1. Cover page (see page 7 for cover letter format)
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Project Title: Chemical characterization of leachate produced from RCA

Funding Area: Research

Applicant Organization:

Name: University of Wisconsin - Madison
Address: 21 N. Park Street, Suite 6401, Madison, WI 53715-1218

Phone: (608) 262-3822 Fax: (608) 262-5111
E-mail: preawared@wisc.edu
Contact Person: Brenda Egan

Amount of Funding Requested: $ 244,108
Duration of Project (weeks, months, etc.): 18 months

Brief Description of Project (100 words):

The proposed NPDES regulations in the State of Washington, requiring a pH below 8.5 at the point of discharge from RCA, may have the unintended consequence of prohibiting the use of recycled concrete materials in commonly accepted concrete recycling applications; e.g., as unbound base course or fill material or aggregate in ready-mix concrete. A more appropriate method to determine compliance with pH regulations would be to determine a "point of compliance" and enforce pH regulations at that point. However, selection of an appropriate point of compliance is hindered by disagreement in previous studies on the pH of leachate as well as its acid neutralizing capacity (alkalinity). Most laboratory studies and many field studies suggest that the leachate pH should be very high (e.g., >9) for extended periods of time; however, the NAICS data presented in Figure 1 and results of our own field studies (Chen et al., 2012; Chen et al., 2013) suggest that leachate pH values above 8.5 are actually infrequent. Here we propose to couple laboratory leaching studies, utilizing representative saturation and geochemical conditions, with results from a forensic examination of an RCA base course located at the MnROAD test facility to determine mechanisms that may limit the production of high pH of leachate.

Anticipated Outcomes:

This research will utilize a comprehensive approach to reconcile the contradictory results of previous studies of leachate pH from fresh and aged RCA. Inclusion of field and laboratory components will provide fundamental and in situ information to normalize the expected variance of leachate pH and identify when it is or is not a behavior or condition of environmental concern.

2. Statement of purpose

Identification of the problem(s) or issues(s) to be addressed and their relevance and importance to the concrete industry

Concrete recycling reduces the need for mining of virgin aggregate, thereby conserving scarce natural resources and often dramatically decreasing transport costs and impacts. Additionally, recycling concrete reduces the need for landfill space, stockpiles and waste concrete, and illegal concrete dumping. During the recycling process, crushing or fracturing of concrete may expose fresh surface area. Due to the solubility of hydroxide-bearing minerals and other chemical reactions, the pH of water that interacts with recycled concrete may become elevated.

The pH of water percolating through recycled concrete and water discharged from other activities covered under NAICS Code 32799 in Washington State was monitored during 2010 (Figure 1) and revealed that less than 2% of all data points collected exceeded the limit of 8.5 and additionally, nearly half of these points exceeded the proposed regulatory measurement of 8.5 by less than 0.5 of a pH unit. Under the best lab conditions, the uncertainty associated with pH measurement of relatively pure solutions is ~0.1 pH units (Leito et al., 2002) and in high ionic strength solutions (e.g., leachate from RCA), without the use of ionic strength corrected calibration buffers, it may be as high as 0.5 pH units (Wiesner et al., 2006). The remaining data points that fall outside of this uncertainty range represent extreme cases that are likely due to BMP’s not being followed in the storage and/or utilization of RCA materials.

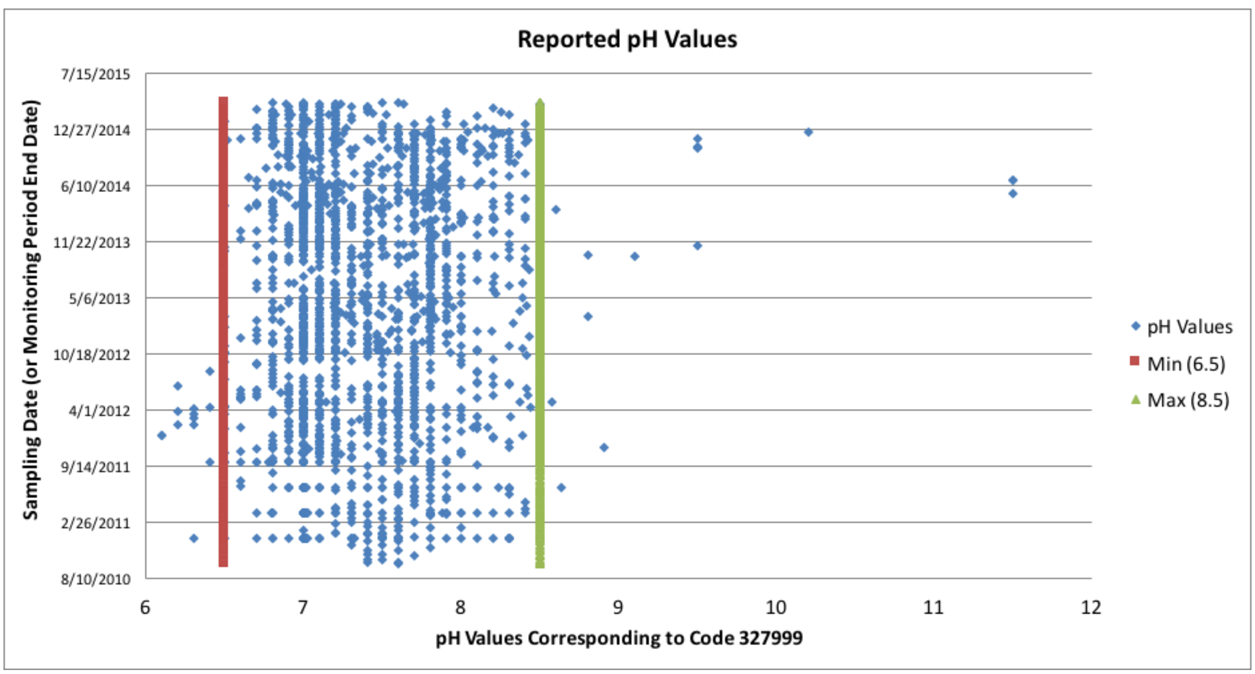

Figure 1 pH measurements recoded under NAICS Code 32799 in the State of Washington. Proposed minimum (6.5) and maximum (8.5) pH limits are indicated by the red and blue lines respectively.

The proposed NPDES regulations in the State of Washington, requiring a pH below 8.5 at the point of discharge from the RCA, may have the unintended consequence of prohibiting the use of recycled concrete materials in commonly accepted concrete recycling applications; e.g., as unbound base course or fill material or aggregate in ready-mix concrete. A more appropriate method to determine compliance with pH regulations would be to define a "point of compliance" and enforce pH regulations at that point. However, selection of an appropriate point of compliance is hindered by disagreement in previous studies on the pH of leachate as well as its acid neutralizing capacity (alkalinity). Most laboratory studies and many field studies suggest that the leachate pH should be very high (e.g., >9) for extended periods of time; however, the NAICS data presented in Figure 1 and results of our own field studies (Chen et al., 2012; Chen et al., 2013) suggest that leachate pH values above 8.5 are actually quite rare. Here we propose to couple laboratory leaching studies, utilizing representative saturation and geochemical conditions, with results from a forensic examination of an RCA base course located at the MNROAD test facility to determine mechanisms that may limit the high pH of leachate.

Brief summary of past efforts to address the problem or issue (including efforts of others)

The Recycled Materials Resource Center (RMRC) at the University of Wisconsin – Madison has studied the issue of high pH leachate production from RCA in both laboratory and field studies (Chen et al., 2012; Chen et al., 2013). Seven RCA samples from a wide geographical range were used in this study: California, Colorado, Michigan, Minnesota, Texas, Wisconsin fresh (WR-F), and Wisconsin stockpiled (WR-SP). Minnesota, WR-F, and WR-SP RCA were also used as the base course in the two field sites. Two sources of natural aggregate (similar in mineralogy to the aggregate used in concrete production) were used as control material in the field sites: Minnesota Road Research (MnROAD) Class V and Wisconsin aggregate (WA).

The two samples of RCA from Wisconsin have detailed source information. WR-F RCA was from the demolition of concrete pavement in Madison, WI. The material was obtained 3 days after demolition and processing; thus, WR-F RCA is considered a fresh RCA sample. WR-SP RCA was from the demolition of a concrete building in Madison and had been stockpiled in a quarry for over 5 years; thus, WR-SP RCA represents a weathered material.

The two field leaching test (FLT) sites, the MnROAD site and the University of Wisconsin (UW) site, were constructed with RCA as base course and lysimeters were installed. The MnROAD site was constructed on the MnROAD test facility mainline (westbound of I-94) between Saint Cloud and Minneapolis, Minnesota, in September 2008 (Figure 2**a**). Three experimental cells were installed and paved on the mainline: Cell 16 contained 100% Minnesota RCA, Cell 17 contained 50-50 Minnesota RCA-Class V mix, and Cell 19 contained 100% Class V natural aggregate. A 127-mm-thick, warm-mixed asphalt was placed above the base course, which consisted of one of these three materials, each 305 mm thick underlain with a 305-mm-thick Class 3 aggregate and 178-mm-thick select granular material over the clay subgrade. Cell 16 was originally designed to investigate high-pH effluent from RCA, and Cell 17 was designed to test the neutralization of highly alkaline material by mixing with natural aggregate. Cell 19 was the control cell. Pan lysimeters (3 m x 3 m) were installed under each of the test materials (RCA, RCA-Class V, and Class V) to collect percolated leachate. The UW site was constructed in Parking Lot 60 on the campus of the University of Wisconsin–Madison in September 2011 (Figure 2**b**). Three small experimental cells each with a pan lysimeter (1.5 m Å~ 1.5 m) were installed in parking lot aisles: Cell 1 with WR-F RCA, Cell 2 with WR-SP RCA, and Cell 3 with WA. One layer of 127-mm-thick porous asphalt (porous mix asphalt, DRS Ltd., Wisconsin) was paved above each 0.3-m-thick base course section. Batch testing of the asphalt with deionized water showed insignificant heavy metal leaching and that the leachate pH was 7.8 (pH_{DI} = 8.1).

A weather station was installed at both sites. A standard 20-cm tipping bucket rain gauge and thermocouples were installed, and data were collected with a Campbell CR-23 datalogger (all supplied by Campbell Scientific, Inc.). Leachate samples were collected with a polyvinylchloride bailer from the collection tanks. Remaining leachate was pumped out to record the total volume of leachate collected during each sampling period. Leachate samples from the MnROAD site were collected every 1 or 2 months from April 2009 through November 2010. At the UW site, leachate samples were collected weekly from September 2011 to September 2013.

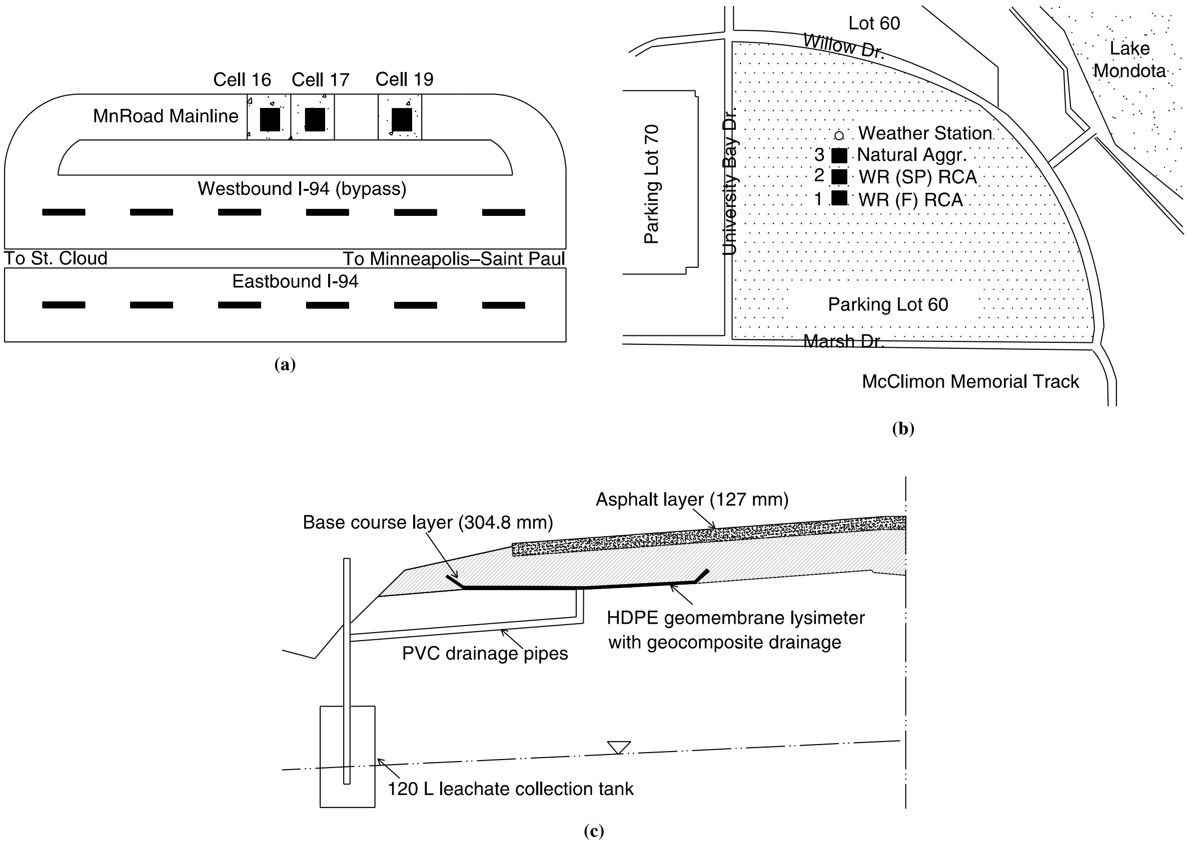

Figure 2. Site locations and lysimeter layout for (a) MnROAD and (b) UW sites and (c) lysimeter design (HDPE = high-density polyethylene, PVC = polyvinylchloride).

Long-term column leaching tests (CLTs) were conducted with California, Colorado, Michigan, Minnesota, and Texas RCAs. The specimens were compacted with modified Proctor effort (ASTM D1557) at 90% of maximum dry unit weight (field specification) and optimum water content into a polyvinylchloride column (diameter = 20 cm, height = 10 cm). All fittings in contact with RCA were nonmetallic. Synthetic rainwater, as described by Scalia and Benson (2011), was used as inflow. A continuous, upward flow was generated by a peristaltic pump at a Darcy flux of 1.6 cm/day (approximately 0.5 PVF per day), which was sufficient to avoid preferential flow paths, wet–dry cycles, and air bubbles in the system. Specimens were saturated 24 h before test initiation, and leachate samples were collected every 3 days from sealed teflon sampling bags. Readings of pH, electrical conductivity, and redox potential were recorded immediately after sampling.

Field Leaching Tests (FLTs): Leachate pH from the MnROAD and UW sites is shown in Figure 3*a.* The leachate pH of the cells containing Minnesota RCA and Minnesota RCA/Class V aggregate mix ranged from 6.5 to 8.0 for the entire monitoring period and was similar to the Class V cell (pH = 6.5 to 8.4). At the UW site, the WR-F RCA cell started with a high leachate pH (12.6) and remained relatively constant for the first 5 PVFs, with a peak pH of 12.9 at 2.8 PVFs. In contrast, the WR-SP RCA started at a lower pH (7.3) and gradually increased upward, to pH of 12.1 after 2 PVFs. The natural dolomite aggregate (Wisconsin Aggregate, WA) showed a neutral leachate pH (between 5.0 and 8.5). The material pH of all three RCAs showed the potential of leaching high pH effluent, with pH = 11.3 for Minnesota RCA, pH = 12.3 for WR-F RCA, and 11.8 for WR-SP RCA, whereas WA also had a material pH of 10.0. The differences in pH in the FLT and the material pH from WA could be limited by water residence time, exposed surface, and saturation degree, which are obstacles to chemical equilibrium (Engelsen et al., 2012).

Column Leaching Tests (CLTs): Leachate pH from long-term, continuous-flow CLTs was strongly related to the corresponding material pH (Table 1), with a decreasing order of the Michigan, Texas, Colorado, California, and Minnesota RCAs (Figure 3b). The CLTs had very consistent pH levels for all five RCA specimens, and RCA showed elevated leaching potential of alkaline substances over 100 PVFs. Minnesota RCA showed different trends of leachate pH between the FLTs and lab CLTs. Compared with the neutral leachate pH (6 to 8) at the MnROAD field site, pH levels for Minnesota RCA were consistently high (11.3 to 11.6) during the first 6 PVFs in the CLTs; this finding presented a continuous leaching of alkaline substances.

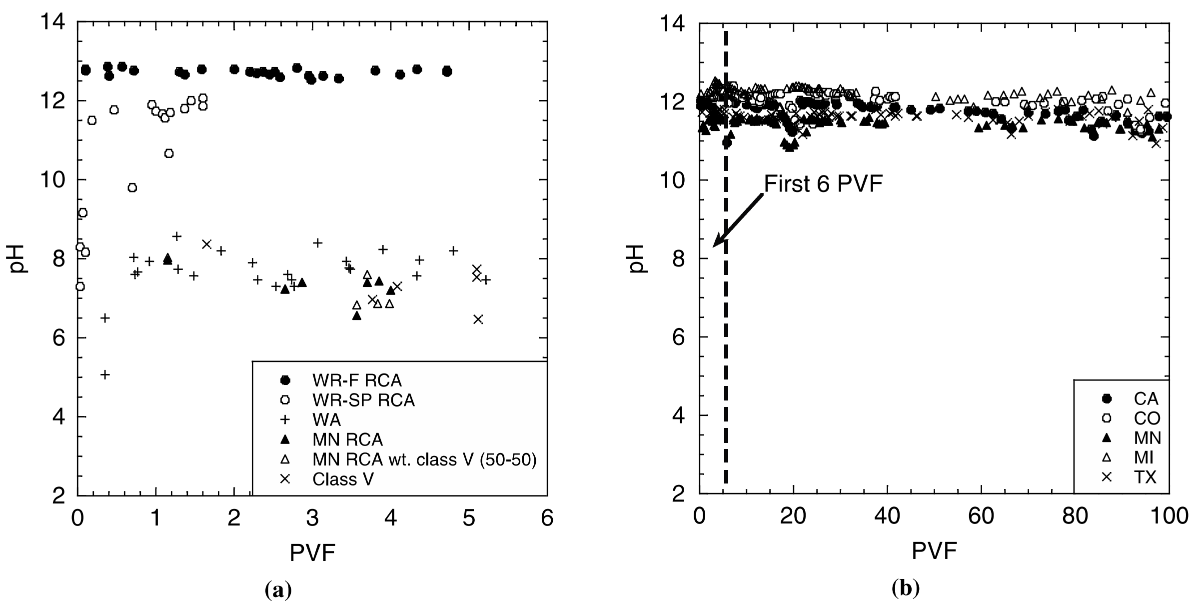

Figure 3: Leachate pH from FLTs (a) and CLTs (b)

Similarly, studies performed by other research groups have reported high pH leachate from RCA, although the pH is dependent on the age of RCA, and installation environment. For example, Engleson et al. (2012) studied the pH of leachate produced in a field site in Norway. The test was performed without an asphalt cover, directly exposing the RCA to air and rain, and with an asphalt cover. The pH of the infiltration water from the road sub-base with asphalt covered concrete aggregates decreased from 12.6 to below pH 10 after 2.5 years of exposure, whereas pH 10 was reached within only one year for the uncovered field site. These results, coupled with the variability in our results clearly demonstrate that the pH of RCA leachate is quite dependent on environmental conditions (saturation conditions, temperature, and confinement) all of which will control the degree of RCA carbonation and the pH of leachate.

Additionally, pH alone is not a sufficient indicator of the threat of a solution to the environment. The alkalinity, ability of the solution to resist changes in pH, must also be considered when determining the threat posed by high pH leachate. Leachate that has a high pH but relatively low alkalinity can be easily neutralized in the environment, while leachate with both a high pH and high alkalinity may be an environmental issue.

Given this complexity, sensible regulation of RCA applications requires a holistic assessment of both chemical characteristics of RCA leachate and the ability of the surrounding environment to ameliorate the high pH of the leachate. Unfortunately, previous research on RCA leachate does not provide a scientific basis for this type of regulation or take into account the total alkalinity (acid neutralizing capacity) as opposed to straight pH readings. Thus, it is important to develop a knowledge base that encompasses the pH characteristics of hardened concrete rubble under different exposure conditions (e.g., stockpiling), the fate of high pH leachate as it enters ground and its potential to alter groundwater or surface water quality, and, if needed, what cost-effective mitigation measures can be used. The following objectives are proposed to develop the knowledge base required to regulate RCA leachate in a reasonable and scientifically sound manner.

Proposed goals and objectives (outcomes)

The overarching objective of this project is to provide a sound scientific basis for the reasonable regulation of leachate pH in a variety of RCA applications

Objective 1: Utilize column-leaching tests to determine role of environmental conditions on the pH of leachate from RCA

Objective 2: Perform a forensic investigation of RCA and soil from the MnROAD field site to determine the causative mechanisms of the near neutral pH of the leachate at the field site

Objective 3: Utilize information developed from objectives 1 and 2 to propose an appropriate "point of compliance" for regulation of RCA leachate in various applications

Anticipated outcomes and benefits for the concrete industry

This research will utilize a comprehensive approach to reconcile the contradictory results of previous studies of leachate pH from fresh and aged RCA. Inclusion of field and laboratory components will provide fundamental and in situ information to normalize the expected variance of leachate pH and identify when it is or is not a behavior or condition of environmental concern.

3. Methodology

Proposed methodology

Column Leaching Tests: CLT's will be performed using similar methodology as used in the previous studies performed at the RCMC. Briefly, a broad range of RCA specimens will be collected from across the United States. Grain size distribution will be determined using accepted techniques (ASTM D422) and their mineralogy will be determined using X-ray diffraction. The chemical composition will be determined using EPA method 3050B, while physical and hydraulic properties will be determined using the methods described in ASTM D1557, AASHTO T85, or ASTM D5856, as appropriate. The specimens will be compacted with modified Proctor effort (ASTM D1557) at 90% of maximum dry unit weight (field specification) and optimum water content into polyvinylchloride columns (diameter = 20 cm, height = 5 cm). All fittings in contact with RCA will be nonmetallic. Synthetic rainwater, as described by Scalia and Benson (2011), will be used as inflow. Generally, the columns will not be completely saturated with water so that the role of variable saturation conditions on RCA carbonation and leachate pH can be investigated, these conditions are more representative of real-world conditions. Continuous saturation, as used in the majority of previous studies, represents an extreme condition and will likely overestimate the high pH nature of leachate produced from RCA.

CLT experiments will be largely focused on determining the role of RCA carbonation on leachate pH. To this end, samples of RCA will be artificially aged by introduction of solutions containing 0.1 molar carbonate (for 1-24 hours), this solution will then be removed followed by the introduction of artificial rainwater. Artificial rainwater will continue to be introduced into these columns and leachate from these columns will be collected and analyzed to determine the pH, alkalinity (acid neutralizing capability), and other chemical constituents will be determined using standard laboratory techniques. pH calibration solutions will all be corrected for ionic strength to allow for maximum accuracy in pH measurements (Wiesner et al., 2006). Upon completion of the experiments the solids will be removed and the extent of carbonation determined using Infrared (IR) Spectroscopy (Ylmén and Jäglid, 2013). This will allow direct comparison among RCAs from various settings.

Additionally, we will test the ability of various soils, with an initial focus on soils common to Washington State, to neutralize leachates produced in the column studies described above that are above the regulatory limit of 8.5. In order to investigate the maximum number of soils, batch experiments with 1 g of soil and 50 mL of leachate will be conducted until the pH remains stable for 48 h. We will then calculate compare the amount of base neutralized to the initial soil pH.

Field Leaching Tests (FLTs): Given the compressed timeline of this project it is will not be possible to establish a new field-site to investigate the production of leachate from RCA. Fortunately, the MnROAD facility described in the project justification is scheduled to be decommissioned during the summer of 2016. We plan on sampling the leachate produced from this site monthly until decommissioning and will quantify the pH and alkalinity of the leachate being produced 8 years after installation. Additionally, upon decommissioning we will perform a forensic investigation of the RCA materials and surrounding soils to determine the reasons for the neutral pH of the leachate from this site as well as the extent of carbonation of the starting RCA. Additionally, if intact concrete slabs are removed as part of the decommissioning we will collect intact cores from the slabs to investigate the pH of leachate from traditional concrete applications.

The pH and acid neutralizing capacity (ANC) of the soils from this site will be determined by using standard EPA methods. The ANC of soils near the RCA site will be compared to the ANC of representative background soils to determine if exposure to leachate from RCA has resulted in a measurable change in soil pH. RCA recovered from this site will be analyzed to determine if grain size distribution, carbonation, or other physical and chemical characteristics have changed during the last 8 years.

Timeline or schedule of activities

Project Task	Jan-Mar 2016	Apr-Jun 2016	Jul-Sept 2016	Oct-Dec 2016	Jan–Mar 2017	Mar-Jun 2017
Column Leaching Tests	X	X				
Leachate neutralization studies			X			
Leachate Sampling at MnROAD facility	X	X	X			
Disassembly of MnROAD field site			X			
Forensic Examination of RCA for MnROAD				X	X	
Publication of CLT results			X			
Publication of MnROAD forensic examination and final report to NRMCA						X

Proposed allocation of staff, consultants, collaborating organizations, and other human resources
The proposed project will be primarily supervised by Professor Matthew Ginder-Vogel with the assistance of professor emeritus Tuncer Edil. Short biographies of Professors Ginder-Vogel and Edil are below. The majority of the work will be performed by Jiannan (Nicolas) Chen. Chen performed the previous leachate work at the RMRC and has agreed to stay on as a post-doc on this project upon completion of his Ph.D. thesis in October of 2015. An undergraduate lab assistant has also been included in the budget to allow intensive sampling of the proposed experiments.

4. Deliverable Product and Dissemination Plan
Define the specifically targeted audience which will benefit from the information

The audiences that will benefit from the information developed in this study include regulators and industry professionals. Additionally, we will work to develop standards and guidelines to allow state DOTs and the FHWA to regulate pH at a point of compliance that allows utilization of RCA while protecting sensitive environments from high pH leachate.

Describe how outcomes will or should be communicated (through vehicles such as meetings, seminars, publications, print or electronic media, etc.) to the concrete community at large
The results from this study will be published as peer-reviewed scientific articles and will be communicated to the NRMCA in series of reports appropriate for dissemination to appropriate regulatory bodies. Additionally, Drs. Ginder-Vogel and Edil will present the research at annual ASCE meetings and will work to develop informational documents for practitioners and industry affiliates.

5. Replicability or Application in Association Community

Publication of peer-reviewed scientific articles will ensure that the work is broadly disseminated and transparent to allow replication by concrete industry members. All data from our studies will be archived and made available on the RMRC website hosted by the University of Wisconsin – Madison. Additionally, reports submitted to the NRMCA that are appropriate for dissemination to the industry affiliates and regulators.

6. Evaluation

Method(s) for assessing achievement of objectives and desired outcomes

Weekly meetings between the PI and post-doc will ensure that the project remains on track in terms of results and timeline. Additionally, Prof. Edil will review the project progress at least quarterly. Additionally, we welcome peer review of the proposed work by regional experts to assure that relevant issues are being addressed.

7. Qualifications

Matthew Ginder-Vogel, Ph.D. is an assistant professor in the Geological Engineering and the Environmental Chemistry and Technology programs at the University of Wisconsin – Madison. Prior to joining the Madison faculty, Dr. Ginder-Vogel was the manager of process and analytical chemistry at Calera Corporation. At Calera he led teams responsible for production of cemetitious materials derived from industrial CO_2 sources. Previously he worked as an associate scientist in the Delaware Environmental Institute at the University of Delaware. He received his Ph.D. from Stanford University. Despite centuries of study, fundamental environmental processes controlling the dynamics of contaminants within the environment remain poorly defined. Ginder-Vogel's research seeks to define the fundamental processes controlling the dynamics and contaminants within complex media. Therefore, his research combines field-based experiments with simplified lab-based experiments, in order to reveal the dominant mechanisms affecting contaminant cycling and mobility in environmental systems. Data developed using this approach has redefined the understanding of the kinetics of contaminant transformation and transport in the environment. Ginder-Vogel is author of 45 peer-reviewed manuscripts and holder of four patents on the reuse of CO_2 in cementitious materials.

Tuncer B. Edil, PhD, PE is Professor Emeritus of Civil and Environmental Engineering, and of Geological Engineering at the University of Wisconsin-Madison (UW). He has been on the faculty at UW since November 1973. Dr. Edil has a BS and MS from Robert College and PhD degrees from Northwestern University (all in Civil Engineering). He conducts experimental and analytical research on topics related to geotechnical construction and environment, including the reuse of industrial byproducts in civil, geotechnical, and transportation engineering. He has conducted more than $15,000,000 in research projects for a variety of federal agencies (e.g., National Science Foundation, Dept. of Energy, Environmental Protection Agency, Dept. of Transportation, NOAA, USGS), state agencies (e.g., Minnesota Dept. of Transportation, Wisconsin Solid Waste Research Program, Wisconsin Dept. of Transportation, Wisconsin Dept. of Natural Resources, Wisconsin Department of Administration, Wisconsin Groundwater Research Program, Wisconsin Sea Grant Program), and corporations. These research projects have included laboratory studies, large-scale field experiments and demonstrations, and development of predictive computer models regarding the use coal combustion byproducts, foundry byproducts, scrap tires, and scrap asphalt shingles in construction applications. Dr. Edil has published more than 260 articles and 100 reports on his work, including more than 140 articles in refereed journals and 2 ASTM standards. He is Co-

Director of the UW Consortium for Fly Ash Utilization in Geotechnical Engineering, and a licensed professional engineer in Wisconsin. Dr. Edil has received several individual and team awards for his work, including the Dow Outstanding Young Faculty Award from the American Society of Engineering Education, Young Civil Engineer of the Year, Merit for Individual Achievement as an Engineer in Education, and Outstanding Civil Engineer in SW Branch awards from the ASCE Wisconsin Section, and Journal of Cold Regions Engineering Best Paper Award from ASCE. Dr. Edil has also received the International Achievement Award from the Industrial Fabrics Association International and Blue Pencil Award for Professional Paper Award from National Association of Government Communicators. Dr. Edil is a member of TRB, ASTM, ASCE, and the ASCE Geo-Institute and is the past Editor-in-Chief of the ASCE/GI *Journal of Geotechnical and Geoenvironmental Engineering* (2004-2006) and the current Editor-in-Chief of the *Geotechnical and Geological Engineering* journal published by Springer.

All work will be performed at the Recycled Materials Resource Center (RMRC) at the University of Wisconsin – Madison. The RMRC has a fully equipped lab to perform all wet chemical analyses described in the proposal.

The RCMC has four basic missions:

- To systematically test, evaluate, develop appropriate guidelines for and demonstrate environmentally acceptable increased use of recycled materials in transportation infrastructure construction and maintenance
- To make information available to State transportation departments, the Federal Highway Administration, the construction industry, and other interested parties
- To encourage the increased use of recycled materials by using sound science to analyze potential long-term considerations that affect the physical and environmental performance
- To work cooperatively with Federal and State officials to reduce the institutional barriers that limit widespread use recycled materials and to ensure that such increased use is consistent with the sustained environmental and physical integrity. The Center has a special interest in the long-term physical and environmental consequences of recycled material use

Given the 4 missions of the RCMC we plan on reaching out State DOT funding pools to participate as partners in the research and/or petition FHWA for possible grant funds given their ongoing support in advancing material recycling.

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