Increasing the Recycling of Materials Used for Highway Construction

Requested by
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Executive Summary

Background

Caltrans is examining ways to make greater and more consistent use of recycled highway construction waste materials. Recycling efforts at the district level vary, which precludes the establishment of a statewide baseline. The lack of a tracking mechanism for recycling-related data adds to the challenge of establishing a statewide baseline for recycling highway construction and demolition waste (CDW). Caltrans is seeking information from other state departments of transportation (DOTs) about the recycling and reuse of construction waste materials that could inform similar efforts in California.

To assist with this information-gathering effort, CTC & Associates conducted a brief survey of selected state DOTs; results of a literature search of recent domestic publications supplemented survey results.

Summary of Findings

Survey of Practice

An email survey distributed to 16 states expected to have experience with recycling and reusing construction waste materials received responses from six state DOTs—Minnesota, New Jersey, New York, Oregon, Pennsylvania and Washington. This survey gathered information about the types of construction waste that is recycled, the benefits and costs of recycled construction waste, contractor reporting associated with recycled material, and methods to track the amount and disposition of recycled material. Key findings from respondents are highlighted below.

Construction Waste Diverted for Reuse

Most respondents reported on recycled asphalt pavement (RAP) and recycled concrete when asked about the types of construction waste their agencies divert from landfills for reuse on highway construction projects. Agencies are using RAP as new pavement, subbase or millings; concrete is recycled for use as aggregate base or fill. The Oregon DOT respondent reported on the widest range of construction wastes—from asphaltic concrete pavement (ACP) millings that are recycled as new ACP, to the cut trees and woody materials that are placed in wetland or along streams for habitat enhancement.

Benefit–Cost of Recycled Materials

Only the Oregon DOT respondent provided a definitive response when asked about a benefit–cost assessment of construction waste, noting that ACP produces the highest benefit–cost ratio for the agency. (The respondent did not, however, provide agency-specific data that supports this conclusion.) Other respondents offered more general information about the economic and other benefits of recycled materials. Additional information about the benefits and costs of recycled materials appears in the **Related Research and Resources** section of the report beginning on page 21.

Contractor Reporting

Only the New Jersey and Washington State DOT respondents reported on the submission of contractor data related to the disposal and recycling of CDW. The Washington State DOT practice is more formalized and is described in detail in the case study appearing on page 13. A January 2018 Washington State DOT report, *Recycled Concrete Usage in Aggregate Materials*, which provided information for this case study, describes the state law that requires use of recycled concrete materials, the conditions for its use, contractor reporting requirements, and the issues and challenges the agency has encountered since the 2016 implementation of the state law.

Contractor Incentives

None of the respondents reported on contractor incentives to encourage contractors to recycle highway CDW. While not providing details of a specific contractual incentive, the Oregon DOT respondent noted that the agency requires a certain amount of RAP to be included in ACP mix, which reduces the cost to the contractor and the DOT.

Recycling Successes and Challenges

Respondents offered few details when asked about recycling program successes. In Minnesota, Pennsylvania and Washington, the use of RAP is a common or long-standing statewide practice. Washington State DOT has minimal experience with using recycled concrete aggregate (RCA) though has completed some sizeable projects where concrete was recycled from the project and used as base course.

Respondents reported primarily on materials-related issues when asked about the factors that are limiting their agency's recycling of highway CDW. The Washington State DOT respondent noted that cost determines when contractors use recycled materials.

Agency Tracking Practices

Only two respondents reported on the software or other methods used to track the amount and disposition of recycled highway CDW. New Jersey DOT uses AASHTOWare Project SiteManager to track recycled materials. (The respondent did not specify how this tracking is performed.) Washington State DOT requires contractors to submit a Recycled Materials Report at the end of every project to show the amount of RCA used. If the 25 percent minimum requirement is not achieved, the contractor must submit a cost estimate demonstrating that the cost with RCA was greater than without RCA. (See the case study on page 13 for more details of this reporting requirement.)

Related Research and Resources

Construction Waste Recycling Studies and Guidance

A 2017 study by the U.S. Environmental Protection Agency that examined the state of the practice of CDW recovery and reuse offers recommendations for successful recycling strategies and tracking mechanisms. Relevant volumes of an eight-volume 2013 NCHRP synthesis report provide guidance to agencies revising materials specifications to encourage greater use of recycled materials.

Agency Practices to Reuse Waste Materials

The tables below highlight the measures and opportunities proposed by five states—Arizona, Florida, Maryland, Missouri and Pennsylvania—for increasing the use of construction waste materials in highway projects.

Practices to Increase the Use of Specific Recycled Materials

Recycled Material	State	Description
Construction and demolition waste	Arizona	• Conduct a long-term study of material characteristics. • Develop incentives to encourage use among contractors and the recycling industry. • Develop specifications that allow CDW use.
	Florida	• Require that demolished concrete be delivered to a recycling facility. • Require that mix designs for nonstructural concrete utilize RCA.
Recycled asphalt pavement	Arizona	• Revise specifications that allow for increased RAP utilization. • Train the local paving industry in methods to successfully incorporate higher levels of RAP into asphalt mixtures. • Improve quality control in the mixture design and construction processes. • Develop incentives to encourage contractors to increase RAP utilization beyond 15 percent.
	Florida	Implement a research initiative to develop an engineering specification for the use of RAP material as a surfacing treatment for low-volume roads.
	Pennsylvania	• Require each district to develop a five-year plan to coordinate mill/overlay projects. • Develop coordination programs between the department, contractors, producers and local municipalities and counties to identify needs and share materials and services. Investigate opportunities for municipal education about RAP. • Develop and implement performance testing requirements for the use of RAP in new pavement mixtures.

Practices to Increase the Use of Specific Recycled Materials		
Recycled Material	**State**	**Description**
Recycled concrete aggregate	Arizona	• Revise specifications for using RCA in aggregate base and as a coarse aggregate in new portland cement concrete (PCC). • Provide training to better understand how to incorporate RCA into aggregate bases and new PCC. • Improve quality control. • Provide incentives to encourage contractors to increase RCA utilization.

General Practices to Encourage the Reuse of Recycled Materials		
Practice	**State**	**Description**
Benefit–cost analysis	Pennsylvania	Conduct a benefit–cost analysis before shipping recycled materials greater than 75 miles.
Contractual language	Florida	Recommend that requests for proposal for design-build projects and design consultant procurement ask respondents to include design considerations that improve recycling and reuse opportunities.
Identification of barriers	Missouri (Kansas City metropolitan area)	Identified issues unique to the region that limit recycling: • Unlimited landfill space. • Lack of markets for recycled CDW products. • Lack of facilities to recycle CDW. • Lack of educational programs and recycling information. • Poor supply chain management for CDW.
Incentives	Florida	Develop incentives to encourage use of CDW: • Permissive technical specifications. • Construction contract incentives. • Construction contract mandates. • Statutory requirements.
	Pennsylvania	Employ a system using incentivized thresholds versus punitive damages that will encourage innovation and better performance of pavement mixtures that use recycled materials.

General Practices to Encourage the Reuse of Recycled Materials		
Practice	**State**	**Description**
Pavement design changes	Arizona	• Recommend slight increases in RAP replacement level (up to 25 percent or more) in asphalt concrete pavement, especially in asphalt concrete base and binder levels. • Increase the use of RAP in unbound roadway base and subbase, especially for in-place recycling. • Increase the use of RCA in roadway base and subbase (unbound layers) applications.
Pilot studies	Maryland	Modify testing standards and revise specifications after completion of pilot studies to assess the impact on recycled material use.

Benefits, Costs and Barriers to Use of Waste Materials

This section highlights guidance from a 2013 NCHRP synthesis and publications produced by the Recycled Materials Resource Center (RMRC), a fourth-generation pooled fund study that conducts research on the economic, environmental and other impacts of the use of recycled materials in highway construction. Also summarized are publications describing the practices of five states—Arizona, Florida, Maryland, North Carolina and Virginia. Key findings from these resources are presented below. See page 21 of this report for further details. *Note*: References to cost savings in the publications we reviewed for this report tended to be fairly general and not associated with specific calculations that have been applied across multiple projects or agencies.

Cost Savings Associated With Recycled Material Use		
Material	**Benefit**	**Agency/Source**
Multiple materials	Total systemwide economic savings from use of recycled materials estimated at $62.5 million.	Recycled Materials Resource Center
Recycled asphalt pavement	Using 50 percent RAP in hot-mix asphalt applications reduces energy consumption to about the level needed to produce cold mix asphalt.	Maryland State Highway Administration
	Using between 20 and 50 percent RAP can result in a cost savings of between 14 and 34 percent per ton.	NCHRP Synthesis 435: Volume 6
	Potential cost savings of up to 30 percent could be realized with the use of 50 percent RAP by weight.	Virginia DOT
Recycled concrete aggregate	Diverting concrete from landfills results in a reported savings of $134 per ton.	Florida DOT
	• Using RCA to replace virgin aggregates can save about $4 per ton for PCC and up to $5 million on a single project.	Maryland State Highway Administration

Cost Savings Associated With Recycled Material Use		
Material	**Benefit**	**Agency/Source**
Recycled concrete aggregate	• Using 30 percent RCA in PCC can reduce the environmental impact by 6.5 percent while using 50 percent RCA can reduce the environmental impact by 20 percent.	Maryland State Highway Administration

Details of the cost models used by Florida and North Carolina DOTs to analyze the reuse of highway construction materials are provided on pages 26 and 27, respectively.

Barriers to Use

Volume 6 of the 2013 NCHRP Synthesis 435 cited a range of barriers that limit the broader use of recycled materials. Some of these barriers, listed below, are also noted in other publications cited in this report.

- Lack of a stable market for recycled materials.
- Lack of appropriately located recycling facilities.
- Absence of appropriate technology for processing some byproducts.
- Lack of data for waste management byproducts.
- Low-cost dumping fees.
- Small amounts of byproducts generated at widespread locations.
- Lack of policies.
- Need for stakeholder joint participation.
- Inadequate resources and technologies.

Long-Term Opportunities

An August 2016 Arizona DOT report identified a series of long-term opportunities for the state to increase its use of recycled materials in transportation infrastructure. Below are a few of the opportunities described in more detail on page 25 of this report:

- Re-evaluate and modify existing construction specifications to become more accommodating to the use of recycled materials.
- Conduct training and technology transfer activities within the state on best practices for using recycled materials.
- Develop a database to track materials usage, supply and demand. Consider tying this database to pavement performance.
- Develop a framework for a systematic, quantitative approach to consider costs and benefits of using recycled materials.

<u>Tools to Monitor Recycled Material Use</u>

Four tools are described in this section of the report: BE^{2}ST-in-Highways, Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE), RMRC's material tracking tool and a recycled material web map. These tools allow agencies to conduct a life-cycle

assessment or life-cycle cost analysis that assesses the environmental and economic effects of pavement and road construction, track the systemwide use of recycled materials in pavement mix designs, and connect producers and users of recycled highway construction materials.

Gaps in Findings

The survey received a limited overall response, and some questions garnered few details from survey participants. Other state transportation agencies appear to be grappling with some of the issues of interest to Caltrans (development of a database to track the amount and disposition of recycled material, and practices that will increase the use of recycled materials), but these agencies have not published definitive findings or continue to work with internal and external stakeholders to achieve agency goals.

Next Steps

Moving forward, Caltrans could consider:

- Contacting Washington State DOT to learn more about the agency's efforts to collaborate with material suppliers and contractors to increase the use of RCA in the state.
- Examining in detail the cost models used by Florida and North Carolina DOTs to inform development of a similar model for Caltrans' use.
- Requesting a demonstration or examples of New Jersey DOT's use of AASHTOWare Project SiteManager to track recycled materials.
- Reviewing the monitoring tools described in this report to determine their applicability for assessing the benefits and costs of recycled material use in California.
- Consulting with agencies that did not respond to the survey to inquire about:
    - Arizona DOT's interest in developing a database to track recycled materials.
    - Florida DOT's implementation of the strategies identified in its December 2014 study that sought to improve opportunities for the recycling and reuse of construction materials.
    - Maryland State Highway Administration's plan to conduct pilot studies to evaluate recycled materials and progress in completing the implementation plan included in an October 2016 synthesis study that examined recycled material availability in Maryland.

Detailed Findings

Background

Implementation of California Senate Bill 1, the Road Repair and Accountability Act of 2017, presents the potential for a shortage of highway construction materials. The cost of construction materials is expected to increase when there is low supply and high demand. Recycling materials used on highway construction projects can limit the impact of higher material prices, limited material availability and higher trucking costs, and reduce greenhouse gas emissions. However, several challenges inhibit Caltrans' ability to make greater and more consistent use of recycled materials:

- Recycling efforts at the district level vary, which precludes the establishment of a statewide baseline.
- Contractors are expected to complete Construction Form CEM-4401, Solid Waste Disposal and Recycling Report, annually for each project. Caltrans has found that use of this data collection practice is inconsistent and nonmandatory, and the data may not be verified by an inspector (Construction Form CEM-4401 is available at https://forms.dot.ca.gov/v2Forms/servlet/FormRenderer?frmid=CEM4401).
- Currently, Caltrans does not employ a tracking mechanism for recycling-related data.

This Preliminary Investigation seeks to inform Caltrans' examination of the following topic areas:

- The types of highway construction wastes that are currently directed to landfills and other agencies' practices to divert these materials from landfills for reuse on highway construction projects.
- The types of highway construction solid-waste recycling with the highest benefit–cost ratios.
- Tools and practices used by other state departments of transportation (DOTs) to track and report on the amount and disposition of recycled highway construction waste.

To gather this information, CTC & Associates conducted a brief survey of selected state DOTs; results of a literature search of recent domestic publications in these topic areas supplemented survey results.

Survey of Practice

Survey Approach

We contacted a select group of 16 state DOTs expected to have experience with the recycling of highway construction waste:

- Arizona.
- Florida.
- Indiana.
- Maryland.
- Michigan.
- Minnesota.
- Missouri.
- New Jersey.
- New York.
- North Carolina.
- Ohio.
- Oregon.
- Pennsylvania.
- Tennessee.
- Texas.
- Washington.

Potential respondents received the following brief survey by email:

1. What types of highway construction and demolition waste (CDW) is your state diverting from landfills for reuse on highway construction projects?
2. What types of recycled highway CDW have had the highest benefit–cost ratios in your state?
3. Does your agency require contractors to submit data on the disposal and recycling of CDW? If yes, please describe how contractors submit this data and provide sample forms, if available.
4. Does your agency use, or has your agency considered the use of, incentives to encourage the recycling of highway CDW rather than directing this material to landfills? If yes, please describe these incentives.
5. Please describe the e-construction software, database, tool or other method your agency uses to track the amount and disposition of recycled highway CDW in your state. Include a discussion of how the tool or method addresses CDW taken to landfills, diverted from landfills to recycling facilities, and reused on the project on which it was generated.
6. What successes has your agency experienced in connection with its recycling of highway CDW?
7. What factors, if any, are limiting your agency's recycling of highway CDW?
8. Do you have documents related to your agency's recycling of highway CDW that you can share? Please provide links to relevant documents available online or email documents to chris.kline@ctcandassociates.com.

We also contacted a representative from the Recycled Materials Resource Center (RMRC), a fourth-generation pooled fund study that conducts research and outreach on environmental and material properties of recycled materials, to inquire about the center's research and state DOTs with exemplary practices in the recycling and reuse of highway construction waste.

Summary of Survey Results

Six states responded to the survey:

- Minnesota.
- New Jersey.
- New York.
- Oregon.
- Pennsylvania.
- Washington.

Survey results are summarized below in six topic areas:

- Construction waste diverted for reuse.
- Benefit–cost of recycled materials.
- Contractor reporting.
- Contractor incentives.
- Recycling successes and challenges.
- Agency tracking practices.

Construction Waste Diverted for Reuse

Respondents were asked to identify the types of CDW their agencies divert from landfills for reuse on highway construction projects. Most respondents reported on recycled asphalt and concrete. The table below summarizes survey responses.

Types of Construction Waste Diverted for Reuse

State	Type of Construction Waste
Minnesota	• Recycled asphalt pavement (RAP) recycled as new pavement or base. • Concrete recycled as aggregate base.
New Jersey	• Recycled concrete aggregate (RCA) used for subbase. • RAP used for subbase.[1]
New York	• Asphalt is reused by contractors as millings or buried in the right of way. The respondent estimated that as much as 90 percent of asphalt used in state DOT projects is recycled and reused. • Concrete will be rubblized by contractors and removed from the site for use in other locations.
Oregon	• Asphaltic concrete pavement (ACP) millings recycled as new ACP. • Portland cement concrete (PCC) pavement used as structural fill. • All types of metals sent to metal recyclers. • Vegetative materials used as ground cover or compost. • Cut trees and woody materials placed in wetland or along streams for habitat enhancement.
Pennsylvania	• Concrete pavement slabs used for fill. • Asphalt pavements used in RAP.

Types of Construction Waste Diverted for Reuse	
State	**Type of Construction Waste**
Washington	Specifications allow use of: • Recycled hot-mix asphalt (HMA). • Concrete aggregate. • Steel slag.

1 RAP is used for 15 to 20 percent of all HMA; some recent projects have used a high percentage of RAP (30 to 50 percent RAP).

Benefit–Cost of Recycled Materials

State Practices

Only the Oregon DOT respondent provided a definitive response when we asked about a benefit–cost assessment of construction waste, noting that ACP produces the highest benefit–cost ratio for the agency. (The Oregon DOT respondent did not provide agency-specific data that supports this conclusion.) Other respondents offered more general information about the economic and other benefits of recycled materials:

- In Minnesota, materials removed from the right of way are the property of the contractor, and the contactor determines how to most efficiently make use of waste materials. Contractors will crush and reuse materials on site whenever possible, as that practice is the most cost-effective, but they may also haul material to another site for storage and processing for use on another project.
- In New Jersey, the use of RCA for subbase (the agency's dense graded aggregate base course) "is very helpful in about one-half of our state where no quarries are present." Use of RAP in HMA "has been a good move," but the agency has more asphalt millings than can be used on construction projects.
- In New York, economics drive contractors' reuse of construction waste, not agency specifications or incentives. Any benefit–cost determination is made by the contractor, not the DOT.
- The Washington State DOT respondent noted that there is not enough statewide usage to determine a benefit–cost ratio for RCA and steel slag. Asphalt pavement is typically recycled at a rate less than 20 percent by weight of new asphalt. The agency awarded just over 1 million tons of new asphalt in 2018, which equates to about 200,000 tons of recycled asphalt.

Recent Research

A sampling of the recent research conducted by RMRC, a fourth-generation pooled fund study, on the costs and benefits of recycled highway construction materials appears in **Related Research and Resources** (see page 23). We contacted RMRC's managing director to inquire about ongoing efforts and learned that the center is currently working with North Carolina DOT to examine that agency's reuse of CDW. This project is in the information-gathering stage; the center anticipates publishing results in summer 2019.

Contractor Reporting

Only two respondents reported on the submission of contractor data related to the disposal and recycling of CDW:

- In New Jersey, any reporting required of contractors is not coordinated through the DOT but may be required by the New Jersey Department of Environmental Protection (NJDEP). New Jersey DOT tests contractor stockpiles as part of engineering quality assurance, and approves and monitors the stockpiles. Contractors must be registered as a Class B recycler through NJDEP before New Jersey DOT will consider engaging that contractor (unless the recycled material is reused on the same construction project).
- Washington State DOT requires contractor reporting in connection with RCA. The case study below presents information taken from the January 2018 report, *Recycled Concrete Usage in Aggregate Materials* (see **Supporting Documents** below).

Case Study: Washington State Department of Transportation

Background	State law requires Washington State DOT to "specify and annually use a minimum of 25 percent construction aggregate and recycled concrete materials on its cumulative transportation, roadway, street, highway and other transportation infrastructure projects" unless construction aggregate and recycled concrete materials are not readily available or cost-effective. State law also requires the DOT and its "implementation partners" to "collaboratively develop and establish objectives and strategies for the reuse and recycling of construction aggregate and recycled concrete materials."
Stakeholders	Three primary stakeholders—Washington State DOT, material suppliers and contractors—collaborate to "implement changes and incorporate best practices from the collective experience gained by industry as this issue continues to evolve and develop over time."
Contracts and Reporting Period	Contracts executed after January 4, 2016, include language requiring a minimum of 25 percent use of RCA for aggregate-related items where RCA is an option. Contractors are required to submit a Recycled Materials Report for each reporting period, which runs from November 1 to October 31.
2017 Results	Washington State DOT received 55 Recycled Materials reports from contractors for the 2017 reporting period. Of the 28 contracts that included RCA-eligible materials, only two contractors met the 25 percent minimum RCA usage. Twenty-four contractors identified cost as the reason for not meeting the 25 percent minimum.
Issues and Challenges	The agency has concluded that incorporating RCA requires close collaboration with all stakeholders and identified these factors that impact contractors' RCA usage: • *Material testing*. Will the contractors' RCA source be approved? RCA must be tested for contamination and strength/durability.

Issues and Challenges (continued)

- *Stockpile management*. Will a sufficient supply of RCA be available? Limited sources of RCA in some regions of the state are due to the lack of preapproved sources and stockpiles, and significant trucking costs to import RCA compared to local aggregate supplies.

- *Perceived risks associated with RCA*. Will contractors encounter compaction and inefficiency issues on the project site? RCA has different characteristics than native aggregate related to compaction and inspection.

The 2018 report noted that these risk issues "translate to additional costs, which then create a situation where the use of RCA is no longer competitive with native aggregates."

Future Plans

To eliminate obstacles to use of RCA and increase its use, Washington State DOT proposes to:

- Use established quarterly team meetings that bring together members of the concrete industry and the DOT to advance RCA-related efforts.
- Reduce testing requirements when the RCA comes from an approved source.
- Develop an alternative compaction testing method appropriate for RCA.
- Continue the effort to use pilot projects to develop and test specifications to assess RCA produced from stockpiles.
- Develop a resource for contractors to make it easier to locate and gain approval for RCA sources.
- Develop best practices for suppliers with regard to handling, documenting and approving RCA.

Supporting Documents

Recycled Concrete Usage in Aggregate Materials, Washington State Department of Transportation, January 2018.
http://www.wsdot.wa.gov/publications/fulltext/LegReports//17-19/RecycledConcrete2017.pdf
This report provides the results of Washington State DOT's recycling efforts in connection with concrete aggregate during 2017.

RCW 70.95.805, Develop and establish objectives and strategies for the reuse and recycling of construction aggregate and recycled concrete materials, Revised Code of Washington, Washington State Legislature, January 2016.
https://app.leg.wa.gov/rcw/default.aspx?cite=70.95.805
This is the state law that requires Washington State DOT to use recycled concrete materials unless "construction aggregate and recycled concrete materials are not readily available and cost-effective."

Contractor Incentives

None of the respondents reported on contractor incentives to encourage contractors to recycle highway CDW. While not providing details of a specific contractual incentive, the Oregon DOT respondent noted that the agency requires a certain amount of RAP to be included in ACP mix, which reduces the cost to the contractor and the DOT.

Recycling Successes and Challenges

Respondents offered few details when asked about recycling program successes. In Minnesota, Pennsylvania and Washington, the use of RAP is a common or long-standing statewide practice. Washington State DOT has minimal experience with using RCA though has completed some sizeable projects where concrete was recycled from the project and used as base course.

Respondents reported primarily on materials-related issues when asked about the factors that are limiting their agency's recycling of highway CDW:

- The Minnesota DOT respondent noted that there "may be some technology limitations with asphalt plants primarily designed to handle no more than 30 percent RAP," and "proper limitations of water to cementitious ratio in concrete mixtures containing recycled aggregates are difficult to establish." He was unsure of the long-term benefits and performance of mixtures using higher RAP contents and various rejuvenators on the market.
- In New Jersey, the use of RCA can be an issue with "less than scrupulous" recyclers.
- Pennsylvania DOT has had issues using recycled concrete as aggregate due to tufa, a calcium carbonate precipitate, leaching from the material and clogging pavement underdrains.
- In Washington, cost determines when contractors use recycled materials.

Agency Tracking Practices

Only two respondents reported on the software or other methods used to track the amount and disposition of recycled highway CDW:

- New Jersey DOT uses AASHTOWare Project SiteManager to track recycled materials. (The respondent did not specify how tracking is performed.) The DOT's regions handle RAP approvals for HMA on a project-by-project basis or when a problem occurs. Each quarry or HMA plant (often the same entity) monitors RAP stockpiles.
- Washington State DOT requires contractors to submit a Recycled Materials Report at the end of every project to show the amount of RCA used. If the 25 percent minimum requirement is not achieved, the contractor must submit a cost estimate demonstrating that the cost with RCA was greater than without RCA. (See the case study on page 13 for more details of this reporting requirement.)

Minnesota DOT does not perform any tracking because materials removed from the right of way become the property of the contractor. While New York State DOT does not conduct formal tracking, on occasion New York State Department of Environmental Conservation will ask the DOT for estimates of recycled asphalt and/or concrete. The respondent noted that the quantities provided by New York State DOT in response to these requests are estimates based on percentages of capital program work involving asphalt or concrete replacement.

Related Research and Resources

Presented below are publications and other resources related to the handling of highway construction waste in four categories:

- Construction waste recycling studies and guidance.
- Agency practices to reuse waste materials.
- Benefits, costs and barriers to use of waste materials.
- Tools to monitor recycled material use.

Construction Waste Recycling Studies and Guidance

The State of the Practice of Construction and Demolition Material Recovery, National Risk Management Research Laboratory, U.S. Environmental Protection Agency, May 2017. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100SSJP.PDF?Dockey=P100SSJP.PDF
This report provides an overview of construction and demolition (C&D) recovery efforts for materials generated during the construction, renovation and demolition of buildings and other structures in addition to roads and bridges. Information within the report is intended for agencies "interested in incorporating C&D recovery as an element of a sustainable materials management (SMM) program." Topics include C&D processing facilities and material end uses, factors impacting C&D recovery and the impact of green building materials on C&D recycling. Investigators also summarize areas for further research: tracking the amount, composition and disposition of C&D materials; compiling and disseminating successful recycling strategies with considerations to social and environmental factors; and documenting the benefits of C&D recycling.

Note: See page 21 of this Preliminary Investigation for information about an eight-volume 2013 NCHRP synthesis "designed to help serve as a guide to states revising the provisions of their materials specifications to incorporate the use of recycled materials and industrial byproducts."

"The Forward Path of Construction and Demolition Waste Reuse and Recycling: Market Forces, Regulatory Efforts and Actions From Construction Stakeholders," Wai Kiong Chong, *TRB 88th Annual Meeting Compendium of Papers DVD*, Paper #09-3103, 2009. Citation at https://trid.trb.org/view/882098
From the abstract: This research investigates, through a survey conducted on 27 companies, and two panelist discussion sessions (via teleconference with 17 professionals from the constructors), the perceptions of CDW reuse and recycling from the constructors' point of views. In addition, the research also investigates the factors that drive the rates of CDW reuse and recycling. The research concluded with an industry framework for the continuous development of CDW reuse and recycling.

Research in Progress

Recycled Materials Resource Center—4th Generation, Study Number TPF-5(352), Transportation Pooled Fund Program, estimated completion date: April 30, 2022.
https://www.pooledfund.org/Details/Study/603
This fourth generation of the RMRC pooled fund study has been cleared by the Federal Highway Administration with an unspecified start date. The initial RMRC was founded in 1998 at the University of New Hampshire; Wisconsin DOT is the current lead agency.

The following research efforts that began in earlier generations of this pooled fund study could continue in RMRC's fourth generation:

- Determining the value of using recycled materials using a life-cycle assessment (LCA) and life-cycle cost analysis (LCCA).
- Further development of LCA and LCCA methodologies for transportation infrastructure.

See Completed Research, available at http://rmrc.wisc.edu/category/research/past-research/, for a wide range of published research that examines the use of recycled materials in transportation construction. A sampling of these publications appears throughout this Preliminary Investigation.

Agency Practices to Reuse Waste Materials

Below are measures and opportunities proposed or undertaken by five states—Arizona, Florida, Maryland, Missouri and Pennsylvania—for increasing the use of construction waste materials in highway construction projects.

Arizona

Recycled Industrial and Construction Waste for Mutual Beneficial Use, Arizona Department of Transportation, August 2016.
https://apps.azdot.gov/ADOTLibrary/publications/project_reports/pdf/SPR725.pdf
Using the results of a literature review and survey of contractors, material suppliers and industry associations, Arizona DOT prioritized the use of industrial waste (recycled materials, byproducts and waste materials) in highway applications based on material cost and availability. Among the six materials researchers identified for use in constructing transportation structures:

- RAP as a partial replacement for asphalt binder and virgin aggregate in asphalt concrete mixtures and for other applications.
- RCA from existing structures such as pavements and barrier walls for use as aggregate or as base/subbase material or as an aggregate in new concrete.
- CDW, including refuse concrete, bricks and masonry, to be crushed and used as aggregate in asphalt mixtures, concrete, roadway base and subbase, or as nonstructural fill.

The discussion of each material provides a review of national and state practice, its current use in Arizona and challenges to increasing the material's use. Common practices for increasing the use of these materials in Arizona include modifications to state construction specifications, training and outreach, and contractor incentives. Below are specific recommendations for recycled highway construction material:

Reclaimed Asphalt Pavement

- Revised specifications that allow for increased RAP utilization.
- Training the local paving industry in methods to successfully incorporate higher levels of RAP into asphalt mixtures.
- Improved quality control in the mixture design and construction processes.
- Incentives to encourage contractors to increase RAP utilization beyond 15 percent.

Recycled Concrete Aggregate

- Revised specifications for using RCA in both aggregate base and as a coarse aggregate in new PCC.
- Training to better understand how to incorporate RCA into aggregate bases and new PCC.
- Improved quality control.
- Incentives to encourage contractors to increase RCA utilization.

Construction and Demolition Waste

- Long-term study of material characteristics.
- Incentives to encourage use among contractors and the recycling industry.
- Specifications that allow CDW use.

Florida

Developing Improved Opportunities for the Recycling and Reuse of Materials in Road, Bridge and Construction Projects, Ralph Ellis, Duzgun Agdas and Kevin Frost, Florida Department of Transportation, December 2014.
http://www.fdot.gov/research/Completed_Proj/Summary_SMO/FDOT-BDV31-977-09-rpt.pdf
Researchers interviewed state DOT representatives, recycling industry professionals, construction contractors and Florida DOT construction engineers about opportunities for recycling and reusing RAP, RCA, recycled tires and crushed glass in road and bridge construction. Section 2 summarizes the findings of a state DOT survey about mandates or incentives that are included in construction contracts to encourage the use of recycled construction materials (page 11 of the report, page 27 of the PDF). Four types of initiatives were reported:

- Permissive technical specifications.
- Construction contract incentives
- Construction contract mandates.
- Statutory requirements.

Section 5 (beginning on page 50 of the report, page 66 of the PDF) includes strategies recommended by recycling industry professionals for improving recycling and reuse opportunities. Implementation measures for each strategy are provided beginning on page 59 of the report (page 75 of the PDF). The recommended strategies follow:

- On Florida DOT projects with structural demolition, require that demolished concrete be delivered to a recycling facility.
- Require that mix designs for nonstructural concrete utilize recycled concrete aggregates.
- In design-build project RFP under the typical section "Evaluation Criteria," subsection "Design," include "Design Considerations That Improve Recycling and Reuse Opportunities" in the list of elements to be considered.
- Provide a link to the agency's current recycling web page on the homepages of Florida DOT's State Materials, Construction and Design offices. Add additional content (such as recycling updates, project showcase and news) when available.
- Implement a research initiative to develop an engineering specification for the use of RAP material as a surfacing treatment for low-volume roads.
- In design consultant procurement RFP under the section "Evaluation Criteria," subsection "Approach," include "Design Considerations That Improve Recycling and Reuse Opportunities" in the list of elements to be considered.

Maryland

Recycled Material Availability in Maryland—A Synthesis Study, Dimitrios Goulias, Ahmet Aydilek and Yating Zhang, Maryland State Highway Administration, October 2016.
http://www.roads.maryland.gov/OPR_Research/MD-16-SHA-UM-4-03_Recycled-Materials-Availability_Report.pdf
Four types of recycled materials were reviewed in this study: RCA, RAP, dredged materials and foundry sand. The report includes state DOT practices for using these materials along with potential concerns related to material performance, environmental considerations, design and field performance. Chapter 4 includes needed modifications to testing standards and Maryland State Highway Administration specifications (beginning on page 43 of the report, page 48 of the PDF). Before developing revised specifications, pilot studies are needed "for developing the experimental data to assess impact on highway material properties, defining rational acceptance values and statistically based specification tolerances." An implementation plan that includes recommended studies and actions for each material begins on page 79 of the report (page 84 of the PDF).

Missouri

"Recycling Construction and Demolition Waste for Construction in Kansas City Metropolitan Area, Kansas and Missouri," Josh D. Warren, Wai Kiong Chong and Changwan Kim, *Transportation Research Record 2011*, pages 193-200, 2007.
Citation at http://dx.doi.org/10.3141/2011-21
From the abstract: Although several coastal cities across the United States continue to see growth in the recycling of construction and demolition (C&D) waste, the Kansas City metropolitan area (KC metro area), straddling the states of Kansas and Missouri, continues to lag behind. A study was conducted to examine the reasons behind the lag and to explore the barriers to C&D waste management policies and practices in the region. The research involved a thorough investigation of published literature and websites from the region and coastal cities; interviews with local officials, designers, contractors and owners in the regional construction industry (Topeka, Kansas; Lawrence, Kansas; KC metro area; and other bordering cities); and emails from designers and local officials from some coastal cities. The research found that the KC metro area faces problems unique to the region, such as unlimited landfill space, lack of markets for recycled C&D products, lack of facilities to recycle C&D wastes, lack of educational

programs and recycling information, legislative issues and poor supply chain management for C&D wastes. The interviewees identified several solutions and barriers to the implementation of comprehensive C&D waste management policies and practices. However, most interviewees agreed that combining regional and national efforts is the key to successful C&D waste management policies and practices in the KC metro area.

Pennsylvania

Reclaimed Asphalt Pavement Optimization Study, Bureau of Maintenance and Operations, Pennsylvania Department of Transportation, March 2018.
http://www.pa-asphalt.org/assets/_control/content/files/Final%20RAP%20Optimization%20Study%202018-03-05.pdf
From the purpose:

> This study will develop a RAP Implementation Plan (including a literature review, research, interviews, surveys, etc.) for PennDOT to best recycle and utilize the existing and future RAP resource that PennDOT has in its existing pavements, as well as those RAP materials that could be used for both additional Construction and/or Maintenance activities.

Recommendations begin on page 25 of the report (page 27 of the PDF):

> From the short-term recommendations:
>
> > In order to ensure that transport of RAP is economical, a benefit cost analysis should be performed before shipping longer than 75 miles. Asphalt and aggregate prices will fluctuate and influence the benefit cost analysis.
>
> From the long-term recommendations:
>
> 1. Each District should develop a 5 year overall plan to coordinate mill/overlay projects to minimize transport, minimize storage time, efficiently schedule Department maintenance force manpower, and match higher SRL [skid resistance level] millings with the need for higher SRL overlays. Each District should evaluate the capacity of their stockpile locations versus how much their maintenance forces can realistically use. A comprehensive review of needed resources (equipment, manpower, material, etc.) will need to be undertaken by each District and/or County to determine a best practice approach for the use of millings. Each District should monitor projects throughout the year to make sure they maintain sufficient amounts to meet their needs but ensure they do not exceed stockpile capacity. Districts should not retain more RAP than they can use within the confines of current PennDOT policy for minimum amounts required to be given to contractors.
>
> 2. Develop and implement performance testing requirements for the use of RAP in new pavement mixtures. The design tiers for RBR [reclaimed asphalt binder] values can be finalized and utilized until these performance testing requirements are ready to be implemented. Performance testing requirements should be developed collaboratively with PAPA [Pennsylvania Asphalt Pavement Association] and industry. A system utilizing incentivized thresholds versus punitive damages will encourage innovation and better performance of RAP mixtures. Additionally, it is anticipated that this will increase RAP usage.
>
> 3. Develop coordination programs between the Department, contractors, producers and local municipalities and counties in order to identify needs and share materials and

services in a mutually beneficial manner. In conjunction with this effort, opportunities for municipal education about RAP should be investigated and implemented. Ensure that PennDOT and municipal representatives are aware that millings are approved for Agility programs without a service tied to them. Legislative changes may be required in order to maximize the sharing of material between certain parties.

Benefits, Costs and Barriers to Use of Waste Materials

The publications below are organized into three categories:

- National guidance.
- RMRC publications.
- State practices.

National Guidance

Note: The two citations immediately below are associated with an eight-volume 2013 NCHRP synthesis "designed to help serve as a guide to states revising the provisions of their materials specifications to incorporate the use of recycled materials and industrial byproducts."

NCHRP Synthesis 435: Recycled Materials and Byproducts in Highway Applications—Summary Report, Volume 1, Mary Stroup-Gardiner and Tanya Wattenberg-Komas, 2013.
Description at http://www.trb.org/Publications/Blurbs/169144.aspx
From the summary:

> This study gathered the recent experiences of state agencies, both foreign and domestic, in determining the relevant properties of recycled materials and industrial byproducts and the beneficial use for highway applications. It includes strengths and weaknesses of material applications. The synthesis serves as a guide to states revising the provisions of their materials specifications to incorporate the use of recycled materials and industrial byproducts and can assist producers and users in "leveling the playing field" for a wide range of dissimilar materials.

Chapter 12 (beginning on page 63 of the report, page 71 of the PDF) presents conclusions and recommendations that address a range of topics:

- Test methods.
- Byproduct preparation and quality control.
- Handling considerations.
- Design adaptations.
- Construction adjustments and product quality control.
- Cost considerations.
- Environmental considerations.
- Gaps.

- Barriers.
- Recommendations for research roadmap.

NCHRP Synthesis 435: Recycled Materials and Byproducts in Highway Applications—Reclaimed Asphalt Pavement, Recycled Concrete Aggregate and Construction Demolition Waste, Volume 6, Mary Stroup-Gardiner and Tanya Wattenberg-Komas, 2013. Description at http://www.trb.org/Publications/Blurbs/169149.aspx
This synthesis report provides an estimate of costs associated with recycled materials commonly used in transportation construction and describes barriers that limit the use of certain types of recycled materials in highway construction:

- *RAP* (from page 7 of the report, page 15 of the PDF): Using between 20 and 50 percent RAP can result in a cost savings of between 14 and 34 percent per ton.
- *RCA* (from page 54 of the report, page 62 of the PDF): The costs of recycling PCC byproducts varied by source of PCC byproduct, region of country, and the quality needed for a given highway application. RCA used in unbound or nonstructural concrete had less restrictive physical and chemical requirements. The cost of using RCA needed to be less than the tipping fees charged for landfilling PCC waste. The cost of RCA also needed to compete with the cost of purchasing new aggregates.

  In some cases, the contractor achieved cost savings when using RCA because of the reduced number of haul trucks and reduced fuel consumption. Agencies limited project costs because of declining needs to alter existing highway features such as curbs, gutters and overhead clearances.
- *CDW* (from page 67 of the report, page 75 of the PDF):

  Barriers
  A number of barriers limited the increased use of RAP, RCA and CDW byproducts in highway applications:
  - Lack of a stable market for recycled materials.
  - Lack of appropriately located recycling facilities.
  - Lack of awareness of byproduct potential.
  - Absence of appropriate technology for processing some byproducts (e.g., CDW).
  - Lack of government support.
  - Lack of standards.
  - Low cost dumping fees.
  - Small amounts of byproducts generated at widespread locations.
  - Lack of data on waste management byproducts.
  - Lack of understanding of environmental impact.
  - Lack of necessary expertise.
  - Lack of policies.
  - Responsibilities divided between different agencies and local administrations.
  - Weak coordination of education and training programs.

- Lack of public awareness.
- Need for stakeholder joint participation.
- Inadequate resources and technologies.

Costs
The economics of recycling focused on the beneficial use of engineering and environmental life-cycle costs, tax incentives and disincentives, and restrictive landfill taxes and policies. High-quality recycled byproducts needed to compete favorably with conventional materials. In one case, annual benefits from recycling included revenue of about $50,000 per year from recycled steel, and a cost avoidance savings of $500,000 per year.

Gaps

- Formal policy for sustainable development in highway construction that actively promotes the use of recycled materials.
- Promotion for using recycled materials within a market system.
- Agency–industry cooperation by risk and profit sharing.
- Unambiguous technical and environmental standards.
- Government assistance in starting companies specializing in marketing lightly contaminated soils.

Recycled Materials Resource Center Publications

The RMRC pooled fund study conducts research on the economic, environmental and other impacts of the use of recycled materials in highway construction. The citations below—a sampling of the center's recent research—offer conclusions about the systemwide impact of recycling and describe tools that can be used to conduct LCA and LCCA on a project-by-project basis. Details about the tools developed or used by RMRC appear in **Tools to Monitor Recycled Material Use**, which begins on page 28.

"Life-Cycle Benefits of Recycled Material in Highway Construction," Kelly Del Ponte, Bharat Madras Natarajan, Angela Pakes Ahlman, Andrew Baker, Erik Elliott and Tuncer B. Edil, *Transportation Research Record 2628*, pages 1-11, 2017.
Citation at https://trrjournalonline.trb.org/doi/abs/10.3141/2628-01?journalCode=trr
From the abstract: To determine the benefits of using recycled materials for six member state departments of transportation in a pooled fund, the Recycled Materials Resource Center at the University of Wisconsin–Madison was tasked with a project that would quantify the environmental and economic life-cycle benefits associated with the incorporation of recycled materials and industrial by-products in highway construction. An analysis of the environmental benefits (i.e., carbon dioxide emissions, energy consumption and water consumption) associated with the substitution of recycled materials for conventional virgin materials in highway construction was conducted using the pavement life-cycle assessment tool for environmental and economic effects, a tool developed with the sponsorship of the Recycled Materials Resource Center. An economic impact analysis was conducted by comparing the unit prices of virgin and recycled materials. The analysis showed significant environmental and economic savings in all member states. Total environmental savings from use of recycled materials were approximately equal to the energy consumption of 110,000 U.S. households per

year, 9,300 bathtubs of water, and the carbon dioxide emissions produced by 58,000 cars per year. Total systemwide economic savings from use of recycled materials was estimated to be $62.5 million.

"Environmental Benefits of Using Recycled Materials," Angela Pakes Ahlman and Tuncer Edil, Recycled Materials Resource Center, *Wisconsin Concrete Pavement Association Annual Concrete Pavement Workshop*, February 2017.
http://www.wisconcrete.org/wp-content/uploads/2017/02/6-Pakes-Ahlman-Environmental-Benefits-of-Recycled-Materials.pdf
This conference presentation includes detailed case studies, information about a material tracking tool and a recycled materials web mapping tool that connects users and producers of recycled material.

"State DOT Life Cycle Benefits of Recycled Material in Road Construction," Eleanor Bloom, Kelly Del Ponte, Bharat Madras Natarajan, Angela Pakes Ahlman, Tuncer Edil and Gary Whited, *Geo-Chicago 2016*, August 2016.
Citation at https://ascelibrary.org/doi/10.1061/9780784480120.070
From the abstract: To determine the benefits of using recycled materials for DOTs, the Recycled Materials Resource Center (RMRC) is undertaking a project with the objective of providing a tool to quantitatively analyze and report the environmental and life cycle benefits of using recycled materials in highway construction. Subsequently, an analysis of the environmental benefits was conducted using PaLATE, a life cycle assessment (LCA) tool developed with RMRC sponsorship. The LCA analysis of four environmental parameters (energy use, water consumption, carbon dioxide emissions, and hazardous waste generation) showed significant environmental benefits when states used recycled industrial byproducts such as fly ash and recycled roadway materials such as recycled concrete aggregate (RCA) and recycled asphalt pavement (RAP).

"Assessing the Life Cycle Benefits of Recycled Material in Road Construction," Eleanor Bloom, Gregory Horstmeier, Angela Pakes Ahlman, Tuncer Edil and Gary Whited*, Geo-Chicago 2016*, August 2016.
http://rmrc.wisc.edu/wp-content/uploads/2017/05/GeoChicago-Conference-Paper-I-94-and-Beltline-LCA.pdf
Researchers performed two case studies to analyze the impacts of incorporating recycled material in the reconstruction of two major roadways using LCA and LCCA tools. The first case study required the use of assumptions about the recycled materials used in the project. To address this, a second case study was undertaken to determine a better methodology for data collection with fewer assumptions, and to assess the benefits of recycled material use. As the authors note, "[t]he methodology for data collection and analysis developed through the second [case study] can be used to conduct LCAs and LCCA for future highway construction projects with greater confidence."

State Practices

Below we highlight publications from five states—Arizona, Florida, Maryland, North Carolina and Virginia—that examine the costs, benefits and barriers to use of recycled materials in highway construction. Some of the publications cited below that examine the use of recycled materials more broadly are cited in other sections of this report to highlight other key findings.

Arizona

Recycled Industrial and Construction Waste for Mutual Beneficial Use, Arizona Department of Transportation, August 2016.
https://apps.azdot.gov/ADOTLibrary/publications/project_reports/pdf/SPR725.pdf
In this study of industrial waste (recycled materials, byproducts and waste materials) suitable for highway applications, Arizona DOT conducted a benefit–cost analysis for using six materials in state highway applications. Tables 13 through 22 (beginning on page 76 of the report, page 88 of the PDF) summarize the ratings for risk; relative cost and performance when compared to conventional materials; relative environmental and societal impacts; and benefits, advantages and issues for use in pavement applications.

Among the applications identified, the following could be implemented immediately:

- Target slight increases in RAP replacement level (up to 25 percent or more) in asphalt concrete (HMA and warm mix asphalt (WMA)) pavement, especially in asphalt concrete base and binder levels.
- Increase the use of RAP in unbound roadway base and subbase, especially for in-place recycling.
- Increase the use of RCA in roadway base and subbase (unbound layers) applications.

Other opportunities that required additional research:

- Investigate opportunities to significantly increase RAP replacement level (30 percent or greater) in lower lifts of asphalt concrete (HMA/WMA) pavement.
- Investigate RCA as a partial replacement of coarse aggregate in highway concrete, especially for nonstructural applications and some pavements.
- Facilitate the use of CDW in transportation applications through a coordinated effort between Arizona DOT, local agencies, contractors and waste haulers/landfill operators to establish source control and a market for the use of CDW.
- Conduct research to improve the performance of recycled, co-product, and waste materials (RCWMs) identified as having comparable or diminished performance to reduce risk and make them more cost-effective.

Long-term opportunities for the state to increase its use of recycled materials in transportation infrastructure follow:

- Re-evaluate and modify existing construction specifications to become more accommodating to the use of recycled materials.
- Collaborate with materials suppliers and contractors to identify potential barriers to the use of RCWMs, and develop and execute research to support greater use.
- Conduct training and technology transfer activities within Arizona on best practices for using RCWMs.
- Construct and monitor test sections designed to investigate the performance of RCWMs.
- Establish a rigorous monitoring and reporting program to collect and disseminate the results.

- Work with Arizona DOT's pavement management system to identify future facilities that are scheduled for reconstruction, and develop plans for incorporating materials recovered during demolition.
- Develop a database to track materials usage, supply and demand, including RCWMs. This database can be tied to pavement performance, possibly through Arizona DOT's pavement management system in an effort to link materials (particularly RCWMs) to performance in future studies.
- Adopt techniques to begin quantifying environmental impacts using a more structured approach such as environmental LCA. This could be tied to the database development effort discussed in the previous bullet to provide inventory data on commonly used materials.
- Develop a framework for a systematic, quantitative approach to consider costs and benefits of using RCWMs. This may include both environmental LCA and economic LCCA.
- Work to understand sustainability benefits and how they are quantified. Consider benchmarking current practices.

Florida

Developing Improved Opportunities for the Recycling and Reuse of Materials in Road, Bridge and Construction Projects, Ralph Ellis, Duzgun Agdas and Kevin Frost, Florida Department of Transportation, December 2014.
http://www.fdot.gov/research/Completed_Proj/Summary_SMO/FDOT-BDV31-977-09-rpt.pdf
Section 3 presents a discussion of cost models for RAP and RCA (beginning on page 33 of the report, page 49 of the PDF). From page 34 of the report (page 50 of the PDF):

> Concrete has a reported savings of $134/ton by diverting from the landfills. With an estimated 94,175 tons of waste concrete being produced in 2012 from [Florida DOT] construction, there is an estimated savings of $12,431,100 resulting from diverting all of the concrete waste from landfills. … [T]his does not take into account the value of recycling and/or reusing the material.

The cost models are taken from a 2011 study on the state of construction and demolition waste recycling in Florida conducted by the Hinkley Center for Solid and Hazardous Waste Management (see *Related Resource* below) and address the savings resulting from avoiding landfill disposal costs. Details of the models for these materials are provided in Appendix E (beginning on page 94 of the report, page 110 of the PDF).

Related Resource:

> **Cost Model for Diverting Construction and Demolition Waste in North Central Florida**, James Sullivan, Charles Kibert and Tricia Ketchey, Hinkley Center for Solid and Hazardous Waste Management, August 2011.
> https://www.hinkleycenter.org/images/stories/Sullivan89161.pdf
> This study provided the cost models used by Florida DOT in the research project cited above.

Maryland

Recycled Material Availability in Maryland—A Synthesis Study, Dimitrios Goulias, Ahmet Aydilek and Yating Zhang, Maryland State Highway Administration, October 2016.
http://www.roads.maryland.gov/OPR_Research/MD-16-SHA-UM-4-03_Recycled-Materials-Availability_Report.pdf
Key benefits and cost savings of using RCA, RAP, dredged materials and foundry sand in highway construction projects are provided. Highlights from the report follow:

- Using RCA to replace virgin aggregates can save about $4 per ton for PCC, and up to $5 million on a single project. Using 30 percent RCA in PCC can reduce the environmental impact by 6.5 percent while using 50 percent RCA can reduce environmental impact by 20 percent.
- Using 20 to 50 percent RAP in granular aggregate base mixtures can result in a cost savings of 14 to 34 percent per ton.
- Using 50 percent RAP in HMA applications reduces energy consumption to about the level needed to produce cold mix asphalt.

North Carolina

Cost Analysis on the Reuse of Concrete Residuals, Nicholas Tymvios, Tara Cavalline and Christopher Albergo, North Carolina Department of Transportation, June 2017.
https://connect.ncdot.gov/projects/research/RNAProjDocs/2015-12%20Final%20Report.pdf
Researchers developed a model that can be used to predict the costs associated with handling, disposal and reuse of concrete residuals. The model incorporates a risk analysis to compare several feasible alternatives to disposal of concrete residuals, and a tool for contractors to use to estimate anticipated costs for disposal or reuse of concrete. Recommendations are also provided on acceptable methods for handling concrete residuals after monetary, environmental and risk factors have been considered.

The model, developed using Palisade @Risk 6, an add-in module for use with Excel, can be used to estimate the variability of costs for 20 different disposal/reuse combinations for the hydrodemolition, diamond grinding and diamond grooving debris described in this report.

Simulations were conducted using the model along with project constraints typical of North Carolina projects generating concrete residuals. Findings indicate that “disposal options for solids vary across the state and are highly dependent on the tipping fees waste disposal facilities charge, and solid disposal options using beneficial fill were determined to be the least expensive.”

Virginia

Feasibility of Reclaimed Asphalt Pavement (RAP) Use as Road Base and Subbase Material, Edward Hoppe, D. Stephen Lane, G. Michael Fitch and Sameer Shetty, Virginia Department of Transportation, January 2015.
http://www.virginiadot.org/vtrc/main/online_reports/pdf/15-r6.pdf
This study used a literature review to analyze the current state of the practice with regard to use of RAP material for road base and subbase and the potential for this use by Virginia DOT. Study recommendations are based on other state DOT practices and call for allowing the use of RAP in road base material. As the report indicates, “[b]ased on the past 5-year usage, it is estimated that on average V[irginia] DOT uses approximately 10 million tons of virgin aggregate material annually on projects for base and subbase layer applications. Potential cost savings of up to

30% could be realized with the use of 50% RAP by weight." The authors note that these cost estimates are based on the average price of $30 per ton for aggregate base material Type 1 and $12.50 per ton for RAP.

Tools to Monitor Recycled Material Use

The tools described below allow agencies to conduct an LCA or LCCA that assesses the environmental and economic effects of pavement and road construction, track the systemwide use of recycled materials in pavement mix designs, and connect producers and users of recycled highway construction materials.

BE^{2}ST-in-Highways, Recycled Materials Resource Center, undated.
http://rmrc.wisc.edu/be2st-in-highways/
Developed at the University of Wisconsin–Madison through RMRC, the Excel-based BE^{2}ST-in-Highways system provides a quantitative comparative analysis and rating method for sustainable highway construction.

Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE), Recycled Materials Resource Center, undated.
http://rmrc.wisc.edu/palate/
PaLATE, a spreadsheet-based LCA and LCCA program designed by the Consortium on Green Design and Manufacturing from the University of California, Berkeley, is used by RMRC and others to assess the environmental and economic effects of pavement and road construction. Inputs include initial designs, construction and maintenance materials and processes, equipment and project costs.

Material Tracking Tool, Recycled Materials Resource Center, 2015.
http://rmrc.wisc.edu/material-tracking-tool/
This Excel-based spreadsheet allows agencies to track systemwide use of more than 20 recycled materials found in pavement mix designs for transportation projects. Material types include fly ash in concrete, RAP and RCA. Although the tool cannot be used to calculate the benefits of substituting these recycled materials for conventional materials, agencies can use the total quantity calculations in LCA and cost comparison estimates.

Related Resource:

> **Material Tracking Tool User Manual**, Recycled Materials Resource Center, April 2016.
> http://rmrc.wisc.edu/wp-content/uploads/2016/07/RMRC-Material-Tacking-Tool-User-Manual.pdf
> This user manual for the material tracking tool provides step-by-step instructions for installing and using the tool.

Recycled Materials Web Map, Recycled Materials Resource Center, undated.
https://rmrc.wisc.edu/tools/recycled-materials-web-map/
This web map "promotes the use of recycled materials by connecting consumers to producers and providing location, quantity and contact information."

Related Resources:

"Recycled Material Web Map: Connecting Consumers and Producers," Andrew Graettinger, Brittany Shake, Randy Smith and Megan Huval Bucy, *Transportation Research Record 2571*, pages 1-9, 2016.
Citation at http://dx.doi.org/10.3141/2571-01
This journal article describes an online geographic information system web application that connects producers and consumers of recyclable material used in highway construction. The web map includes four core layers:

- *Producers* of recycled material can locate their facility and enter contact information.
- *Stockpile* layer, connected to the producer layer, allows facility managers to add or update information about their recycled material stockpiles, including material type, application, availability and cost. Multiple stockpiles can be associated with each producer.
- *Specification* layer includes DOT specifications and environmental regulations pertaining to the beneficial reuse of nonhazardous recycled material on the basis of specific location, material type and application.
- *Case study* layer locates projects that successfully used recycled materials and has information about the material type, application, volume data and any additional documentation.

Recycled Material Web Map User's Guide, Recycled Materials Resource Center, August 2015.
http://rmwm.caps.ua.edu/Documents/Recycled%20Material%20Web%20Map%20User%20Guide.pdf
This user guide describes the web map's functionality and offers guidance for three user types: general users, providers, and researchers and agencies.

SimaPro, PRé, 2018.
https://simapro.com/
This LCA software package is used internationally and by RMRC in its LCA evaluation of recycled materials used in highway construction.

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