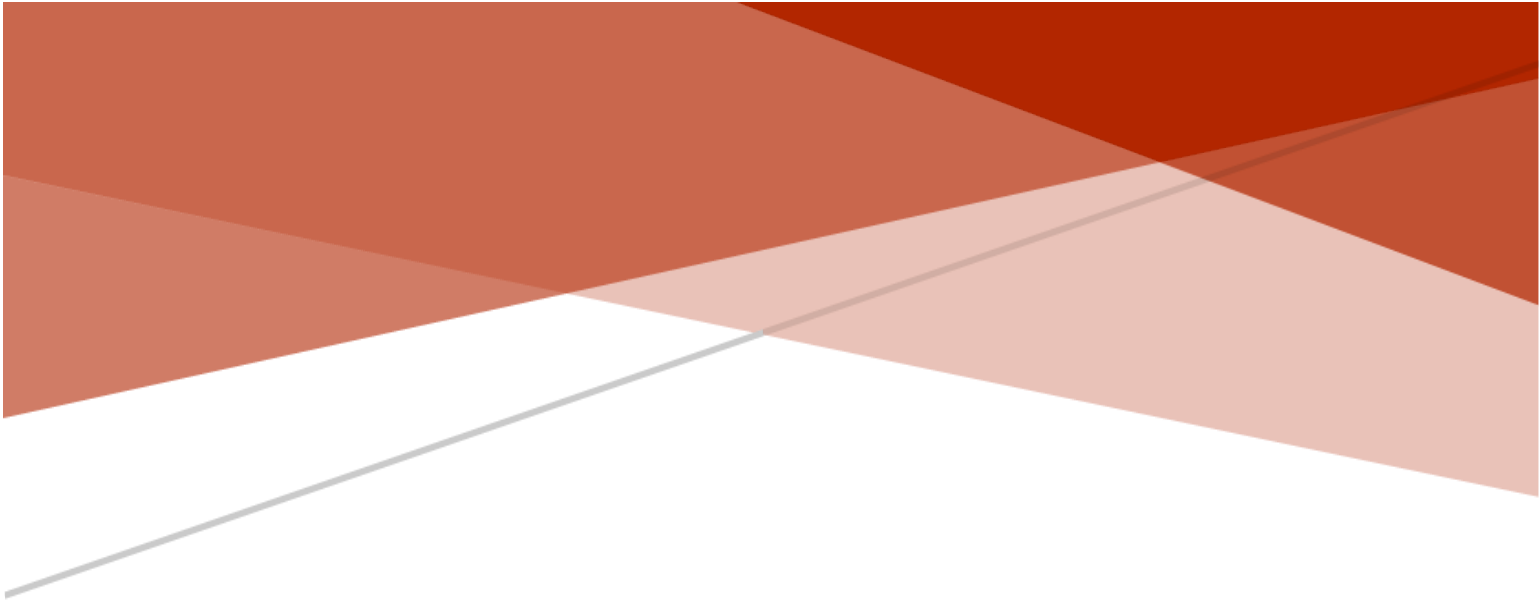




ILLINOIS HIGHWAY MATERIALS SUSTAINABILITY EFFORTS 2017

Prepared by: Kelly Morse
Kelly.Morse@illinois.gov

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. PRR 167	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A	
4. Title and Subtitle Illinois Highway Materials Sustainability Efforts of 2017		5. Report Date August 24, 2018	
		6. Performing Organization Code N/A	
7. Author(s) Kelly Morse		8. Performing Organization Report No. PRR 167	
9. Performing Organization Name and Address Illinois Department of Transportation Central Bureau of Materials 126 East Ash Street Springfield, IL 62704		10. Work Unit No. N/A	
		11. Contract or Grant No. N/A	
12. Sponsoring Agency Name and Address Illinois Department of Transportation Bureau of Research 126 East Ash Street Springfield, IL 62704		13. Type of Report and Period Covered Calendar Year 2017	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract This report provides a summary of the sustainability efforts of the Illinois Department of Transportation (IDOT) in recycling reclaimed materials in highway construction during calendar year 2016. This report meets the requirements of Illinois Public Act 097-0314 by documenting IDOT's efforts to reduce the carbon footprint and achieve cost savings through the use of recycled materials in asphalt paving projects. Research efforts undertaken and those that will have a future impact on IDOT's sustainability efforts are highlighted. In 2017, 1,451,675 tons of recycled material were used, an 19% decrease in recycled tonnage from the 1,795,408 tons in 2016. The value of 2017 recycled materials was \$51,488,535, a 1.5% increase from 2016. In 2017, the miles of roadway improvement decreased, the number of bridges constructed or rehabilitated increased, and value of projects awarded was higher, as compared with 2016 figures. Despite the decrease in recycled tonnage in 2017, the overall value of the recycled materials increased due to increase in the price for some of the individual recycled materials.			
17. Key Words Reclaimed asphalt shingles (RAS), recycled materials, Illinois Public Act 097-0314, sustainability, reclaimed, recycled, reclaimed asphalt pavement (RAP), recycled concrete material (RCM), fly ash, hot-mix asphalt (HMA), concrete aggregate.		18. Distribution Statement No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 20 + appendices	22. Price N/A

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

DISCLAIMERS

The contents of this report reflect the view of the author(s), who is (are) responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Center for Transportation, the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Trademark or manufacturers' names appear in this report only because they are considered essential to the object of this document and do not constitute an endorsement of product by the Federal Highway Administration, the Illinois Department of Transportation, or the Illinois Center for Transportation.

EXECUTIVE SUMMARY

The Illinois Department of Transportation (IDOT) continues to use a variety of reclaimed and recycled materials in highway construction. Recycled materials are used in highway construction to supplement aggregates, concrete, hot-mix asphalt (HMA), steel, and sealants, as well as for soil modification and pavement markings. This report summarizes the materials used in 2017, along with specific reporting on the use of shingles, efforts to reduce the carbon footprint, and efforts to achieve cost savings by using recycled materials, as required by Illinois Public Act 097-0314.

The recycled materials tracked by IDOT are summarized in four major groups: aggregate, HMA, concrete, and other. The aggregate group includes recycled concrete material (RCM) and reclaimed asphalt pavement (RAP) used as an aggregate in lieu of natural aggregates used as granular fill or as a replacement for natural aggregates in HMA. The HMA group includes slags used as friction aggregate, crumb rubber, RAP, and reclaimed asphalt shingles (RAS). The concrete group includes fly ash, ground granulated blast furnace slag, and microsilica used to replace cement or supplement the cement and provide specific properties to the final concrete product. The “other” category group includes by-product lime used for soil modification, glass beads used for pavement-marking retroreflectivity, and steel used for reinforcement in concrete.

In 2017, reclaimed and recycled materials totaling 1,451,675 tons were used in Illinois highways. This represents nearly a 343,733-ton or 19% reduction from 2016 quantities. Funding availability and the portfolio of project types are the major factors influencing recycle levels. On a tons-per-mile basis, the amount of recycled materials used in 2017 decreased slightly from 2016 levels. In 2016 there were 1,967.12 tons/mile, compared to 1,813.46 tons/mile in 2017. Despite the reduced quantities, the materials had higher values than the previous year, which resulted in a total value of \$51,488,535, an increase of 1.5% from 2016.

The amount of RAS used in 2017 was 42,820 tons, which is a 47% increase from the 2016 use of 29,113 tons. A major factor that increased the overall RAS usage was the increase in the amount of RAS used in District 1 from 9,652 tons in 2016 to 28,555 tons in 2017, or a 196% increase. The number of paving projects, lane miles, and types of mixes used heavily influences the amount of RAS used each year. The number of IDOT districts for which contractors produced HMA containing RAS remained at seven in 2017.

The amount of reclaimed asphalt pavement (RAP) used for HMA increased from 748,991 tons in 2016 to 801,776 tons in 2017, or a 7% increase.

While reporting tons of materials is an easy measure, it does not represent the true environmental benefit of recycling the various materials. This report estimates the equivalent carbon dioxide (CO₂EQ) emissions savings of the recycled materials used by IDOT. The use of fly ash resulted in the greatest environmental benefit by replacement of energy-intensive cement. It is estimated that IDOT's recycling efforts reduced CO₂EQ emissions 105,638 tons in 2017. The use of fly ash accounted for approximately 41% of the reduction in emissions documented herein.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION.....	4
CHAPTER 2: USE OF RECLAIMED AND RECYCLED MATERIALS IN ILLINOIS HIGHWAY CONSTRUCTION IN 2017	5
2.1 REPORTING HISTORY	5
2.2 RECLAIMED AND RECYCLED MATERIALS ADDED OR DELETED IN 2017	5
2.3 MATERIALS RECLAIMED AND RECYCLED IN 2017	5
2.3.1 Determining Recycle Quantities	5
2.3.2 Economic Values of Recycled Materials	6
2.3.3 Recycled and Reclaimed Material Use and Values for 2017	6
2.4 HISTORICAL RECYCLING TRENDS AND DATA ANALYSIS	7
2.4.1. Recycling Relationship to Program Budget	7
2.4.2 Determination of Recycled Content.....	8
2.5 REGIONAL/DISTRICT RECYCLING EFFORTS	9
CHAPTER 3: RECLAIMED ASPHALT SHINGLES.....	10
3.1 RAS POLICIES AND SPECIFICATIONS IN EFFECT FOR 2017	10
3.1.1 RAS Policy for Sources	10
3.1.2 RAS Specifications.....	10
3.2 QUANTITY OF RAS USED IN CALENDAR YEAR 2017	10
CHAPTER 4: ENVIRONMENTAL EVALUATION OF RECYCLED MATERIALS USED IN 2017	12
4.1 LIFE-CYCLE ASSESSMENT	12
CHAPTER 5: SUSTAINABILITY RESEARCH ACCOMPLISHMENTS AND INITATIVES ..	15
5.1 SUSTAINABILITY RESEARCH ACCOMPLISHMENTS DURING 2017	15
5.1.1 R27-180: Concrete Pavement Mixtures with High Supplementary Cementitious Materials (SCM) Content.....	15
5.1.2 R27-175: Development of Long-Term Aging Protocol for Implementation of the Illinois Flexibility Index Test (I-FIT).....	15
5.1.3 R27-168: Field Performance Evaluations of Sustainable Aggregate By-Product Applications (Phase II)	15

5.2 PROJECTS INITIATED IN 2018.....	16
5.2.1 R27-196HS: Rheology-Chemical Based Procedure to Evaluate Additives used in Asphalt Binders for Performance Enhancements (Phase 2).....	16
5.2.2 R27-193-1: Flexible Pavement Recycling Techniques	16
5.2.3 R27-193-2: Flexible Pavement Recycling Techniques (Full-Depth and Rubblization)	16
 CHAPTER 6: CONCLUSIONS.....	17
 REFERENCES	18
 APPENDIX A: RECYCLED AND RECLAIMED MATERIALS QUANTITIES USED AND EQUIVALENT VALUES, 2017	21

CHAPTER 1: INTRODUCTION

This report is part of a series of annual reports published since 2010 to document recycling and sustainability efforts of the Illinois Department of Transportation (IDOT). This report also meets the reporting requirements of Illinois Public Act 097-0314 (Illinois General Assembly 2012).

Various past reports by IDOT and the Illinois Center for Transportation (ICT) provide excellent background information on reclaimed and recycled materials used in highway construction (Brownlee 2011, 2012; Brownlee and Burgdorfer 2011; Griffiths and Krstulovich 2002; IDOT 2013; Lippert and Brownlee 2012; Lippert et al. 2014, 2015, 2016, 2017; Rowden 2013).

In 2012, Illinois Public Act 097-0314 called on IDOT to report annually on efforts to reduce its carbon footprint and achieve cost savings through use of recycled materials in asphalt paving projects (IDOT 2013; Lippert and Brownlee 2012; Rowden 2013). The act also required IDOT to allow the use of reclaimed asphalt shingles (RAS) in all hot-mix asphalt (HMA) mixes only if such use does not cause negative impacts to pavement life-cycle cost.

Illinois has many years of experience using various reclaimed materials in highway construction. These materials tend to be materials that reduce the use of virgin materials such as aggregate, cement, or asphalt. Fly ash and ground granulated blast furnace slag (GGBFS) have been added to concrete in Illinois for over 50 years. These additions reduce the amount of cement (a carbon-intensive material) required, while also lending other desirable properties to concrete. Reclaimed asphalt pavement (RAP) has been in use since the early 1980s, and its use is widely accepted.

Other materials, such as RAS, have a much shorter history of use. Until 2011, IDOT was conducting experimental projects using RAS in HMA. With the passage of Public Act 097-0314, specifications were developed and adopted to allow use of RAS on all IDOT projects as a contractor option (Lippert and Brownlee 2012). As with the adoption of any new specification or policy, issues and areas of improvement were identified and changes implemented. Earlier versions of this report documented the resulting changes and improvements.

This report is structured with each chapter covering various aspects of the use of reclaimed and recycled materials. Chapter 2 presents IDOT's overall use of reclaimed and recycled materials in highway construction projects. Chapter 3 provides a specific look at IDOT's efforts in utilizing RAS in HMA paving. Chapter 4 presents a life-cycle assessment based on available information which portrays the environmental benefits of recycling the various materials. Chapter 5 provides an overview of research projects that will provide long-term improvements to the life-cycle of pavements using recycled materials.

CHAPTER 2: USE OF RECLAIMED AND RECYCLED MATERIALS IN ILLINOIS HIGHWAY CONSTRUCTION IN 2017

2.1 REPORTING HISTORY

The first recycling report was published in 2002 to answer various inquiries on recycling (Griffiths and Krstulovich 2002). After that first effort to report on recycled materials, a follow-up report was not produced until construction information was available in 2010 (Brownlee and Burgdorfer 2011). Reporting of recycled material use has since been on an annual basis (Brownlee 2011, 2012; Lippert et al. 2014; Rowden 2013). The 2012 report on use of recycled materials provided the most in-depth overview of how each material is derived and used in highway construction (Rowden 2013). The 2013, 2014, and 2015 reports provided benchmark performance measures on recycled material use on a per-mile basis rather than total quantity (Lippert et al. 2014, 2015, 2016, 2017).

This report uses the same basic methodology for determining quantities as used in past reports from IDOT's Materials Integrated System for Test Information and Communication (MISTIC). Information from MISTIC is summarized to report quantities of each recycled material. The data reporting followed the same data collection methodology from the 2013 report on use (Lippert et al. 2014). Beginning with the 2016 sustainability report, the RAS data collection methodology was modified from a contactor survey on use to reliance on data contained in MISTIC (Lippert et al. 2017).

2.2 RECLAIMED AND RECYCLED MATERIALS ADDED OR DELETED IN 2017

The list of reclaimed and recycled materials used by IDOT was reviewed while preparing this report. During the 2017 reporting year, no new materials were added or old materials deleted.

2.3 MATERIALS RECLAIMED AND RECYCLED IN 2017

2.3.1 Determining Recycle Quantities

The quantities presented in this report pertain to the materials for which the amount of recycled material can be soundly documented through existing records. Items such as steel reinforcement and glass beads are composed of 100% recycled materials, by means of how those materials are manufactured, and thus are simple to report. Many additional tons of recycled materials are used, but tracking quantities used is impractical. For example, recycled steel is used in large steel shapes for bridge construction; however, the amount of recycled material varies in each steel heat or batch. Information on the recycled content of such items is not available in the database and therefore not reported.

While MISTIC reports are the source of material quantities for most of the reported materials, there is an exception—namely, glass beads. The reported quantity for glass beads is based on quantities accepted for use in the state of Illinois. This quantity includes use by some local agencies that take part in statewide purchase agreements.

Previous versions of this report determined RAS quantities via a contractor survey. The reason this method of data collection was done was that MISTIC reporting of RAS quantities needed to be developed and shown to be reliable. Improvements in MISTIC documentation and reporting have progressed to the point that there is no longer a need to survey contractors for RAS quantities.

2.3.2 Economic Values of Recycled Materials

Economic values for the various materials were updated to provide a reasonable comparison from year to year. For 2017 pricing, a statewide average was determined from supplier- and contractor-provided information. For items that have price indexes, such as steel, the monthly IDOT index was averaged for the year (IDOT 2017b).

2.3.3 Recycled and Reclaimed Material Use and Values for 2017

2.3.3.1 Data for 2017

Appendix A presents the 2017 recycled and reclaimed material quantities and values. In total, 1,451,675 tons of recycled material were used in 2017, which is an 19% decrease in recycled tonnage from the 1,795,408 tons in 2016. The value of 2017 recycled materials was \$51,488,535, a 1.5% increase from 2016. In 2017, the miles of roadway improvement decreased, the number of bridges constructed or rehabilitated increased, and value of projects awarded was higher, as compared with 2016 figures. Despite the decrease in recycled tonnage in 2017, the overall value of the recycled materials increased due to increase in the price for some of the individual recycled materials.

2.3.3.2 Data Analysis of 2017 Use

To present a more accurate picture of IDOT's recycling effort, a series of figures is presented which provides information on 2017 results, as well as historical trends. As shown in Figure 1, the bulk of the recycled tonnage was made up of three materials: RAP in HMA, recycled concrete material (RCM), and RAP as an aggregate.

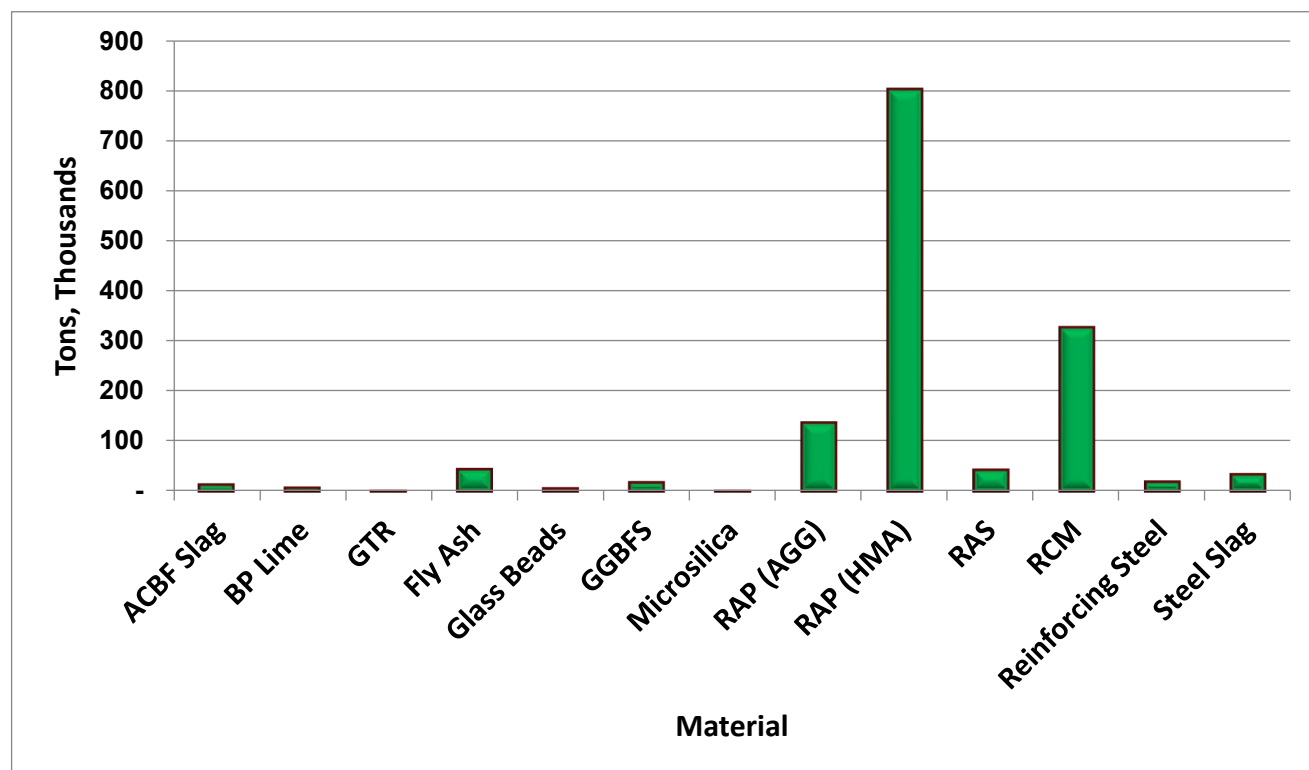


Figure 1. Reclaimed material use in 2017.

Figure 2 breaks out quantities by related uses for HMA, aggregate, Portland Cement Concrete (PCC), and other. The other category consists of by-product lime, glass beads, and steel. The HMA category includes slags used as friction aggregate (in HMA), crumb rubber, RAP, and RAS. PCC-related materials include fly ash, ground granulated blast furnace slag (GGBFS), and microsilica used to replace cement or provide specific properties to the final concrete product. Aggregate use consists of RCM and RAP used in lieu of natural aggregates. From this summary, recycled materials related to HMA and aggregate use represents the majority of IDOT recycled tonnage.

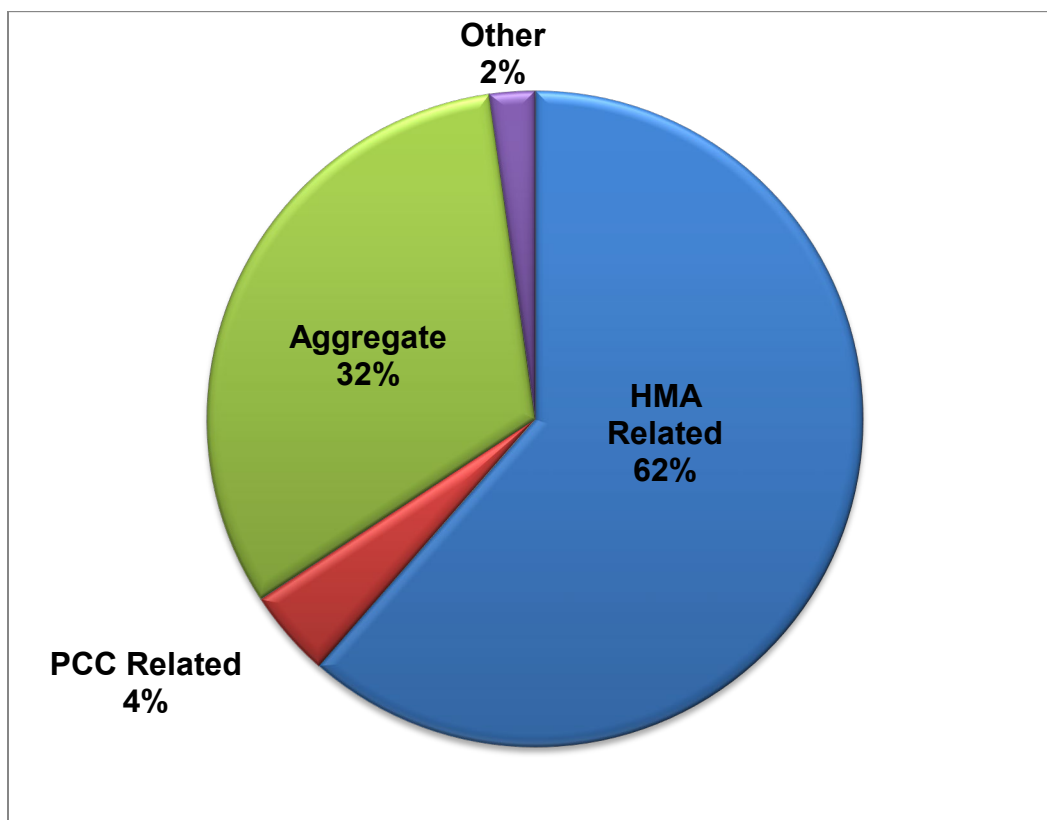


Figure 2. Reclaimed materials by related tons of use in 2017.

2.4 HISTORICAL RECYCLING TRENDS AND DATA ANALYSIS

2.4.1. Recycling Relationship to Program Budget

Recycling quantities are highly correlated to the overall budget and portfolio of project types (bridge vs. pavement resurfacing vs. reconstruction) within a budget year. In general, resurfacing projects result in RAP being both produced and used. Major reconstruction or new alignment (greenfield) projects can use substantial amounts of recycled material. By contrast, bridge projects tend to use limited amounts of materials because of the short lengths involved with these types of projects. Presented in Figure 3 are the total tons recycled from calendar years 2009 through 2017.

Also presented in the chart by fiscal year (FY; IDOT's FY is July 1 through June 30) are the values of projects awarded, centerline miles paved/improved, and number of bridges built/improved (IDOT 2017a). Note that this timeframe is not the same as the calendar year (CY) reported for recycled tonnage. However, the values tend to align themselves roughly on a CY basis because of the delay between the award of contracts and the use of materials in the project. For this report, it was considered reasonable to use all data as if they had been from the same time-period by CY.

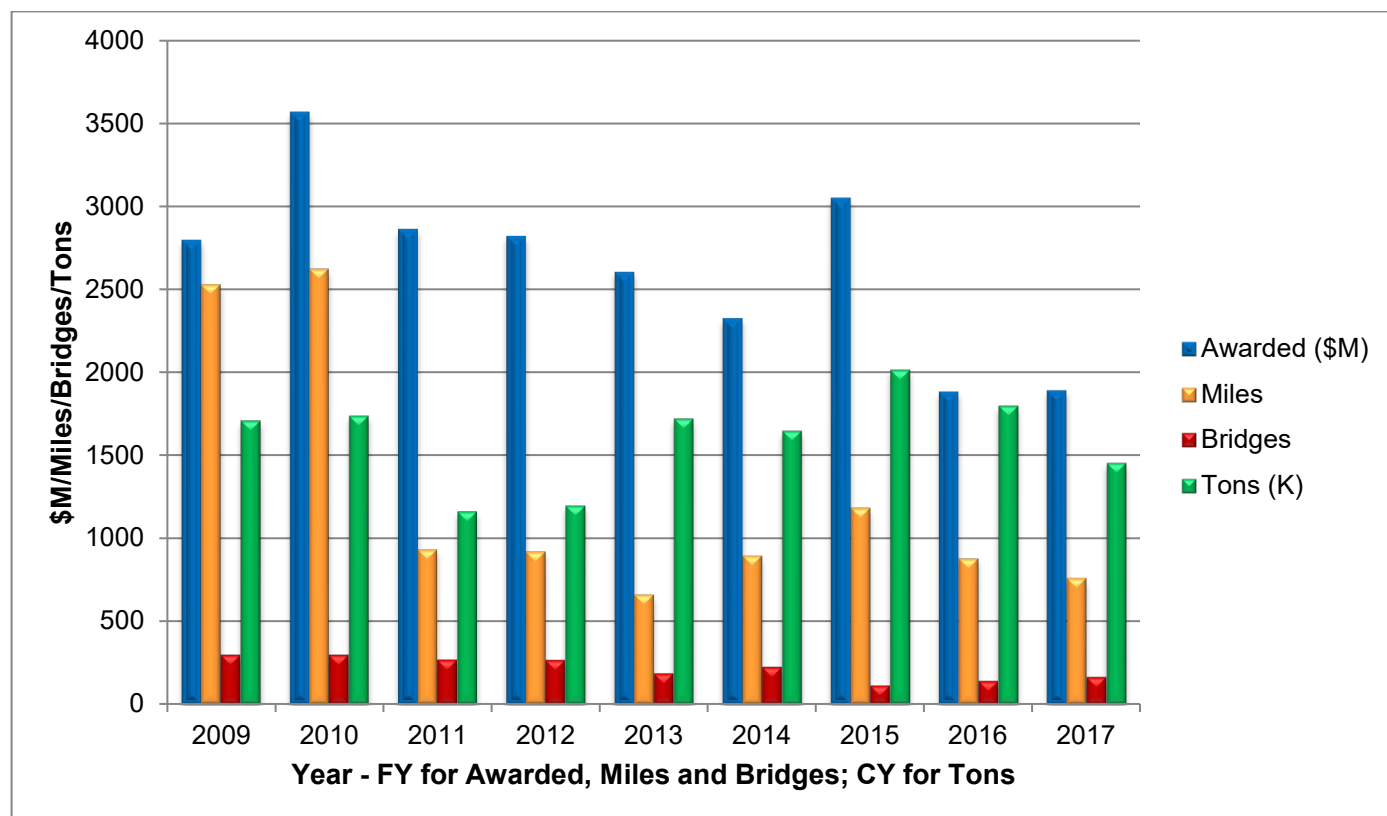


Figure 3. Annual projects awarded (FY), miles improved (FY), bridges built/improved (FY), and recycled tons (CY).

2.4.2 Determination of Recycled Content

To provide a more representative performance measurement of IDOT's recycling efforts, previous reports presented the general recycle content by calendar year (Lippert et al. 2014, 2015, 2016, 2017). That approach is continued in this report. Figure 4 represents the results of determining the average tons of recycled material for each centerline mile of improvement since 2009. On a tons-per-mile basis, 2017 represents an 19% decrease in recycle quantity from 2016.

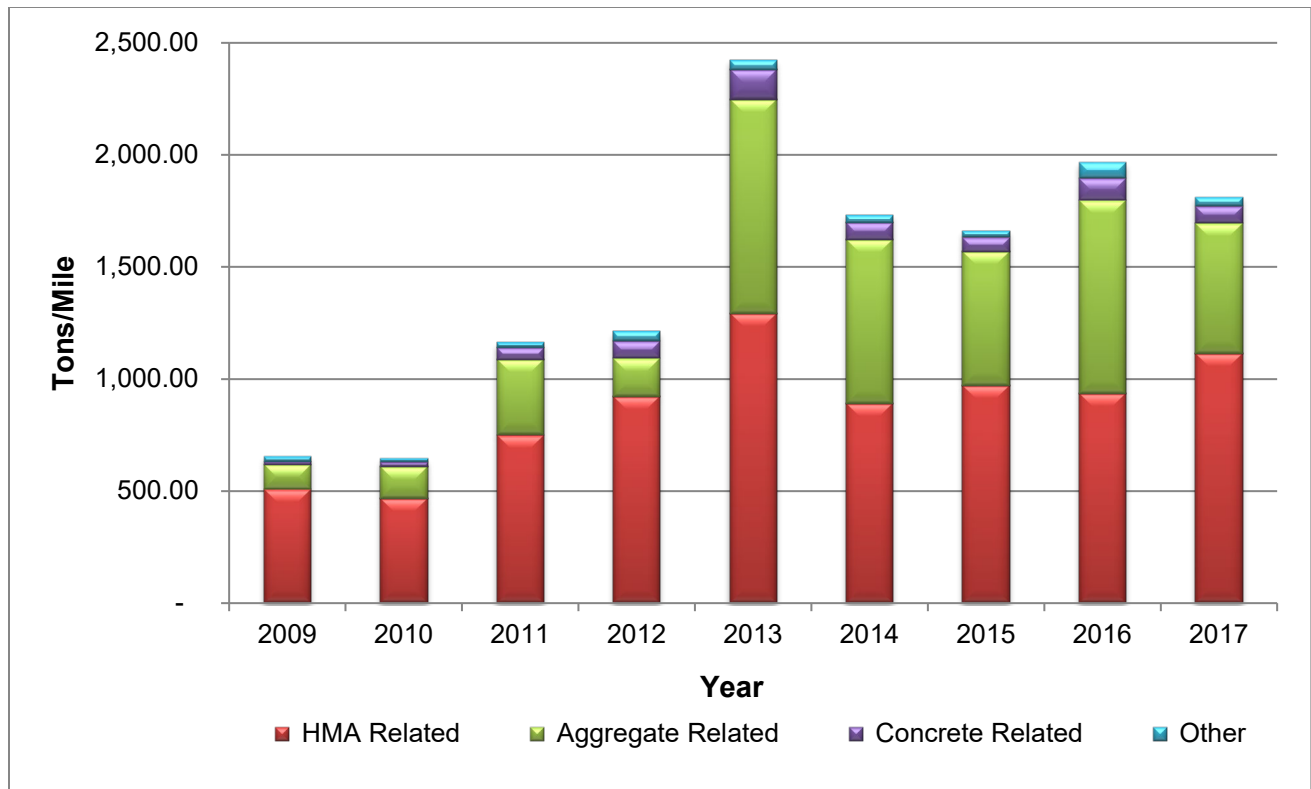


Figure 4. Historical recycle content.

2.5 REGIONAL/DISTRICT RECYCLING EFFORTS

District 1 developed their own special provision to use resources unique to their area. The previous report described the special provisions in effect at the time (Lippert et al. 2014, 2015, 2016, 2017). No changes, additions, or deletions were made to Regional/District special provisions in 2017.

CHAPTER 3: RECLAIMED ASPHALT SHINGLES

This chapter is a continuation of reporting on the specific status and use of RAS as required by Illinois Public Act 097-0314 (Illinois General Assembly 2012). Several reports provided details of RAS adoption (IDOT 2013; Lippert and Brownlee 2012; Lippert et al. 2014, 2015, 2016, 2017). MISTIC data were used to report 2017 RAS usage.

3.1 RAS POLICIES AND SPECIFICATIONS IN EFFECT FOR 2017

3.1.1 RAS Policy for Sources

The Bureau of Materials and Physical Research (BMPR) Policy Memorandum, “Reclaimed Asphalt Shingle (RAS) Sources” (28-10.3), continued to be in effect for all 2017 RAS production and represents no change in policy since 2012. The policy can be found in the report on RAS use in 2012 (IDOT 2013). During 2017, IDOT added new RAS suppliers, increasing the total to 23 (IDOT 2016).

3.1.2 RAS Specifications

3.1.2.1 Statewide Specifications

There were no changes to the Bureau of Design and Environment (BDE) specification, “Reclaimed Asphalt Shingles (RAS) (BDE),” effective November 1, 2012, for 2017.

3.1.2.2 Regional/District Specifications

The District 1 Special Provisions did not change for 2017.

3.2 QUANTITY OF RAS USED IN CALENDAR YEAR 2017

In 2017, IDOT experienced an increase in RAS use. The total used in 2017 was 42,820 tons which was a 47% increase from 2016 at 29,112 tons. (Lippert et al. 2017). The increase can be attributed to a significant increase in RAS usage by District 1 from 9,652 tons in 2016 to 28,555 tons in 2017.

In 2017, seven of the districts reported use of RAS, which is the same number as the previous year. Figure 5 presents the percentage of the 2017 statewide total RAS used by each IDOT district.

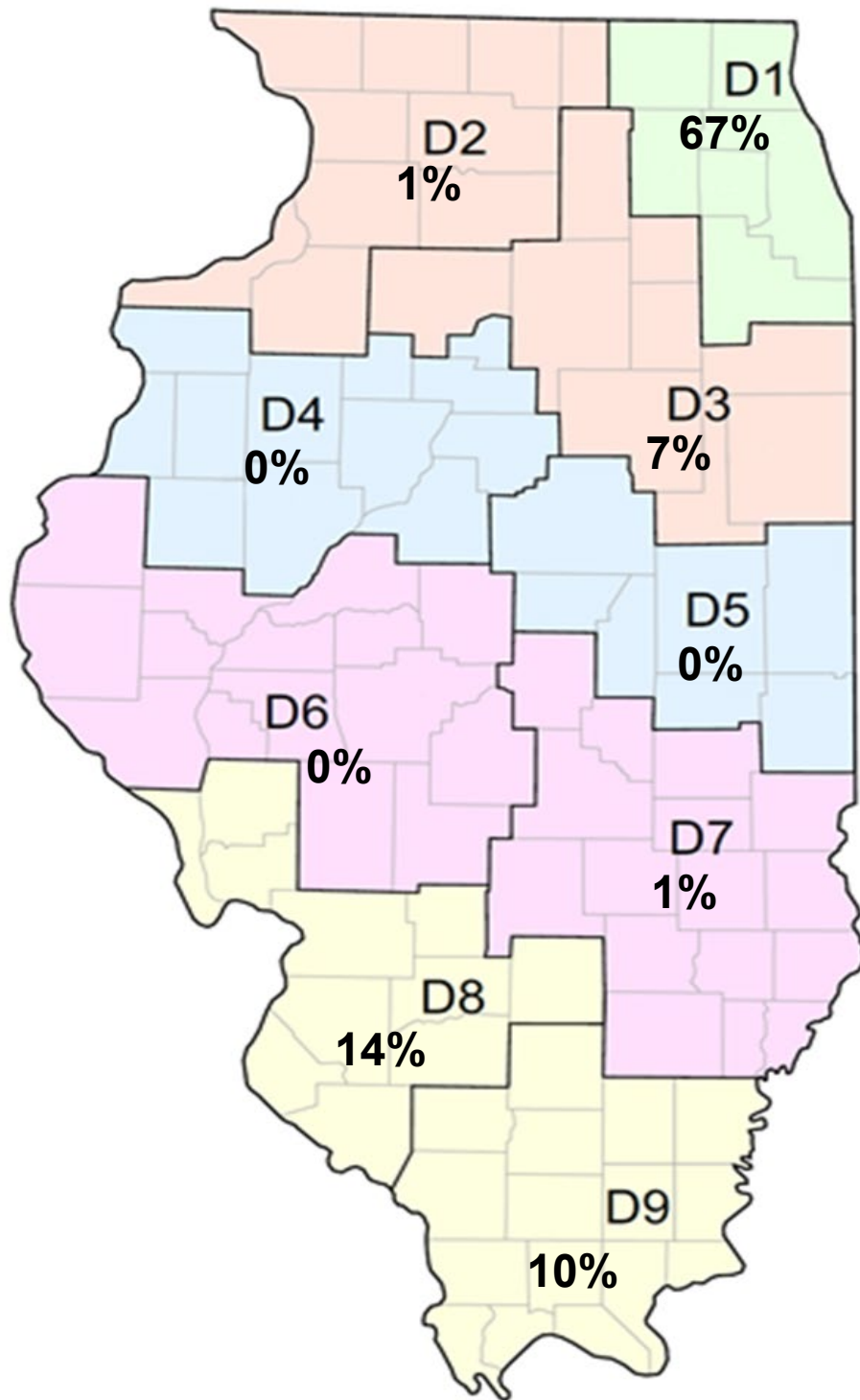


Figure 5. Percentage of RAS used by each district in calendar year 2017.

CHAPTER 4: ENVIRONMENTAL EVALUATION OF RECYCLED MATERIALS USED IN 2017

Over the years, the prime driver for use of recycled materials has been the initial cost savings of using reclaimed materials. Often these materials have a low economical value due to the need to remove or dispose of them from the site of generation. Often these materials can be used to replace more costly virgin materials, provided they are produced to a consistent quality standard. The ability to fully or partially replace virgin and/or manufactured materials with a product that otherwise would be landfilled or stockpiled as a waste can also greatly reduce the environmental burden of highway materials. As such, this chapter provides a summary of quantitative analysis for using recycled materials in terms of carbon emissions.

4.1 LIFE-CYCLE ASSESSMENT

An approach used for evaluation of the environmental burden of processes in life-cycle assessment (LCA) can also be applied to pavements and paving materials. This approach estimates, based upon documented processes, all aspects of a material used for a given application from cradle to grave. As part of the LCA process, each step of material production is analyzed in detail to determine a common and simple environmental-burden measure. Typically, the measure used is carbon dioxide equivalents per ton of the material used, or CO₂EQ/ton.

For a simple example of aggregate production, fuel and electricity use can be assigned to each step. For virgin aggregate, the material must be mined, crushed, sized, transported to the site, placed, compacted, and used for the duration of the facility, then salvaged or wasted at the end of the facility's life. Recycled aggregates have an advantage in that they do not have the economic or environmental burden of mining, which is a major part of the environmental savings in recycled aggregate.

This report used LCA values from the literature for both virgin materials and recycled materials used in Illinois to estimate a CO₂EQ/ton for each material recycled and the virgin material being replaced. The difference in CO₂EQ/ton between virgin and recycled material is the "savings" noted in Table 1 for each material, in kilograms equivalent of CO₂ for each ton of material recycled, for which information was available (Chen et al. 2010; EarthShift 2013; Prusinski 2003; Sunthonpagasit and Duffey 2004; World Steel Association 2011). For 2017, the total CO₂EQ savings in tons is also presented. This estimate includes typical transportation distances for Illinois. A main assumption is that the performance of the highway infrastructure item is equivalent for both virgin and recycled options.

Materials that have low CO₂EQ, such as aggregates, have very low values of savings when recycled materials are used. By contrast, when energy-intensive materials such as lime and cement are replaced with by-products such as fly ash, by-product lime, or GGBFS, very high savings of CO₂EQ can be realized.

From this simple analysis, it is estimated that a total of 105,638 tons of CO₂EQ was saved in 2017. Appendix A presents an accounting of CO₂EQ saved in 2017 for each of the materials used. As noted previously, using total tons of recycled material alone is limited as a performance measure for recycling. The environmental burden saved by material for 2017 is presented in Figure 6. This picture is very different from the tons of material as presented in Figure 1. Likewise, Figure 7 shows the distribution of CO₂EQ savings by related use, which differs greatly from the tonnage distribution presented previously in Figure 2.

Material	Savings per Ton of Use, CO₂EQ (kg)	2017 CO₂EQ Savings (Tons)
Air-Cooled Blast Furnace Slag	13	195
By-Product Lime	920	7,339
Crumb Rubber	1,704	63
Fly Ash	894	43,506
Glass Beads	929	5,986
Ground Granulated Blast Furnace Slag	763	15,278
Microsilica	NA	NA
Reclaimed Asphalt Pavement Used For Aggregate	0.8	121
Reclaimed Asphalt Pavement Used For HMA	17	15,025
Reclaimed Asphalt Shingles	79	3,729
Recycled Concrete Material	0.8	289
Steel Reinforcement	640	13,467
Steel Slag	17	639

Table 1. Estimated Environmental-Burden Savings by Use of Recycled Material

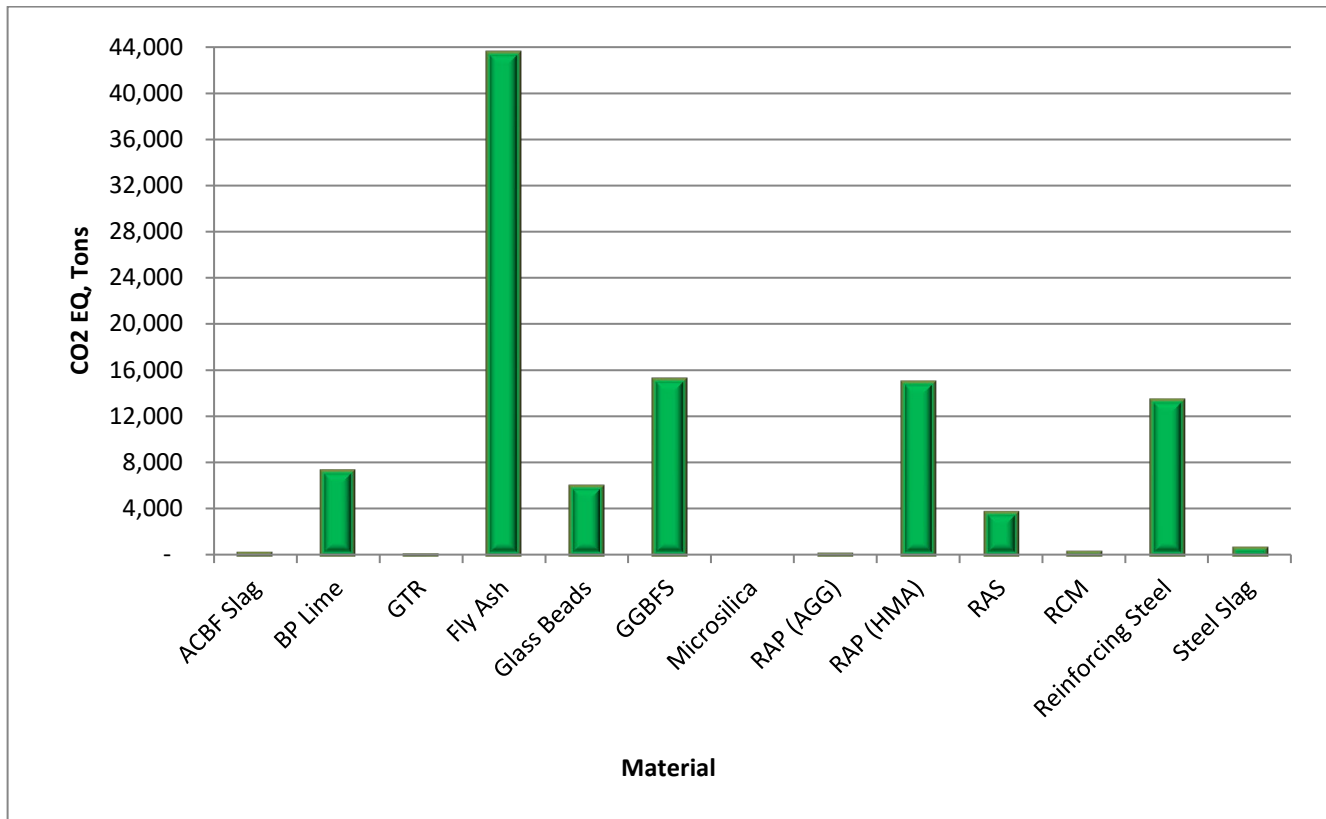


Figure 6. CO₂EQ saved, by material, in 2017.

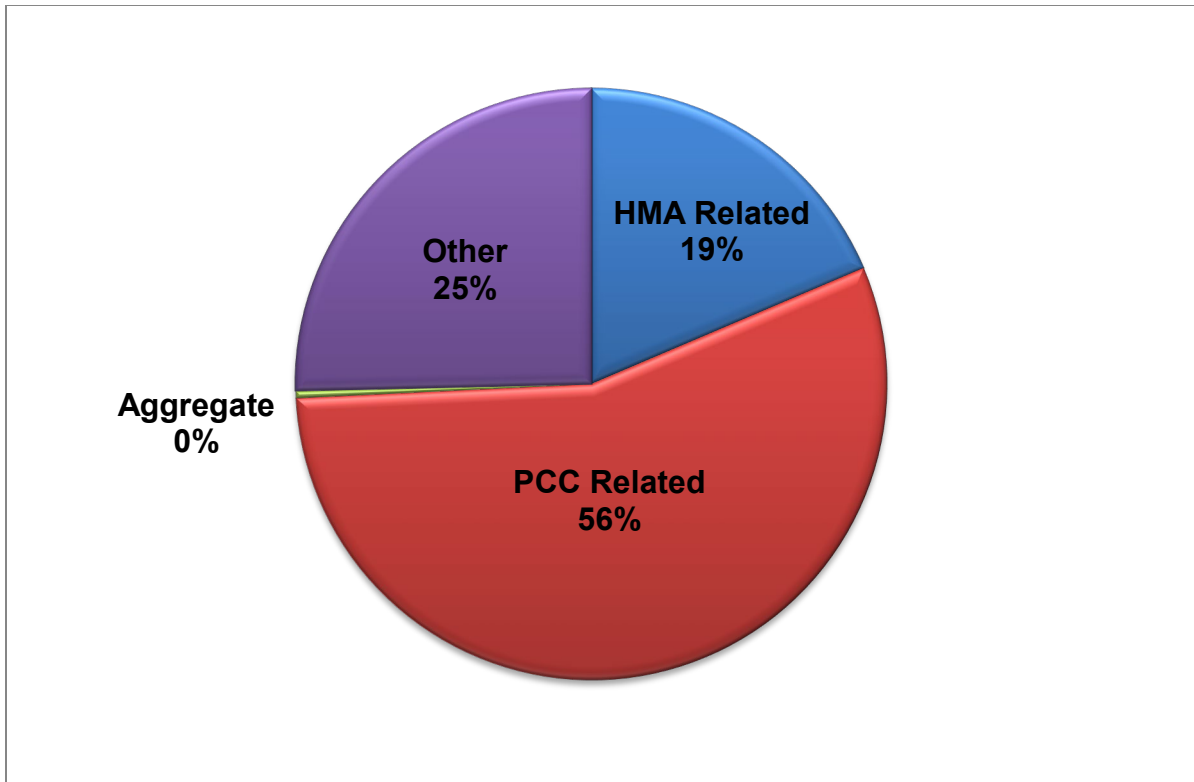


Figure 7. CO₂EQ saved, by related use, in 2017.

CHAPTER 5: SUSTAINABILITY-RESEARCH ACCOMPLISHMENTS AND INITIATIVES

During 2017, IDOT had several sustainability-related studies underway with ICT. These efforts focused on the use of recycled materials. Each of these studies resulted in an interim or final report. A brief description of each effort is provided.

5.1 SUSTAINABILITY RESEARCH INITIATED AND ONGOING DURING 2017

5.1.1 R27-180 Concrete Pavement Mixtures with High Supplementary Cementitious Materials (SCM) Content

This project began in October 2017 and is scheduled to be completed in June 2021. The principal objectives of Phase I of this project are to first validate/calibrate existing fly ash compositional equations that predict properties of concrete materials for pavements and then extend and/or develop new characterization protocols for high SCM replacement rates of cement (fly ash and slag) available in the State of Illinois. The goal is to have simple characterization and testing protocols that will allow the use of high volume SCMs in concrete pavement without compromising workability, air content, initial setting time, early strength gain, long term mechanical properties, and durability. Phase II objectives will be focused on using the compositional characterization protocols to predict the fresh and mechanical properties and durability performance for concrete containing high SCMs applied to pavements.

5.1.2 R27-175 Development of Long-Term Aging Protocol for Implementation of the Illinois Flexibility Index Test (I-FIT)

This project began in January 2017 and will conclude in December 2018. Because of ICT project R27-128, the Illinois Flexibility Index Test (I-FIT) was developed to screen AC mixes' capacity for cracking resistance. This test method evaluates AC mixes at 25 °C and at a loading head displacement rate of 50 mm/min. The flexibility index (FI), derived from the I-FIT results, is a simple index parameter correlated to fundamental crack growth mechanisms in the process zone. The parameter can distinguish mixes with varying characteristics that may result in different cracking resistance capacities. A provisional AASHTO test specification was prepared and accepted by the relevant AASHTO subcommittee as TP-124. Integration of the I-FIT method into IDOT's AC mix design specifications is underway. Several steps are required to complete the implementation. Therefore, the following research objectives are identified as follows: (1) Development of Long-Term Aging Protocol with specification criteria, and (2) Development of thresholds for long-term aged plant and laboratory produced mixtures.

5.1.3 R27-168 Field Performance Evaluations of Sustainable Aggregate By-Product Applications (Phase II)

This project began in September 2015 and will conclude in September 2018. In its last year, this study is intended to determine from field performance evaluations the most successful sustainable/green applications utilizing large quantities of quarry by-product fines (QB) in road construction. Full-scale test sections have been constructed to demonstrate innovative and sustainable uses of QB applications. The constructed pavement sections are in the process of being tested using the

University of Illinois's accelerated pavement-testing equipment to evaluate field performances of the most promising QB applications. The study will produce draft specifications for beneficial QB utilization, which is expected to have an immediate impact on sustainable construction practices in the state of Illinois by reducing total energy consumption and greenhouse gas emissions per ton of aggregate production and resulting in significant savings on IDOT construction projects. By utilizing an optimized quantity of QB in soil modification, thus lowering the quantity of lime and or cement required to meet soil modification requirements for subbase, the environmental impacts of construction are greatly reduced.

5.2 PROJECTS INITIATED IN 2018

5.2.1 R27-196HS Rheology-Chemical Based Procedure to Evaluate Additives/Modifiers used in Asphalt Binders for Performance Enhancements (Phase 2)

This project started July 2018 and will conclude December 2020. The overall goal of the project will be to develop an advanced and systematic binder screening protocol that includes a long-term aging procedure for modified binders with rheological and chemical characterization methods. At the end of the proposed study, it is also expected that preliminary thresholds established in project ICT R27-162 will be validated and fine-tuned based on various combinations of rheology-chemistry space diagrams.

5.2.2 R27-193-1 Flexible Pavement Recycling Techniques

This project began in July 2018 and will conclude in July 2021. The objective of this project is to further develop and refine specifications, procedures, and policies for flexible pavement recycling techniques (Cold Central Plant Recycling and Full-Depth Reclamation with Cement).

5.2.3 R27-193-2 Flexible Pavement Design (Full-Depth and Rubblization)

This project began in July 2018 and will conclude in July 2021. Project activities will focus on utilizing BDAT (Best Demonstrated Available Technology) as related to Full-Depth HMA pavements and Rubblized Portland Cement Concrete Pavement with HMA Overlay.

CHAPTER 6: CONCLUSIONS

The goal of this report is to provide a single-source document for 2017 sustainability efforts in highway materials that serves to meet the reporting requirement of Illinois Public Act 097-0314. In summary, the 2017 efforts in recycling resulted in the following:

- In 2017, recycled materials used in highway projects totaled 1,451,675 tons, with a value of \$51,488,535.
- Usage of reclaimed asphalt shingles (RAS) in 2017 increased 47% from 2016 levels. The increase can be directly attributed to the significant increase, 196%, in RAS use by District 1 from 9,652 tons in 2016 to 28,555 tons in 2017. Reclaimed asphalt pavement (RAP) used for HMA increased from 748,991 tons in 2016 to 801,776 tons in 2017, or a 7% increase.
- Using Life-cycle assessment (LCA) and available information, it is estimated that carbon dioxide–equivalent emissions were reduced by 105,638 tons in 2017. The major contribution to the reduction was the use of fly ash to replace cement at a reduction of 43,506 tons. Also, the use of Ground Granulated Blast Furnace Slag and RAP for HMA reduced by over 15,000 tons each.
- With respect to material sustainability research projects in 2017, the department had three projects active or initiated in 2017, with another three projects starting in 2018. These research projects will result in a total of six publications in the form of interim/final reports and white papers.

REFERENCES

- Bhatterai, R., Kalita, P., Azeem, A., and Jha, R. 2016a. *Evaluation of Curb and Gutter Inlet Protection Products for Sediment Retention*. Report FHWA-ICT-16-001. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Bhatterai, R., Kalita, P., Garcia, C. B., Monical, J., and Schumacher, P. 2016b. *Evaluation of Ditch Checks for Sediment Retention*. Report FHWA-ICT-16-002. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Bhatterai, R., Kalita, P., Garcia, C. B., Monical, J., Stoklosa, M., and Azeem, A. 2016c. *Evaluation of Ditch Inlet Protection Products for Sediment Retention*. Report FHWA-ICT-16-003. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Bhatterai, R., Kalita, P., Azeem, A., and Jha, R. 2016d. *Evaluation of Flared-End Inlet Protection Products for Sediment Retention*. Report FHWA-ICT-16-004. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Brownlee, M. 2011. *Utilization of Recycled Materials in Illinois Highway Construction in 2010*. Physical Research Report No. 160. Springfield, IL: Illinois Department of Transportation, Bureau of Materials and Physical Research.
- Brownlee, M. 2012. *Utilization of Recycled Materials in Illinois Highway Construction in 2011*. Physical Research Report No. 161. Springfield, IL: Illinois Department of Transportation, Bureau of Materials and Physical Research.
- Brownlee, M., and Burgdorfer, R. 2011. *Utilization of Recycled Materials in Illinois Highway Construction in 2009*. Physical Research Report No. 158. Springfield, IL: Illinois Department of Transportation, Bureau of Materials and Physical Research.
- Chen, C., Habert, G., Bouzidi, Y., Jullien, A., and Ventura, A. 2010. LCA Allocation Procedure Used as an Incentive Method for Waste Recycling: An Application to Mineral Additions in Concrete. *Resources Conservation and Recycling* 54(12):1231–1240.
- EarthShift. US-Ecoinvent Database. 2013. Version 2.2. Zurich: Swiss Center for Life-Cycle Inventories.
- Griffiths, C.T., and Krstulovich, J.M. Jr. 2002. *Utilization of Recycled Materials in Illinois Highway Construction*. Physical Research Report No. 142. Springfield, IL: Illinois Department of Transportation, Bureau of Materials and Physical Research.
- Illinois Department of Transportation (IDOT). 2013. *Use of Reclaimed Asphalt Shingles in Illinois: Second Edition: A Report in Accordance with Public Act 097-0314*. Physical Research Report No. 163. Springfield, IL: Illinois Department of Transportation, Bureau of Materials and Physical Research.
- Illinois Department of Transportation (IDOT). 2016. *Qualified Producer List of Certified Sources for Reclaimed Asphalt Shingles*. Springfield, IL: Illinois Department of Transportation, Bureau of Materials and Physical Research.

- Illinois Department of Transportation (IDOT). 2017a. *For the Record, Fiscal Year 2017*. Springfield, IL: Illinois Department of Transportation.
- Illinois Department of Transportation (IDOT). 2017b. "Price Indices." <http://www.idot.illinois.gov/doing-business/procurements/construction-services/construction-bulletins/transportation-bulletin/price-indices>. Springfield, IL: Illinois Department of Transportation.
- Illinois General Assembly (2012). *Public Act 097-0314*. <http://www.ilga.gov/legislation/publicacts/fulltext.asp?Name=097-0314>.
- Lippert, D. L., and Brownlee, M. 2012 (August). *Use of Reclaimed Asphalt Shingles in Illinois: A Report in Accordance with Public Act 097-0314*. Physical Research Report No. 162. Springfield, IL: Illinois Department of Transportation, Bureau of Materials and Physical Research.
- Lippert, D. L., Kang, S., and Ozer, H., 2015. *Illinois Highway Materials Sustainability Efforts of 2014*. Report FHWA-ICT-15-014. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Lippert, D. L., Ozer, H., Al-Qadi, I.L., El-Khatib, A.K., Yang, R., Khan, T.U., Dahhan, A.Z., Vespa, J.W., and Trepanier, J.S. 2014. *Illinois Highway Materials Sustainability Efforts of 2013*. Report FHWA-ICT-14-015. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Lippert, D. L., Wu, S., and Ozer, H., 2016. *Illinois Highway Materials Sustainability Efforts of 2015*. Report FHWA-ICT-16-017. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Lippert, D. L., Wu, S., and Ozer, H., 2017. *Illinois Highway Materials Sustainability Efforts of 2016*. Report FHWA-ICT-17-014. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Lippert, D. L., Wu, S., Ozer, H., Al-Qadi, I. L., Meister, J. M., Renshaw, G., Barry, M. K., Said, I. M., Luque, A., Safi, F., Murphy, T. R., Trepanier, J. S., and Vespa, J. W. 2017. *Construction and Performance Monitoring of Various Asphalt Mixes in Illinois: 2016 Interim Report*. Report FHWA-ICT-17-003. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Ozer, H., Renshaw, G., Hasiba, K., and Al-Qadi, I. L., 2016. *Evaluation of the Impacts of Re-Refined Engine Oil Bottoms (ReOb) on Performance Graded Asphalt Binders and Asphalt Mixtures*. Report FHWA-ICT-16-006. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Prusinski, J. 2003. *Life-cycle Inventory of Slag Cement Manufacturing Process*. CTL Project No. 312012. Skokie, IL: Construction Technology Laboratories, Inc.
- Rowden, L. 2013. *Utilization of Recycled Materials in Illinois Highway Construction in 2012*. Physical Research Report No. 164. Springfield, IL: Illinois Department of Transportation, Bureau of Materials and Physical Research.

- Sharma, B. K., Ma, J., Kunwar, B., Singhvi, P., Ozer, H., and Rajagopalan, N. 2017. *Modeling the Performance Properties of RAS and RAP Blended Asphalt Mixes Using Chemical Compositional Information*. Report FHWA-ICT-17-001. Rantoul, IL: Illinois Center for Transportation, University of Illinois at Urbana-Champaign.
- Sunthonpagasit, N., and Duffey M.R. 2004. "Scrap Tires to Crumb Rubber: Feasibility Analysis for Processing Facilities." *Resources Conservation and Recycling* 40(4):281–299.
- World Steel Association. 2011. *Life-cycle Assessment Methodology Report*. Brussels: World Steel Association.

APPENDIX A: RECYCLED AND RECLAIMED MATERIALS: QUANTITIES USED AND EQUIVALENT VALUES, 2017

Material	Unit Equivalent Value	Quantity ¹ Tons	Total Equivalent Value to Department	CO ₂ Equivalent Savings Tons ⁶
Air-cooled blast furnace slag	\$16.00	13,639	\$218,224	195
By-product lime	\$35.00	7,237	\$253,295	7,339
Crumb rubber ²	\$400.00	33.6	\$13,434	63
Fly ash	\$20.00	44,148	\$882,960	43,506
Glass beads ³	\$596.000	5,845	\$3,483,858	5,986
Ground granulated blast furnace slag	\$85.00	18,165.0	\$1,544,025	15,278
Microsilica	\$500.00	43	\$21,500	-
Reclaimed asphalt pavement used for Aggregate	\$11.00	136,935	\$1,506,285	121
Reclaimed asphalt pavement used for HMA	\$30.00	801,776	\$17,825,962	15,025
Reclaimed asphalt shingles	\$35.00	42,820	\$1,498,700	3,729
Recycled concrete material	\$12.00	327,834	\$3,934,008	289
Steel reinforcement ⁴	\$1,028.00	19,090	\$19,624,104	13,467
Steel slag	\$20.00	34,109	\$682,180	639
Wet-bottom boiler slag ⁵	NA	NA	NA	NA
Totals	—	1,451,675	\$51,488,535	105,638

¹ Quantities were calculated from amounts assigned to projects in calendar year 2017. Prior to summation of values, metric values were converted to English values using factors located in Appendix B of the *Standard Specifications for Road and Bridge Construction*.

² Crumb rubber: This material quantity was calculated as 5% of the quantity of hot-poured joint sealant used in 2017.

³ Glass beads use is based on tested and approved quantities and not projects assigned through MISTIC.

⁴ Steel reinforcement: For this report, the IDOT monthly steel index was averaged for 2017 and used to represent the value of just the steel contained in these products. This approach does not include the epoxy coating value in the calculation of the material being recycled, which is a more accurate representation.

⁵ Wet-bottom boiler slag: No records were found in MISTIC that indicated WBBS was used for any IDOT projects in 2017.

⁶ Based on typical haul distances for Illinois and industrial averages between virgin material and recycled/reclaimed material found in the literature.