Bituminous Pavement Constructed with Municipal Solid Waste Combustor

Ash: Construction, Performance, and Economic Issues

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1.0 Introduction

The Polk County Solid Waste Department, located in Polk County 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 municipal waste combustor (MWC) that combusts 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-processable or objectionable materials prior to combustion. The energy produced is sold in the form of steam to businesses adjacent to the facility. The ash generated by combustion prior to the 1996 installation of the MRF is referred to as “old ash” and was 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”, and is also placed in the permitted landfill. The chemical and physical differences between the new and old ash are important enough to warrant the two ashes being addressed separately for purposes of this utilization demonstration project.

In 2000 and 2001, Polk County performed a demonstration of the feasibility of utilizing combined MWC ash as a partial replacement of aggregate in bituminous paving materials. The demonstration consisted of building and evaluating a section of county road using the MWC ash-amended bituminous.

This paper presents the performance, construction and economics issues and results of this demonstration. The up-front environmental evaluations performed as part of this demonstration were previously presented by Lucido and Wilson. The final environmental evaluations of this demonstration are presented in this paper. Therefore, after a summary of the following relevant publications, the remainder of this paper will focus on the structural performance, construction and economics issues and results of this demonstration.

The project was approved by the MPCA and supported by the Minnesota Resource Recovery Association, the Association of Minnesota Counties, the Minnesota Office of Environmental Assistance, the Minnesota State Representative for District 2A, the four partner counties adjacent to Polk County, the Polk County Board, the Polk County Highway Department, and the citizens of Polk County.

2.0 Background

NATIONAL/WORLDWIDE

In 1999, 102 MWCs were in operation in the United States, serving the disposal needs of more than 37 million people. These facilities generated about 2800 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 MWCs, promote landfill abatement and decrease the use of more valuable resources such as natural aggregates.

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. 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.iii

Environmental testing in this project, as well as many other demonstrations around the United States, has shown that the use of MWC ash in pavement construction is safe. A selection of the most directly applicable projects are discussed below:

ROCHESTER, MINNESOTA
Aggregate replacement using MWC ash was investigated by Dewey, Movrich, and Cousinov. This bench-scale work replaced up to 100 percent of the fine aggregate in hot-mix bituminous mixtures. The results indicated that, even at the highest aggregate replacement rate, MnDOT specifications for particle size distribution and Marshall stability were met. However, as the ash content increased, voids in mineral aggregate (VMA) increased along with requirements for asphaltic cement. The typically low density of the ash also resulted in reduced unit weight of the bituminous.

ALBANY, NEW YORK
Bottom ash from the OGS Boiler Facility in Albany, New York, replaced gravel as the subbase for a parking lot constructed in 1983 at a waste shredding plant near the Rapp Road landfill. Twelve inches of bottom ash were placed on a geotextile filter membrane. The ash was covered with a 2 1/2-inch wearing course of asphalt concrete. In this project, ferrous metal was recovered from the ash before use (at Polk County, ferrous metal is removed prior to combustion). Environmental testing in 1987 sampled groundwater and detected no heavy metals in the water. The parking lot was in good physical condition in June 1997, 14 years after constructionv.

ROCHESTER, MASSACHUSETTS
The SEMASS MWC facility developed an aggregate product called Boiler Aggregate™ from its bottom ash. The product grew from extensive development and field demonstrations in Albany, New York, and Rochester, Massachusetts. Field demonstrations took place over a period of about 12-13 years. On December 24, 1996, the Massachusetts Department of Environmental Protection issued a final beneficial use determination to Engineered Materials Company for use of SEMASS Boiler Aggregate™ in Massachusetts paving projects. The aggregate product is manufactured from MWC ash by removing ferrous metals and screening it to the desired particle size range. No other treatment occurs.vi It replaced 30 percent of conventional rock aggregate in a new asphalt concrete (bituminous) access road to the facility. The binder course was placed in January 1992 and the surface course followed in April of that year. A comprehensive risk assessment concluded that the asphalt paving composition would not pose a significant risk to the environment or human health.

LACONIA, NEW HAMPSHIRE
Bottom ash from the Concord, New Hampshire, MWC replaced half of the natural aggregate in an asphalt paving binder course that was used to repave a section of U.S. Route 3 in Laconia, New Hampshire, during May 1993. Two years of intensive sampling and testing found no environmental or health risks.vii

CONCORD, NEW HAMPSHIRE
Gress et.al. evaluated the performance of an asphaltic concrete replacing 25 percent of the aggregate with bottom ash from a mass-burn combustor in Concord, New Hampshire.viii The mix was paved, compacted, and broken up after a 7-day period with a backhoe into large pieces, typical of what might be expected to be dumped into a landfill as construction debris. The broken up pavement, ranging in size from small palm size to large 2- by 3-ft. plates, was put in a double-lined roll-off container. This container was used as a lysimeter to generate time-dependent data on the leachate properties of the 25 percent ash asphalt pavement mix. The leachate, originating from natural precipitation, was collected and analyzed. The resulting leachate met drinking water standards.

FUGITIVE DUST STUDIES
In 1990, Mullen reported the results of a study that characterized the dust generated from uncontrolled stockpiles of processed MWC bottom ash, and from road construction activities where the processed bottom ash was used as a road subbase and base course aggregate.ix Results of modeling and simulations demonstrated that dust generated from the construction activities using this bottom ash did not represent a significant source of exposure to heavy metals in the ash. Air quality dispersion models were performed to predict the potential for fugitive particulate emissions from storage and construction uses of Boiler Aggregate™ and their effects on ambient air quality. Results compared favorably with Massachusetts Allowable Ambient Levels (AALs).

In a recent National Renewable Energy Laboratory-sponsored study, the air was monitored to measure fugitive emissions associated with processing MWC bottom ash that involved conveying, screening, and
ferrous metals removal. The processed ash was stockpiled before use in a paving demonstration, and monitored for fugitive dust emissions during static conditions (no human activity) and during repeated turning by a front-end loader to simulate repeated retrieval and replacement. High volume air samplers monitored upwind and downwind emissions and personnel samplers were used to measure total suspended particulates (TSPs) and respirable particulates (PM<sub>10</sub>) during processing periods.

Results of this study show that:

> There were no measurable differences between the ambient air TSPs and trace metal concentrations upwind and downwind of the stockpile during static monitoring.

> The TSP concentrations measured in the ambient air near the stockpile were similar to the TSP concentrations reported at the other air monitoring stations in New Jersey and were below New Jersey’s annual TSP criteria of 75 µg/m<sup>3</sup>. The TSP concentration downwind of the bottom ash stockpile was 62 µg/m<sup>3</sup>.

> During ash processing, PM<sub>10</sub> concentrations, and TSP trace metal concentrations in the emissions were significantly below OSHA permissible exposure limits (PELs).

> During the stockpile turning events, PM<sub>10</sub> concentrations were one to two orders of magnitude, TSP concentrations at least two orders of magnitude, and TSP trace metal concentrations several orders of magnitude below OSHA PELs, respectively. This was the case even though there was visible dust observed and a measurable increase in the ambient PM<sub>10</sub>, TSP, and TSP trace metal concentrations. Scanning electron microscope analyses of TSP and PM<sub>10</sub> samples collected during stockpile turning indicated that the major fraction of TSP particulate matter was in the PM<sub>10</sub> size ranges (<10 microns, with 55 percent to 95 percent evenly distributed throughout the PM<sub>10</sub> range).

> Soil quality near the stockpile was not adversely affected. Soil samples collected had elemental concentrations comparable to other soils typically found in New Jersey.

WORLDWIDE
The United States boasts some success stories in ash utilization, but the European countries have led the way in the successful practice of using the benefits of ash in roadways. Germany uses 60 percent of WTE bottom ash as material for road paving and similar projects. The Netherlands uses more than 90 percent of the bottom ash in road base and road embankments. In 1994, France put about 45 percent of its bottom ash to beneficial use in civil engineering projects.

PRIMARY PROJECT CONTACTS
The primary contacts associated with this project and report are provided in Table 1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Role</th>
<th>Contact Information</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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</tr>
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<td>Phone: 218-751-5413</td>
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<tr>
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</tr>
</tbody>
</table>

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3.0 Objectives and Schedule

3.1 OBJECTIVES
The objectives of the demonstration project were as follows:

- Evaluate the constructability of a roadway using bituminous paving materials in which a portion of the aggregate has been replaced with MWC ash;

- Utilize the ash in a way that uses as much ash as possible, in the most cost effective way, while maintaining engineering integrity, and environmental acceptability;

- Evaluate the structural performance of the ash-amended bituminous;

- Evaluate the potential for environmental impact;

- Utilize both old ash and new ash independently, thus improving the applicability of the demonstration project to other potential ash utilizers and supporting rulemaking efforts and/or precedence for future ash utilizers for the State of Minnesota;

- Utilize combined ash (fly ash and bottom ash) to further demonstrate cost effectiveness and broaden applicability;

- Collect data that supports the evaluation of the method of utilization by the MPCA and MnDOT for larger scale approvals. Data collection includes impacts to surface water, groundwater, adjacent soils, and air quality;

- Evaluate the economics of utilizing MWC ash in bituminous.
3.2 SCHEDULE
The realized schedule of the demonstration project was as follows:

<table>
<thead>
<tr>
<th>Period</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997-1998</td>
<td>Obtained political, public and financial support for the project</td>
</tr>
<tr>
<td>Summer/fall 1999</td>
<td>Collected analytical data in preparation for environmental evaluations. Performed preconstruction environmental evaluations and prepared preliminary trial mix designs</td>
</tr>
<tr>
<td>Winter/Spring 2000</td>
<td>Obtained MPCA approval for the project</td>
</tr>
<tr>
<td>Spring/Summer 2000</td>
<td>Advertised for bids from contractors for project construction</td>
</tr>
<tr>
<td>Fall 2000</td>
<td>Installed underpavement monitoring devices, collected preconstruction soil samples, performed breathing space monitoring on landfill operators and bituminous plant operator, placed 1st lift of unamended and old-ash-amended bituminous and a partial lift of new-ash-amended bituminous, and performed surface water runoff evaluation.</td>
</tr>
<tr>
<td>Spring/Summer 2001</td>
<td>Completed road construction and began monitoring. Evaluated plant stack emissions. Evaluated breathing space impacts on road construction personnel.</td>
</tr>
</tbody>
</table>

4.0 Design

The Polk County Highway Department constructed a 2.25-mile section of road in the summer of 2000. The project location was shown on Figure 1. The design of the road section called 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. The Polk County Highway Department supported this approach.

For this demonstration project, ash-amended bituminous was incorporated into the bituminous base course and the bituminous binder course. No ash was placed in the wear course. The 2.25-mile road section was constructed as follows:

- 0.75 miles with no ash as a control section;
- 0.75 miles, replacing 10 percent of the aggregate with old ash in the bituminous base and binder courses for a total of 416 tons of new ash in 4,000 tons of bituminous;
- 0.75 miles, replacing 10 percent of the aggregate with new ash in the bituminous base and binder courses for a total of 463 tons of old ash in 4,000 tons of bituminous.

In addition, about 8 tons of new ash was utilized in bituminous pavement at the Polk County Landfill. A 10-percent replacement was used.

Standard bituminous production, placement equipment, and procedures were used, as documented later in this report.

The old combined ash and new combined ash have sufficiently distinct characteristics so that Polk County evaluated the two ashes independently. In addition, the bituminous material produced utilized old ash and new ash independently. The old ash was mined from previously landfilled areas, thus freeing up landfill space for future use, while the new ash was from current generation. Independent evaluation of the two ash types makes the demonstration project results applicable to a wider range of combustors within and outside the State of Minnesota.

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 MnDOT mix design. In preparing the MnDOT trial mix designs, the ash was screened to remove oversized (0.75") and deleterious materials. This removal of 0.75" material had the effect of slightly decreasing the ratio of bottom ash to fly ash. Therefore, the percentage of fly ash was slightly more than 1-2% and the percentage of bottom ash was slightly less than 98-99%.
During initial project design, 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 Mix Design bituminous that meets all MnDOT specifications. After several iterations, the lab determined that an acceptable 2350 design could be prepared while replacing 20 percent of the aggregate with new ash, or by replacing 40 percent of the aggregate with old ash.

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. New ash is less dense than old ash due to reduced particulate metal and glass. The Polk County up-front MRF removes waste metals and glass before combustion.

The paving contractor that was ultimately awarded the project, Thorson Inc., uses a different aggregate pit than was used in the preliminary trial mix designs. Therefore, new trial mix designs were prepared for the project. As a conservative measure, Thorson limited the trial mix designs to 20 percent of each ash. This is further explained below. Ultimately, in order to maintain the most efficient bituminous plant operation, the percentage of ash was reduced to 10 percent of each old and new. The replacement rate of 10 percent for each ash was used for the project.

5.0 Bituminous Production and Placement

5.1 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. While one of the objectives of the study was to use as much ash as possible, the contractor assumed that the use of ash would reduce the efficiency of his bituminous plant. Therefore, he did not attempt to use 40 percent old ash, as identified in preliminary mix designs. As previously stated, the final percentage of ash used in the mix is 10 percent. The reason for this 10-percent replacement rate is discussed later.

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. The results of trial mix designs are provided in the Results section.

5.2 BITUMINOUS PRODUCTION
Ash for the project was taken from the lined MWC ash monofill cells 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 and stored in the lined cells. When bituminous production commenced, ash was hauled to the bituminous plant where it was stockpiled in a bermed area. The two ash piles (new ash and old ash) were covered with a plastic membrane until needed. Ash was stored, transported and stockpiled in a damp 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. Only enough ash for 1 to 2 days of bituminous production was stored at the bituminous plant.

Bituminous was produced using a parallel-flow drum-mix asphalt plant. Figure 2 is typical of the plant used. Four aggregate feeder bins contained fine aggregate, coarse aggregate, and ash (when used). The feeder bins were replenished from stockpiles using a 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 rotated at 7.5 revolutions per minute. A burner at the front of the drum mixer dried the aggregate blend to less than 1.5 to 2 percent moisture. The mix was heated to 275 to 280 degrees F for base and binder course material and 290 to 300 degrees F for wear course. Asphaltic cement was injected into the drum mixer near the midpoint at a specified rate. This rate was specified by the initial trial mix designs to be 5.4 percent for the traditional bituminous and 6.8 percent for the ash-amended bituminous. The updated trial mix designs, using 10 percent ash, specified 5.0 percent asphaltic cement when not using ash, and 6.1 percent with ash. The hot mix asphalt (HMA) was discharged to a slat conveyer for transfer to a storage silo and to haul trucks.
Figure 2: Typical Hot Mix Asphalt Plant
Parallel Flow Drum Mix
The drum mixer is maintained at a negative pressure by the baghouse induced draft fan to collect fugitive dust. The baghouse is designed to move approximately 82,000 cubic feet per minute of air. Materials collected in the baghouse are reintroduced into the drum mixer.

A total of approximately 10,100 tons of bituminous were placed in the 5.2-inch thick base course. This included 4,350 tons without ash and 5,750 tons with ash. In addition, approximately 3,300 tons of bituminous were placed in the 2-inch thick binder course. This included 1,050 tons without ash and 2,250 tons with ash. The wear course contained about 5,300 tons of bituminous without ash. This resulted in about 880 tons of ash utilized for the demonstration. Finally, 134 tons of bituminous were placed at the Polk County Landfill. This included 58 tons without ash and 76 tons with ash. A total of 10,758 tons of bituminous without ash and 8,076 tons of bituminous with ash was placed.

5.3 BITUMINOUS PLACEMENT

Standard bituminous placement equipment and procedures were used. Seventeen-cubic-yard belly-dump trucks hauled the HMA to the prepared road construction site where it was dumped in windrows about 4 feet wide by 2 feet deep. A self-propelled 5510 BlawKnox track paver then spread and compacted the HMA to dimensions about 4 inches thick and 12.5 feet wide. The HMA was placed at the road at a temperature of 265 to 270 degrees F for base and binder course material and at 280 to 285 degrees F for wear course. A 31,817-pound Ferguson rubber tire roller followed by a 28,435 pounds DD130 Ingersoll Rand steel smooth drum roller then further compacted the HMA to a thickness of about 2 to 3 inches.

5.4 BITUMINOUS QUALITY CONTROL

The contractor and Polk County Highway Department performed quality control testing during bituminous production. Testing was performed for particle size gradation, percent asphaltic cement, density and percent voids. Samples of aggregate and bituminous mix were collected at a frequency of one sample per 500 tons produced during the first 2,000 tons, and one sample per 1,000 tons thereafter. In addition, one sample per day was sent to the MnDOT Materials Lab for testing.

6.0 Results

6.1 STRUCTURAL

The results of the trial mix designs prepared for the base and binder courses are identified in Table 2. The trial mix design for the wear course did not contain ash and is not presented.

Table 2: Trial Mix Design Results

<table>
<thead>
<tr>
<th>Field ID</th>
<th>Lab stability (lbs.)</th>
<th>Lab flow (in.)</th>
<th>AC (%)</th>
<th>Bulk Sp. G.</th>
<th>Density (lbs./ft.³)</th>
<th>Contractor voids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No ash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>31BI506</td>
<td>1,663</td>
<td>0.07</td>
<td>5.0</td>
<td>2.347</td>
<td>146.25</td>
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<td>31BI507</td>
<td>1,767</td>
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<td>2.348</td>
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<td>-</td>
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<td>2.342</td>
<td>145.92</td>
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<tr>
<td>Average</td>
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<td>0.070</td>
<td>5.0</td>
<td>2.358</td>
<td>146.93</td>
<td>4.8</td>
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<tr>
<td>New ash</td>
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<td></td>
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<td>31BINA107</td>
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<tr>
<td>Average</td>
<td>2,439</td>
<td>0.081</td>
<td>6.1</td>
<td>2.324</td>
<td>144.78</td>
<td>5.0</td>
</tr>
</tbody>
</table>
As shown in Table 2, the stability of the mix averaged 1,771 pounds, without ash, and about 2,400 pounds with 10 percent ash. Therefore, the bituminous with ash was about 36 percent more stable than the bituminous without ash. Stability is a measure of the amount of force required to "break" a compacted sample of the bituminous.

Also as shown in Table 2, the use of ash had an impact on bituminous flow. Flow is a measure of the amount of deformation, or flex, the bituminous sample will undergo before it breaks in the stability test. Flow is measured in hundredths of an inch.

A significant increase in stability often raises a concern with increased "brittleness". However, the ash-amended bituminous not only had an increase in stability, but it also had a 19 percent increase in flow, as shown in Table 2. The lab flow for the bituminous without ash was 0.070 inches, while the lab flow for the bituminous with new ash and old ash was 0.081 inches and 0.085 inches respectively.

The fourth column in Table 2 shows the mix design requirement for asphaltic cement or AC. As shown, the AC for the bituminous without ash was 5.0 percent while the use of ash required an additional 1.1 percent AC. The MnDOT lab supervisor suggested that the higher porosity of ash particles resulted in an increased surface absorbency. This more absorbent surface required more AC. However, it is reasonable to expect that the more absorbent particles and higher AC resulted in greater adhesion between the particles. This increased adhesion probably improved stability, while the increased AC content increase flow.

Columns five and six list the bulk specific gravity and density of the bituminous mixes.

Column seven lists the percentage of voids obtained on the contractor-compacted samples. This measurement is used to continually verify that the mix is being produced to obtain the specified design voids.

Other Structural Considerations
Due to construction schedules, the production and placement of bituminous did not begin until late in the fall of 2000. This late start resulted in only one lift of unamended bituminous, one lift of old-ash-amended bituminous and a partial lift of new-ash-amended bituminous being placed prior to the winter end-of-construction. The subsequent lifts and construction completion occurred in the spring of 2001. However, this unintended timing provided some very valuable information. After the winter of 2000/2001 and immediately prior to the resumption of bituminous placement, the previously placed lift of bituminous was inspected. During that inspection, pronounced cold-temperature-transverse-cracking was observed in the unamended and old-ash-amended bituminous sections. However, it was also observed that there was a significant disparity in the relative number of cracks in each section. The 0.75-mile section of unamended bituminous had 50 full-width transverse cracks, while the 0.75-mile section of old-ash-amended bituminous had only 6 full-width transverse cracks. The new-ash section had no cracks, however, this section was only a couple of hundred feet long. This issue is discussed further in the Discussion and Conclusions section.

6.2 PRODUCTION ISSUES
The bituminous plant was identified to have an average production rate of about 400 tons per hour (TPH). However, the contractor had never worked with ash and had to perform adjustments to the plant operation to accommodate ash use. A sampling of production rates is provided in Table 3. As shown, the production...
run times on those three days ranged from 1 hour to 6.2 hours. The average production rates were 251 TPH for new-ash-amended bituminous, 254 TPH for old-ash-amended bituminous, and 229 TPH for unamended bituminous. The contractor indicated that the lower production rate for the unamended bituminous was due to lack of available haul trucks. Therefore, it would be reasonable to assume that increased hauling capacity would have improved the production rate for the traditional mix. However, the traditional aggregate was saturated due to rainfall. This saturated aggregate would have also reduced plant production rate. The rate of bituminous production is an important factor in the economics of a project. Therefore, the impacts of ash utilization on production rate must be carefully evaluated.

Table 3: CSAH 13 Bituminous Production Rates

<table>
<thead>
<tr>
<th>Start time(a)</th>
<th>End time(a)</th>
<th>Run time</th>
<th>Production</th>
<th>Production rate</th>
<th>Material(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(hrs:min)</td>
<td>(hrs)</td>
<td>(english tons)</td>
<td>(english TPH)</td>
<td></td>
</tr>
<tr>
<td>29-May-01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14:06</td>
<td>17:06</td>
<td>3.00</td>
<td>697</td>
<td>232</td>
<td>virgin</td>
</tr>
<tr>
<td>17:14</td>
<td>18:12</td>
<td>0.97</td>
<td>269</td>
<td>278</td>
<td>old ash</td>
</tr>
<tr>
<td>7:44</td>
<td>13:57</td>
<td>6.22</td>
<td>1483</td>
<td>239</td>
<td>new ash</td>
</tr>
<tr>
<td>30-May-01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7:08</td>
<td>8:49</td>
<td>1.68</td>
<td>447</td>
<td>266</td>
<td>old ash</td>
</tr>
<tr>
<td>8:56</td>
<td>11:20</td>
<td>2.40</td>
<td>604</td>
<td>251</td>
<td>new ash</td>
</tr>
<tr>
<td>11:29</td>
<td>13:59</td>
<td>2.50</td>
<td>604</td>
<td>242</td>
<td>virgin</td>
</tr>
<tr>
<td>14:05</td>
<td>16:18</td>
<td>2.22</td>
<td>585</td>
<td>263</td>
<td>old ash</td>
</tr>
<tr>
<td>16:26</td>
<td>18:39</td>
<td>2.22</td>
<td>630</td>
<td>284</td>
<td>new ash</td>
</tr>
<tr>
<td>31-May-01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7:44</td>
<td>9:56</td>
<td>2.20</td>
<td>608</td>
<td>276</td>
<td>virgin</td>
</tr>
<tr>
<td>10:00</td>
<td>12:23</td>
<td>2.38</td>
<td>496</td>
<td>208</td>
<td>old ash</td>
</tr>
<tr>
<td>12:27</td>
<td>14:52</td>
<td>2.42</td>
<td>560</td>
<td>232</td>
<td>new ash</td>
</tr>
<tr>
<td>14:58</td>
<td>16:49</td>
<td>1.85</td>
<td>303</td>
<td>164</td>
<td>virgin</td>
</tr>
</tbody>
</table>

Averages

<table>
<thead>
<tr>
<th></th>
<th>new ash 3.3 hours of run time at</th>
<th>251</th>
<th>Tons per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>old ash</td>
<td>1.8 hours of run time at</td>
<td>254</td>
<td>Tons per hour</td>
</tr>
<tr>
<td>virgin</td>
<td>1.9 hours of run time at</td>
<td>229</td>
<td>Tons per hour</td>
</tr>
</tbody>
</table>

(a) Values provided by Polk County Highway Department

6.3 ECONOMICS

6.3.1 Introduction
Economic issues are obviously a critical component in the consideration to utilize MWC ash in bituminous. If a potential user does not realize a financial benefit, there is not much incentive to use the ash. Components that must be considered in the financial equation include:

- The avoidance of ash disposal costs,
- The costs for using the ash,
- Avoidance of use of traditional bituminous components, as well as
- Implications on pavement performance.

6.3.2 Landfilling or Disposal Costs
An economic analysis must consider the cost for landfilling the MWC. Landfill costs in the upper Midwestern United States have been shown to range from $15 to more than $50 per ton. While in most cases, a disposal option must be available as a back up to utilization; the extension of landfill life is an important benefit. Disposal cost savings from the use of ash were estimated at $2.25 per ton of bituminous. This is further discussed in Section 7.3.

6.3.3 Costs of Utilization
The cost for utilization of MWC ash must be taken into account. This cost is less clearly defined than landfilling costs since utilization has a less established history in the United States. Based on the Polk County
demonstration, several cost factors have been identified. These factors are described below. Potential cost savings factors are also provided in Section 7.3.

6.3.3.1 Dewatering and Drying
Polk County staff dewatered the ash by mechanically working the pile at the landfill. However, this was quite labor intensive and showed less than ideal results. A more efficient method for drying the ash would improve overall bituminous production efficiency. A reasonable per ton cost associated with dewatering is calculated by assuming 4 day’s of effort (staff and equipment time) at $500 per day to manage the 900 tons of ash used in 8,000 tons of bituminous. This results in a cost of $0.22 per ton of ash-amended bituminous produced.

6.3.3.2 Hauling
Aggregate for bituminous is normally transported to the HMA plant, whether it is traditional aggregate, or ash. However, an ash-amended bituminous will likely have a much higher percentage of traditional aggregate than ash. Therefore, the bituminous plant will most likely be located as near the traditional aggregate source as possible which means that the ash would have to be hauled to the HMA plant. Assuming a hauling cost of $0.10 per mile-ton with a 100-mile round-trip haul and a 10 percent aggregate replacement, the additional cost per ton of ash-amended bituminous is $1.00.

6.3.3.3 Cost for Asphaltic Cement
As previously identified, the use of ash required an additional 1.1 percent asphaltic cement, or AC. This increase correlates to an additional 22 pounds of AC per ton of bituminous. MnDOT identified that the commonly used AC is standard PG-58-28. MnDOT staff identified that the average cost of PG-58-28 was $145 per ton. Therefore, the cost for additional AC due to ash use was about $1.60 per ton of bituminous.

6.3.3.4 Cost for Fuel
The fuel used to run the burner for drying and heating the aggregate and AC was used motor oil. The cost for this fuel was reported at $0.50 to $0.80 per gallon (average = $0.65 per gallon). Production data maintained during the air emissions stack testing showed a fuel usage of 2.3 gallons per ton of unamended bituminous, 2.8 gallons per ton of old ash-amended bituminous and 2.5 gallons per ton of new ash-amended bituminous (average = 0.35 gallons more fuel per ton of ash-amended bituminous). This results in an average cost of $0.23 more for fuel to produce a ton of ash-amended bituminous.

6.3.3.5 Cost for Environmental Protection
Costs for environmental protection must also be to be taken into account. This cost was more pronounced due to the demonstrative nature of this project. The results of environmental evaluations indicate that very little environmental protection should be needed for future projects that are performed under similar conditions. Two environmental protection costs that may be needed in future projects include upfront testing, and air emissions protection. The bituminous contractor has indicated that, due to the dusty nature of the ash in this project, upon completion of the project, they replaced the bags in the baghouse. The contractor identified that this resulted in a cost to them of about $23,000. With a total bituminous production of 18,800 tons for the project, this results in a cost of $1.22 per ton of bituminous. However, if only 10 percent ash had been used from the outset, the impact to the bags may have been much less. For a 10 percent ash replacement, we assume a potential bag replacement cost of $0.61 per ton of bituminous.

6.3.3.6 Cost Due to Reduced Bituminous Production
An important cost implication to consider is the impact of the use of ash on the rate of bituminous production. As previously discussed, the bituminous plant had an average production rate of 400 tons per hour (tph), while the production during ash use was 250 tph. This is a 37 percent reduction. It was clear though, that as the operator gained experience with the ash, production rate increased. An important impediment to production rate was the increased generation of low-density dust, which fouled the baghouse at a faster than usual rate. However, as previously discussed, rainfall resulted in saturated aggregate and ash, which would have reduced production rate.

The 37 percent reduction at an average mix price of $22.50 per ton could result in an additional cost to the project of $8.32 per ton of bituminous. However, as previously discussed, the production rate of well under 400 tph may have been acceptable for this project whether ash was used or not. Modifications to the production with ash should be pursued to reduce the fouling rate and improve production. These efforts should be able to reduce this cost by at least 50 percent to a cost of less than $4.16 per ton.

6.3.3.7 Longterm Performance
The longterm performance of ash-amended bituminous must be considered as part of an economics evaluation. Information sited by Wiles indicated that the bituminous pavements are safe and long lasting. Preliminary data from the Polk County project suggests that ash-amended bituminous may be more durable and
long lasting than unamended bituminous. If true, this may be a function of the porous surface of the ash particles and the increased percentage of asphaltic cement. Potential cost savings due to improved longterm performance were estimated at $2.25 per ton of bituminous. This is further discussed in Section 7.3.

6.3.4 Avoidance of Use of Traditional Aggregate
By using MWC ash, less traditional aggregate is needed. In some parts of Minnesota, natural aggregates are in increasingly short supply. Assuming an aggregate cost of $3.00 per ton, a 10 percent savings would be $0.30 per ton of bituminous. Reducing the rate of depletion of this resource is an important consideration. The use of MWC ash does not require any damage to the environment, while excavation of natural aggregates does cause environmental damage and necessitates repair.

6.3.5 Implications of Bituminous Performance
As previously described, it appears that the ash-amended bituminous may demonstrate higher stability and flow characteristics. These characteristics were not originally intended as performance enhancements in this project, since the unamended bituminous met the required specifications. However, such characteristics have the potential for increased bituminous performance. In addition, the appearance of improved freeze/thaw crack resistance has important implications for increased bituminous performance. This will be further discussed in the Discussion and Conclusions section.

7.0 Discussion and Conclusions

7.1 STRUCTURAL
Most, if not all, of the previous demonstrations of the use of MWC ash in bituminous have promoted ash use by claiming “acceptable” or “adequate” structural performance. However, as identified in this paper, the standard measurements of stability and flow were substantially increased in the Polk County ash-amended bituminous when compared to the unamended bituminous. These increases should improve the longterm durability of bituminous pavements and improve resistance to freeze/thaw cracking. The potential economic benefits of such performance enhancements would be substantial. These potential performance improvements must be further investigated in a more quantitative way. Recall that, in this demonstration, all of the ash-amended bituminous was overlain with a wear course of unamended bituminous. One important recommendation that was made by professors Gene Skok and Mihai Marasteanu of the University of Minnesota is to construct test sections using ash-amended bituminous throughout the pavement column. This would keep the surficial layer (wear course) of unamended bituminous from masking the structural performance of ash-amended performance. Freeze/thaw crack resistance may be further observed in this project as is suspected that subsurface cracking will reflect up through the wear course. However, another important consideration is that having an unamended wear course greatly expedites public and regulatory acceptance.

7.2 CONSTRUCTION
Significant progress was made, and understanding developed, in the construction issues associated with the use of MWC ash in bituminous production. For example, the Thorson bituminous plant operator learned that the bituminous plant used could operate continuously with an ash substitution rate of 10 percent. However, a substitution rate much higher than that (20 percent) caused the air pollution equipment to become over loaded. This limitation is specific to this particular plant, this particular ash, and the particular mode of operation. Other plants, ashes, or modes of operation may allow a higher percentage of ash.

Other construction issues that need to be addressed include the following:

➤ The Polk County MWC ash management system quenches the ash prior to discharge from the combustion unit. This results in the ash being saturated, which prevents generation of fugitive dust emissions. However, since the aggregate must be dried to a very low moisture content (1.5 to 2 percent) in the bituminous production process, a significant amount of energy is required to dry the ash. Polk County attempted to dewater and dry the ash by mechanically working the pile at the landfill. However, this was quite labor intensive and showed minimal results. A more efficient method for drying the ash would improve overall bituminous production efficiency.

➤ Another opportunity to improve bituminous plant production rate may be the method of introducing the ash into the drum drier. In this demonstration the ash was introduced through the aggregate bins at the beginning of the process. The ash and aggregate was then blended and heated in a tumbling process. It is suspected that the tumbling process resulted in the ash particles being mechanically ground up, which generated increased fine particles. In addition, the ash particles have a lower density than the natural
aggregate. Therefore, these lighter, finer ash particles were drawn into the air pollution control system at an increased rate, which required the production rate to be decreased. However, if the ash were introduced through the recycled asphalt pavement (RAP) bin, the amount of fines generated may be reduced, which would increase the production rate. Prior to introduction of the ash through the RAP bin, the moisture content would have to be reduced. Thorson staff were able to improve production rate with increased experience using the MWC ash. Due to the relatively short production runs with each mix, it is difficult to get a clear picture of the production potential of ash-amended bituminous. Producing and placing larger continuous quantities of ash-amended bituminous would provide a better understanding of the potential production rate.

### 7.3 ECONOMICS

The identifiable components associated with the economics of producing and using an ash-amended bituminous were previously identified. These components included dewatering/drying and hauling ash, additional asphaltic cement and fuel, environmental protection, decreased bituminous production rate, longterm and short-term performance of bituminous pavement, the avoidance of use of traditional aggregate, and the avoidance of disposal costs. Table 4 contains a quantification of each of these components.

#### Table 4: Summary of Ash Use Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Additional cost/savings per ton of bituminous</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ash dewatering/drying</td>
<td>$0.22</td>
</tr>
<tr>
<td>2 Hauling</td>
<td>$1.00</td>
</tr>
<tr>
<td>3 Asphaltic cement</td>
<td>$1.60</td>
</tr>
<tr>
<td>4 Drying and heating fuel</td>
<td>$0.23</td>
</tr>
<tr>
<td>5 Environmental protection</td>
<td>$0.61 for baghouse maintenance.</td>
</tr>
<tr>
<td>6 Bituminous production</td>
<td>$4.16 (this is a maximum cost and should be significantly reduced)</td>
</tr>
<tr>
<td>7 Savings from reduced aggregate requirement</td>
<td>$0.30 per ton (assuming an aggregate cost of $3.00 per ton of aggregate).</td>
</tr>
<tr>
<td>8 Savings for longterm performance</td>
<td>Conservatively assume that this ash-amended bituminous will last 10 percent longer than traditional bituminous. This would result in a cost saving of $2.25 per ton (10% of $22.50)</td>
</tr>
<tr>
<td>9 Savings in ash disposal</td>
<td>$2.25 savings (900 tons of ash @ $20 per ton over 8,000 tons of ash-amended bituminous)</td>
</tr>
<tr>
<td><strong>TOTAL ADDITIONAL COST</strong></td>
<td>~ $3.02 per ton of bituminous</td>
</tr>
</tbody>
</table>

As summarized in Table 4, the total cost to produce ash-amended bituminous is about $3 per ton. This is based on the conditions identified. This cost assumes that the use is not a demonstration project and that environmental and regulatory approvals were previously obtained. A typical cost for production and placement of bituminous is about $22.50 per ton. An increased cost of $3 is 13 percent over typical costs. The value of this increased cost must be considered within the overall project social and environmental impacts.

### 7.4 CONCLUSIONS

The conclusions of this paper are as follows:

- The use of municipal solid waste combustor (MWC) ash as a partial replacement for aggregate in the production and use of bituminous paving materials is viable;
- The potential for impact to the environment, with a ten percent replacement rate, is very low (many of the environmental tests that were performed at much higher ash replacement rates also support this conclusion);
- The cost to produce bituminous with 10 percent MWC ash was approximately $3 per ton of bituminous, or an increase of about 13 percent. However, this cost would likely be reduced significantly by process
modifications and by improved bituminous performance;

➢ There is a very distinct possibility that the use of MWC ash results in improved stability, flow and freeze/thaw characteristics;

➢ While ash-amended bituminous was not used in the wear course of the Polk County project, environmental, structural and economic data suggests that this use may also be appropriate;

➢ While the environmental safety of the use of ash-amended bituminous is clear, additional production and placement of ash-amended bituminous is necessary to better quantify, economic, production, and short-term and long-term structural issues;

➢ Prior to the future use of other MWC ashes, preliminary lab-scale environmental testing and confirmation of HMA plant stack emissions will be required.

7.5 RECOMMENDATIONS

This demonstration has allowed the drawing of some very important conclusions, as identified in Section 7.4. However, future demonstrations should be performed to fill in some gaps, as identified below. Recommendations are provided below:

✓ Testing of bituminous strength and crack resistance characteristics should be performed.

✓ Ash amended pavement demonstrations should be constructed full-depth, with ash in the wear course. This will more conclusively identify freeze/thaw crack resistance and overall pavement performance. The environmental testing performed in this Polk County project indicates the environmental acceptability of MWC ash in the wear course.

✓ CSAH 13 in Polk County should be tested and monitored for structural performance.

✓ Future demonstration projects should evaluate the potential for incorporating higher percentages of ash into the bituminous.

✓ Bituminous plant operations should be investigated to identify methods to minimize effects on baghouse fouling. Such methods may include:
  o Removal of ash “fines” before bituminous production, and/or
  o Introducing the ash into the drum closer to the AC to allow the ash fines to be quickly incorporated into the asphaltic matrix,

✓ Investigate opportunities to minimize requirements for pre-drying the ash.
References


v Ibid. pg 54.


xi Wiles, pg. 64.


xiv Personal communication with Dan Boerner, MnDOT, February 25, 2002.

xv Wiles, 1999