Construction and Evaluation of a Bituminous Roadway Constructed with Municipal Solid Waste Combustor Ash

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1.0 ABSTRACT
County State Aid Highway (CSAH) 13, located in Polk County Minnesota, was to be paved with 2.25 miles of new bituminous in October of 2000. Prior to the end of the 2000 construction season, a portion of one lane of the base course was installed, with the remainder to be completed in spring of 2001. The bituminous was amended with ash generated at the municipal solid waste combustor located in Fosston Minnesota. One third of the road was to be paved with traditional bituminous, one third was to be paved with bituminous in which a portion of the aggregate was replaced with “new” ash and one third was to be paved with bituminous in which a portion of the aggregate was replaced with “old” ash. “New” combustor ash is ash generated after the installation of an up-front materials recovery facility (MRF) and “old” combustor ash is ash generated before the installation of the MRF. Ash-amended bituminous was to be used in the base course and binder course of the pavement profile. Significant environmental and structural testing was performed prior to construction. Environmental and structural testing was also performed simultaneously with the construction process. Environmental testing completed in 2000 included: analysis of stack emissions from the bituminous plant, evaluation of breathing zone particulates at the bituminous plant, and analysis of surface water runoff from the ash-amended bituminous. Structural testing included trial mix design parameters. The road was also instrumented to collect water that may infiltrate through the ash-amended bituminous. Environmental testing to be completed in 2001 includes: evaluation of impacts to soils adjacent to the roadway and evaluation of infiltration water collected in the under-pavement collectors. Post-construction pavement testing is also to be completed in 2001. This paper presents the initial results of environmental and structural testing as well as construction issues.

2.0 INTRODUCTION
It was identified by Kiser and Zannes\(^1\) that in 1999, 102 Waste-to-Energy (WTE) facilities were in operation in the United States, serving the disposal needs of more than 37 million people. These facilities generated about 2,800 MW of electricity from the combustion of 30 million tons of MSW. In the process, about 7 million tons of ash were produced. Most was used as landfill daily cover, as roadbed, or was disposed of in landfills. Enabling the beneficial use of ash will assure the continued operation of these valuable facilities. While most municipal waste combustors (MWCs) recover energy, there is a very small number that do not. In this paper we will refer to MWCs whether they recover energy or not.
The responsible utilization of MWC ash can also result in positive environmental benefits. Such benefits may include reduction of landfill development for the ash, and reduction of the many environmental impacts that occur from mining, processing, and hauling of natural aggregates or other materials replaced through ash utilization.

As described by Wiles, the ash from MWCs is an excellent resource material that has proved to be of particular benefit in the construction of roads and highways. Field tests and demonstration projects show that processed ash can be successfully used in road base, bituminous paving, and concrete products. Substituting ash for rock aggregate in bituminous pavement, also called asphalt concrete, has proven to be a straightforward procedure in 14 field demonstrations. According to Wiles, one thing is clear from the many field tests: asphalt pavement made from MWC ash lasts as long as conventional pavement and no environmental or health effects were reported. Ash pavements are safe and long lasting.

Polk County, located in northwest Minnesota, participates in a complete integrated solid waste management program that includes four other counties in northwest Minnesota. One component of the integrated solid waste management program includes the operation of a MWC that combusters approximately 65 tons per day of processed solid waste. The starved air design of the combustor causes low turbulence in the primary burning chamber minimizing particulate carryover through the system. This results in generation of approximately 12 tons per day of combined ash comprised of 98 to 99 percent bottom ash and 1 to 2 percent fly ash, by weight.

In 1996 the facility installed an up-front separation facility, or materials recovery facility (MRF), that removes recyclable materials as well as non-processible or objectionable materials prior to combustion. The MWC operates at an average temperature of 1450°F in the primary chamber and 1850°F in the secondary chamber. The energy produced is sold in the form of steam to adjacent businesses near the facility. The ash generated by combustion prior to the 1996 installation of the MRF is referred to as “old ash” and is landfilled in a MWC ash landfill permitted by the Minnesota Pollution Control Agency (MPCA). The ash generated since installation of the MRF is referred to as “new ash” which is also placed in the permitted landfill. The chemical and physical differences between the new and old ash were important enough to warrant the two ashes being addressed separately for purposes of utilization. The specifics of the chemical and physical characteristics of the two ashes were described by Lucido, and are discussed later.

The objective of this paper is to describe the feasibility of using MWC ash as a partial replacement for aggregate in bituminous paving material. Items addressed include:

a. Project background,
b. Structural testing,
c. Environmental testing,
d. Construction issues, and
e. Economic issues.

Due to a late construction start, and an unusually rainy fall, the proposed construction and testing was not completed, as of the date of preparation of this paper. However, enough of the construction and testing had been completed to provide significant input into the body of knowledge of MWC ash utilization. The following tasks were competed in 2000 and are documented in this paper:

a. Preliminary structural testing (trial mix designs) and environmental testing were completed,
b. Regulatory approvals were obtained,
c. A paving contractor was selected for the project,
d. Preconstruction bituminous trial mix designs were completed by the contractor,
e. Job mix formula (JMF) working ranges were defined,
f. Air emissions stack testing at the bituminous plant was partially completed,
g. A breathing zone evaluation for the bituminous plant operator was completed,
h. One lift of one lane of non-ash-amended bituminous was installed,
i. One lift of one lane of old-ash-amended bituminous was installed,
j. One lift of one lane of new-ash-amended bituminous was partially installed,
k. A surface water runoff study was completed,
l. A background study of impacts to adjacent soils was completed,
m. Underpavement water collectors were installed.

3.0 PROJECT BACKGROUND

Previous work performed for this project was described by Lucido⁴, and is summarized in the following sections.

3.1 Project Participants
The participants in this project include:
a. The Polk County Solid Waste Department, based in Fosston Minnesota, provided the majority of the funding for the ash utilization aspects of the project, the inspiration and direction for the project, as well as important input into this paper.
b. The Polk County Highway Department, based in Crookston Minnesota, provided the paving project that was modified to implement the ash utilization project.
c. Thorson, Inc., based in Bemidji Minnesota, under contract to the Polk County Highway Department, was the paving contractor for the project.
d. The Minnesota Pollution Control Agency, based in St. Paul Minnesota, provided the regulatory oversight and approval for the project.
e. The Minnesota Office of Environmental Assistance (OEA), based in St. Paul Minnesota, provided important grant funding for the project.
f. The Minnesota Department of Transportation (MnDOT) Materials Lab, located in Bemidji Minnesota, provided preliminary and follow up structural testing.
g. Wenck Associates, Inc., based in Maple Plain Minnesota, provided environmental and regulatory consulting services for the project.

3.2 Roadway Design
The project consists of a 2.25-mile section of CSAH 13, which is 4 miles east of Crookston Minnesota. The design of the road section calls for a 5.2-inch thick bituminous base course 25 feet wide, overlain by a 2-inch thick bituminous binder course 24 feet wide, overlain by a 1.5-inch thick bituminous wear course 24 feet wide. Since this road section was already scheduled for construction, this provided an excellent opportunity to incorporate the demonstration project into the County’s construction project.

Ash-amended bituminous was utilized in the bituminous base course and the bituminous binder course. The bituminous wear course does not contain ash. As data provided later in this paper shows, ash in the wear course is not expected to be an environmental issue. However, for political purposes, the wear course remained unamended. In addition, there is limited information on the longterm performance of ash-amended bituminous. Since this will be a
public road with an assumption of standard road life, this limited performance data justified not using ash in the wear course. The 2.25-mile road section was to be constructed as follows:

a. 0.75 miles with no ash, as a control section;
b. 0.75 miles, replacing 20 percent of the aggregate with new ash in the bituminous base and binder courses for a total of 935 cubic yards of new ash;
c. 0.75 miles, replacing 40 percent of the aggregate with old ash in the bituminous base and binder courses for a total of 1,495 cubic yards of old ash.

(Note: a difference in ash density resulted in a non-1:1 ratio of ash percentage to ash volume.)

The ashes used in the bituminous were combined ash (1-2% fly ash and 98-99% bottom ash). Combined ash provides the appropriate particle size gradation to meet the Minnesota Department of Transportation (MnDOT) mix design. In preparing the MnDOT trial mix design, the ash was screened to remove oversized (+0.75-inch) and deleterious materials. This removal of +0.75-inch material had the effect of slightly decreasing the ratio of bottom ash to fly ash.

3.3 Structural Testing

Samples of old ash and new ash were submitted to the MnDOT Northwest District Bituminous Lab. The ashes were utilized to replace a portion of the aggregate in the development of two trial mix designs for a MnDOT 2350 plant mixed bituminous pavement material. A third (non-ash) aggregate was used from a MnDOT-approved source identified as J&S Pit (#63001) located in Marcoux, Minnesota and operated by Northern Paving. The non-ash bituminous served as a control. The MnDOT lab was instructed to utilize as much old ash and new ash as possible in independent trial mixes while preparing a 2350 bituminous that meets all MnDOT specifications. After several iterations, the lab determined that acceptable 2350 designs could be prepared while replacing 20 percent of the aggregate with new ash, or by replacing 40 percent of the aggregate with old ash. These were set as maximum percentages for the demonstration project.

These trial mix designs demonstrated that both the Polk County MWC old ash, as well as the new ash, can produce a bituminous mix that meets MnDOT specifications for a standard 2350 Type 31 Mix Design. The preliminary mix designs replaced 40 percent of the traditional aggregate with old ash, and 20 percent of the traditional aggregate with new ash. The volume resulting from 40 percent replacement is less than 2 times the volume resulting from 20 percent replacement due to the density differences in the two ashes. The percentages of ash were set for engineering purposes only. The MnDOT District Lab Supervisor that oversaw the testing indicated that the reduced percentage of new ash was due to its lower density. The old ash was mined from previously landfilled areas while the new ash was from current generation. The paving contractor that was awarded the project, Thorson Inc., utilizes a different aggregate pit than was used in the preliminary trial mix designs. Therefore, new trial mix designs were prepared for the project. The percentages of ash utilized in the subsequent trial mix designs were also revised as detailed later.

3.4 Environmental Testing

3.4.1 Introduction

Environmental assessment was performed to assess the potential for the ash-amended bituminous to adversely impact human health or the environment. Assessment tools
were used to evaluate potential impacts to surface water, groundwater, air, and soil. These four media (surface water, groundwater, air, and soil) constitute the human exposure pathways of ingestion of drinking water or surface water, inhalation of particulates, and dermal contact and/or ingestion of ash-amended products. Surface water, groundwater, air (particulates), and soil also constitute the expected potential ecological exposure pathways. The ash product flow was evaluated from the point of production at the landfill or incinerator to the point of recycling or disposal.

A list of constituents of concern was identified for evaluation. This list included inorganic metals, since they are known to occur in all ashes, and dioxins and furans, since they are known to occur in some MWC combustor ashes, including ash from the Polk County MWC. This list is provided in Table 1.

Polk County, as well as all other MWC operators, has been evaluating MWC ash for many years. Organic constituents, other than dioxins and furans, have been shown by Wiles to be insignificant.

A risk-based site evaluation model developed by the MPCA was employed to evaluate all risk pathways to all potential receptors. The model, currently in “working draft” form as of October 1998, reflects one of the best available tools for evaluating whether ash incorporated into a bituminous matrix may cause an unacceptable potential for environmental degradation.

### 3.4.2 Recoverable and Leachable Metals versus Regulatory Standards

Constituent-specific concentrations, above which an unacceptable risk to human health is predicted to exist through direct exposure, are referred to as Soil Reference Values (SRVs). Additional criteria are also available for protection from exposures that might be possible through the pathway of soil contamination leaching to groundwater. These criteria are known as the Soil Leaching Values (SLVs). The SRVs and SLVs have been derived by MPCA staff using standard risk assessment methodology, reference doses, modeling, and risk management policy.

In 1996 the EPA established soil screening levels (SSLs). In 1999, EPA Region 9 updated the SSLs as preliminary remediation goals (PRGs). The relevant MPCA SLVs and SRVs as well as the EPA PRGs are listed in Table 1.

A detailed discussion of the development of the Tier 1 and 2 SRVs and SLVs was presented by Lucido. This discussion resulted in a determination that the MPCA Tier 2 Industrial SRVs and Tier 2 SLVs are the most applicable standards for the evaluation of potential impacts to the environment. Almost all of the exposure to the bituminous is via passing automobiles. This exposure duration is much less than that anticipated by the tier 2 industrial scenario. Therefore, while the industrial SRV is the most applicable standard, it is still much more conservative than the expected exposure.
Table 1. MPCA and EPA Risk Based Values\(^{(a)}\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MPCA Tier 2 SLV(^{(b)})</th>
<th>MPCA Tier II Residential SRV</th>
<th>MPCA Tier II Industrial SRV</th>
<th>Preliminary remediation goals(^{(c)})</th>
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</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td><strong>B</strong></td>
<td><strong>C</strong></td>
<td><strong>D</strong></td>
<td><strong>E</strong></td>
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<tr>
<td>Aluminum ppm Al</td>
<td>Na</td>
<td>26,000</td>
<td>40</td>
<td>100,000</td>
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<td>Antimony ppm Sb</td>
<td>30</td>
<td>14</td>
<td>100</td>
<td>100</td>
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<td>Arsenic ppm As</td>
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<td>11,500</td>
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<td>100,000</td>
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<td>Boron ppm B</td>
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<td>96,000</td>
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<td>930</td>
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<td>Chromium III ppm Cr III</td>
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<td>100,000</td>
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<td>425</td>
<td>64</td>
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<td>Copper ppm Cu</td>
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<td>Mercury ppm Hg</td>
<td>44</td>
<td>0.7(^{(d)})</td>
<td>2(^{(d)})</td>
<td>560</td>
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<td>37,000</td>
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<td>Selenium ppm Se</td>
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<td>9,400</td>
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<td>Silver ppm Ag</td>
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<td>1,250</td>
<td>9,400</td>
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<td>Strontium ppm Sr</td>
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<td>NA</td>
<td>100,000</td>
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<td>Thallium ppm Tl</td>
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<td>Tin ppm Sn</td>
<td>42,360</td>
<td>15,000</td>
<td>100,000</td>
<td>100,000</td>
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<td>Vanadium ppm V</td>
<td>5,502</td>
<td>210</td>
<td>1,340</td>
<td>13,000</td>
</tr>
<tr>
<td>Zinc ppm Zn</td>
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<td>8,700</td>
<td>70,000</td>
<td>100,000</td>
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<tr>
<td>2,3,7,8-TCDD equivalents ppm</td>
<td>0.0205</td>
<td>0.0002</td>
<td>0.00035</td>
<td>0.00003</td>
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</table>

**NOTES:**

\(^{(a)}\) This table was originally presented in "The Use of Municipal Waste Combustor Ash as a Partial Replacement of Aggregate in Bituminous Paving Material" Lucido, S.P.

\(^{(b)}\) Calculated by Lucido, S.P., using MPCA RBSE Model (version 11/99) with inputs representative of Polk County project.

\(^{(c)}\) Developed as soil screening levels (SSLs) by EPA in 1996. These values were updated as preliminary remediation goals (PRGs) for industrial soils in 1999 by EPA Region 9.

\(^{(d)}\) Mercury as inorganic (elemental and mercuric chloride).
The SRVs are designed to model the potential impact to human health via pathways of inhalation, ingestion, and dermal contact. The SLVs are designed to model the potential impact to human health via groundwater contamination. However, a second mechanism was used to evaluate the potential impact to drinking water supplies, whether that supply is groundwater or surface water. That method was by direct leaching of the ash-amended bituminous with EPA Method 1312, also referred to as the Synthetic Precipitation Leaching Procedure.

The pre-utilization evaluation showed that, once the ash is incorporated into the bituminous matrix, the metals are very effectively encapsulated and adsorbed by the highly organic asphaltic matrix. None of the metals evaluated exceeded any of the Tier 2 Industrial SRVs or the Tier 2 SLVs. In addition, the results of the EPA Method 1312 leach test were compared to the lower of the Minnesota Department of Health (MDH) Health Risk Limits (HRLs) which are the Minnesota drinking water standards or EPA Maximum Contaminant Limits (MCLs) federal drinking water standards. With only one exception, all leaching results were less than the drinking water standards and/or less than the leachability of the bituminous that had not been amended with ash. The one exception was antimony, which, in the worst case, exceeded the drinking water standards by 5 times.

### 3.4.3 Dioxins/Furans

The ash-amended bituminous was also evaluated for dioxins and furans. This is a well-known contaminant of concern in MWC ash. Therefore, this evaluation was appropriate.

The contaminant, 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), is one of several dozen isomers of dioxins. However, it is the most toxic and has been designated with a toxicity equivalent factor (TEF) of 1. The calculation of 2,3,7,8-TCDD equivalent multiplies the concentration of all of the dioxin and furans by their associated TEF.

The MPCA Industrial SRV for 2,3,7,8-TCDD equivalent is 0.35 ug/Kg (ppb).

The industrial site standard for this contaminant is not exceeded in the bituminous with new ash or with old ash. In addition, there is very limited exposure potential to the ash-amended bituminous since it is not used in the pavement wear course.

### 3.4.4 Cumulative Effects

Long-term cumulative effects were evaluated by performing the MPCA Tier 2 Industrial Scenario Risk Evaluation (1999 Version). This model is based on a limited multiple pathway scenario that evaluates risk to non-cancer endpoints, the whole body, as well as excessive lifetime cancer risk. The model showed that cumulative site excess lifetime cancer risk for all contaminants was $6.42 \times 10^{-6}$ for bituminous with 40 percent old ash and $1.26 \times 10^{-5}$ for bituminous with 20 percent new ash. The MPCA recommended criteria for an industrial exposure is $1 \times 10^{-5}$. Therefore, if the ash-amended bituminous were utilized as a wear course (which it is not) where longterm exposure were a potential, the material would be below the industrial exposure limit for old-ash-amended bituminous and 26 percent above the industrial exposure limit for new-ash-amended bituminous. This potential exceedance of the MPCA-recommended...
limit is primarily driven by concentration of 2,3,7,8-TCDD equivalent. However, as previously discussed, the tier 2 industrial standards are much more conservative than the expected exposure would dictate. Therefore, the authors conclude that, even if the ash-amended bituminous is utilized as a wear course, cumulative exposure concerns are minimal.

3.5 Regulatory Approvals
As a regulated solid waste, the utilization of MWC ash in bituminous paving required approval by the MPCA. Typically, the utilization of a solid waste in Minnesota requires the issuance of an MPCA solid waste permit, which requires a significant effort to obtain. However, since this project is a one-time demonstration, the MPCA was able to issue a letter of approval, in lieu of a permit. While the letter of approval required significant upfront environmental testing and safeguards, substantially less administrative effort was required than would have been to obtain a permit.

Polk County chose to proactively issue a public notice and solicit public input for the project. This proactive solicitation of public input was an important factor in prompt regulatory and public approval.

MnDOT has also taken a position of requiring their own environmental approval process for utilization of byproducts in road construction. However, since this project does not include any MnDOT funding, MnDOT approval was not required. Prior to this project, no approvals for the utilization of MWC ash have been issued in Minnesota.

It is Polk County’s intention to use the results of this demonstration project to pursue an MPCA permit and MnDOT approval for future, larger-scale utilization of MWC ash in bituminous paving.

4.0 METHODS
4.1 Trial Mix Designs
Thorson submitted samples of old ash, new ash, and unamended aggregate to the MnDOT Materials Lab for preparation of project-specific trial mix designs. The Unamended aggregate was obtained from Thorson’s aggregate source, identified as Delorme Pit (29-150-44). The trial mix designs were prepared with approximately 20 percent ash. In order to minimize his operational risk, the contractor did not attempt to use 40 percent old ash, as identified in preliminary mix designs.

An air voids update was performed on the first day of construction. In addition to recalculating the density and percentage of asphaltic cement, the update also included a calculation of flow and stability.

4.2 Bituminous Production
MWC ash for the project was initially stockpiled within the lined area at the Polk County Landfill. Old ash was excavated from pre-1996 in-place ash and new ash was stockpiled upon receipt from the incinerator. The ash was screened to pass a 0.75-inch sieve. When bituminous production was to commence, ash was hauled to the bituminous plant where it was stockpiled in a bermed area. The two ash piles were covered with a plastic membrane until needed. Ash
was stored, transported and stockpiled in a wet state so fugitive dust emission was not an issue. Short-term temporary storage of the ash at the bituminous plant was approved by the MPCA.

Bituminous was produced using a parallel-flow drum-mix asphalt plant. Four aggregate feeder bins contained fine aggregate, coarse aggregate, and ash (when used). The feeder bins were replenished from stockpiles using a rubber-tire front-end loader. The feeder bin discharge metered and layered the aggregates onto a belt conveyor that fed a parallel-flow drum mixer. The 52-foot long by 10-foot diameter drum mixer rotates at 7.5 revolutions per minute. A burner in front of the drum mixer dries the aggregate blend to less than 1.5 to 2 percent moisture. The mix is heated to 275 to 280 degrees F for base course material and 290 to 300 degrees F for wear course. Asphaltic cement is injected into the drum mixer near the midpoint at a specified rate. This rate was specified by the trial mix designs to be 5.4 percent for the traditional bituminous and 6.8 percent for the ash-amended bituminous. The hot mix asphalt (HMA) is discharged to a belt conveyor for transfer to a storage silo and to haul trucks.

The drum mixer discharge is under vacuum to collect fugitive dust. Fugitive emissions are collected under 82,000 cubic feet per minute of flow. The flow continues through a baghouse to remove particulates prior to discharge.

Plant production of unamended bituminous was about 350 to 400 tons per hour. However, the contractor had never worked with ash and had to perform significant adjustments to the plant operation to accommodate ash use. Therefore, production dropped during ash use to about 200 tons per hour, or less. In fact at times, the plant was stopped completely to address performance difficulties with the bag house. These issues are discussed later.

A total of approximately 9,600 tons of bituminous are expected to be placed in the 5.2-inch thick base course. This includes 3,200 tons without ash and 6,400 tons with ash. In addition, approximately 3,700 tons of bituminous are expected to be placed in the 2-inch thick binder course. This includes 1,240 tons without ash and 2,460 tons with ash. The wear course will contain about 2,770 tons of bituminous without ash. If the ash-amended bituminous contains 10 percent ash, about 890 tons of ash will be utilized for the demonstration. However, an effort will be made to increase the percentage of ash as feasible.

4.3 Bituminous Placement
All grading and subbase preparations were previously completed. Standard bituminous placement, equipment, and procedures were used. Seventeen cubic yard belly-dump trucks hauled the HMA to the road construction site where it was dumped in windrows of about 4 feet wide by 2 feet deep. A self-propelled paver then spread and compacted the HMA to dimensions of about 4 inches thick and 12.5 feet wide. The HMA is placed at the road at a temperature of 265 to 270 degrees F for base course material and 280 to 285 degrees F for wear course. A smooth drum roller then further compacted the HMA to a thickness of about 2 inches.

4.4 Bituminous Recyclability
Almost all bituminous paving material is ultimately recycled back into new bituminous or used as a subbase for road construction. One of the concerns raised by regulators is the recyclability of the ash-amended bituminous. Since the CSAH 13 bituminous will not likely be recycled for many years, a sacrificial test strip was to be constructed to address this issue. To do this a 350-foot section of the main access road into the Polk County landfill will be paved with ash-
amended bituminous. It will include the same mixtures used on the CSAH 13 project. The landfill pavement section will include the binder course and wear course but not the base course. After a period of 3 years the landfill road will be recycled using standard cold in-place recycling methods to evaluate the recyclability.

4.5 Bituminous Quality Control
The contractor and county performed quality control testing during bituminous production. Testing was performed for particle size gradation, percent asphaltic cement, density and percent voids. Since only a limited quantity of bituminous was produced and placed during the 2000 construction season, only a limited number of tests were performed.

4.6 Environmental Testing

4.6.1 Underpavement water collection
Underpavement water collectors were installed beneath each of the three test sections (no ash, old ash, and new ash). The objective of these collectors was to evaluate, if surface water migrates through the ash-amended bituminous, does this infiltration water have the potential to impact groundwater or surface water.

The collectors are designed to collect water that infiltrates through either of the ash-amended layers. The collector design is shown in Figure 1. Water that runs off of the surface of the bituminous or infiltrates only the wear course before moving laterally out of the road will not be collected.

Figure 1: Lysimeter Cross-Section

![Lysimeter Cross-Section Diagram]

4.6.2 Adjacent soils
Prior to placement of any bituminous, soil samples adjacent to each of the three test sections were collected. Samples were collected approximately 150 feet south of each of the underpavement water collectors. One sample was collected on each side of the road for a total of six samples. Each sample consisted of a composite of 15 subsamples of about 10 milliliters each. Subsamples were collected at least 12 inches apart and between 12 and 24 inches outside of the toe of the road shoulder location. Only stainless steel
utensils were used. Total composite samples of about 120 milliliters were transferred into glass sample jars as provided by the analytical lab. Samples were digested by SW-846 Method 3050 and analyzed for total recoverable metals. Parameters analyzed were as identified in Table 2. The list of parameters includes only those metals that were found to be recoverable to at least 50 percent of the Tier 2 SRV or Tier 2 SLV or leachable to at least 50 percent of the HRV or MCL. Method detection levels (MDLs) are maximums based on 50 percent of the HRL, Tier 2 SLV or Tier 2 SRV.

Table 2. Analytical Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method Detection Limit (ug/L)</th>
<th>Method Detection Limit (ug/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Arsenic</td>
<td>25</td>
<td>8.6</td>
</tr>
<tr>
<td>Beryllium</td>
<td>0.04</td>
<td>44</td>
</tr>
<tr>
<td>Boron</td>
<td>300</td>
<td>11,500</td>
</tr>
<tr>
<td>Lead</td>
<td>7.5</td>
<td>290</td>
</tr>
<tr>
<td>Nickel</td>
<td>5.0</td>
<td>1,050</td>
</tr>
<tr>
<td>Selenium</td>
<td>15</td>
<td>0.1</td>
</tr>
<tr>
<td>Thallium</td>
<td>0.3</td>
<td>0.23</td>
</tr>
</tbody>
</table>

This soil sample evaluation will be repeated upon completion of the installation of the bituminous sections.

4.6.3 Surface Water Runoff

The design of the demonstration project is to construct a non-ash-amended bituminous wear course over the ash-amended courses. This will effectively remove, or dramatically reduce the potential for impact to the environment via the pathway of surface water runoff. However, a decision was made to evaluate this pathway during the interval after the placement of ash-amended base or binder course and before the placement of unamended wear course.

The evaluation was performed by simulating a rainfall event, and collecting the surface water runoff after it traveled across the bituminous surface. A rain simulation device was constructed using a five-gallon bucket, polyethylene tubing, and a typical lawn sprinkler. Water used for the simulation was lab-prepared according to EPA Method 1312 (Synthetic Precipitation Leaching Procedure). All equipment was thoroughly rinsed with this water before each event. To minimize the impact of particulates that settled on the road surface after construction, the surface was thoroughly scrubbed using a brush and Method 1312 water before each event. The samples were preserved and analyzed for the total concentrations of parameters identified in Table 2.

4.6.4 Operator Breathing Zone

Employee exposures to total particulate dust were evaluated. This was performed on County landfill operators during excavation and screening of the ash at the landfill, and on a bituminous plant operator during bituminous production using all traditional materials and during bituminous production with ash. The bituminous plant employee performed general duties associated with plant operation. The bituminous plant employee
chosen for the evaluation was that employee most directly exposed to the generation of airborne particulates.

The air sample collection media were pre-weighed, 37 mm diameter polyvinyl chloride filters with 5-micron pore size. Air was drawn through the filters using a battery-operated air pump. The employees wore the media and pump during the sampling to evaluate personal (breathing zone) exposures. The airflow of the sampling pump was calibrated before and after the sampling.

Each sample collection period was at least 4 hours. After sampling, the media were submitted to a laboratory accredited by the American Industrial Hygiene Association for analysis by NIOSH Method 0500. Samples were analyzed for total airborne particulate (dust). Based on the dust concentration, and previously identified concentration of 2,3,7,8-TCDD, a calculation of concentration of 2,3,7,8-TCDD exposure was performed.

4.6.5 Bituminous Plant Air Emissions
The bituminous plant utilized for this demonstration project operates under an air emissions permit issued by the MPCA. One of the objectives of this demonstration was to evaluate the potential impact of ash utilization on air emissions. To obtain this information, a stack test was performed downstream of the plant’s air pollution control equipment. The objective of the stack test was not to evaluate the plant’s compliance with Minnesota air quality standards. Rather, the objective was to compare the emissions while utilizing ash to those emissions while no ash was being utilized. The stack test was performed according to EPA Methods 5 and 202 for total particulate and Method 29 for metals.

4.6.6 Future Environmental Testing
4.6.6.1 Flushing of the Underpavement Water Collector
Since bituminous pavement installation was not completed in the year 2000 construction season, the installation of the underpavement water collectors was not completed. Therefore, this installation will be completed in the year 2001 construction season. The tops of the collectors have been open through the winter, therefore, it is expected that they will be full of water and contaminants. Pumping the collectors dry in the spring, and flushing them thoroughly will address this. The final volume of water removed from the collector will be analyzed as a base line.

4.6.6.2 Sampling of the Underpavement Water Collector
Once the bituminous road and underpavement water collector construction is complete, monitoring of the collectors will begin. Following rainfall events of at least 1 inch over a 24-hour period, an attempt will be made to collect a water sample from the collectors. If a sample is collected, it will be analyzed for the parameters identified in Table 2. The collectors will be pumped dry and the volume will be documented.

4.6.6.3 Adjacent Soils
A follow up round of soil samples will be collected adjacent to the bituminous road in accordance with the previously defined procedure. This will determine if dust from the bituminous placement has impacted the adjacent soils.
4.6.6.4 Paving Operator Breathing Zone
During the placement of ash-amended bituminous in the year 2000 construction, some of the paver operations personnel complained of a noxious odor. This complaint was limited to some of the individuals working most closely with the paving process. Not all of the individuals noticed the odor. Upon start up of the placement of ash-amended bituminous in 2001, a breathing zone evaluation will be performed for organic constituents. The specifics of this evaluation have not yet been identified.

4.6.6.5 Air Emissions Stack Testing
Since a comprehensive stack test was not completed in the year 2000 construction, a follow up stack test may be performed.

5.0 RESULTS AND DISCUSSION
5.1 Structural Testing
5.1.1 Trial Mix Designs
The results of the trial mix designs prepared for the base and binder courses are identified in Table 3. The trial mix design for the wear course did not contain ash and is not presented.

| Table 3. Ash amended bituminous trial mix designs<sup>A</sup> |
|-----------------|-----------------|-----------------|
| Percent ash (%) | Virgin (no ash) | Old ash | New ash |
| Percent asphal
tic cement (%) | 0               | 20        | 18 |
| Marshall density (lbs./ft.<sup>3</sup>) | 145.8       | 142.6     | 140.5 |
| Design voids (%) | 5.0            | 4.0       | 5.0 |
| Flow<sup>B</sup> | 6.4            | 10.08     | NA |
| Stability<sup>B</sup> | 1,784        | 3,085     | NA |

<sup>A</sup> Trial mix designs performed by the MnDOT Materials Lab on 10/17/2000.

<sup>B</sup> This evaluation was performed by the MnDOT Materials Lab in an air voids update, dated 10/25/2000.

As shown in Table 3, the trial mix designs were prepared with approximately 20 percent ash. The contractor did not attempt to use 40 percent old ash, as identified in preliminary mix designs.

Similar to the preliminary mix designs, the use of ash required an additional 1.4 percent asphaltic cement. This may affect project economics, as discussed later.

The use of ash also affected the Marshall density of the bituminous. As expected, the lighter new ash had a more dramatic effect on density than the old ash did. Even though only 18 percent new ash was utilized in the bituminous mix, the paving contractor noticed the resulting decrease in density. The density decrease was identified by a decrease in the tonnage of mix that was transported in each truckload since the haul trucks had a fixed volume capacity. Since the contractor is paid on a per-ton basis, hauling fewer tons per load had a financial impact.

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The design voids for the old-ash-amended bituminous was 4.0 percent while the design voids for the virgin material and the new-ash-amended material was 5.0 percent. This was due to a lower percentage of fine aggregate in the old-ash-amended aggregate.

As shown in Table 3, the bituminous amended with old ash demonstrated a 57 percent increase in flow with a 73 percent increase in stability. This update had not yet been performed on the bituminous amended with new ash. This increase in stability is suspected to be due to the increased porosity of the ash, combined with the increased oil content. This much more stable bituminous, thus much harder bituminous, may be more resistant to rutting with longterm usage. However, stabilities is excess of 3,000 may display increased brittleness. Yet with a 57 percent increase in flow, the author questions whether increased brittleness is really an issue.

5.1.2 Bituminous Quality Control Testing
The contractor and county performed quality control testing during bituminous production. Since only a limited quantity of bituminous was produced and placed during the 2000 construction season, only a limited number of tests were performed. The results of this QC testing demonstrated that the material was within the job mix formula working range.

5.1.3 Future Structural Testing
Structural testing of the bituminous material will continue throughout the production and paving process. In additional, after the road is constructed and placed into service, performance testing will continue for a minimum of 5 years. Testing will include, deflection testing the first year after completion, as well as annual ride testing.

5.2 Environmental Testing
5.2.1 Discussion of current environmental testing
5.2.1.1 Adjacent Soils
As described in the Methods Section, soil samples were collected adjacent to the proposed road sections. The intent of this evaluation is to determine if any constituents of concern migrate to adjacent soils during the construction process. The greatest opportunity for this airborne contamination transport is during the paving process. Therefore, upon completion of pavement placement, follow-up samples will be collected and analyzed.

A limited number of parameters were selected for analysis. These parameters were selected based on their concentration in or leachability from the ash-amended bituminous, as identified in the preliminary environmental testing. Any parameters that exceeded 50% of the Tier 2 SLV or Tier 2 SRV, or 50% of the HRL or MCL, were selected. The results of this evaluation were not available at the time of publication of this paper.

5.2.1.2 Surface Water Runoff
The surface water runoff evaluation demonstrated that the metals analyzed for are not solubilized from the ash-amended bituminous under the conditions tested. The results are provided in Table 4. The only data point above the MDL is 3.7 ug/L for lead from the old ash amended bituminous. This is well below the Minnesota HRL of 15 ug/L,
and is likely due to a non-ash source that was on the road surface and was caught in the sample.

**Table 4. Surface water runoff**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unamended bituminous (ug/L)</th>
<th>Old-ash amended bituminous (ug/L)</th>
<th>New-ash amended bituminous (ug/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Arsenic</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Beryllium</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Lead</td>
<td>&lt;2</td>
<td>3.7</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Nickel</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Selenium</td>
<td>&lt;2.3</td>
<td>&lt;2.3</td>
<td>&lt;2.3</td>
</tr>
<tr>
<td>Thallium</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

These results are not surprising for several reasons.

a. Since the road surface is crowned, the flow path is relatively short, traveling only half the width of the road. This is likely a minor reason.

b. The ash is well bound up within the asphaltic matrix of the bituminous. Since this is an oily material, the repelling forces of the oil and water minimize the opportunity for the water to come in contact with the ash.

5.2.1.3 Breathing Zone Particulates and Dioxins

The breathing zone evaluation demonstrated that there was an increase in possible inhalation exposure of total airborne particulate dust when the bituminous is amended with ash. However, the exposure is well below any health standards. The operator evaluated was exposed to 0.47 mg/m³ of total dust while traditional bituminous was being produced. When the bituminous was produced with 20 percent ash, the operator was exposed to 0.79 mg/m³ of total dust. The OSHA PEL for total inert or nuisance dust (also known as “Particulate Not Otherwise Regulated” or PNOR) is 15 mg/m³. In addition, the American Conference of Governmental Industrial Hygenists (ACGIH) publishes guidelines known as Threshold Limit Values or TLVs. The TLV for “Particulate Not Otherwise Classified” or PNOC is 10 mg/m³.

Based on the dust exposure identified above, a calculation was performed on the possible inhalation of 2,3,7,8-TCDD. As previously described by Lucido, the ash has been analyzed and found to contain 1.647 ug/Kg of 2,3,7,8-TCDD. This is the 2,3,7,8-TCDD concentration for “new” ash. The concentration in “old” ash was shown to be 0.205 ug/Kg. If this concentration is also present in the airborne dust, the employee’s exposure to 2,3,7,8-TCDD could be 1.3 x 10⁻⁹ mg/m³. There is neither an OSHA PEL nor an ACGIH TLV for 2,3,7,8-TCDD. Recently, however, the Minnesota Department of Health, in conjunction with the Minnesota Pollution Control Agency, has developed DRAFT “Health Risk Values” (HRVs) for 2,3,7,8-TCDD and many other chemical materials. The intent of the HRVs is to establish safe exposure limits that are applicable to all members of the population for 24 hours per day, seven days per week, for a normal lifetime of 70 years. Note that the PELs and TLVs are directed at the exposures of 40 hours per week for a working lifetime.
The HRV for 2,3,7,8-TCDD is based (generally) on ingestion of contaminated food. However, inhalation is also a usual route of exposure. The HRV for 2,3,7,8-TCDD is 0.07 picograms (pg) per kilogram of body weight per day. For a standard 70-kilogram (154 pound) person, the daily HRV dose is 4.9 pg per day (A picogram is one trillionth ($10^{-12}$) of a gram).

Using the standard volume of air breathed by a working person during a work shift of 10 m$^3$, the 2,3,7,8-TCDD dose is $13 \times 10^{-9}$ mg or 13 pg for the monitored employee. However, the exposure is expected to be far below the 24 hours per day, 7 days per week, 70-year exposure scenario that forms the basis for the HRV.

Therefore, based on this evaluation, the use of the combustor ash as a partial replacement for aggregate in bituminous production does not constitute a health risk for particulate dust or 2,3,7,8-TCDD, when used as described.

5.2.1.4 Bituminous Plant Air Emissions Stack Testing

The stack test that was performed indicated an increase in emissions during the use of ash in the production of bituminous. During Run 1, production of unamended bituminous, an emission of 0.063 grains per dry standard cubic foot was measured (26.13 lb/hr). During Run 2, production of bituminous amended with old ash, an emission of 0.149 grains per dry standard cubic foot was measured (53.24 lb/hr). A stack test was not completed during the production of bituminous with new ash, due to the minimal opportunity during the short run time. Metals analyzed and qualitative changes in emissions due to the use of ash are displayed in Table 5.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Concentration increased up to 10X with the use of ash</th>
<th>Concentration increased more than 10X with the use of ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>arsenic, beryllium, chromium, selenium, silver, thallium</td>
<td>Antimony, barium, cobalt, mercury, nickel, zinc, phosphorus</td>
<td>cadmium, copper, lead</td>
</tr>
</tbody>
</table>

The appropriate use of the stack test for this demonstration must be determined. A case can be made that the stack test only evaluates the performance of the contractor's baghouse. On the other hand, the results suggest that certain performance characteristics of the baghouse may be necessary to utilize ash. The allowable percentage of ash in the mix may be controlled by the performance of the bag house. It is important to note that the results of this stack test do not allow a quantitative evaluation. This is due to the fact that the performance of the bituminous plant was quite inconsistent due to shut downs and due to a steep learning curve for utilization of the ash. This inconsistency means that correlating the emissions data with production data would be very imprecise. More quantitative emissions testing will be attempted in 2001.
5.3 Construction Issues

5.3.1 Drying the ash
The ash is maintained in a nearly saturated state from the time it is generated until it is
disposed at the landfill. Consequently the ash is quite wet when hauled to the
bituminous plant. This is advantageous since it minimizes concerns of fugitive dust
generation. However, the aggregates must be dried to 1.5 to 2 percent moisture content
for the asphaltic cement to adhere. Therefore, significant drying effort is required. This
added drying effort reduces the production rate of the plant. The added drying effort
also requires additional fuel.

5.3.2 Fines plugging bag house
The use of ash resulted in a significantly increased percentage of fine particulates. In
this case fines are defined as particles that are sufficiently low in density to be drawn
into the baghouse. Only a small percentage of the fines would be expected to consist of
fly ash. Therefore, the term “fines” reflects more a function of total particle mass and
density than particle size. This increase in fines resulted in the bituminous plant
baghouse not being able to discharge the fines as fast as the filter material was
collecting it. When the mix was produced with 20 percent ash, this baghouse plugging
actually caused the plant to shut down during production. When the ash percentage in
the mix was reduced to 10 percent, the baghouse appeared to be able to keep up. The
mechanics of the fines generation were considered. One mechanism considered was the
mechanical grinding of the less-durable ash in the drum mixer with the more durable
natural aggregate. Another mechanism considered was the dramatically reduced
moisture content required of the ash in the bituminous production process. As
previously stated, the aggregates are dried to 1.5 to 2 percent moisture content prior to
the introduction of the asphaltic cement. This dramatic reduction in moisture content
may be reducing the particle density to such a degree that a problematic fraction of the
material is drawn into the baghouse.

Discussions with Musselman suggested using a portable vacuum truck to remove a
portion of the fines to reduce the load on the baghouse. However, the plant baghouse
provides a flow of 82,000 cfm, while the portable vacuum truck would only provide
about 4,000 cfm of flow. Therefore, it was determined that the portable vacuum truck
would be of little help in this situation.

5.3.3 Reduced bituminous production rate
The use of ash resulted in a significantly reduced rate of bituminous production. This
was likely a result of at least 2 factors:
   a. The overtaxing and shutdown of the baghouse that occurred several times had a
dramatic impact on the overall production rate.
   b. The unfamiliarity of the contactor with the use of ash was also an obvious
      contributing factor.
Since this was a demonstration project, production was not the overall objective.
However, productivity is an understandable objective of the contractor. This identifies
one of the difficulties in combining a demonstration project with a commercial
endeavor.
5.3.4 Fluffyness/dryness of bituminous upon placement
When the ash amended bituminous was placed and compacted for the first time by the paver, the material appeared to be unusually fluffy or dry. This appearance may be due to the lower density of the material and/or the greater absorption of the asphaltic cement by the ash. Once the material is smooth rolled by the follow up compactor and allowed to cure, it appeared more similar to the unamended bituminous. Its not yet known if this observed quality has any impact on performance.

5.4 Economic Issues
5.4.1 Cost of landfilling
The cost for landfilling of MWC ash must be taken into account when considering the economics of utilization. We have found landfilling costs have been shown to range from $15 to $50 per ton in the upper MidWest. The avoidance of these costs must be considered when evaluating the economics of MWC ash utilization.

5.4.2 Costs of utilization
The cost for utilization of MWC ash must be taken into account. This cost is less defined than landfilling costs since utilization has a less established history in the United States. Based on the demonstration of utilization in bituminous aggregate in Crookston Minnesota, several cost factors have been identified.

5.4.2.1 Hauling costs
One of the more significant cost factors in the use of ash in bituminous, or aggregate in bituminous, is the cost of hauling. Hauling costs can range from $0.50 to $10.00 per ton. Such a wide range can have a dramatic impact on the economic feasibility of replacing bituminous aggregate with ash.

Since the ash-amended bituminous is lighter than the traditional mix, the contractor observed a noticed decrease in the tonnage of mix that was transported in each truckload. Since the contractor is paid on a per-ton basis, hauling fewer tons per load had a negative financial impact. This would have to be accounted for in the method of compensation in an ash utilization project.

5.4.2.2 Cost for asphaltic cement
As previously identified, the use of ash required an additional 1.4 percent asphaltic cement, or AC. It is suspected that this is due to the porous nature of the ash. This increase correlates to an additional 28 pounds of AC per ton of bituminous. AC at the Crookston project cost $190 per ton. Therefore, the cost for additional AC due to ash use was about $2.50 to $3.00 per ton of bituminous.

5.4.2.3 Cost for fuel
As previously discussed, the ash typically has a higher moisture content than traditional aggregate. This may be due to, or exacerbated by, the higher porosity of the ash. This higher moisture content and porosity results in a greater demand for fuel in the drying process. The fuel used at the Crookston project was used motor oil, which costs $0.50 to $0.80 per gallon. This increased cost was not quantified on a per ton basis, but it is clear that the cost will further impact economic viability.
5.4.2.4 Cost for environmental protection
Costs for environmental protection would also have to be taken into account. This may include control of surface water run on and runoff, and emissions of fugitive dust.

5.4.2.5 Cost due to reduced production
An important cost implication is the impact of the use of ash on the rate of bituminous production. A reduction in productivity is likely due to the unfamiliarity with the use of ash and/or the need for equipment modifications. However, as contractors increase their familiarity with the use of the ash, productivity should increase.

5.4.2.6 Longterm performance
The longterm performance of ash-amended bituminous must be evaluated. While information site by Wiles\textsuperscript{10} indicates that the bituminous pavements are safe and long lasting, the details of the long-term durability issues are as yet unknown.

5.4.3 Impact of higher performance bituminous
As previously described, it appears that the ash-amended bituminous results in significantly higher stability and flow characteristics. While these were not defined as performance enhancements in this project, such characteristics have the potential for increased bituminous performance. In addition, the lightweight characteristic identified in 5.4.2.1, which was identified as a cost liability, could indeed be a value enhancement. The potential advantages of decreased weight in the hauling and use of a construction material are obvious.

6.0 CONCLUSIONS

6.1 Cost
The cost implications in the use of MWC ash in bituminous production must take into account many factors. These factors include:

a. The costs of landfilling the ash,
b. The availability and hauling of an ash source compared to traditional aggregates,
c. Costs for production, including additional asphaltic cement, additional fuel, environmental protection, and others,
d. Costs for regulatory approvals.

6.2 Environmental Impacts
The potential environmental impacts of the use of MWC ash in bituminous have been partially evaluated in this demonstration. Additional evaluations will be completed through follow up of this project. Potential impacts of surface water were shown to be very small or non-existent. Potential impacts on human health were shown to be within safe standards at the bituminous plant. Impacts on stack air emissions are inconclusive at this time. Lab tests have shown that the potential to impact groundwater is very small or non-existent. Empirical evidence on the potential to impact groundwater will be provided during follow up of this project.
The potential environmental impacts of the use of MWC ash in bituminous must not only take into account the impacts of ash use, but must also consider the environmental impacts of using traditional aggregates. Aggregate mining and hauling, certainly have a measurable negative impact on the environment. In addition, the encapsulation of ash in a bituminous matrix may be an environmentally advantageous process.

6.2 Bituminous Performance
As previously cited, the stability and flow of ash-amended bituminous is substantially increased over unamended bituminous. However, the increase in these indices has not really been identified as a performance enhancement. This suggests an opportunity to identify bituminous products for which such indices are seen as performance enhancements.

The longterm durability of ash-amended bituminous also needs further evaluation.

7.0 ACKNOWLEDGMENTS
The following participants in this project have provided valuable input to this project:

a. Bill Wilson, of the Polk County Solid Waste Department, provided the inspiration and direction for the project, as well as important input into this paper.

b. Roger Diesen and Rich Sanders, of the Polk County Highway Department, provided regular input and willingness to accommodate the use of ash throughout the project as well as important input into this paper.

c. Dennis Sorenson of Thorson, Inc., provided his expertise in bituminous production and willingness to accommodate the use of ash throughout the project as well as important input into this paper.

d. Kathy Holland-Hanson, of the MPCA, provided her usual common-sense approach to environmental regulation.

e. Kristi Olson of the MnDOT Materials Lab provided expertise in materials characteristics and bituminous testing.

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6 Lucido, May 2000
7 Lucido, May 2000
8 Musselman, personal communication, June 22, 2000
9 Wiles, 1999