE determined that reclaimed asphalt shingles (RAS) are no longer considered a recyclable material in the state of Colorado. In their determination, they cited that "during 2014. . . 107,000 tons of waste asphalt shingles were stockpiled at registered recycling facilities in Colorado and only 15 tons of waste shingles were recycled," representing a recycling rate of only 0.01%. Recycling facilities were contacted to gather information about the state of shingle recycling prior to making this determination and all cited extreme limitations in end markets.[1] Due to this policy, any site accepting asphalt shingles is required to have a certificate of designation as a solid waste disposal site. Further history of RAS use in Colorado is addressed in Section 3.

Asphalt shingles were selected for this report by Recycle Colorado's C&D Council, despite going against CDPHE's policy that they are not eligible for the regulatory classification as a recyclable material. As such, end market opportunities listed in this section would have to be in place and proven to work prior to reversing the policy and allowing the exchange of asphalt shingles at any facility other than a certified solid waste facility.

1. Statewide material volume

Table 11: Asphalt shingles as a percent of total C&D[lxxiii]

Percent of total C&D
18%

Table 12: Asphalt shingle generation estimates by region in 2016, 2019, 2021, 2026 and 2036[lxxiv]

Region	2016 tonnage	2019 tonnage	2021 tonnage	2026 tonnage	2036 tonnage
Front range	289000	302200	315500	342300	394700
Mountains	12700	13200	13800	15300	18100

[1] See Baughman, G. W. *Policy: Asphalt Shingles Are Not a Recyclable Material*. (2015).

Eastern/Southeastern	7500	7800	8100	8800	10000
Western slope	19800	20800	21800	24100	28700
Total	328900	344100	359300	390500	451500

1.1 Diversion rate

All material generated in state is being landfilled due to asphalt shingles not being designated as a recyclable material.

2. Recovery process

2.1 Collection

A common replacement period for roofs is 20 years,[lxxv] however due to severe hail in Colorado the average replacement period is seven years in some regions of the state. In the typical re-roofing process a roofing contractor removes the old shingles and replaces them with new materials or places them over the older shingles. A benefit of re-roofing projects is they produce a relatively large amount of uniform material over a short time. In this scenario, the material also is not mixed with any other C&D material and should have low contamination.

2.1.1 Source-separated systems

Most recyclers specify that loads of shingles must be free of any substances deleterious to the shingle recycling process. The primary collection method is for generators to sort shingles from other materials at the jobsite and use separate roll-offs or trailers and self-haul to recycling facilities.[lxxvi]

2.1.2 Mixed load systems

Mixed load sorting systems have also been used in practice and can take on various forms. “Many tear-off shingle recyclers use a simple ‘dump and pick’ operation to remove other debris and waste C&D waste materials. Some of these recyclers use a concrete tipping floor within enclosed or semi-enclosed (open on one side) transfer station buildings. [lxxvii]

2.2 Processing

Non-asbestos asphalt shingles that are segregated for recovery (by a roofing contractor) are often managed at stand-alone recovery facilities, though in some cases mixed C&D MRFs may periodically contract with mobile shingle processing companies to size-reduce shingles for desired end markets. During the first processing step at recovery facilities, unwanted materials (e.g., roofing paper, wood pieces) are removed from the load, and the material is passed through a grinder for size reduction. A magnet extracts nails from the ground material before screening. Screening then allows the facility to obtain the desired size of end products to meet local market demand. [lxxviii]

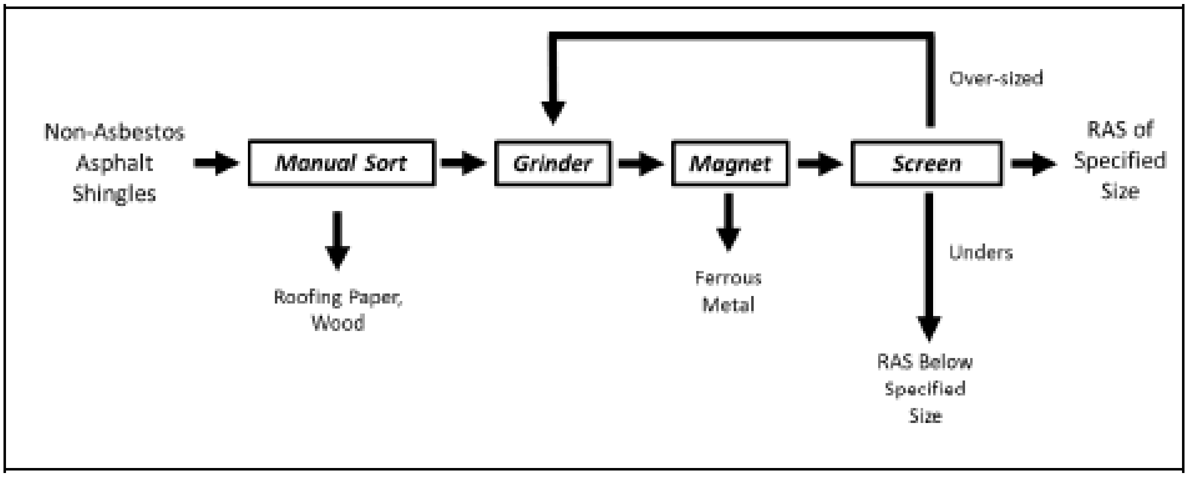


Figure 4: Typical asphalt shingle recovery facility process[lxxix]

2.1.1 Typical processing steps

The content of this section is based on a CDRA best management practice guide for handling post-consumer shingles[lxxx] and supplemented with information from CalRecycle's asphalt shingle guide.[lxxxi]

1. Feedstock quality assurance

If shingles are received in source-separated loads, then usually only visual inspection is performed as a front-end loader or skid steer operator loads material into the feed hopper. Mixed waste sorting systems may use more intensive manual inspection and grapple cranes to assist with pile management and remove bulky items before loading cleaner shingle scraps to the feed hopper. [lxxxii]

2. Receiving and stockpiling of raw feedstock

Material may be tipped onto a tipping floor and then stockpiled for potentially long durations. For example, one interviewee explained that the shingle recycling facility in their state stockpiles material throughout the year and only performs further processing every six months. [lxxxiii]

3. Size reduction and screening

Grinding
Grinders generally include a loading hopper, feeding drum to convey shingles to the grinding chamber, and a grinding chamber with cutting teeth, sizing screen and an exit conveyor with an added pulley head magnet to remove nails and other ferrous metals. [lxxxiv] Grinding may be easier in the winter when the asphalt is more brittle. If the shingles begin to stick together in hot weather, or from the heat of the equipment, spraying with water or blending with sand or gravel may help.

Sizing
Depending on the equipment used, primary grinding may yield 2" or 3"-minus size pieces. Secondary grinding may be required to make smaller pieces if needed; for example, aggregate base may require 3/4"-minus, and asphalt pavement may require 1/2"-minus or 1/4"-minus – preferably as small as possible.

Grading
Depending on the use, the shingles may have to be sieved after grinding, to conform to grading requirements.

Contaminants
For virtually all uses, contaminants must be removed. Possible contaminants may include:

- Metals, which can be removed by a rotating magnet.
- Wood, which sometimes accompanies shingles when the plywood is also replaced in a re-roof job. Wood can be removed by hand or floated off in a water flotation unit.
- Plastic membrane waterproofing liner
- Mastics/adhesives
- Other C&D waste generated during tear-off process and common solid waste (e.g. food, plastic packaging) generated by work crews

4. Final RAS product stockpiling

Stockpiling of the finished product is difficult, as the material tends to re-agglomerate in storage. It may be feasible to blend the material with RAP or "bituminous aggregate" (BA) sand meeting HMA specifications. This pre-blending may help alleviate the re-agglomeration problem during stockpiling.

5. Final QA/QC
6. Transport to end market

2.3 Asbestos
As with gypsum wallboard, the presence of asbestos is a concern when handling asphalt shingles at end of life. Please refer to Chapter 2 Section 2.2.1 for more information about asbestos requirements.

3. Summary of available manufacturing or processing options

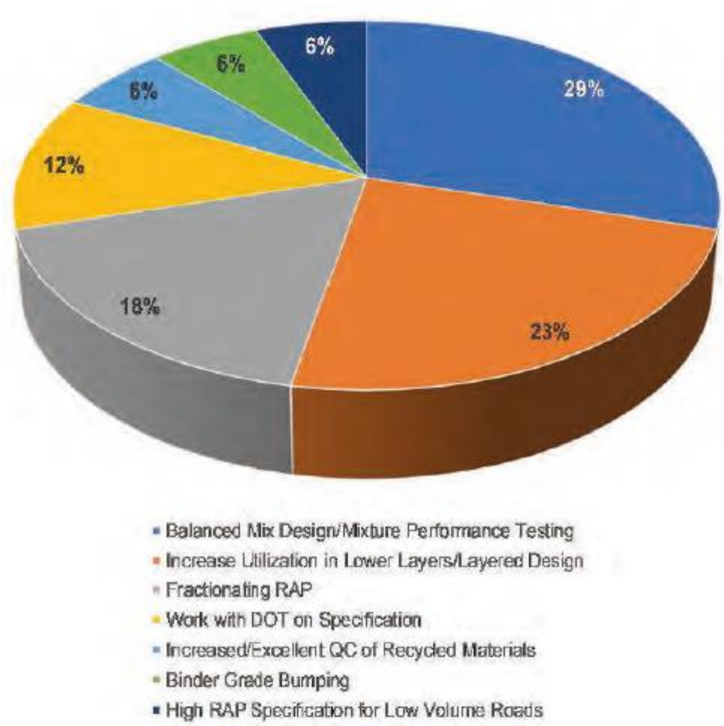
3.1 Recycling

3.1.1 Asphalt pavement
Postconsumer non-asbestos tear-off asphalt shingles are typically recycled in road paving applications, with all but 12 states having used at least some RAS in paving applications. A number of state studies have shown benefits of RAS use in HMA, including: "Increased stiffness of the asphalt; decreased cracking, no effect on moisture sensitivity, decreased susceptibility to rutting, decreased optimum content of virgin asphalt cement." Due to these benefits, certain states permit a small percentage of total feedstock to be from asphalt shingles. Although RAS is widely used in pavement, each state sets its own limit on RAS use. For example, one state allows no more than 5% of RAS in its pavement while another has a 25% RAS mixture limit.[lxxxv]

When it comes to paving, state-funded projects must meet specifications "which are based on Federal pavement performance standards and local climatic conditions and reflect engineering intended to maximize pavement durability. Paving projects not using state or federal funds, such as those controlled by either local authorities or private parties, are not required to meet state specs but often voluntarily follow the state specs rather than develop their own, separate specs."[lxxxvi] The main guiding principles of using recycled content asphalt in the industry are that the product should “1) meet the same requirements as asphalt mixtures with all virgin materials, and 2) perform equal to or better than asphalt mixtures with all virgin materials.”[lxxxvii]

Hot Mix Asphalt[lxxxviii]

The use of grounded recycled asphalt shingles (RAS) in hot mix asphalt (HMA) is by far the most popular method of recycling. Waste shingles are ground and screened to produce 1/2"-minus-size pieces for batch plants, or 1/4"-minus-size pieces for continuous feed plants. The ground shingles are usually fed into and mixed with the aggregate before adding the virgin asphalt binder.[lxxxix]



The economics of RAS use in HMA can vary from location to location and depends on factors such as shingle processing costs (e.g. grinding and moving on site), the cost of landfilling, and most importantly, the price of virgin asphalt cement.[xc]

In the National Asphalt Pavement Association’s (NAPA) Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt 2018, state associations were asked “What limits the use of RAS in your state?” Figure XX indicates the primary responses given during the survey:

Figure 5: What limits RAS use in your state survey[xci]

Based on informal conversations with Recycle Colorado stakeholders and various interview subjects, perceptions of poor performance and competition with RAP and virgin materials are common barriers to utilizing RAS and were mentioned as challenges in CO in the past.

HMA/WMA use in Colorado

Three companies representing 15 production plants in Colorado responded to NAPA’s Asphalt Pavement Industry Survey for 2018. A total of 7.8 million tons of HMA/WMA was estimated to be produced in 2018 according to NAPA’s 2018 annual survey. CDOT produced 1.2 million tons, other agencies[2] produced 3.5 million tons, and 3.1 million tons by the commercial & residential sector. If 5% of RAS was applied in all of these projects, there would have been a theoretical statewide demand of 390,000 tons of material in 2018.

[2] “Other Agency” includes public works agencies, toll authorities, city, county and tribal transportation agencies, as well as US military and federal agencies such as the FAA, National Park Service and U.S. Forest Service (NAPA, 2018)

Warm Mix Asphalt[xcii]
Warm mix asphalt (WMA) is a similar technology to HMA but newer. Similar to results seen with HMA, RAS is seen as a viable addition to WMA mixes and it helps to improve the rutting resistance of the pavement.

Porous Asphalt Pavement[xciii]
A study conducted in 2011 by researchers for the U.S. Green Building Council was one of the first to look at the use of RAS in porous asphalt pavement. The addition of RAS was believed to add stiffness to the otherwise soft porous asphalt pavement mixture. This property of RAS binder could offset the cost of using a more expensive and stiffer asphalt binder. The study found that mixtures containing RAS had better rutting performance than mixtures containing a higher-grade asphalt binder. Brittleness of the RAS mixture at cold temperatures was not evaluated in the study.

Cold Mix[xciv]
Cold mix (or cold patch) asphalt is made of asphalt, aggregate, and a solvent. "High performance" cold patch is made of a higher grade of asphalt, aggregate, and various additives such as fibers and proprietary solvents. One of the primary uses of cold patch is filling potholes, so it is also called "pothole patch." The product can also be used to construct sidewalks, fill utility cuts, and repair driveways, ramps, bridges, and parking lots.

Use of RAS in cold patch has been shown to have a longer lifetime than cold patch without. Cold patch containing RAS has been reported in New Jersey, Washington, and California as well as the city of Chicago. The RAS cold patch mix does not “clump” compared to other cold patch mixes and can be applied without heavy equipment to patch potholes. The patches have a longer life compared to other patch materials, likely due to the fibers from the felts or fiberglass in shingles.

3.2.3 Rural road maintenance and dust control
RAS can be used to mitigate noise and dust generated by traditional rural unpaved roads, reduce aggregate loss, increase lifetime and decrease maintenance requirements.

The use of RAS in rural roads is being studied in Vermont. Currently, Vermont requires recycling of "architectural waste," which includes asphalt shingles, if a project produces more than 40 cubic yards of this waste and is within 20 miles of a facility that recycles it. The Vermont Agency of Transportation (VTrans) and the Vermont Department of Environmental Conservation (VDEC) are partnering on a pilot project looking at the use of RAS in unpaved roads. The organizations are subsidizing the cost of 3,300 tons of 20% RAS and 80% natural aggregate to be distributed to municipalities for use as a driving course on unpaved town roads. If the roads are shown to be feasible and beneficial compared to current unpaved conditions, VTrans and VDEC will promote increased shingle recycling and use of RAS/gravel in the future. [xcv]

Interview with Vermont Department of Environmental Conservation (VDEC)

Through a $10,000 grant, VDEC and VTrans are providing up to five cities with $2,000 each to pilot the use of RAS in addition to gravel for rural road construction and maintenance. Cities voluntarily agreed to pilot the program by being responsible for providing gravel and installing the mix, while the $2,000 is used to cover the RAS and trucking costs. In order to find cities to engage through the program, the project manager explained that the agency partners conducted significant outreach to present the idea to different stakeholder groups including public works agencies and road foremen.

VDEC is also working closely with their shingle processor to ensure the RAS is meeting quality standards. The state's sole recycler is capable of processing about 10% of Vermont's total generation – or 2,500 tons annually.[xcvi] The facility accepts other C&D materials but has a separate bay for asphalt shingles that are dropped off by roofers. The facility rents a grinder twice per year and processes material to under 3/8" and over 3/8", where material under 3/8" is sold to HMA and gravel markets.

Through the partnership VTrans is providing technical expertise to perform quality testing on road performance and so far, only one summer season has been evaluated. If performance is not deteriorated and material costs are competitive with virgin material, there will hopefully be uptake of this recycled material in the market, said the interviewee. The pilot was still underway at the time of writing so final reports will be available in the future.

For further reference, see an initial report on the pilot program[3] and Vermont's 2015 Policy on Recycling Asphalt Roofing Shingles.[4]

3.1.2 Aggregate Base

Little research has been conducted into this market, but shingles have been used as part of the sub-base in road construction. Processed shingles may be blended with recycled asphalt pavement and concrete. It is suspected that the addition of RAS may improve the compaction of the sub-base.[xcvii] This market was reportedly used in Colorado in the past.

3.1.4 Temporary Roads or Driveways

RAS has been used in temporary roads, driveways, or parking lot surfaces. RAS is typically ground to 1/4 inch and passed under a magnetic separator in order to sufficiently remove all nails. The processed shingles are spread and compacted for an easily installed surface.[xcviii]

3.1.5 New Roofing Shingles

Using RAS in new shingle production would close the loop on shingle recycling, however, this application is not being heavily pursued. The Department of Energy and Owens Corning partnered on a project looking at the feasibility of using RAS in different components of new shingle production. The main barrier identified was an increased manufacturing cost resulting from additional transportation and handling to mix RAS with raw granules to prevent re-agglomeration of the recycled material. [xcix]

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[3]Anderson, I. (2019). *Recycled Asphalt Shingles (RAS) in Town Gravel Roads—Initial Report*. Vermont Agency of Transportation.

[4]State of Vermont Department of Environmental Conservation. (2015). *Policy on Recycling Asphalt Roofing Shingles in Vermont*. Retrieved from https://dec.vermont.gov/sites/dec/files/wmp/SolidWaste/Documents/FINALShingleMgtPolicy4.pdf

Interview with Owens Corning

An Owens Corning roofing manufacturing plant was identified in the Denver area and the organization was contacted to explore this end market opportunity further. During an interview with their Science and Technology Director based in Granville, OH, a number of technical and economic challenges were identified that limit the viability of closed loop recycling. According to the interviewee, in order to use RAS in new shingles, the old shingles must be broken down into their constituent parts, which is costly and with technology currently difficult to scale. Furthermore, with relatively cheap prices for virgin material it is not attractive to utilize RAS.

Owens Corning has previously been involved in collaboration with the United States Department of Transportation (DOT) to promote RAS use in asphalt pavement and the interviewee suggested this application was most feasible and could be a significant market.

3.1.6 Fuel

"Fiberglass mat asphalt shingles are estimated to have a BTU value between 3,800 and 4,400 BTU/lb making it a good candidate for combustion. The recovery of the BTU value of waste shingles is an established market in Europe but has limited applications in the US". [c]

3.3 Exploratory solutions

3.3.1 Shingle recycling technologies

During the course of the research, two companies were identified with patented processing technologies claimed to break asphalt shingles down into their constituent parts. Through proprietary technology, both processes generally include several steps to separate the asphalt binder and aggregate material from the base mat, allowing each to be recovered and handled as separate waste streams.

3.4 History of RAS use in CO[5]

Asphalt Specialties Companies, Inc (ASCI), a paving company, was the first to begin experimentation with RAS use in HMA in Colorado. Drawing from extensive experience incorporating RAS into HMA on the east coast, ASCI began testing this practice in Colorado in 2008.

ASCI began accepting post-industrial manufacturer scrap from Owens Corning and source separated loads of RAS from roofing companies at their facility and used a grinder to get material below -1/4" to incorporate into HMA. The type of asphalt used in shingles is 'harder' than what is used in HMA, so they developed a 'softer' mix that better accommodated RAS and performed as well as other traditional products without RAS. The activity was also reported to be financially viable, in that taking the time to collect, process and sell RAS added value to their bottom line. Through a partnership with the Denver Arapaho Disposal Site (DADS) landfill operated by Waste Management, they secured space to perform recycling operations and minimize transportation costs for RAS and residual materials that had to be landfilled.

Roofs to Roads: Boulder County pilot project[ci]

The Roofs to Roads project in Boulder County in 2010 brought together support from CDPHE, the PPAB, the Advanced Technology Grant, EPA Region 8, and Boulder County agencies to test RAS use in an applied setting. The project set out to demonstrate that 100% of RAS in

[5] Combined notes from interview with CDPHE staff and with previous employee of ASCI.

Colorado can be diverted from landfill, establish an ongoing market for RAS use, and avoid greenhouse gas emissions.
Boulder County selected a section of North 63rd St. that was the first road in Colorado to have been paved with RAS in 2009. The one-mile project laid 6 inches of pavement using a 20% RAP/5% RAS (from manufacturer scrap) mix.

RAS market challenges – what happened?
According to the interviewee, the key issue that arose was once this market opportunity was identified, numerous collection facilities opened and began accepting material before sufficient demand had been developed by the paving industry. This caused and relates to several other reported issues that led to the 2015 CDPHE decision to prohibit RAS recycling that should be considered prior to starting a new shingle recycling initiative.

- Improper application of RAS in HMA using too high of a percentage of RAS in the mix that led to poor performing product and reduced demand.
- Abuse of shingle recycling – Facilities opened to collect tip fees for material but had not established end markets, closed their operation and left material stockpiled. This resulted in illegal disposal sites and substantial site remediation costs for property owners.
- Lack of support from CDOT makes municipalities and other agencies hesitant to use material – DOT specs are usually seen as the industry standard in each state.

According to the CDPHE account, during the years when RAS recycling was permitted, Colorado saw various size operations from small scale pilots to large scale stockpiles but none of the initiatives were able to meet material turnover rates due to lack of market demand and processing (sorting, screening and grinding) and sampling (each source of waste shingles needs at a minimum of 2 samples tested by a lab for asbestos) costs outweighing commodity value. Most of the shingle sites opened too quickly assuming that the value from the petroleum within the shingles would make recycling cost-effective but that was not always the case.

4. Plan to bring end markets to Colorado

To complete this section, research performed by Recycle Colorado staff was presented to the C&D Council through multiple stages of in-person meetings, conference calls, and web-based communications to collect feedback that ultimately guides the end market development recommendations.

Sections 4.1 and 4.2 establish the current situation and market forecast for RAS. The end markets plan is outlined in Section 4.3 and is not meant to be prescriptive; but rather this section lays out an analysis of different potential end market strategies based on their estimated ability to divert materials, the scalability of that process or end market, and costs to operate (when information could be found).

This section recognizes that shingles are currently not recyclable in the state and therefore offers guidance for how shingle recycling *could* be resurrected in Colorado.

4.1 Description of status of existing market including current and near-future capacity or demand.

It is assumed that 100% of asphalt shingles generated are landfilled and there is presently no demand for recycled material in Colorado. The NAPA's annual survey of asphalt pavement producers surveyed three companies representing 15 production facilities in Colorado that provided responses to the 2018 survey.[cii] The survey respondents reported that no RAS was used in pavement mixes in 2018 and that 7200 tons of RAS was still being stockpiled in 2018.

Demand will remain at zero if no action is taken to cultivate secondary markets for RAS. Without more in depth research on the subject potentially including gauging interest of hypothetical users of material (e.g. CDOT, municipalities, CAPA), it is difficult to anticipate the potential capacity or demand for this material.

4.2 Market trends

During the previous ten years that NAPA collected data, 2014 and 2015 were the peak of RAS use in the paving industry in the United States. Decreasing steadily until 2017, 2018 saw an uptick in RAS usage but the volume of material used for HMA/WMA is about half of what it was at the peak.[ciii] The fact that RAS is successfully used for paving in other parts of the country is encouraging for Colorado's diversion efforts.

A primary market to consider is the price of virgin asphalt cement since RAS must compete on price with virgin asphalt material. For the first eight months of 2019, the average price of one ton of liquid asphalt binder was about $300 according to the Colorado Asphalt Pavement Association.[civ]Prices can fluctuate significantly which will impact the economic outlook for RAS as an alternative.

4.3 End market development opportunities

The greatest market opportunity remains using RAS in paving applications as evidenced by numerous other states. Due to problematic market development in the past, a controlled and regulated approach will be needed to ensure best practices are followed for collecting, processing and mixing RAS into pavement mixtures,

4.3.1 Establish best practices and market demand for RAS use

Developing markets for RAS would be dependent on preventing the same issues that arose when Colorado previously allowed RAS in paving and ensuring there is a viable market before lifting the prohibition on recycling. As such, it would be advisable to take a phased, precautionary approach to rebuilding a market for RAS.

Potential phased approach to market development

1. <u>Cultivate buy-in from key partners</u>
    a. Disposal site – DADS (Waste Management/City & County of Denver)
    b. Colorado Roofers Association
    c. End users
        i. Colorado Asphalt Pavement Association
        ii. Cities, counties, CDOT, other government agencies
    d. Select a landfill site to collect and process RAS – ASCI previously partnered with DADS and performed grinding onsite
    e. Outreach to potential end users – CAPA, cities, counties, CDOT, other government agencies

i. Create case studies of other states, model specifications, survey the industry

2. Create new pilot project
    a. Use best practices for allocating space, collection quantity and quality, processing, material specifications and end user participation
    b. Determine a source of material – It is recommended to begin with manufacturer scrap, not tear-offs
    c. Ensure appropriate quality standards are followed when using RAS for the targeted end market
    d. Conduct testing – Collect qualitative and quantitative data about product quality at the processing facility, asbestos, on the job site from contractors and regulators

If the test produces positive results:

3. Do further marketing to promote RAS use as standard practice
    a. CDOT is a key stakeholder to influence, however favorability from large cities and counties would also be influential in starting to change industry perception

If demand for RAS is created:

4. Create safeguards and slow rollout of additional projects
5. Change policy – Only if satisfactory market development and controls have been established

CDRA Shingle Recycling Best Practices Guide[cv]
For recycling operations, best practices can be established that guarantee their product quality to end use customers, such as being:

- Asbestos free
- Nail free
- In specified mix ratios for blended product (e.g. 75% RAS/25% sand or RAP)
- ½ - inch minus
- Less than 10% moisture
- Meet or exceed state QA/QC requirements for traditional products

Additional QA testing can also be done by a recycler to verify:

- Gradation with sieve analysis
- Asphalt cement content
- Deleterious materials

Theoretical demand for HMA
A total of 7.8 million tons of HMA/WMA was estimated to be produced in Colorado in 2018. If 5% RAS was used in all projects, the theoretical demand for RAS would be 390,000 tons. Paving activities ebb and flow based on macroeconomic trends so this potential demand would change year to year, however this could be a significant market if initiative is taken to resurrect RAS recycling in the state.

CDOT has reported a general hesitancy towards using RAS in paving mixes for reasons cited previously and so they may not be the most reliable market to begin with. Focusing on the commercial & residential and “other agency” sectors, the market could still represent a total demand of 330,000 tons. CDOT's buy-in is important for larger scale adoption of RAS across the industry but they need additional proof regarding performance.

4.3.2 Asphalt shingle processing

Once demand or a pilot project is set up, some form of processing capacity for asphalt shingles will be needed. Since Colorado currently lacks a mixed C&D sorting facility and the general infrastructure for processing shingles, it is suggested that shingle recovery initially focus on manufacturer scrap rather than from C&D sites because to reduce sorting time and improve quality. Once processes are established, we could transition to source separated C&D materials.

Guidance is taken from CDRA[cvi] on the different components required of a shingle recycling facility and its related operational and economic variables.

Site criteria:
According to CDRA, a grinding operation should ideally be located as close to the supply of the feedstock and end users as possible, whether a HMA plant or otherwise, to reduce transportation costs. If Colorado wants to begin pursuing shingle processing, it must take place at a designated solid waste disposal site. Shingles are already brought to landfills by roofers so a feedstock supply would be readily available.

Material can also be stored outdoors and does not require an enclosed space to protect from the elements. However, outside storage requires properly designed stormwater management and controls to prevent windblown debris.

Equipment and personnel
Two operators are recommended to safely perform the recycling process, although some observed facilities utilize only one employee. Operators may be paid an estimated $25/hr in the Denver area based on heavy equipment operator salaries listed on online job boards in October 2019.

Table 13: Shingle processing equipment needs

Equipment	Purchase Cost*	Operating Cost (fuel + maint.)	Avg. Life Span	FTEs to Operate
Excavator	$300,000	$80/hr	10,000 hrs	1
Grinder	$850,000**	$100/hr	10,000 hrs	0.5
Trommel screen	$325,000	$50-$70/hr	6-8 years	0.5
Total	$1,475,000			

**Estimates based on interview with Power Screening, LLC, web research and research collected for Boulder County C&D Market Study (UHG Consulting, 2011).*
***Grinders may also be rented from Power Screening LLC for $12,000/week or $36,000/month*

Processing costs
Typical processing capacities range from 40 to 100 tons per hour[cvii] depending on facility design and whether materials are source separated prior to being accepted. The processing rate used in the model below is taken as the average, 70 tons per hour. The model to calculate processing cost was adapted from RW Beck & SCS Engineers (2003)[cviii] that evaluated wallboard processing costs.

A new shingle recycling operation may consider renting a grinder due to high upfront capital costs and the intermittent nature of the tear-off business. It is understood this is a fairly common practice based on the responses of various project interviewees. The excavator and trommel screen are assumed to be purchased and the costs shown below is the estimated monthly payment based on an 8-year service life.

$$\text{Cost per processed ton} = \frac{\dfrac{\text{(Grinder rental + excavator + screen cost)}}{\text{Hours per month}} + \text{excavator fuel \& service} + \text{grinder fuel \& service} + \text{screen fuel \& service} + \text{1-2 operators}}{\text{Processing rate}}$$

$$\text{Cost per processed ton} = \frac{\dfrac{(36000 + 3125 + 3400)}{25^{*}} + 80.00 + 100.00 + 60.00 + \text{2 operators } (50.00)}{\text{70 tons/hr}}$$

$$\text{Cost per processed ton} = \frac{77.95 + 12.50 + 25.00 + 25.00}{\text{70 tons/hr}}$$

Cost per processed ton = **$28.01**

*10,000-hour service life over 8 years equals about 25 hours per week.

There may be other indirect costs for testing and engineering design including asbestos monitoring, mix design, or other QA/QC activities not listed here. In another analysis of RAS recycling[cix], a recycling facility found the following costs for each step of the recycling process that may be used as a general guide for making projections about costs.

1. Staging & testing = $5/ton
2. Chipping = $13/ton
3. Sieving = $8/ton
4. Blending = $5/ton
5. Storage & loading = $1.50/ton

Scalability:

Scalability of this activity is conditional on whether RAS can be produced economically and if markets are developed first. A processing pilot would have to begin at an existing permitted solid waste facility and demand for the material must already be secured to make it worthwhile to process RAS. In 2009, ASCI reported diverting over 50,000 tons of asphalt shingles (manufacturer scrap) from landfill. While the collection and processing steps look slightly different for tear-off shingles due to greater levels of contamination, this strategy still represents a significant opportunity to divert material.

Vermont's sole shingle recycling operation processes about 2500 tons of material annually, or about 10% of the total generated in the state. The facility was reported to only process material biannually by renting equipment for a day or two each time, and otherwise stockpiles material until inventory has gone down.

4.4 Surveying attitudes of RAS use in the Colorado paving industry

A general takeaway from the research is the lack of consensus in the industry in Colorado on the quality of using RAS in paving applications. RAS is used heavily in HMA applications in other parts of the country, but conflicting opinions and conflicting scientific evidence were raised on its appropriateness in Colorado. It would be beneficial to understand where our industry stands as a whole to assess whether it would be worthwhile to put more energy into RAS end market development. As the state-level affiliate of the National Asphalt Pavement Association, the Colorado Asphalt Pavement Association could be a valuable partner to help carry out this initiative.

Feedback from CDOT indicated that agency engineers are reluctant to incorporate RAS feedstocks in state projects citing a feasibility study conducted in the early 2010s that raised quality concerns about RAS use in HMA. Instead of targeting CDOT, the interviewee suggested it could be more relevant to develop markets by working with the private sector and municipal level actors. Through other interviews, it was reported that private sector and municipal actors did use RAS in the past and that it had worked well in HMA applications.

To truly develop a market for RAS, we need to know where our industry stands and potentially carry out an education campaign to prove mixes with RAS perform well if the evidence supports that assertion.

Additional Resources

Krivit, D. (2007). *Recycling Tear-Off Asphalt Shingles: Best Practices Guide*. Retrieved from Construction Materials Recycling Association website: https://www.shinglerecycling.org/sites/www.shinglerecycling.org/files/shingle_PDF/ShingleRecycling-BPG-DFK-3-22-2010.pdf

Best practices guide for operating shingle recycling and RAS market development.

National Academies of Sciences, Engineering, and Medicine 2013. *Recycled Materials and Byproducts in Highway Applications Reclaimed Asphalt Pavement, Recycled Concrete Aggregate, and Construction Demolition Waste, Volume 6*. Washington, DC: The National Academies Press. https://doi.org/10.17226/22547.

Provides comprehensive guidance on the use of recycled materials in highway applications.

SECTION 4 - Carpet tiles

Carpet tiles are a composite product constructed with a face fiber, backing, and adhesive and the face fiber may be composed of Nylon 6, Nylon 6.6, PP, PET, polytrimethylene terephthalate (PTT), or approximately five percent other material (such as acrylic, wool, or cotton).[cx] The synthetic fibers account for most of the US carpet industry and each type has varying strengths, weaknesses and applications. Nylon 6 is softer and easier to dye, and 6,6 is more resilient and stain resistant[cxi], and their molecular constructions mean that "nylon 6 can be de-polymerized into back into its monomer and nylon 6 has a melting point of 216 degrees Celsius, while nylon 6.6 has a melting point of 263 degrees Celsius.[cxii] As such, the two Nylon types are used in different recycling end markets.

Carpet tiles are mainly used in commercial applications so as a waste stream they are generated primarily from the renovation and demolition of commercial buildings. Carpet constructed with Nylon 6 and Nylon 6,6 face fibers – and specifically vinyl-backed carpet tiles – hold the most value out of any other material, so they are the primary focus of recovery programs and the primary focus of this report.

1. Statewide material volume

Waste generation data for carpeting are typically not disaggregated from general C&D debris so it is not possible to gain specific figures for the total volume of material in Colorado. As such, assumptions are made to calculate the volume in this report based on a previous report written for Boulder County. According to their synthesis of waste composition analyses carpet and carpet pad was assumed to comprise 3% of C&D waste by weight and 10% by volume.[cxiii]

Table 14: Carpet as a percent of total C&D[cxiv]

Percent of total C&D
3%

Table 15: Carpet generation estimates by region in 2016, 2019, 2021, 2026 and 2036 (extrapolated from Colorado ISWMMP Appendix G, 2016 and Gracestone, Inc. et al., 2009)

Region	2016 tonnage	2019 tonnage	2021 tonnage	2026 tonnage	2036 tonnage
Front range	48200	50400	52600	57000	65800
Mountains	2100	2200	2300	2500	3000
Eastern/Southeastern	1200	1300	1400	1500	1700
Western slope	3300	3500	3600	4000	4800
Total	54800	57400	59900	65000	75300

1.1 Diversion rate

Minimal diversion is currently taking place in Colorado due to lack of infrastructure. The only known recovery operations are based in the Denver area and bring in used carpet tile to resell or recycle in relatively small quantities compared to total generation. The national recycling rate for carpet is estimated to range from 4% - 7.5%[cxv], with California leading the way at 18% due to their own extended producer responsibility legislation.[1] Colorado's estimated diversion rate is below 1% based on what was reported during the research.

2. Recovery process

California has the most successful carpet recovery program in the country and CalRecycle has extensive information about how their program works. CalRecycle's website was used as a reference for explaining how a recovery process should work.

2.1 Collection & sorting infrastructure

Similar to the installation and removal of gypsum wallboard as described previously in this report, carpet installation and removal may be done by a specialized carpet installer for a discrete, relatively short period. During a renovation, it is expected that a specialized carpet installer will perform the work of removing old tiles and installing the new, whereas during demolition the work will be done simultaneously as the stripping of other materials by a demolition contractor. As such, the material can be more easily separated at the source.

When preparing material for collection in source separated loads, contamination from several sources should be reduced to improve recyclability, including[cxvi]:

- Mixed demo debris
- Metals like carpet tack strips and nails
- Paint and drywall mud
- Asbestos
- Excessive moisture makes carpet heavier, interferes with fiber testing devices and may lead to mold buildup

Before being sent to end users, carpeting must first be analyzed by fiber type, sorted into stockpiles of uniform face fibers, then baled and palletized.

2.1.1 Collector/sorter facilities

In essence, collector/sorter facilities bring in carpet materials, separate them by material (e.g. tile vs. broadloom) and fiber type and then ship them throughout the U.S. or overseas.

Planet Recycling, based in Phoenix, AZ was interviewed for more specific information on how a collector/sorter facility operates[2]. The facility is the only collector/sorter operation in the Phoenix area. To collect material, the company provides roll-offs services for job sites, accepts free drop-offs of carpeting if material is palletized and for a fee if not palletized. The rolled broadloom carpet they bring in is immediately landfilled due to no value, vinyl backed carpet tile is sold or donated for reuse or recycled through the CARE program, and carpet padding is baled and sold at a profit to carpet pad recyclers/manufacturers.

Once materials arrive at the collector facility, they must be separated by type to determine which carpeting can be sent off to recycling end markets and which will be landfilled. To do this, recyclers use near-infrared spectroscopic analyzers (~$20,000[cxvii]) to identify the face fiber composition. The materials that are presently most desirable for recycling are vinyl-backed carpet tiles with Nylon face fibers.

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[1] Communications with National Stewardship Action Council in August 2019

[2] Planet Recycling was named as a strong partner for Interface's ReEntry program by a company representative

2.1.2 Manufacturer takeback programs

Large carpet manufacturers like Interface, Shaw, Mohawk Industries and Tandus have established direct takeback programs for carpeting urged in part by the national CARE program. Each organization appears to have their own specifications for how the programs work, for instance what fees might be involved, which party is responsible for hauling, and how the materials will ultimately be diverted from landfill. As an example, Interface's ReEntry 2.0 program is highlighted in the box below.

Interface's ReEntry 2.0 program guidelines[cxviii]

Through Interface's ReEntry 2.0 program, they will work one-on-one with contractors to collect vinyl backed nylon tiles and they also partner with over 40 collector/sorter stations around the US to collect material through CARE.

Program overview:

- Interface will pay for freight on full truckloads of 'approved vinyl tile' from any manufacturer, which equates to 4,000 – 4,400 yds2 or 38,000 – 42,000 lbs.
- Interface will also pay for a drop trailer for full truckloads if they are available at the project location.
- Broadloom and non-vinyl tile are accepted when Interface carpet tile is being installed at rates of $0.55/yd for broadloom and $0.90/yd for non-vinyl tile.

In addition to having no tolerance for contaminants like moisture, asbestos, and other C&D debris, carpet tile must be prepared for pickup according to Interface's specs. "Approved carpet tile must be palletized and secured for shipping, i.e. shrink wrap, banding, strapping. Pallets must be a minimum size of 40"x40" and stacked approximately 54" high. Pallets cannot be double stacked on the trailer and baled material will not be accepted.[cxix]"

Approved vinyl tile includes products from Interface, Shaw, Tandus, Lees, Mohawk, Milliken, Masland and Mannington.

2.2 Carpet America Recovery Effort (CARE)

CARE was established in 2002 after a convening of state and local government agencies, the U.S. EPA, waste managers and carpet manufacturers to develop a solution for diverting carpet from landfills in the United States. The parties established an industry-led product stewardship program with an initial target to divert 40% from landfill and recycling 20-25% of material collected by 2012[cxx], which obviously still has not been met.

Since 2015, CARE has developed several programs to advance their mission, including:

- *Voluntary Product Stewardship (VPS) Program* – Subsidizes collector/sorter entrepreneurs (CSEs) who accept and manage post-consumer carpet, regardless of polymer type through funding by the Carpet and Rug Institute
- *DoubleGreen* certification program for products made with at least 10% recycled post-consumer carpet content

2.2.1 Voluntary Product Stewardship Program (VPS)[cxxi]

The VPS Program is a voluntary, nationwide effort to support CARE's carpet sorting network for diversion of post-consumer carpet from landfills. The main objectives of the program are to provide for economic viability of their carpet sorting network and activities and to pre-empt the enactment of mandatory EPR legislation at all levels of government. The program is funded by voluntary dues paid by Carpet and Rug Institute members (manufacturers and other industry stakeholders) which goes towards financial incentives paid out to CSEs who reuse, recycle, or send carpet materials for WTE disposal.

The payout structure in Q1 of 2019 is[cxxii]:

- Sorted output sold and shipped to processors - $0.02/lb
- Material sent to WTE (pyrolysis, cement kilns, other) - $0.01/lb
- Broadloom reuse - $0.02/lb
- Carpet tile reuse - $0.02/lb

2.2.2 California Carpet Stewardship Program[cxxiii]

Finding that the CARE program had been largely ineffective in reaching the diversion targets decided through the original stakeholder process, the State of California passed AB-2398 in 2010 to establish the California Carpet Stewardship Program. It is the only mandatory carpet stewardship program in the U.S. that most recently assessed a fee of $0.35 per square yard of all carpet sold and/or shipped in California.[3] CalRecycle manages the program while CARE is charged with administering it.

Funds from the carpet assessment are used to:

- Support and incentivize the development and markets for products made from recycled carpet.
- Underwrite the collection and transport of carpet to/from drop-off sites.
- Inform and educate stakeholders about the importance, opportunities and challenges of keeping carpet out of landfill.

The program provides subsidies for actors along the carpet recycling supply chain. For example, collector/sorters receive payouts of:

- $0.02/lb for broadloom carpet collected, sorted, shipped & sold for recycling
- $0.05/lb for carpet tile that is recycled
- $0.10/lb for broadloom sold or donated for reuse
- $0.10/lb for carpet tile sold or donated for reuse

Another noteworthy element of the program is their support to establish Carpet Recycling Drop-Off Sites in every county in California, including rural areas. For free of charge, CARE provides a container for collection, on-call pick-up, transportation and tip fees to recyclers, promotional materials for the local government and host facility and other assistance from CARE staff.[cxxiv]

Challenges with CARE and California

While the mandatory program has been successful in improving diversion rates from 9% to 18% in nine years, CARE has drawn criticism in California from CalRecycle and other concerned parties for not complying with their obligations under the law. Most recently, opponents have contended that the "stewardship program has lacked transparency around recycling costs; provided insufficient financial support to recyclers; and insufficient support to installers who keep the carpet clean, roll it properly and get it to recyclers." Due to ongoing challenges, the state recently passed a new bill AB-729 that guarantees funding to recyclers if CalRecycle decides to seek out a new program administrator.[cxxv]

[3] The recent passage of bill AB 729 in 2019 requires that CARE change the fee structure from the $0.35 flat fee per square yard to a variable rate for different products based on their environmental impact and recyclability.

2. Summary of available processing or manufacturing options

Once carpet leaves an intermediary collector/sorter facility or leaves a specific job site, there are different reuse and recycling processes available. The recycling processes described in Section 2.2 – Section 2.3 were adapted from a Carpet America Recycling Effort (CARE) publication.[cxxvi] Carpet recycling activities are mostly owned and operated by carpet manufacturers centralized around the Atlanta, Georgia area.

3.1 Reuse

Carpet tile can technically be reused as long as it is still in good condition, has minimal contamination, rips or stains, and if it is still aesthetically pleasing to a potential consumer.[cxxvii] They may be reused within the same building or entity to cover break rooms or storage areas, or potentially donated to building material reuse operations[4]. Milliken, a carpet manufacturer, offers their own reuse program for carpet that has been well-maintained. The company facilitates the reuse of gently worn carpet by connecting job sites with their network of local partners. Preparing the material for shipment and freight costs are at the expense of the property owner and/or contractor.[cxxviii]

Four for-profit entities were identified in Colorado that sell carpet tiles for reuse at the time of writing. ReVolve Recycling, Recycled Mat-ters, Repurposed Materials and iCarpets, Inc. all based in the Denver Metro area, collect carpet tiles for free to resell to homeowners, small businesses, school districts, general contractors looking to achieve recycled content goals in construction, and others. ReVolve Recycling was the only facility found to also recycle carpet through CARE.

3.2 Chemical recycling

Chemical recycling processes all require some mechanical pre-processing including size reduction through shredding and calcium carbonate reduction with hammer mills or textile tearing. The mechanical processing can be performed either on site or at an outside pre-processor. Capital requirements are expensive, so these recycling processes are operated on a large scale, mostly by the manufacturers themselves. [cxxix] Nylon depolymerization is the main chemical recycling taking place today.

3.2.1 Nylon Depolymerization

Nylon-6 is broken down into its monomer building blocks and can be used to make recycled content nylon. Non-nylon components can be recycled for other uses or left as a waste sludge. The Evergreen Nylon Recycling facility in Augusta, GA is owned and operated by Shaw Industries, Inc, a carpeting manufacturer and is currently the only nylon depolymerization facility in the United States. With the plant currently in operation, ENR is drawing from over 40 carpet collection facilities across the nation and has collectively kept over 200 million pounds of carpet out of landfills.[cxxx]

3.2.2 End uses for depolymerized material

Depolymerization of Nylon-6 support closed loop recycling processes. Post-consumer material is broken down into the building blocks for new carpet face fibers.

[4] The Denver area Habitat for Humanity ReStore currently only accepts donations of new carpeting

3.3 Mechanical Recycling

Mechanical methods of recycling separate the face fiber from the backing system through a pounding and beating process which can be followed by a series of shredders, grinders, screens, and, in some cases, wash systems. There are several more specific mechanical processing systems described in Section 3.3.1 – 3.3.5 taken from Carpet Recycling 101.

3.3.1 Dry Systems

There are two types of dry processing systems.

1. Beating process uses size reduction through shredding and sequential steps of cleaning and hammer mills to remove ash.
2. Textile process uses size reduction and sequential opening and combing to remove ash.

3.3.2 Wet/Dry Systems

Wet/dry systems comprise several processes and are only economically feasible for Nylon post-consumer carpets.

- Process 1 – Fine particle size reduction using mechanical systems
- Process 2 – Polymer separation using wet separation which separates backing from face components
- Process 3 – Polymer continuous drying
- Process 4 – Densification of polymer streams

These systems produce separated Nylon face and PP backing components and relatively pure Nylon pellets (95%).

3.3.3 Shearing systems

Shearing systems remove the face yarn from carpet via a lateral cutting action, shaving the carpet face from the rest of the carpet. The preferred material that is focused on is Nylon 6 and Nylon 6.6. Required equipment are leather slitting machines converted to specifically do carpet shearing. System outputs include:

- Face fiber – Still in yarn form and fiber is typically baled, typically 99% purity and commands good value in the market
- 60-75% of carpet weight is leftover after this process since only the face is removed so of 1 MM lbs of carpet sheared, 600k to 750k lbs are landfilled.

3.3.4 Calcium carbonate recycling

Filler represents large portion of carpet weight (40% to 50%)

- Process recycles filler into new carpet fillers
- Combines recycled filler w/virgin filler & other materials
- Used as post-consumer content in new carpet product
- East coast Site and West Coast Site
- Many carpet mills in trial phase. Some are already using.

3.3.5 End uses for mechanically recycled carpet

Nylon-6,6 fibers are ground up mechanically and the resulting material can be melted into pellets and sold to auto parts manufacturers for inclusion in their products.

- Input for low value plastics
- Input material for further mechanically processed products
    - Fiber carpet underlayment
    - Plastic lumber composites
- Input for higher value output recycling systems
    - Input for de-polymerization operations

3.4 Waste to energy

Carpet can be used for waste to energy at manufacturer-owned recycling facilities like Shaw's Evergreen Nylon Recycling Plant or in cement kilns. Geocycle, a cement producer based in Florence, CO, was cited in a 2011 report[cxxxi] that the facility intended to begin accepting carpet as cement kiln fuel. According to a company representative, the plant has not yet opted to pursue carpet as a feedstock.[5]

3.5 Other end markets

3.5.1 Spinning post-consumer plastic from carpeting into nanofiber

Verdex Technologies, based in Atlanta, received grant funding from CARE to develop a process for spinning post-consumer carpet fibers into nano/microfibers which can be blended with larger fibers to for use in apparel, air filters, sound dampening materials, wipes and other products.[cxxxii]

4. Plan to bring end markets to Colorado

To complete this section, research performed by Recycle Colorado staff was presented to the C&D Council through multiple stages of in-person meetings, conference calls, and an online survey to collect feedback that ultimately guides the end market development recommendations.

Sections 4.1 and 4.2 establish the current situation and market forecast for carpet tile waste generation. The end markets plan as outlined in Section 4.3 is not meant to be prescriptive; but rather the section is intended as a decision-making tool and lays out an analysis of different potential end market strategies based on their estimated ability to divert materials, the scalability of that process or end market, and costs to operate (when information could be found).

4.1 Description of status of existing market including current and near-future capacity or demand

ReVolve Recycling, Recycled Mat-ters and iCarpets, Inc. located in the Denver metro are the only known carpet recovery operations at the time of writing. ReVolve engages in some recycling through CARE and also sells reusable carpet tile, Recycled Mat-ters does tile and mat resale (unsure of CARE participation), Repurposed Materials also collects and sells carpet tile, iCarpets Inc., another business located in Denver was contacted for this research but did not respond.

4.2 Market trends

For the last annual report available in 2018 for the 2017 calendar year, CARE outlines some of the market challenges facing carpet recovery at the time (a more recent report could not be found). They cite market trends including "decreased demand due to lack of end markets. . . lower oil and natural gas prices [which] have made virgin products more cost-effective than

[5] Interview with Don Fraser November 26, 2019

recycled materials" and the "global oversupply of caprolactam (basic building block of nylon 6) and rising logistics costs throughout the country."[cxxxiii]

Another trend cited by interviewees is that new carpet is more commonly being produced using low value face fibers like polypropylene and PET. Recyclers must pay to dispose of these materials compared to the higher value Nylon fibers, which makes the economics of operating a collector/sorter facility more challenging.

4.3 Market development opportunities

Market development opportunities are elaborated here including supporting existing and developing new carpet collection and sorting infrastructure and advocating for EPR legislation over the long term.

4.3.1 Carpet collection and sorting

It may not be realistic to locate actual end markets (mechanical or chemical recycling processing described above) for recovered carpet in the state of Colorado because the vast majority of recycling takes place in large facilities owned and operated by carpet manufacturers in more densely populated parts of the country. As such, the most viable opportunity and first step for Colorado may be to establish a carpet collection and sorting facility that brings in all types of carpet materials. The core process for such an operation would be to:

1. Partner with CARE to access transportation network, VPS program funding, and other resources

2. Secure incoming feedstock by partnering with and marketing to carpet installers. The material streams include:
    a. *Carpet pad* – There is current market demand for this material to be recycled into new pad. Reported that collectors/sorters can pay around 2c per pound to generators and operate at a profit.
    b. *Nylon 6 and Nylon 6.6 PVC-backed carpet tile* – Accept for free if prepared according to recycler specifications (palletized and shrink wrapped) or for a fee if further processing needed.
    c. *All other carpeting materials* – Charge tipping fee. There may be reuse value but no real demand for recycling.

3. Processing and diversion strategy:
    a. *Carpet pad* – Bale and sell to carpet pad manufacturers for recycling.
    b. *Carpet tile* – Sell reusable tiles at fractional price of new or donate, recycle by collecting full loads and shipping to CARE recyclers.
    c. *All other carpeting materials* – Reuse by selling or donating (if possible), otherwise landfill.

Site criteria:

Site criteria
Because carpet recycling on its own is not a money-making venture, it is recommended that carpet collection and sorting be included in the operations of an existing or new facility.[6] Minimal conditions are required other than providing shelter from moisture and weather. If physical space is limited, it's also possible to rent trailers as is done under California's rural carpet recycling efforts. Decision-makers using this report may consider identifying existing facilities where carpet recycling could be an appropriate addition to the scope of the business.

While the focus of this section is on carpet tile, one interviewee suggested that carpet pad recycling could be initiated at a privately owned MRF since only a baler is needed to prepare the material for recycling.

Equipment and personnel
CARE outlines the following equipment requirements for collection and sorting entrepreneurs (CSEs)[cxxxiv].

Table 16: Carpet processing equipment needs

Equipment	Purchase Cost*	Operating Cost (annual)	Avg. Life Span	FTEs to Operate
Baler	$10,000	$400-$600 (Elec.) $400-$600 (Maint.)	5-6 years	-
Fiber Analyzer	$22,000-$30,000	$1500**	5-8 years	-
Forklift	$34,000	$1K-$1.5K (Fuel) $400-$500 (Maint.)	6-8 years	0.5
Truck	Variable	Variable	Variable	0.5
Total	$66,000-$74,000			

**Estimates based on web research and research collected for Boulder County C&D Study.*[cxxxv]
*** XRF machines typically require 2 X-ray tube replacements during their lifetime at $6000/ea*[7]
**** Pickup, box truck or trailer may be used to collect material from job sites if doing pick up collection*

Other potential variable costs may be roll-off containers and trucks as well as freight.

Processing costs
Processing costs can vary by carpeting type and depending on the collection system, including whether material is palletized by the generator or if it is aggregated and palletized by the processor. If palletized at the processing facility, it was estimated that it takes about 15 minutes of labor to load a full pallet, excluding time for fiber analysis.

[6] At the time of writing, research for Boulder County is underway to study the feasibility of investing in a C&D/organics facility in the County.
[7] Email communication with Niton instruments sales representative December 12, 2019

Carpet pad - $0.03-$0.04/lb to bale[8][9]
Carpet tile - $2.77 to load one pallet[10]
Broadloom carpet - $0.03-$0.04 to bale[11]

Scalability:

Diversion capacity
Data on carpet tile turnover was collected from ReVolve and Recycled Mat-ters. ReVolve handles between 10 – 40 tons of material each month and Recycled Mat-ters did just over 4 tons between January – November 2019. The amount collected by Repurposed Materials is unknown, but altogether there is certainly room to increase capacity.

Unless regulatory measures are taken to divert carpet from landfill in conjunction with market development, it is difficult to speculate how much material could theoretically be diverted by additional collection and sorting capacity. It seems based on the findings that additional diversion activities will need to start small.

Challenges
Because carpet recycling is a low-income generating activity, collector/sorters must have diversified sources of income to stay in business. Related to that is the challenge to afford adequate physical warehouse space to accept carpet materials, process them (baling or palletizing), and stockpile until there is sufficient volume to make transport economical. Recycler demand also fluctuates based on their capacity and incoming supply, so it was stated that during certain periods they will not accept new shipments of material which limits collector/sorters' abilities to move inventory.[12]

4.3.2 Extended Producer Responsibility (EPR)

In 2011, California found that CARE's voluntary program had not been effective in meeting the high targets developed through the initial stakeholder process in the early 2000s. In response, they legislated the country's first and only mandatory product stewardship program for carpet and today California has a significantly higher diversion rate than the national average. Though CARE did begin providing financial incentives to collection and sorting entrepreneurs (CSEs) that subsidize material recovery through their nationwide Voluntary Product Stewardship program, carpet diversion rates are still low on average nationwide.

Carpet collection and sorting in the absence of regulation and incentives is economically challenging and provides only small marginal profits. At the time of writing, other states Minnesota, Illinois and New York are discussing the feasibility of their own EPR legislation for carpet materials. Policymakers in Colorado may be prioritizing EPR and other policies for different waste streams, however California's carpet program could be looked to as a model in the future. EPR legislation of any kind is of course contentious but in the case of carpet, the economics do not appear to favor purely market-driven recovery efforts.

For more information on carpet stewardship and market development, see The Product Stewardship Institute's (2015) *Advancing Carpet Stewardship: A How-To Guide* page 8-9.[cxxxvi]

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[8] Interview with Planet Recycling September 6, 2019
[9] One vertical baler estimate said it can process 2 bales/hr,and up to 750lbs per bale[9]
[10] Based on one hourly worker ($11.10 minimum wage) loading four pallets per hour.
[11] Assumed similar price as baling carpet pad, however bale characteristics are likely different.
[12] Interviews with ReVolve Recyciing and Planet Recycling

This guide also contains information regarding best practices for collection and storage of material as well as addressing the challenges of rural communities.

Additional Resources

The Product Stewardship Institute. (2015). *Advancing Carpet Stewardship: A How-To Guide*. Retrieved from
https://cdn.ymaws.com/www.productstewardship.us/resource/resmgr/PSI_Reports/2015.10.14_PSI_Carpet_Report.pdf

Carpet America Recovery Effort. (2018). *Annual Report 2017*. Retrieved from
https://carpetrecovery.org/wp-content/uploads/2018/05/CARE-Annual-Report-2017-FINAL.pdf

Provides detailed analysis of the carpet recycling industry in the United States for 2017, including market trends and surveys of CARE participants.

SECTION 5 - Plastics

Plastics are a diverse category of materials whose applications and end of life management practices can vary significantly. As such, the research attempted to identify the most prevalent types of plastic found in the C&D sector and describe the available processing and end market solutions. A 2011 analysis for Boulder County[cxxxvii] stated that the primary plastics used in C&D activities are rigid PVC (polyvinyl chloride), high density film (HDPE), and low-density polyethylene (LDPE) stretch plastic film and this was assumed to be consistent with the present market.

To further characterize the scope of C&D plastics in Colorado, the relative proportion of different plastic types used in construction activities was estimated in an EU study and is applied here.[cxxxviii] The researchers concluded that of plastics consumed in C&D, 51.7% is PVC, 12.8% is HDPE, EPS (expanded polystyrene) is 8% and LDPE at 5.1%. RC stakeholders were then contacted to verify these numbers for Colorado and it was assumed they are roughly accurate.

The plastics are commonly used in the following applications.

Table 17: Plastic applications in construction[1]

Plastic Type	Uses
LDPE	Plastic packaging film, vapor barriers
HDPE	Packaging film, vapor barriers, pipe
PVC	Rigid: pipes, siding, windows Flexible: flooring, roofing, shutters, cables
EPS	Insulation

1. Statewide material volume

In their waste composition study of C&D waste in the US in 2014, the Construction and Demolition Recycling Association (2017) estimate that plastics comprise >1% of the C&D waste stream. This estimation is applied to determine total plastic waste from C&D activities in Colorado.

Table 18: Plastic as a percent of total C&D[cxxxix]

Percent of total C&D
>1%

[1] Table put together drawing from research findings in Section 3.

The following estimate was produced counting plastic as 1% of the C&D waste stream.

Table 19: Plastic generation estimates by region in 2016, 2019, 2021, 2026 and 2036[cxl]

Region	2016 tonnage	2019 tonnage	2021 tonnage	2026 tonnage	2036 tonnage
Front range	16100	16800	17500	19000	21900
Mountains	700	700	800	800	1000
Eastern/Southeastern	400	400	500	500	600
Western slope	1100	1200	1200	1300	1600
Total	18300	19100	20000	21600	25100

1.1 Diversion rate

In 2008 it was estimated that around 5% of plastics in the C&D waste stream were diverted from landfill in the US.[cxli] If the 5% diversion rate is applied to Colorado's estimated 2019 generation, 955.7 tons of material will be diverted across the state this year. However, based on anecdotal evidence collected during this research, 5% diversion is suspected to be a high estimate for the Colorado market.

2. Recovery process

2.1 Collection

"While plastics are highly recyclable, they are often heavily soiled by the time they come off of a C&D jobsite. Both post-consumer scrap such as PVC piping, as well as used LDPE stretch film pick up contaminants easily such that they may not be acceptable for recycling. Furthermore, these materials are costly to haul based on their low density and low market value in small quantities." Receiving clean material and hauling it efficiently are the two primary operational efficiencies." [cxlii]

Some recovery operations target plastics (e.g., plastic buckets) but largely plastics are traditionally not focused on as a material stream to divert from landfills during construction or demolition activities.[cxliii] During new construction, C&D plastics are typically disposed of along with mixed C&D debris and are not source-separated since they comprise a small proportion of total materials by weight and have low value. This low value also makes it impractical or undesirable to separate plastics from renovation or demolition waste as well.

Feedback from the C&D Council and project interviewees indicated that this holds true for the Colorado market. Specific recycling of C&D plastics was not found to take place on any significant scale at the time of writing, other than when contractors have the resources to pursue aggressive waste diversion goals to acquire green building certification credits. A few contractors reported using a program offered by Trex to take back plastic film. For that program, Trex requires a minimum of 500 pounds of material be collected before they will accept, and the contractor reported combining plastic waste collected from their construction operations and office-related wastes.

2.2 Processing

Even in leading materials recovery markets, C&D plastics are typically handled and disposed of as residual waste or shredded along with other mixed debris to produce alternative daily cover or to be used in energy recovery processes.[cxliv] Most plastic recycling focuses on post-consumer sources from household streams or from industrial or commercial entities generating post-industrial material.

Quality and uniformity of material are of chief concern for recovery and the ability to recycle plastics. Due to these concerns, the plastic material currently being recycled in CO is primarily generated by industrial or commercial entities with more homogenous waste streams not that which has been collected from household recycling streams. Material is also typically separated into single-resin streams because different plastics have different melting temperatures. “If two plastics that melt at different temperatures are mixed, the feedstock's appearance and performance will be altered and may prevent its use in a particular end product. For example, HDPE milk jugs are blow-molded, while HDPE margarine tubs are injection-molded. These two processes require different fluidity levels, which, if mixed together, produce a fluidity level that may no longer be suitable for some manufacturing”.[cxlv]

Preparing plastic for secondary uses can essentially be broken down into two categories – mechanical and chemical recycling. Mechanical recycling is the most common form practiced and Colorado has two companies performing this activity at the time of writing - Waste-Not Recycling based in Johnstown and Direct Polymers in Denver. Chemical recycling applies to a range of technologies that are being heavily researched at the time of writing.

2.2.1 Mechanical recycling

Mechanical recycling refers to processes like shredding, sieving, and grinding. Depending on the degree of contamination and the composition of the collected material, the final processed product’s quality can vary substantially. High quality recycled material can be re-used in the same types of plastic applications, whereas low quality material from mixed waste fractions can only be “down-cycled” into different products made from a mix of other material.[cxlvi]

2.2.2 Chemical recycling

Chemical recycling denotes a number of processes, by which the polymer molecules that constitute plastic materials are broken up into smaller molecules. These can either be monomers that can be used directly to produce new polymers or other substances that can be used elsewhere as starting materials in processes of the basic chemical industry” [cxlvii]

3. Summary of available processing or manufacturing options

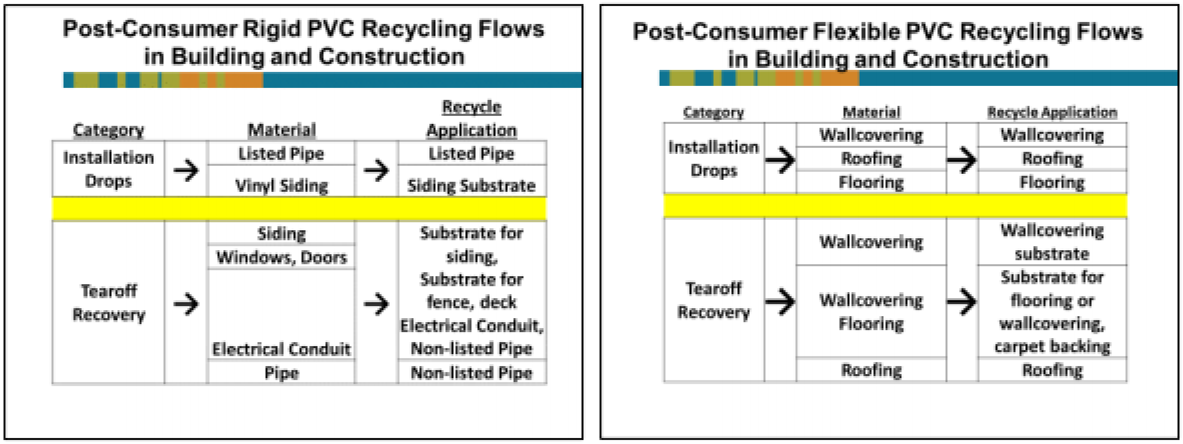
This section outlines known reuse and recycling solutions for the major categories by weight of C&D plastics and identifies Colorado’s plastic recycling infrastructure.

3.1 PVC

The majority of PVC is used in building and construction end-use applications due to its durability, low maintenance and low cost.[cxlviii] Typical applications include windows and doors, pipe, siding, fencing, decking, molding, trim, and wire and cable jacketing. It’s also the least post-consumer recycled plastic in the United States. The EPA calculated that 910,000 tons of PVC waste are generated annually but less than a quarter of 1 percent is recovered for recycling.[cxlix]

One of the reasons for this is the presence of chlorine and other hazardous additives such as lead, cadmium and PCBs. An EU Commission Green Paper cited that most PVC products used in building applications contain lead or cadmium but that this stream also has the highest potential for high value recycling. [cl]

Figure 7 below provides a list of the most common recycling flows for PVC material from building and construction[cli]:



**Listed vs. Non-listed pipe: American National Standards Institute (ANSI), Underwriters Laboratories (UL), National Electrical Manufacturers Association (NEMA). Certifications for quality and safety standards for a wide variety of products and processes*
https://www.ul.com/certification
Figure 7: Recycling flows for PVC products[clii]

The industry commonly practices post-industrial recycling – recovering production trimmings and scrap and returning them to their vinyl extrusion supplier or local recycler for reprocessing into the same or other products.

Recovinyl
In the EU, Recovinyl certifies companies that recycle PVC waste as well as accredited converting companies that purchase recycled PVC to manufacture new PVC products. By certifying the quality and quantity of the recycled PVC that is produced and purchased, Recovinyl stimulates the supply of post-consumer and post-industrial PVC waste being recycled in Europe by creating a demand for recycled PVC material in the converting industry.[cliii]

3.1.1 Vinyl siding

Landfill Reduction and Recycling, Inc, a mixed C&D recovery facility based in Wisconsin, performs mechanical recycling of vinyl siding. The siding is processed into flake form and sold back to siding manufacturers as feedstock for new siding.[cliv]

3.1.2 Windows & doors

This waste stream is assumed to be primarily generated by renovation and demolition/deconstruction activities.

PVC windows and doors are highly engineered products containing multiple materials. Depending on the capabilities of a recycler, windows and doors can either be shipped as is to the recycler or if the recycler does not have the capability to shred and separate the individual components, they will need to be separated before recycling. For windows, this means separating the frames from the glass. Metal fastening components like screws and reinforcements also make up a portion of the total mass, especially in windows.[clv]

AAMA Pilot: Avoiding the Landfill – the Recycling of Vinyl Windows and Doors[clvi]
A pilot project and case study run by the American Architectural Manufacturers Association evaluated the challenges of establishing an industry-led vinyl window and door recycling program.

Key findings presented in the study were:

- Vinyl windows are recyclable but post-consumer window and door recycling is only done on a limited basis.
- An industry-wide window and door recycling program can't feasibly focus on only vinyl windows and doors, but rather products made of all material types.
- Vinyl window units are an inconsistent waste stream due to their high durability and infrequent replacement. However, due to the sheer number of vinyl windows and doors being used in the market since the early 1980's, they will begin entering the waste stream more rapidly in the future.

3.1.3 Light concrete

PVC waste is mixed into concrete to decrease its density. Such 'light concrete' is currently manufactured using polystyrene. Applications include non-structural elements like roofs, insulation walls and slabs covering gutters. Trials with PVC waste were promising, although flexible waste failed to meet all the stringent migration tests. One advantage of this option is that it can be applied in several small plants.[clvii]

3.2 HDPE/LDPE

While rigid HDPE and LDPE film are used for different purposes, their recycling end markets can be similar.

One of the most common applications for HDPE in construction are plastic sheets applied as part of the wall assembly to control moisture and other beneficial properties. A recognizable product in this category is DuPont's™ Tyvek® building wrap which is made from 100% HDPE. According to their website, "Tyvek® or products made from Tyvek® can be mechanically recycled into products such as underground cable protection piping, automotive parts, blown film, packaging cores and trays. Products made from Tyvek® which are printed, glued, welded or sewn can recycled. This includes banners, signs, envelopes and other print products made with Tyvek®".[clviii] Other construction applications for HDPE/LDPE include plastic lumber, buckets and various types of pipe. In addition, one of the most identifiable HDPE products in the C&D waste stream are 5-gallon buckets used for various purposes on job sites during construction and renovation projects. As cited in the introduction, LDPE stretch film packaging is another common material in C&D waste.

3.2.1 Recycling process

When recycled, HDPE is usually separated by grade due to varying thickness, contaminants are removed, and the material is pelletized or granulated for use in new HDPE products.

3.2.2 End market: Plastic lumber and composite lumber

A large portion of recycled HDPE/LDPE goes into plastic lumber or composite wood-plastic lumber manufactured in the U.S. by a few different companies. Plastic lumber is 100% plastic, whereas the composite wood is a blend of plastic and wood residues. Both products are strong and durable building materials that can be customized for a wide variety of applications like decks, fences, furniture and other products to mimic the appearance of wood but with greater durability.

3.3 Expanded Polystyrene (EPS)

In building applications, EPS is sold in panel form and used as building insulation. "Sheathing is one of the most basic and widely used applications for EPS insulation in residential and commercial construction. It helps create an envelope around the structure, covering wall cavities and studs to increase their resistance to heat transfer and moisture protection. It is used in renovations as well as new construction because of its compatibility with wood and steel framing, and masonry".[clix]

3.3.1 Recycling process

The process begins with size reducing the material through a shredder. The foam is then densified into a liquid and extruded through a small outlet of the machine to form an ingot of EPS, ready for another use. Compacting the foam makes for easy transportation of the material"[clx].

Nationwide Foam

Nationwide Foam partners with facilities during re-roofing through their Green Disposal Alternative. The company provides on-site trailers and field representatives to ensure materials are prepared correctly for loading and hauling. In April 2009 the Denver Public School system partnered with Nationwide to recycle materials from 11 scheduled school re-roofing projects.[clxi]

Agilyx

An Oregon-based energy company with a PS foam conversion process that uses post-consumer PS to produce a styrene monomer and other products through chemical recycling. In 2017, the company had a processing capacity of 3,000 tons of foam per year.[clxii]

Polystyvert

Montreal-based company that recycles PS using a dissolution technology and purification process to remove contaminants resulting in a high purity recycled product.[clxiii]

3.4 Characterizing Colorado's potential end users

DP and WN were asked about their perceptions of local demand (within Colorado) for recycled plastics. Colorado plastics manufacturers are characterized by relatively small, specialized companies that each have unique specifications with limited ability to blend recycled materials into their products. As such, they would need material blended to their specifications by a recycling processor in order to use recycled feedstock which is a presently lacking capability. It was also said that there are no large-scale manufacturers in state who usually have the greatest capacity to utilize recyclables.

4. Plan to bring end markets to Colorado

To complete this section, research performed by Recycle Colorado staff was presented to the C&D Council through multiple stages of in-person meetings, conference calls, and an online survey to collect feedback that ultimately guides the end market development recommendations.

Sections 4.1 and 4.2 establish the current situation and market forecast for plastic recovery. The end markets plan as outlined in Section 4.3 is not meant to be prescriptive; but rather the section is intended as a decision-making tool and lays out an analysis of different potential end market strategies based on their estimated ability to divert materials, the scalability of that process or end market, and costs to operate (when information could be found).

4.1 Description of status of existing market including current and near-future capacity or demand.

Colorado's current infrastructure for plastics consists of several MRFs, Waste-Not Recycling in Johnstown and Direct Polymers in Denver. MRFs handle primarily post-consumer MSW streams, whereas Waste-Not and Direct Polymers focus on commercial and post-industrial materials. Municipal MRF's sort and bale post-consumer plastics but those materials end up leaving the state for further processing, whereas WN and DP clean, grind, and pelletize the material for domestic markets.

Waste-Not deals mostly with HDPE, LDPE and LLDPE and focuses on commercial and industrial production scrap as its feedstock because post-industrial material is more homogenous and cleaner. In a 2011 market analysis for Boulder County, Waste-Not reported that they would accept full truckloads of baled HDPE and LDPE plastic film and PVC pipes in 4' lengths that are bundled, clean and undamaged.[clxiv] Since then, the facility moved away from accepting PVC due to environmental concerns. The majority of Waste-Not's pellets are LDPE which are sold to the composite decking industry located outside of Colorado.

Direct Polymers accepts all types of plastics from commercial and industrial production scrap to post-consumer feedstocks, but material must be pre-separated. According to their website, they process over 500 tons of material per month.[clxv] A representative explained they do not bring in much C&D material, however they do accept from C&D sources occasionally and have reliable out of state markets for PVC that produce windows, fencing, pipe and siding. Direct Polymers has participated in the NextCycle program and applied for and received grants through RREO to help expand their business. At the time of writing, they are pursuing expansion of their post-consumer material lines and have capacity at their present warehouse to expand the footprint of their operations.

4.1.1 Characterizing Colorado's potential end users

Direct Polymers and Waste-Not were asked about their perceptions of local demand (within Colorado) for recycled plastics. Colorado plastics manufacturers are characterized by relatively small, specialized companies that each have unique specifications with limited ability to blend recycled materials into their products. As such, they would need material blended to spec by a recycling processor in order to use recycled feedstock and our current companies don't possess that capability. It was also said that there are no large-scale manufacturers in state with the greatest capacity to utilize recyclables.

It was the opinion of one respondent that rather than aiming to develop existing or new manufacturing facilities that can accept recycled material, Colorado should focus on upgrading our processing capability.

4.2 Market trends

Generally speaking, plastics recycling remains challenging due to multiple factors but chiefly the current low price of fossil fuels that reduces costs of virgin plastics. As with many markets at the time of writing, material prices are also volatile which makes it difficult to make predictions.

Prices for post-consumer plastics from curbside collection programs may give some indication of overall markets, however C&D plastics are not necessarily the same grade, go through a different collection process than plastics and are not traditionally a focus of C&D recycling programs. According to RecyclingMarkets.net, in November 2019 the national average price of color HDPE was 14.56 cents per pound (up 11% since the previous month), but still significantly below the 30 cents per pound rate five years ago, while Grade A film (LDPE less than 5% contamination) is trading at 8.75 cents per pound.[clxvi] Estimating the value of recycled plastics from C&D demands a better understanding of levels of contamination and how that would impact the recycling process.

Recent news shows encouraging momentum towards increased market demand for recycled plastics in domestic markets:

- Composite decking manufacturer Trex that uses HDPE and LDPE is expanding their manufacturing[clxvii]
- HDPE pallet manufacturer Greystone Logistics is expanding their manufacturing – converts PCR HDPE to pallets[clxviii]
- Composite decking manufacturer Fiberon, based in Meridian, Idaho, is renovating its facility and installing new equipment to expand its capacity to use recycled PVC.[clxix]
- *Every Bottle Back* joint initiative with The Coca-Cola Company, Pepsico, Keurig-Dr. Pepper, World Wildlife Fund, The Recycling Partnership and Closed Loop Partners will invest in PET recycling infrastructure and education.[clxx]

4.3 Market development opportunities

Plastic recovery is challenging in general, and even more so for plastics used in building applications due to high levels of contamination and difficulty to adequately sort. In Colorado, not many contractors are willing to separate the material on job sites unless they have the resources and incentive of a green building certification, and if the material is commingled and sorted downstream then the value is lost. Improving plastic diversion from C&D operations is primarily a collection problem. Further, due to the relatively low proportion of plastic in the total C&D stream and limited secondary markets, these materials are low priority for diversion programs globally and usually end up in residual waste streams.

With those challenges in mind, it's difficult to provide specific guidance on how to improve C&D plastics markets so this section provides recommendations for improving plastic recovery infrastructure in the state more generally. According to project stakeholders contacted for this project, the foremost need for Colorado's plastic recovery market is a greater volume and sophistication of processing infrastructure. Automated systems that incorporate optical sorting were mentioned as the greatest need that would advance plastics recycling in the state going forward. Once Colorado expands recovery for MSW and industrial waste streams this will hopefully spill over into more challenging waste streams like C&D.

4.3.1 Collect better data about C&D plastic waste stream

There is a lack of data about the volume and quality of plastics in the C&D waste stream. In order to write the materials summary in previous sections, assumptions were made about the composition of C&D plastics in Colorado based primarily on visual observations from other research and quantitative data from the EU. More specific data could be gathered about Colorado markets which may be the first logical step towards exploring C&D plastic recovery and whether or not investing in equipment would be financially viable. Better data about levels of contamination, characterization of the materials and their grade and quality is necessary to evaluate what processing equipment is needed to prepare materials for end markets since equipment is highly specialized and calibrated to specific plastics.

This could be achieved by promoting a C&D plastics waste sort at an existing or planned facility. A mixed C&D sorting facility such as the proposed site in Adams County led by 5280 Waste & Recycling Solutions's could be a possible location to perform this work.

4.3.2 Increased processing infrastructure

The current recycling infrastructure (i.e. grinding, pulverizing, pelletizing) is comprised of Direct Polymers, who specializes in rigid plastics, and Waste-Not Recycling that specializes in film. They are the primary material processors in Colorado and run about 6,000 tons and 11,000 tons per year through their equipment respectively. These facilities do not possess sorting capabilities at this time so materials must come pre-sorted and baled or bundled and they also focus on post-industrial scrap rather than post-consumer materials. It was suggested that investments in optical, robotic or other automated processes would be necessary to identify higher from lower grade plastics and clean enough of the contamination to support greater recovery.

Site criteria:

Site criteria
No special requirements are needed to locate a new facility aside from an enclosed building in an industrial zoned area.

Equipment and personnel
As cited previously, plastic processing equipment can vary as much as the targeted materials and desired end markets. But for bulky plastics from contaminated C&D streams, shredding and grinding capacity and especially cleaning systems like washing, metal detection, separation and optical sorting would be required to produce clean material that is efficient to transport. To get an idea of equipment requirements, Waste-Not Recycling provided information about the equipment used at their facility to process post-industrial plastics and the approximate values.

Table 19: Equipment used by existing processors[2]

Equipment	Capital Cost	Avg. Life Span
Grinder	$200,000	12-15 years
Pelletizer	$600,000	12-15 years
Pulverizer	$140,000	12-15 years
QC analysis equipment	$50,000 combined	12-15 years

Automated sorting equipment was cited to range anywhere from $200,000 - $2 million in value at this time and more specific price information was not gathered due to challenges getting numbers from equipment manufacturers.

[2] Collected through interviews with Waste-Not and Direct Polymers on multiple occasions during Fall 2019

Processing costs
Due to the unknowns surrounding the quality and levels of contamination that would be present in C&D plastics, it was not possible to perform a rough cost analysis for this section. But, a general range of processing costs for running common plastics through recycling equipment is about $1.20-$3.60/ton[3] depending on the targeted material types and quality. It was assumed by plastic recyclers that C&D plastic processing would possibly be more costly

Environmental regulations
Plastic recycling facilities may be subject to applicable air, wastewater and solid waste regulations.

Diversion capacity:
C&D plastic comprises a 'relatively' small fraction of C&D waste by overall weight with an estimated generation of about 19,000 tons in 2019. Facilities of similar size to our existing processing operations could theoretically absorb this quantity and there are technically end markets for the materials, however the greatest challenge in C&D plastic recovery is collection.

4.3.2 Other processing facilities

Plastics recycling facilities (PRFs)
One form of infrastructure that could be developed in the future is a plastic recycling facility (PRF). PRFs are industrial facilities that accept mixed plastic items from MRFs or generators and conduct separation and contamination removal to create saleable grades of discrete plastic resin types. A PRF may also conduct preliminary recycling operations such as size reduction to plastic flake.

A facility outside of Baltimore, MD funded by Closed Loop Partners from 2015-2017 run by QRS failed to open. The Baltimore facility was 128,000-square-feet, had capacity of nearly 55,000 tons per year and cost $15 million.[clxxi] Other PRFs in operation have similar processing capacities.

Equipment and personnel
The equipment used in PRFs could include:[clxxii]

- Bale breaker
- Conveyors
- Trommel screen
- Ballistic separator
- Ferrous separator
- Optical sorter
- Color HDPE/PP separator
- Manual presort and manual post sort

Mixed C&D sorting facility
Since plastics are not commonly source separated from other C&D streams on job sites, the most practical way of achieving greater collection and diversion rates of these materials may be with a mixed C&D sorting facility. C&D sorting facilities use a combination of manual and mechanical means much like MRFs to separate mixed loads of materials like concrete and asphalt, clean lumber, cardboard and other C&D wastes. While this would aid Colorado's C&D

[3] Interview with Waste-Not Recycling December 20, 2019.

diversion efforts, difficulties in sorting out bulky plastics and the labor required to better sort plastics makes the practice uneconomical. Often the material is left as a residue after sorting and is broken down for use as alternative daily cover or waste to energy in some cases.

Boulder County has commissioned several reports and feasibility studies over the last decade to evaluate investing in a county-owned C&D sorting operation and 5280 Waste & Recycling Solutions has a planned facility for 2020. If or when these facilities are completed, they could be poised to address C&D plastics recovery with enough support.

4.3.4 End market development

As cited in 4.1, Colorado already has plastic product manufacturers in operation, however the companies were not found to use much if any recycled feedstock due to needing specific resin mixtures and qualities for their manufacturing processes that cannot be produced with existing recycling capabilities. To overcome those challenges, market development for plastics could entail working with existing manufacturers to identify specific opportunities for incorporating recycled feedstock. This effort could begin by compiling a list of plastic manufacturers in the state that utilize common C&D plastics (HDPE, LDPE, PVC) and doing outreach to qualify what gaps are missing that would allow them to use some percent of recycled feedstock. Some of those activities could include determining what percent of recycled materials may be used, what upgrades to production lines can be made and also if there is potential for pilot projects and outlining other market challenges and opportunities.

Based on the highly variable, specialized and technical nature of plastics recycling and manufacturing, it is clear that an individual with plastics industry expertise would be needed to conduct this further research. The PPAB could fund a position or project designed for a technical expert in plastics to conduct further exploration into plastics end market development. This work is already done in the private sector to some degree by Direct Polymers and Waste-Not to find markets for their own materials so a new position could be housed in a non-profit or public agency.

4.3.5 R&D and support of alternative building materials

Further R&D into alternative building materials and supporting their use in Colorado can be employed to reduce the amount of plastic used. For instance, non-plastic alternatives to expanded polystyrene can be used for building insulation such as: mineral wool batt, fiberglass batt, wool, dense pack cellulose, cork and others.[clxxiii]

Additional Resources

“PVC Recycling Technologies.” Brussels: VinylPlus, 2017. https://vinylplus.eu/uploads/downloads/VinylPlus_Recycling_Technologies_06062017.pdf.

Outlines different PVC recycling technologies developed in the EU under the Recovinyl program.

PART III – RECOMMENDATIONS FOR THE RECYCLING RESOURCES ECONOMIC OPPORTUNITY GRANT PROGRAM

As of 2019, the RREO program provides grant funding for four separate categories of activities:

1. Infrastructure grants
2. End market grants
3. Regional study grants
4. NextCycle incubator/accelerator

Recommendations are made that address the existing grants and that provide other general ideas for supporting C&D end market development in Colorado. The recommendations were developed based on the materials research, information from other end market development reports and feedback from the C&D Council, RREO grant administrators and other CDPHE staff.

1. Market development for specific materials

To promote collection, processing and end market infrastructure development for the focus materials in this report, detailed information about projects that could be funded to bring opportunities to Colorado are outlined under 4.3 in Sections 1-5 of Part II – Materials Research.

2. Strategic outreach for C&D infrastructure and market development

RREO has been successful in receiving many high-quality applicants and awarding the maximum funding available each year, however there is currently no strategy for which market sectors are high priority. RREO could fund strategic outreach to specific industrial sectors to focus on C&D or other markets and the most problematic, challenging or high opportunity material streams. According to a grant administrator, the ability to be more proactive and better identify companies that may benefit from grant offerings would be advantageous.

Potential outreach activities could focus on education for trade groups, associations, and other private sector groups, with the caveat that preferential treatment of specific companies be avoided. Funding could be allocated in RREO's budget for such activities. The program's "Marketing Toolkit" available to grantees was produced by an external marketing professional, and funding could similarly be allocated to develop a strategic outreach plan.

3. Leverage grant dollars for C&D research and development

RREO traditionally focuses on providing funding for "shovel ready" ideas, but for challenging material streams such as C&D, researching ways to redesign materials to be more easily recoverable at end of life and developing new recycling technology also need funding. R&D support could be leveraged in the private sector or with universities or NGOs to do specific research on waste materials.

Colorado may explore the potential to establish an end market development center for waste materials in coming years based on the findings of the Zero Waste Interim Committee that worked in in 2019 prior to the 2020 legislative session. A future end market development center should ensure there is research being done on waste management opportunities of specific materials and have a robust feedback loop to communicate with consumers and policymakers.

4. C&D-specific end market and infrastructure grant funding

King County, Washington developed a C&D Grant Program in 2019 to enhance the county's C&D recycling for clean wood, gypsum wallboard, metal, brick, asphalt shingles and fines.[1] The county intends to support projects related to:

- Innovation in approach to increasing waste prevention and/or reuse
- Identification of new recycling streams for specified materials to prevent combustion-based uses
- Increase collection of specified materials through improved infrastructure, equipment, and processes
- Applied research of emerging recycling technologies and/or recycling techniques
- Market development and/or development of new products made from C&D materials
- Improvement of existing recycling infrastructures or processes for construction and demolition recycling
- Piloting new processing technologies for specified materials
- Promote manufacturing of new materials from C&D materials

Combined with a strategic outreach approach, infrastructure and end market development grants could target similar projects and initiatives.

5. Regional study grants

Because C&D material waste management is highly localized due to the unfavorable economics of transporting materials over long distances, could the regional study grants be used to do a deep dive on C&D? A baseline and gap analysis could be useful in many parts of the state to determine where gaps in service are available, especially for C&D materials that do have viable end markets in state like concrete, asphalt, clean wood and metal.

Performing a study of overarching regional waste management issues should be top priority for regions that do not yet have that information is important, but perhaps C&D can be studied in a second phase.

6. Potential actions to support C&D for other agencies

6.1 C&D recycling market directory

When respondents were asked in an open-ended question what information would help further diversion efforts in the future in CDPHE's C&D Survey, 43.2% said a list of material end-users found throughout the state would be helpful. Assistance or funding may be provided to a partner organization to develop and maintain a list of C&D material end users.

Two such resources already exist for Fort Collins and Boulder County, however these documents do not appear to be updated consistently and they are not searchable databases. Another limitation is the lists only provide a limited scope of companies based on the Front Range between Denver and Fort Collins. Although this is the state's population center, there is a lack of information for more southern cities along like Colorado Springs and Pueblo and information is also needed to support C&D diversion efforts in the Western Slope,

[1] C&D grant program—King County. (n.d.). Retrieved November 2, 2019, from https://kingcounty.gov/depts/dnrp/solid-waste/programs/green-building/construction-demolition/cd-grant-program.aspx

Eastern/Southeastern and Mountain regions. Recycle Colorado began developing a statewide directory for a separate project in 2019 that can be used as a starting point.

The North Carolina Department of Environmental Quality's Recycling Business Assistance Center offers a statewide recycling markets directory that can be used as a guideline.[2]

6.2 Partnership development

Interagency coordination and partnerships between stakeholder organizations in Colorado could foster more effective recycling market development. Such groups to engage could be:

- Colorado Office of Economic Development and International Trade
- Colorado Small Business Development Center Network and other statewide agencies to focus on recycling business development
- Work with regional Councils of Governments (e.g. Denver Regional Council of Governments, Upper Arkansas Area Council of Governments) because waste management is a regional, interjurisdictional issue

6.3 C&D market development coordinator

For Colorado to make consistent gains in C&D market development, it is clear that dedicated staff are needed to coordinate these efforts at the state, regional, county and/oror municipal level. A non-governmental and preferably private sector individual could be best suited for such a role to act nimbly and seek out markets that make economic sense. The PPAB could potentially partially fund such a position.

[2] https://deq.nc.gov/conservation/recycling/recycling-business-assistance-center

PART IV – NEXT STEPS FOR THE C&D COUNCIL

Recycle Colorado's subject matter councils focus on one subject to carry out year-long 'Action Projects' that are *actionable, tangible and measurable* in accordance with Recycle Colorado's mission. Councils are comprised of various stakeholders from across an industry and are guided by a Chair, Vice Chair and Recorder and also require a committee of at least eight individuals responsible for carrying out the chosen Action Project. During the first Council meeting with a new group or following a completed project, Recycle Colorado facilitates a brainstorming session to help the group identify challenges, opportunities, available resources and relevant stakeholders for conceptualizing a new project.

In 2019, the C&D Council was formed around two pre-planned, grant-funded projects and had a full-time staff person to organize the group and carry out the projects. Because of this, the traditional structure with Council leadership and project committee was not necessary. In 2020 the Council will revert to a traditional subject-matter council structure and will select a new project to work on. This section provides ideas and guidance for what the C&D Council may work on in the future drawing from the research findings and external events related to C&D that took place in Colorado in 2019.

1. **Pilot an end market recommendation described in the report**

In order to continue the progress made by this report, the C&D Council may select an Action Project that pilots an end market idea for one of the focus materials. Several potentially workable ideas presented themselves through the research, including:

- Closed Loop Wallboard pilot
- Promote increased carpet collection pilot at an existing recycling facility
- HMA paving with RAS

2. **Deconstruction Network**

EPA Region 8, CDPHE, Recycle Colorado and 5280 Waste & Recycling Solutions co-sponsored a "deconstruction workshop" in August 2019 that brought together industry stakeholders to advance the practice of deconstruction in Colorado. Multiple members of the C&D Council attended the event and have a vested interest in deconstruction, so it may be a logical focus area in the future especially when considering deconstruction as a pathway to improve C&D materials diversion since roughly 90% of C&D waste comes from demolitions. As of the end of 2019, the group had stalled due to lack of available resources for an entity or individual to take leadership, so the C&D Council may consider this initiative as a natural evolution.

The Deconstruction Network established after the workshop could be absorbed into the C&D Council. Or if that is problematic since it requires membership, multiple members of the C&D Council may participate more deliberately in that group.

Deconstruction pilot project - Establish a deconstruction pilot project action group (or a few) instead of or as a subgroup of a council for one year. RC could collect data about materials, barriers, end markets and best practices then share those with the community.

- Stakeholders
  - Regulators – EPA/CDPHE

- Deconstruction contractors
- Local government
- End users of material

Appendix

Appendix A: Names, professional title and affiliation of everyone participating on the C&D Council

First Name	Last Name	Company	Title
Alicia	Archibald	A2 Solutions	Consultant
Darla	Arians	Boulder County Resource Conservation Division	Division Manager, Resource Conservation
Jasmin	Barco	Eco-Cycle	Outreach Coordinator
Laurie	Batchelder Adams	LBA Associates	Owner
Bill	Bradley	5280 Waste Solutions, LLC	President
Brian	Chesson	5280 Waste Solutions, LLC	Chief Operating Officer
Matt	Clair	Republic Services, Inc	Major Accounts - Landfills
Lynn	Coppedge	City of Lakewood	Senior Sustainability Planner
Courtney	Cotton	City & County of Denver	Recycling Program Manager
Steven	Derus	Republic Services, Inc	General Manager
Brandy	Dietz	Elevated Entrances	President, BOD Treasurer
Chris	Enright	Citizen	--
James	Gaspard	Biochar Now, LLC	Chief Executive Officer
Annie	Hall	United States Green Building Council	Project Manager
Stella	Hodgkins	GE Johnson Construction Company	Corporate Citizenship Manager
Amanda	Hong	EPA Region 8	Environmental Protection Specialist
Dave	Koscove	Colorado Industrial Recycling	Owner/Founder
Wolf	Kray	Colorado Department of Public Health and Environment	Environmental Protection Specialist
Amanda	Ladas	5280 Waste Solutions, LLC	Vice President of Marketing

Megan	Lane	City and County of Denver	Recycling Program Administrator, Recycle Colorado Board President
Clint	Liniger	Waste-Not Recycling	Transportation Manager
Jesse	Masten	Eagle County Government	Solid Waste and Recycling Manager
Jonathon	Nagel	City of Fort Collins	Environmental Compliance Inspector
Anna	Perks	Perks Consulting LLC	Principal Owner and Consultant
Anne	Peters	Gracestone, Inc.	President
Ryan	Powers	Power Screening, LLC	President
April	Rice	GE Johnson Construction Company	Sustainability Manager
Kat	Slaughter	Vert Sites	Consultant
Jeff	Waites	Power Screening, LLC	Area Manager
Susan	Williams	GE Johnson Construction Company	Logistics Manager
Jerry	Williams	Denver International Airport	"Environmental Public Health Analyst II, BOD Regional"
Emily	Kaps	Colorado Department of Public Health and Environment	Environmental Scientist

Appendix B: Sources contacted in researching this study

Sources were communicated with in person, over the phone and through email. Individuals and organizations listed here are in addition to C&D Council members contacted to carry out the study.

Contact	Affiliation
Adam Hill	Direct Polymers
Amanda Kaminsky	Building Product Ecosystems
Beth Markham	Town of Vail
Bob Yost	A1 Organics
Clinton Sander	A1 Organics
Dallin Brooks	Western Wood Preservers Institute
Eric Heyboer	The Colorado Department of Public Health & Environment
Evan Schmidt	Oregon State University
Gary Heroux	Composite Panel Association
Heidi Sandborn	National Stewardship Action Council
Howard Brand	Brand Technologies
James "Buzz" Surwilo	Vermont Department of Environmental Conservation
Joe Connell	Build Reuse
Kurt Mackes	Colorado Forest Service
Laszlo Horvath	Virginia Tech
Michael Stanford	CDOT
Rachel Palopoli	Planet Recycling
Ryan Puckett	Power Screening LLC
Steve Meima	The Gypsum Association
Taiji Miyasaka	Washington State University
Theresa Wagner	Owens Corning

Tim Dailey	Waste-Not Recycling
Valerie Carey	City of Roses Disposal
Vaughn Miller	ReVolve Recycling
	USDA Forest Products Laboratory
	Interface
	CSU Extension
	CSU College of Agricultural Sciences
	Vail Honeywagon
	JM Eagle
	Colorado Contractor's Challenge Participants*

Contact names are left blank for individuals who did not want to be named directly.

** Observational and anecdotal data gathered from general contractors through a related Recycle Colorado project also shaped the research directly and indirectly.*

Appendix C: C&D materials ranked by value

The spreadsheet it is not copied in this report document due to its size. Click here to access the files saved in cloud storage.

End Notes

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