Guidance for Increasing the Use of Recycled Concrete Pavement Materials

Tara Cavalline, PhD, PE, UNC Charlotte
Mark B. Snyder, PhD, PE, Pavement Engineering and Research Consultants (PERC)
Tom Cackler, PE, Woodland Consulting
Peter Taylor, PhD, PE, National Concrete Pavement Technology Center



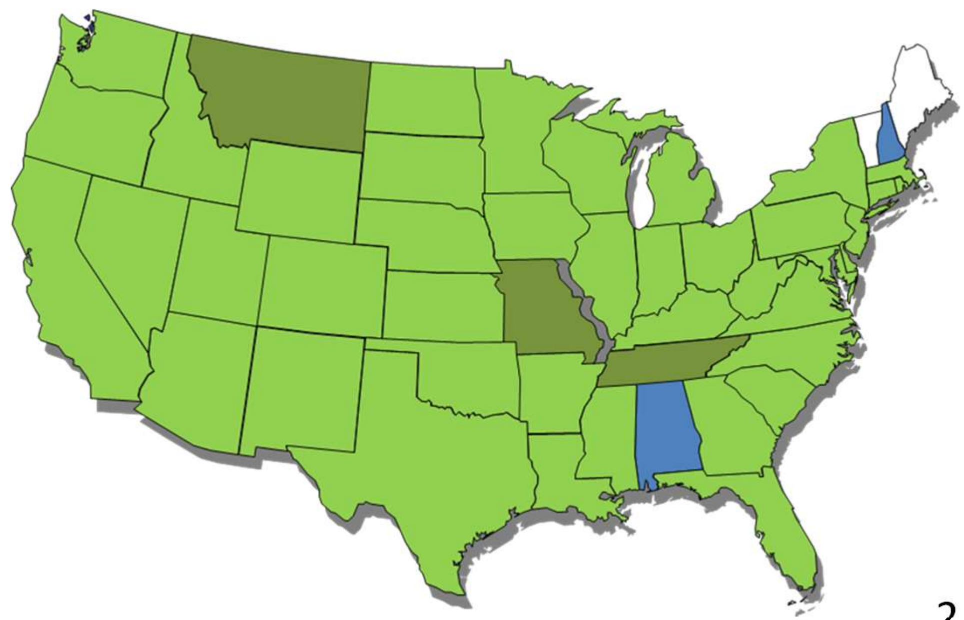

UNC CHARLOTTE

Iowa Better Concrete Conference
November 14, 2019

FHWA Concrete Recycling Initiative

- Part of FHWA Sustainable Concrete Pavement Program
  - Program Goals: Encourage innovation and extended application of sustainable pavement technologies on projects

- *Concrete Recycling Initiative* – promote recycling of concrete pavement materials in cost-effective applications while optimizing the triple bottom line (social, environmental, economic)

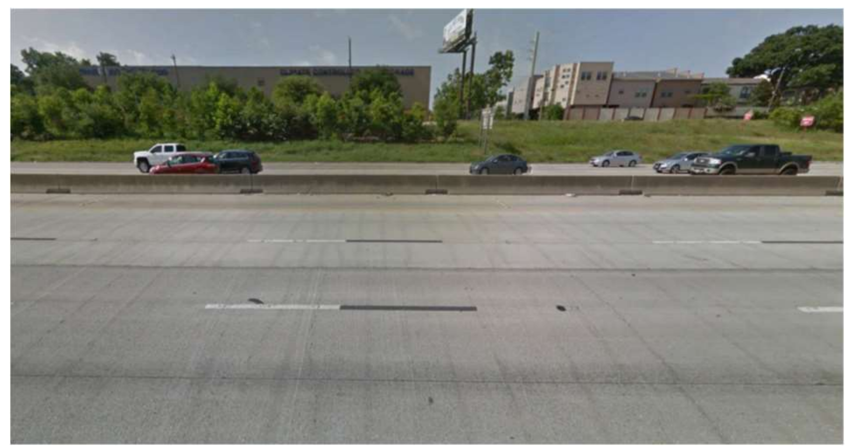


44 of 50 states allow use of RCA in various applications

(FHWA, 2004 + new info)

Reasons for Concrete Recycling

- Dwindling landfill space/increasing disposal costs
  - 50000 U.S. landfills accepting PCC in 1980
  - 5000 U.S. landfills accepting PCC in 2000
- Rapidly increasing demand for aggregates with limited resources
- Sustainability
  - Conservation of materials
  - Potential reduced environmental impact due to reduced construction traffic, reduced landfill
  - Cost savings
- Potential for improved pavement performance
- A proven technology – it works!



IH 10 in Texas, 100% RCA CRCP, 1995 construction (photo: Andy Naranjo, TxDOT)

Overview of Concrete Recycling Initiative

- Survey of state agencies & industry
- Synthesis of existing knowledge, practice, concerns
- Identification and review of ongoing research
- Development of Technical Guidance
  - Webinars (4)
  - Technical Briefs (7)
  - Practitioner's Manual

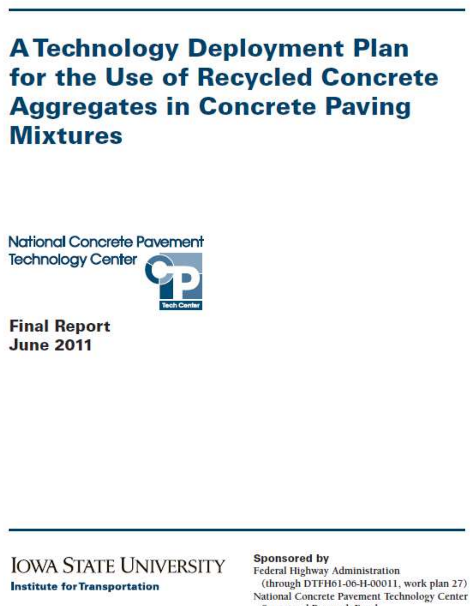
Source: Phillip Lamoureux, FHWA Western Federal Lands

Key Recycling Resources: Prior to this Initiative

- ACPA EB043P (2009) Recycling Concrete Pavements
- CP Tech Center Deployment Plan for RCA in Concrete Paving Mixtures (2011)
- NRMCA Report - Crushed Returned Concrete as Aggregates for New Concrete (2007)


Recycling Concrete Pavements

ACPA

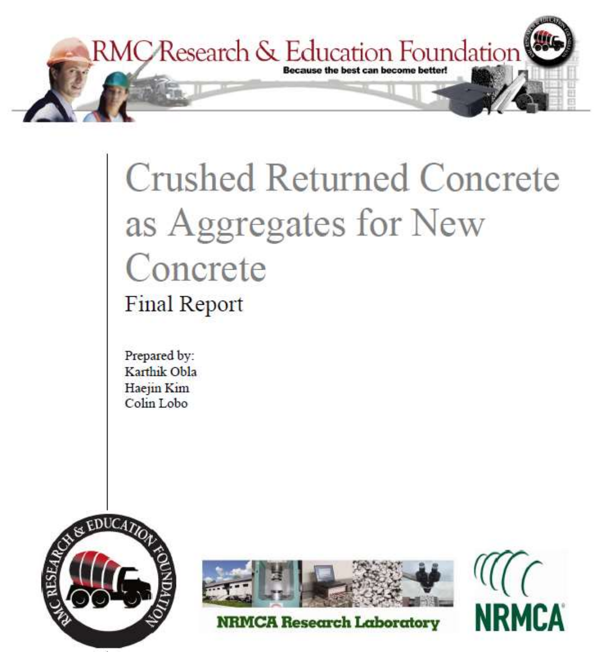

A Technology Deployment Plan for the Use of Recycled Concrete Aggregates in Concrete Paving Mixtures

National Concrete Pavement Technology Center

Final Report
June 2011

Iowa State University
Institute for Transportation

Sponsored by
Federal Highway Administration
(through DTFH61-06-H-00011, work plan 27)
National Concrete Pavement Technology Center
Sponsored Research Fund


RMC Research & Education Foundation
Because the best can become better!

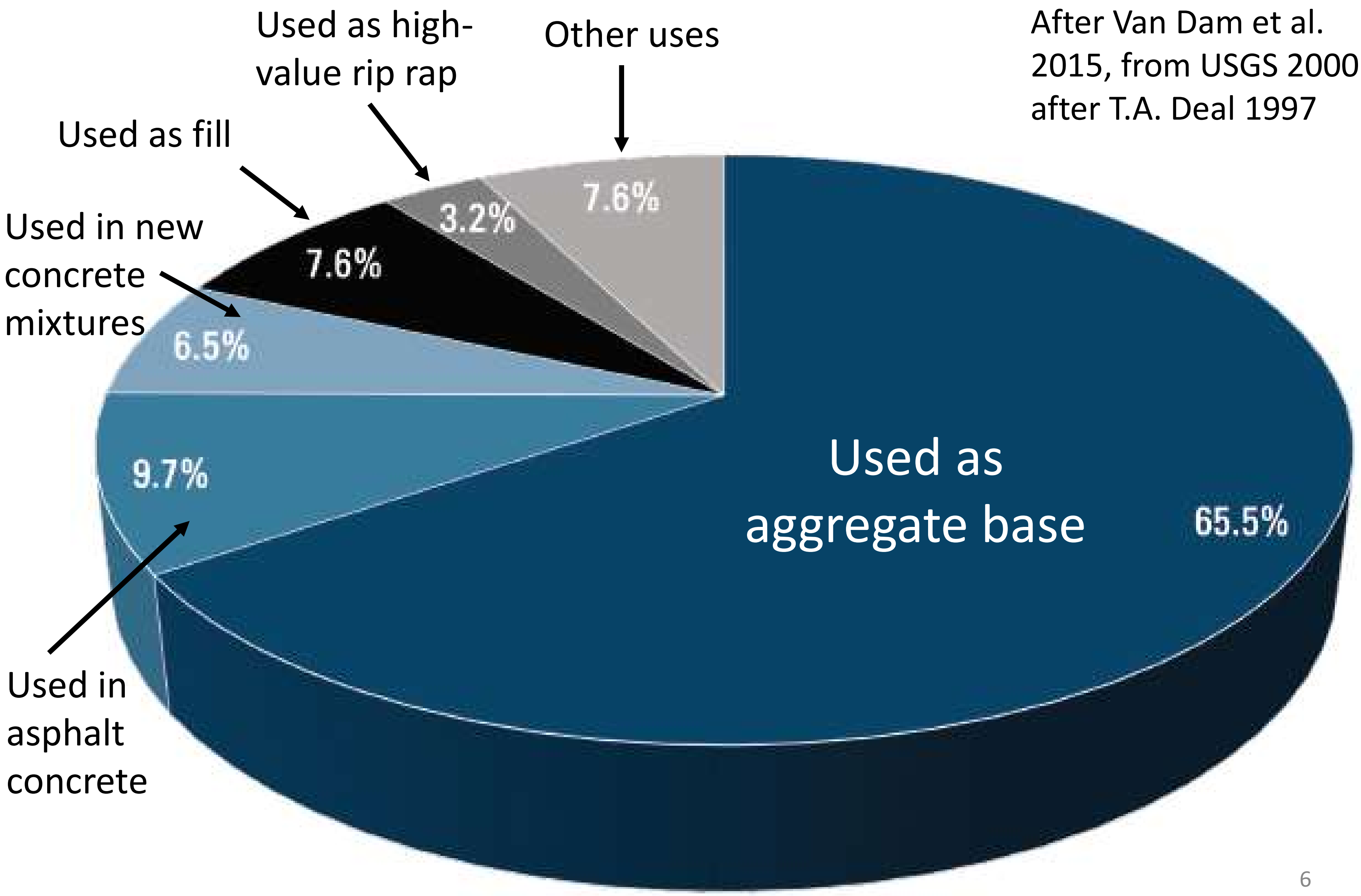
Crushed Returned Concrete as Aggregates for New Concrete
Final Report

Prepared by:
Karthik Obla
Haejin Kim
Colin Lobo

NRMCA Research Laboratory
NRMCA

End uses for crushed concrete

After Van Dam et al. 2015, from USGS 2000 after T.A. Deal 1997



2016 Survey Findings

- Production and use of RCA is common in pavement projects
- Unbound applications of RCA (bases) are most predominant
- Agencies and contractors want to increas the use of RCA
- Opportunities exist to increase volume of RCA used
    - Threshold for economical recycling is relatively low (< 5000 cy)
    - Most agencies have less stringent technical requirements for RCA sourced from agency’s own pavements
    - Agencies rely on state/federal agencies for guidance concerning environmental compliance

Some barriers exist for both bound and unbound uses

Industry Benchmarking Survey

Application	Percentage (% use)
Granular subbase	40
Crushed products for other markets	18
Embankment (includes backfill)	12
Coarse concrete aggregate	9
Other (given to owner agency)	7
Chemically stabilized granular subbase (CTB, lean concrete etc.)	4
Haul road	3
Granular shoulder material	3
Fine concrete aggregate	2
Surplus fines	1
Plant site subbase	1
Erosion control applications	0
Slope stabilization materials	0
Underdrain filter material	0
Rip rap	0

Survey Findings – Agency Barriers

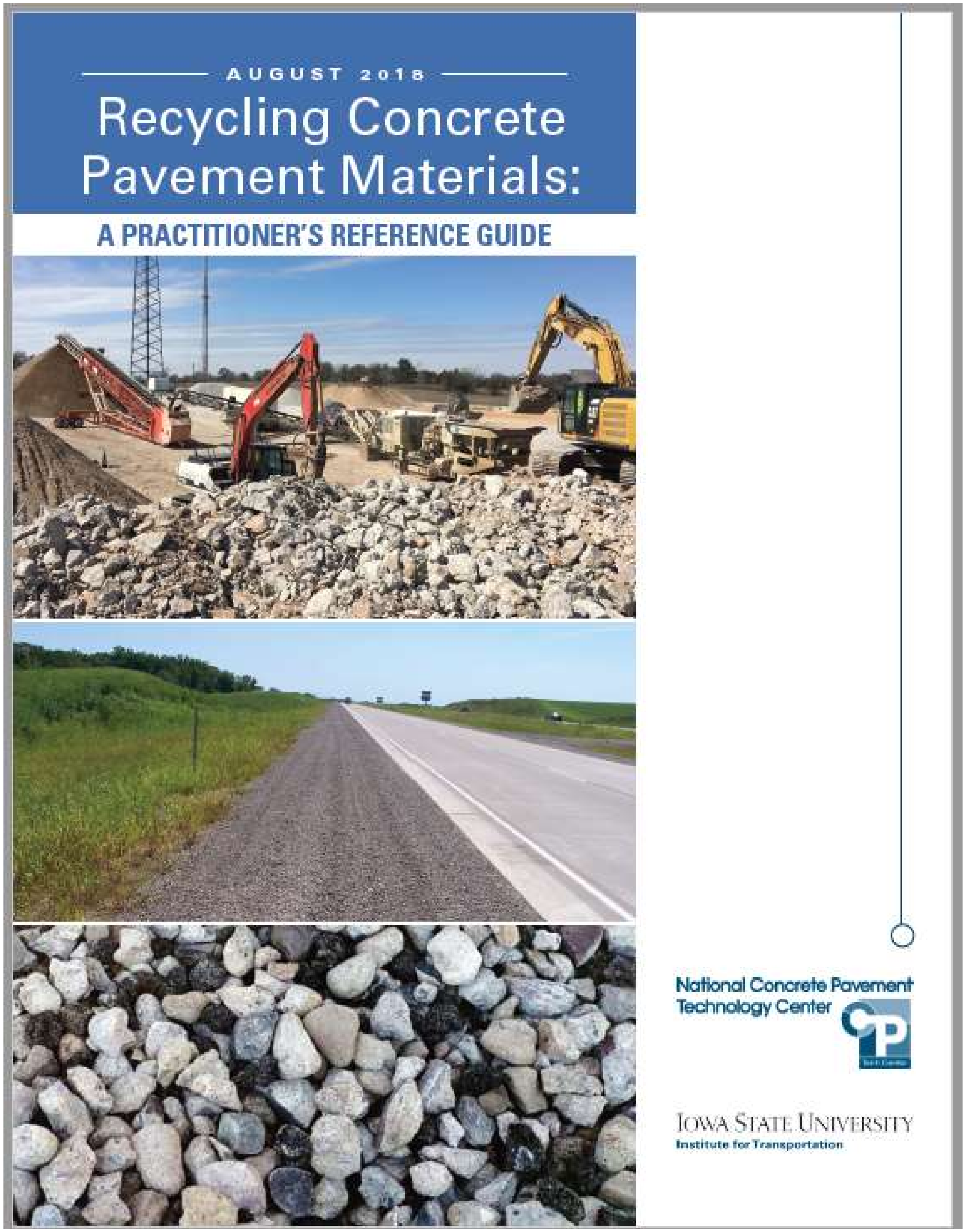
Survey Question	Barriers	Average response
Barriers for RCA use in **pavement foundations**	gradation issues (particularly fines)	2.5
	potential environmental impacts (from runoff, leachate, etc.)	2.3
	cost of producing RCA	2.0
	potential for concrete exhibiting materials-related distress to be incorporated into bases	1.9
	concerns with RCA foundation strength and/or stability	1.7

Barriers for RCA use in **new concrete mixtures**	alkali-silica reactivity (ASR) or D-cracking potential of the RCA	3.5
	availability of good, inexpensive natural sources of aggregate	3.3
	concerns with concrete workability	3.0
	economics	2.9
	lack of guidance on concrete mixture designs with RCA	2.9
	concerns with concrete shrinkage	2.6
	concerns with concrete strength	2.4

Scale: 0 = not a significant barrier to 5 = significant barrier

NEW

CONCRETE RECYCLING RESOURCE DEVELOPED AS PART OF THIS INITIATIVE:



Recycling Concrete Pavement Materials - Practitioner's Reference Guide

Ch. 1: Introduction to Concrete Pavement Recycling

Ch. 2: Economics and Sustainability

Ch. 3: Project Selection and Scoping

Ch. 4: Using RCA in Pavement Base Products

Ch. 5: Using RCA in Unbound Aggregate Shoulders

Ch. 6: Using RCA in Concrete Paving Mixtures

Ch. 7: Mitigating Environmental Concerns

92 pages of useful technical info, many case studies, and up-to-date implementation guidance

Chapter 1: Introduction

- Brief historical background
- Summary of benefits of concrete pavement recycling
  - Economic benefits
    - Cost savings as high as $5M on a single project (CDRA 2008)
    - Illinois Tollway >$45M savings in materials and hauling costs recycling 3.4 million tons of concrete 2008-2016
  - Environmental benefits
    - Introduced, covered extensively in Chapter 2
  - Impact of using RCA on concrete pavement performance
    - RCA may offer improved performance particularly in bases (Ch 4 and 5)
    - Acknowledges impact of RCA on concrete properties, but provides readily implementable strategies to address these impacts (Ch 6)

Ch. 2 Economics and Sustainability

Concrete recycling addresses sustainability "Triple Bottom Line":

- **Environmental benefits**
  - Conservation of aggregates
  - Reduction of landfill use
  - Reduction of greenhouse gases, sequestration of carbon
- **Economic benefits**
  - Metals recovery
  - Fuel savings due to reduced haul distances
  - Reduced disposal costs
  - Extension of landfill life
  - Potential tax credits, other incentives
- **Societal benefits**
  - Reduced land use and reduced impact to landscape

Quantifying Sustainability Benefits

Measurement tools can be used to quantify sustainability benefits, weigh alternatives and facilitate decision-making.

- Economic Analysis
  - Life Cycle Cost Analysis, LCCA
- Environmental Assessment
  - Life Cycle Assessment, LCA
- Rating Systems
  - INVEST
  - Greenroads
  - Envision
  - Others

Incorporate recycling activities into these tools to quantify sustainability benefits

	Economic Analysis (LCCA)	Environmental Assessment (LCA)	Rating Systems (Greenroads, Invest, Envision, etc.)
General considerations for each tool	➢ **Agency costs** • Pavement costs • Non-pavement costs (such as safety, engineering, inspection, testing) ➢ **User costs** • Vehicle operating costs • Travel delay costs • Crash costs ➢ **"Equivalent" designs** ➢ **Rehabilitation options and schedules** • Time to first activity • Activity life • Cost of activities ➢ **Analysis period** ➢ **Discount rate (inflation/$cost)** ➢ **End of Analysis (Residual) Value** • Remaining service life • Salvage value • Value as recycled materials • Demolition costs and landfill tipping fees	➢ **Functional unit** ➢ **System boundaries** ➢ **Inputs of raw materials, feedstock and energy** ➢ **Outputs of waste and pollution** ➢ **Impacts of transport** ➢ **Evaluate over the following phases:** • Raw material acquisition • Material processing • Manufacturing • Construction • Use • End-of-Life	➢ **Most consider pavement as a contributing subsystem to a larger system or project such as:** • Infrastructure project • Roadway project • Site development project • Agency sustainability effort ➢ **Factors considered often include:** • Ecological impact • Community impact • Connectivity • Aesthetics ➢ **Rating systems differ by:** • Grouping of performance criteria • Delineation and computation of metrics • Thresholds for obtaining points and ratings status • Certification methodology (self-certification or third-party certification)

Specific considerations for recycling activities can include:		
Economic Analysis (LCCA)	**Environmental Assessment (LCA)**	**Rating Systems (Greenroads, Invest, Envision, etc.)**
➢ **Economic costs of alternatives to recycling** • purchase and hauling costs for virgin material • landfill tipping fees for disposal of existing material ➢ **Economic costs of recycling** • hauling costs • crushing/grading equipment (onsite or offsite) • contractor efficiency • production efficiency	➢ **Fuel consumption** ➢ **Emissions** ➢ **Non-renewable resource use** ➢ **Freshwater use** ➢ **Hazardous and non-hazardous waste generation** ➢ **Local impacts such as noise and dust**	➢ **Amount of materials reused (mass or volume percentage)** ➢ **Method of recycling utilized** ➢ **Use of recycled materials in new mixtures** ➢ **Emissions reductions** ➢ **Noise reductions** ➢ **Planning initiatives** ➢ **End-of-life considerations**

Quantifying Sustainability

- Beltline Highway – Madison, WI
  - 1.5 mile segment reconstructed using a variety of recycled materials
  - RCA used in base course or embankment fill
  - 9,870 CY of RCA from onsite material utilized, crushed and graded onsite
  - Additional RCA sourced from offsite
    - Source concrete qualified for use using WisDOT's specifications
    - Require AASHTO T 96 abrasion testing for off-site materials

Photo:
Steven Theisen,
WisDOT

Quantifying Sustainability

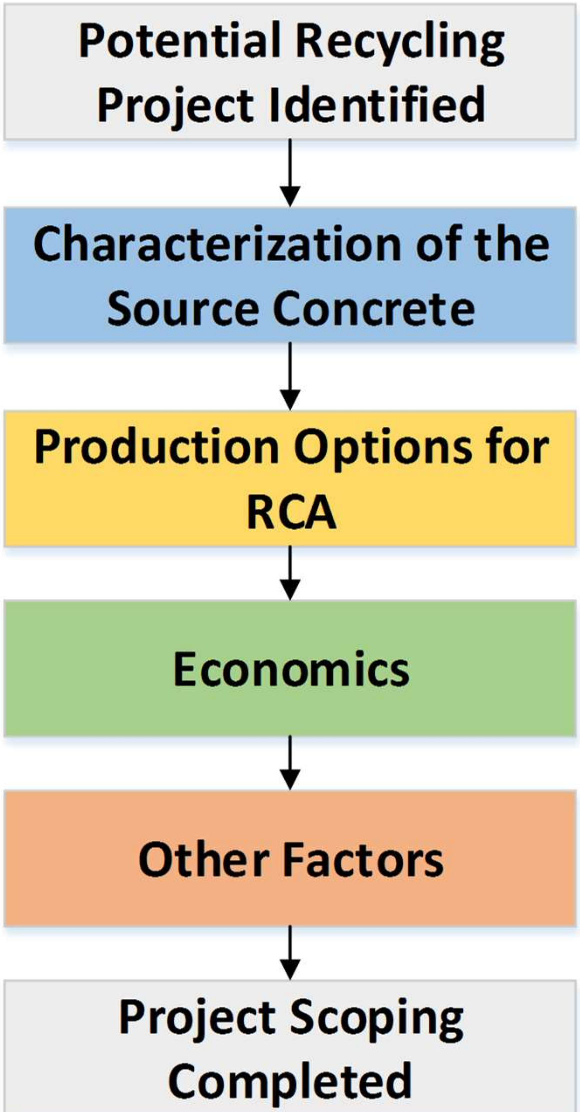
- Beltline Highway – Madison, WI
  - LCCA → cost savings of approx. $130,000 at initial construction from RCA use
  - LCA → lifetime environmental impact reductions of:
    - Energy use (13% reduction),
    - Water consumption (12% reduction)
    - CO_2 emissions (13% reduction)
    - Hazardous waste (9% reduction)
    - LCA was performed with PaLATE tool (Horvath 2007, detailed in Bloom et al. 2016)

Photo: Emily Bloom, UW-Madison

Quantifying Sustainability

- Illinois Tollway
  - Move Illinois: 15-year, $12.1B program started 2011
  - Extensive use of recycled materials
  - LCCA used to identify $50M in savings (through 2014) by use of recycled concrete rather than virgin aggregate in pavement bases.
  - Modified version of INVEST rating system developed to adapt to Tollway needs, used to score (and compare) over 15 projects
  - Tools for LCA for pavements developed and have been in proof-testing (since early 2016)
  - Plans to integrate LCA with LCCA software and INVEST rating system (Gillen et al. 2015 and Gillen and Vavrik 2016)

Ch. 3 Project Selection and Scoping



Structured around a flowchart showing typical project selection and scoping process

- Includes checklist of considerations for use of RCA in different applications
  - Materials considerations
  - Production considerations
  - Other considerations

Ch. 3 Project Selection and Scoping

Checklist of considerations for use of RCA in different applications

RCA use	Materials considerations	Production Considerations	Other considerations
New RCA concrete and stabilized base materials	• Sources • Specifications	• Processing options • Hauling • Crusher types • Production rates/storage • QA/QC • Residuals management	• Project staging • Costs • Environmental considerations • Permitting • Public perception
Unbound bases and drainage layers			
Filter material around drainage structures			
Fill (beneficial reuse of fines) not in pavement structure			

! Highly simplified table shown here !
See Reference Guide for all details…

Ch. 4 Using RCA in Pavement Base Products

Unbound aggregate base applications

- Performance concerns
  - Structural issues
  - Drainage issues
- Qualification testing
  - General
  - Gradation
  - Other tests (abrasion, soundness, etc.)
- Subbase design and construction considerations
- Concrete pavement design considerations
- Environmental considerations

Bound (stabilized) base applications

- Lean concrete subbase and cement-stabilized subbase
- Asphalt concrete and asphalt-stabilized subbase

Includes example projects for each application

Ch. 5 Using RCA in Unbound Aggregate Shoulders

- Constructability considerations
  - particle degradation during roll-down
  - moisture-density control
  - other concerns
- Qualification testing
  - gradation
  - Absorption
  - LA abrasion/MicroDeval
  - unconfined compression
  - Other tests
- Examples and Case Studies

Ch. 6 Using RCA in Paving Mixtures

- Constructability considerations
  - Fresh properties
- Pavement design considerations
  - Hardened properties
- Developing concrete mixture designs using RCA
  - Qualification Testing
  - Proportioning
- Examples and Case Studies
  - D-cracking aggregate
  - ASR
  - Continuously reinforced concrete pavement

Ch. 7 Mitigating Environmental Concerns

- Legislative and regulatory considerations

- Overview of potential environmental concerns
  - water quality
  - air quality
  - noise/local impacts
  - waste generation

- Mitigating environmental concerns during project planning and design
  - Focus on water quality issues

- Mitigating environmental concerns during construction
  - Strategies for mitigating issues on-site

Potential Environmental Impacts

- Water quality
  - Contaminants in runoff and drainage
  - Alkalinity, chemical contaminants, other
  - Transported sediments
- Air quality
  - Equipment emissions
  - Fugitive dust
- Noise, other local impacts
  - Additional processing, handling
  - Traffic
- Waste generation and disposition
  - Solids, wastewater, slurries

Photo: Dwayne Stenlund, MnDOT

Must be mindful of (and mitigate) adverse environmental impacts.
Treat RCA as an engineered material.

Planning and Design Considerations

Characterization of the Source Concrete

Considerations:

- Known (agency) or unknown source
- Exposure conditions during service
- Visual observations in service or demolished

Concrete from known agency project(s)

- Testing for environmental toxicity not needed
- To promote recycling, ensure specifications excempt material from environmental toxicity testing and hazardous materials considerations

Concrete from unknown project(s) or unknown/suspect exposure sonditions

- Testing for environmental toxicity may be warranted
- Incorporate specification provisions that:

1) do not allow concrete from these sources for recycling, or
2) provide guidance for environmental toxicity testing in accordance with appropriate agency regulations or goals (e.g. leaching tests, waste classification regulations, etc.)

Concrete exhibiting contamination beyond that which could be reasonably expected from typical in-service highway conditions OR Exceeding AASHTO M319-02 guidance on contamination limits

- Not recommended for recycling

Mitigating Environmental Concerns: Planning and Design Considerations

- Planning considerations and design techniques that protect water quality

RCA Use	Environmental Consideration	Mitigation Strategies
Unbound bases	• Contamination / pollutants from source concrete • High p... • Polluta... • Sedim...	Guidance on: • Source concrete prequalification • ...guidance ...ps, bioswales, ...ons) ...tion of drain system
Fill (beneficial reuse of fines)	• High pH leachate • Pollutants in leachate	• Detailed site and vegetation guidance provided
New RCA concrete mixtures	• Contamination / pollutants from source concrete	• None required

Mitigation strategies are provided specifically for concrete recycling related planning/design

Mitigating Environmental Concerns: Construction Strategies and Controls

- Construction Controls to Protect the Environment

	Mitigation Strategies			
Consideration	**Location**	**Site Layout and Controls**	**Process Controls**	**Operations**
Air quality (emissions and dust)	• Wind considerations • Natural topography / features	• Hauling strategies • Site maintenance • Wind screens	• Misters • Maintenance / operations of plant & vehicles	• Strategies for weather, vehicle operations, stockpiles
Water quality	• Processing/stockpile location guida	• Runoff trenches	• BMPs	• Stockpile ement olids treatment
Waste generation	• Washing equi guidance • Onsite beneficial reuse of waste		reduction and treatment	ize crushing operations • Beneficial reuses of fines
Community impacts	• Site and hauling considerations	• Two-way transport • Noise attenuation	• Chutes / conveyors	• Minimize drop height • Timing of operations

Mitigation strategies are provided specifically for concrete recycling related activities.

Minimizing Jobsite Footprint

"Be wary of sensitive receptors" (DETR 2000)

Reduce impacts from
- noise
- traffic
- light
- dust
- water pollutants

Site selection: Onsite vs. offsite

Well-implemented onsite material crushing program. Water spray source was freeze depressed by addition of automobile window wash fluid (from Dwayne Stendlund, MnDOT)

Reducing Jobsite Impacts (DETR 2000)

LOCATION

- On-site recycling (or close)
- Location away from sensitive areas
- Account for prevailing wind conditions
- Use buildings, natural topography, or vegetation as wind screen
- Provide noise attenuation barriers

SITE LAYOUT

- Minimize haul distances
- Encourage two-way transport to reduce trips
- Reduce vehicle movements

SITE CONTROLS

- Haul road surfacing, chemical stabilization of surfaces
- Application of water – misters, spray rigs/nozzles for prewetting

Photo: Dwayne Stenlund, MnDOT

Reducing Jobsite Impacts (DETR 2000)

OPERATIONS

- Work during periods of low wind velocities
- Minimize drop height of material
- Use chutes/conveyors
- Reduce vehicle speeds
- Shrouds, tarps on haul trucks
- Vehicle wheel and chassis washes
- Stockpile controls
  - Limit height of stockpiles and disturbance
  - Cover or provide a three-sided wind barrier
- Maintain vehicles and plant equipment
  - Maximize fuel efficiency, utilize emissions checks
  - Avoid leaving plant equipment and/or vehicles operating unnecessarily

reducing vehicle speeds from 30 mph to 20 mph reduces dust emissions by 22 percent (BCPH 2017)

Photos: Dwayne Stenlund, MnDOT

Stockpile Management – Best Practices

- For RCA, many states generally refer to handling/stockpiling practices for conventional aggregates
- Store material sourced from different types of concrete in separate stockpiles

"Clean" stockpile for RCA production

Stockpile of broken concrete with excessive fines

Photos: Iowa DOT - IM 210

Stockpile Management - Best Practices

- Select location to mitigate impact on surface waters
- Traditional physical controls
- *Redundant perimeter controls*
  - Berms, straw bales, filter channels
  - Silt fences
  - Trench encircling stockpile
  - Control drainage to maintained sediment trap
  - Nearby stormwater inlets off-line

Stockpiles for crushing set inside roadway depression with inlets offline
(source: Dwayne Stenlund, MnDOT)

Stockpile Management - Best Practices

Demolished material stockpiled beneath bridge prior to crushing. Silt fence and upland vegetative buffer used.

High-performance perimeter control using concrete blocks wrapped in geotextile fabric.

Could also use crushed concrete wrapped in geotextile.

Source: Dwayne Stenlund, MnDOT

RCA can actually be used in stormwater BMPs as filter material!

RCA used as filter for concrete slurry removal produced by other processes

- Salvaged RCA base reclaimed as berm for perimeter control of sawcutting slurry, along with sediment control "log."
- Water exits clear, checked for pH, adjusted to 7.0 ± 1.0 using CO_2 bubblers

Source: Dwayne Stenlund, MnDOT

Stockpile Management – Best Practices

- Control height (WSDOT - 24 ft max)
- Minimize fines
- Moisture control – recementing of particles
  - Bigger issue in stockpiles of fine aggregate
    - surface area, contact area
  - Open graded materials may not become recemented within short term (1 year) (Snyder 1996)
- Covers – geotextile or plastic
- Mist area with water for dust control

Plastic cover and perimeter berm

Photos: Dwayne Stenlund, MnDOT

Water Quality – Perimeter Control

Source: Dwayne Stenlund, MnDOT

<u>Perimeter control</u> at waterway near demolition and concrete crushing operations

- geotextile wrapped Jersey barriers
- RCA filter berm on inside
- water for dust suppression

Webinars:
http://www.cptechcenter.org/concrete-recycling/

1) Introduction to Concrete Pavement Recycling (Mark Snyder and Tara Cavalline)

2) Environmental Considerations in Concrete Pavement Recycling (Tara Cavalline)

3) Construction Considerations in Concrete Pavement Recycling (Gary Fick)

4) Case Studies in Concrete Pavement Recycling (Mark Snyder)

Tech Briefs

- Introduction to Concrete Recycling
- Quantifying the Sustainability Benefits of Concrete Pavement Recycling
- Concrete Pavement Recycling - Project Selection and Scoping (MAP Brief)
- RCA in Unbound Aggregate Shoulders
- RCA in Concrete Paving Mixtures
- Mitigating Environmental Concerns During Project Planning and Design
- Mitigating Environmental Concerns During Construction

http://www.cptechcenter.org/concrete-recycling/

Photo: CDRA

Acknowledgments

- Mark Snyder, PhD, PE, Engineering Consultant to the CP Tech Center
- Tom Cackler, Woodland Consulting, Inc.
- Dale Harrington, Snyder & Associates
- Peter Taylor, Iowa State University, CP Tech Center Director

  - American Concrete Pavement Association
  - Applied Research Associates, Inc. (formerly ERES Consultants)
  - Gary Fick, Trinity Construction Management Services, Inc.
  - Federal Highway Administration
  - Jeff Roesler, University of Illinois at Urbana-Champaign
  - Jeff Sturtevant, Prof. David Gress and the University of New Hampshire Recycled Materials Resource Center (RMRC)
  - Jim Foringer, PennDOT District 11-0
  - Maria Masten, Minnesota Department of Transportation
  - Moon Won, Texas DOT and University of Texas
  - Todd Hanson, Iowa Department of Transportation

UNC CHARLOTTE

Questions?