U.S. Department of Transportation
Federal Highway Administration

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PROGRAM

Using Life Cycle Assessment (LCA) to Inform the Pavement Treatment Selection Process

FHWA-HIF-23-014

This case study looks at how the FHWA Pavement Life Cycle Assessment Framework could assist with decisions on pavement treatments, using data from two Arizona Department of Transportation projects.

BACKGROUND

The Arizona Department of Transportation (ADOT) was interested in exploring environmental impacts as part of its pavement treatment type selection process. ADOT requested help from the Federal Highway Administration (FHWA) in determining the steps the State would take to implement the FHWA Pavement Life Cycle Assessment (LCA) Framework (FHWA 2016) in selecting between two comparable treatments. These steps used LCA-based metrics, such as life cycle emissions per unit pay-item as well as service life extension and life cycle cost per lane mile.

WHAT WAS DONE?

The process that was developed used LCA to select between Hot-in-Place Repaving (HIPR) and Mill and Fill (M&F) data from two ADOT projects. Project data sources were assessed for their adequacy in conducting pavement LCA and identifying gaps in available data and analysis capability. ADOT helped identify pay items using typical mix designs, material choices, and equipment production rates. In addition, "as built" quantities for the pay items were developed.

The project-specific data collected from ADOT were used to compute the foreground and primary parameters for the LCA model (Bhat, Mukherjee, and Meijer 2021). This information, along with the background/secondary data (discussed in Bhat 2020) was to estimate Global Warming Potential (GWP) and Cumulative Energy Demand (CED) metrics for each of the treatments being considered.

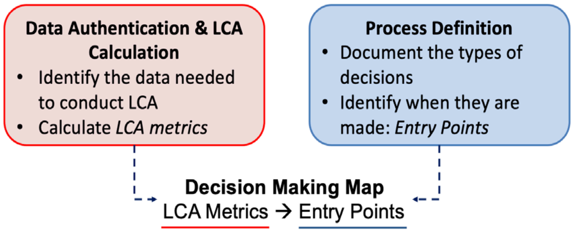

Figure 1: Overview of Research Process for the Case Study

Unless otherwise noted, FHWA is the source of all images and figures.

OVERVIEW

As shown in Figure 1, the approach used for the study involved these steps:

Data Authentication and LCA Calculation:

1. Identify the data needed and collect construction project data from ADOT.
2. Calculate GWP and CED.

Process Definition:

3. Discuss the type of decision that LCA can support for this specific case.
4. Identify points and contexts — referred to as "Entry Points" — at which to include LCA results in decision-making.

Entry Points are the contexts where the calculated LCA metrics are introduced. Entry Points may vary for different decision-making contexts, such as design, procurement, and pavement management. This case study explores the Entry Points within pavement management.

PROJECTS STUDIED

The LCA was conducted using data for two alternatives from real-life projects, designated as H5 and H6.

Project H5 considered the following options:

1. HIPR: cold milled 1 inch in some locations and 1/2 inch in others, prior to paving with a 1-inch depth of HIP; 1 inch of new asphalt concrete (AC), using miscellaneous structural AC PG 76-22TR+ binder, tack coat, and 1/2 inch new asphaltic concrete friction course (ACFC).
2. M&F: a deeper cold mill of 1 inch or 2 inches, a tack coat, and new AC-2 inch, tack coat, and 1/2 inch new ACFC.

Project H6 considered the following options:

1. HIPR: cold mill of 3/4-inch depth prior to paving of 3 inches total, including 1 inch Hot in Place (HIP), 1 1/2-inch new AC using miscellaneous structural AC PG 76-22TR+ binder, tack coat, and 1/2 inch new ACFC.
2. M&F: cold mill of 1 3/4 inch, a tack coat, and new 2 1/2 inches of AC, tack coat and 1/2 inch of new ACFC.

LIFE CYCLE ASSESSMENT

The goal of the LCA was to calculate and analyze the GWP and energy use associated with the HIPR and M&F treatments, including life cycle stages of extraction, production, transportation, and construction. The declared unit to express the metrics was square yard (sq yd) of pavement constructed. Hence, GWP is in kilograms of CO_2 equivalents per square yard (kg of CO_2 Eq./sq yd), and energy is in Megajoule per square yard (MJ/sq yd). Sq yd was chosen as a unit because it was consistent with the pay items for the paving operations being studied. The impact assessment methods used were the U.S. Environmental Protection Agency's (EPA) TRACI 2.1 for GWP and the National Renewable Energy Laboratory (NREL) U.S. Life Cycle Inventory (USLCI) CED method for energy.

Figure 2 and Figure 3 illustrate the system boundaries for the HIPR and M&F processes. The included processes and operations reflected the formal models within OpenLCA, developed for the FHWA Pavement LCA Framework (Bhat et al. 2021).

The scope was limited to the cradle-to-gate life cycle stages, including the following items representing the construction stage.

1. Impacts due to the upstream life cycle stages of extraction, production/manufacturing, and transportation of fuels (diesel and propane), electricity, and materials used.
2. Impacts due to the total weight of new materials used during construction. These items, which are illustrated in Figure 2 and Figure 3, include rejuvenator, asphalt emulsion, and new asphalt mixture.

3. Impacts due to the transportation of new asphalt mixture from production plant to site, and asphalt millings away from the site, including the use of diesel in trucking.
4. Impacts due to construction operations modeled for the milling and asphalt paving operations that are used in both the HIPR and M&F operations. In addition, the HIPR operation is modeled. These items, which are illustrated in Figure 2 and Figure 3, include identifying the equipment used for each and the associated impacts due to the use of diesel and propane.
5. Impacts due to materials such as additives, rejuvenators, and asphalt emulsions. These items are included in the system boundary but are considered as a data gap. This study uses a suitable approximation for these materials.

Excluded from the system boundary are the upstream impacts from production and manufacturing of the construction equipment.

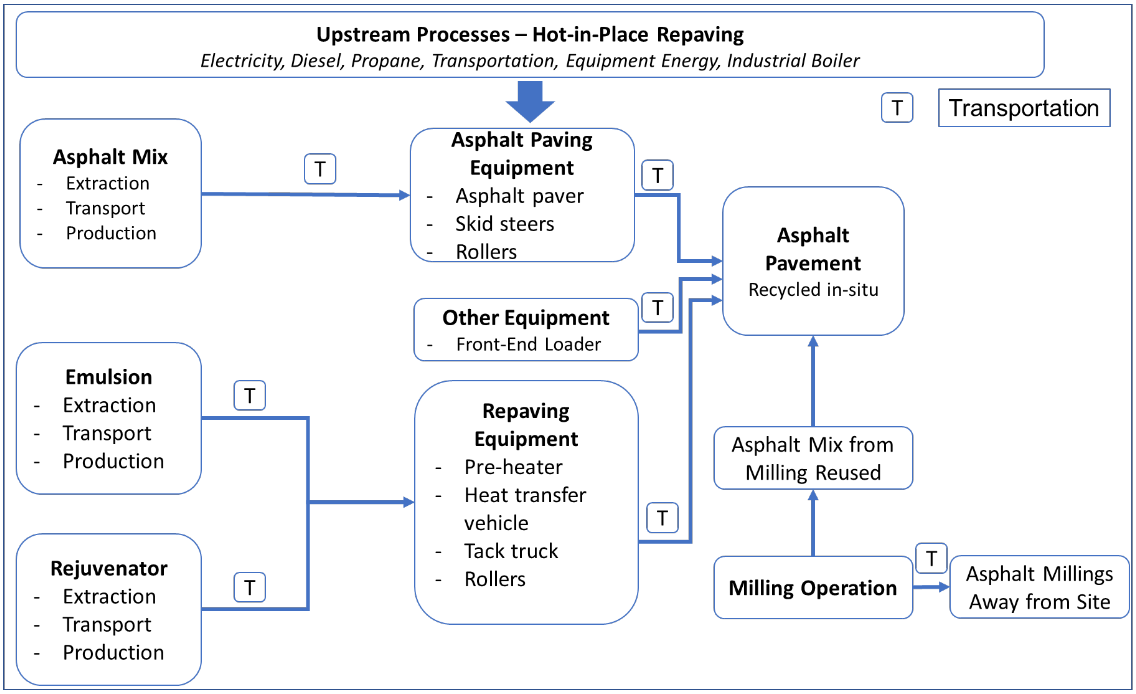

Figure 2. System Boundary for Hot-in-Place Repaving Process

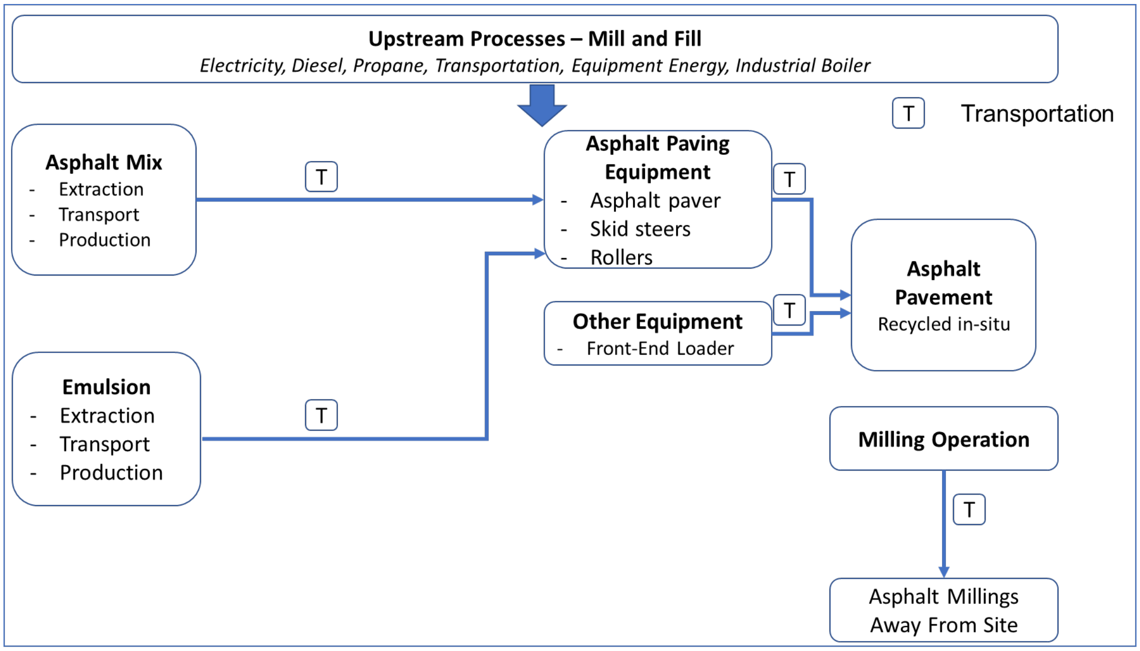

Figure 3. System Boundary for Mill and Fill Process

DATA AUTHENTICATION AND MAPPING

Background data and foreground data were both considered. Background data includes life cycle inventories (LCI) for upstream processes, while foreground data includes the data that was observed directly for the operations being studied. They can be listed as follows.

Background Data: Public upstream LCI developed as part of the FHWA's work with the Federal LCA Commons included the following:

1. NREL's U.S. Life Cycle Inventory (USLCI), using the Federal Elementary Flow List (FEDEFL)
2. Publicly available electricity baseline inventories from the U.S. Department of Energy (from the National Energy Technology Laboratory)
3. Transportation and fuel inventories developed by the EPA, as included in the Federal LCA Commons
4. Impact assessment method, using the FEDEFL conformant TRACI 2.1[1]
5. Inventories developed from publicly available reports and Environmental Product Declarations

All these open source data sets are compatible with a publicly available LCA software, as a result of the FHWA's work with the Federal LCA Commons.

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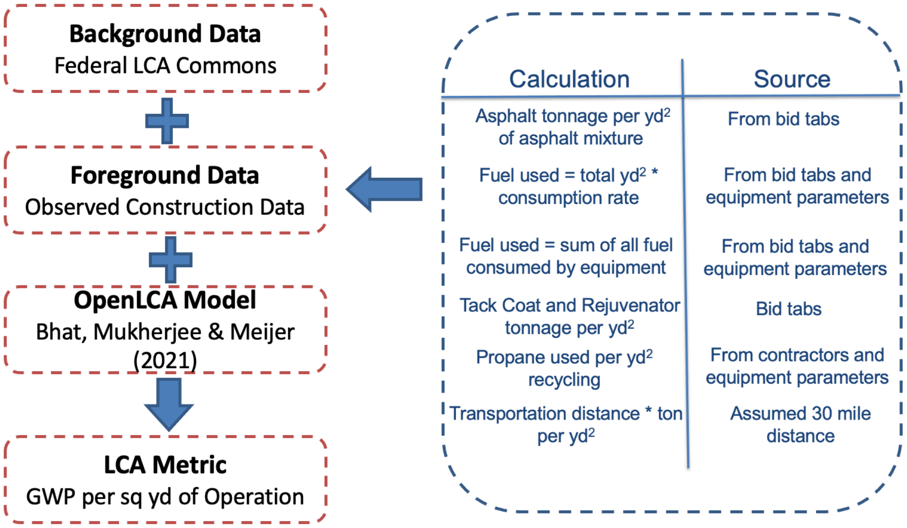
[1] Bare, J. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User's Guide. U.S. EPA Office of Research and Development, Washington, D.C., EPA/600/R-12/554, 2014.



Calculation	Source
Asphalt tonnage per yd^2 of asphalt mixture	From bid tabs
Fuel used = total yd^2 * consumption rate	From bid tabs and equipment parameters
Fuel used = sum of all fuel consumed by equipment	From bid tabs and equipment parameters
Tack Coat and Rejuvenator tonnage per yd^2	Bid tabs
Propane used per yd^2 recycling	From contractors and equipment parameters
Transportation distance * ton per yd^2	Assumed 30 mile distance

Figure 4. The Data Mapping Process

Foreground Data: The items identified in Figure 4 directly relate to the items that were collected from bid tabs, equipment parameters, and information provided by ADOT contractors. These data items map directly onto the underlying LCA model. This data included:

1. Asphalt mixture used, in tonnage, from bid tabs, expressed as tons per square yard (sq yd) of pavement.
2. Rejuvenator used, in tons, from bid tabs, expressed as tons per sq yd of pavement.
3. Tack coat used, in tons, from bid tabs, expressed as tons per sq yd of pavement.
4. Fuel used in equipment such as front-end loader, skid steer, rollers, asphalt pavers, and tack trucks. Fuel use is estimated based on typical equipment fuel consumption rates (gallons of diesel per hour) and production rates (sq yd per hour), expressed as gallons per sq yd of pavement.
5. Energy use during scarification by the repaving machine units was provided by the ADOT contractor and estimated at British thermal units (BTU) of energy consumed per hour and a production rate of sq yd per hour, expressed as liters of propane per sq yd of pavement.
6. Asphalt mixture produced at the plant and transported to the plant were hauled in from the same distance for both projects. The milled asphalt pavement was assumed to be hauled out 30 miles, expressed as ton-mile per sq yd.

The asphalt mixture inventory available from the asphalt mixture Environmental Product Declaration program for North America was used for asphalt concrete for paving as well as for the asphalt in the asphaltic concrete friction course (NAPA 2021). The primary data gap in this analysis was due to lack of publicly available upstream data for the rejuvenators and emulsion used for tack coats. A data set was developed as a proxy using the asphalt mixture inventory.

LCA OUTCOMES

The calculated metrics for the HIPR and M&F for projects H5 and H6 are provided below. While the metrics per sq yd were calculated based on the total tonnage of material used per sq yd, the conversion to per lane mile (ln-mile) was based on the assumption of a 12 ft wide lane that is 1 mile long. Hence, the conversion used is 7,040 sq yd in 1 ln-mile. This equivalent unit was included because even though the pay item for construction is in square yards, the Pavement Management System units for decision-making are typically per lane miles.

Project H5 with a total of 138,235 sq yd:

- HIPR: 7.55 kg of CO_2 per sq yd (53,147.85 kg of CO_2 per ln-mile), 242.42 (MJ) per sq yd
- M&F: 9.29 kg of CO_2 per sq yd (65,413.92 kg of CO_2 per ln-mile), 359.68 (MJ) per sq yd

Project H6 with a total of 183,675 sq yd:

- HIPR: 8.47 kg of CO_2 per sq yd (60,902.55 kg of CO_2 per ln-mile), 282.87 (MJ) per sq yd
- M&F: 9.61 kg of CO_2 per sq yd (72,411.61 kg of CO_2 per ln-mile), 390.43 (MJ) per sq yd

Figure 5 illustrates the breakdown of GWP and energy metrics for projects H5 and H6 by the operational categories of ***materials, construction operation, and transportation in and out***.

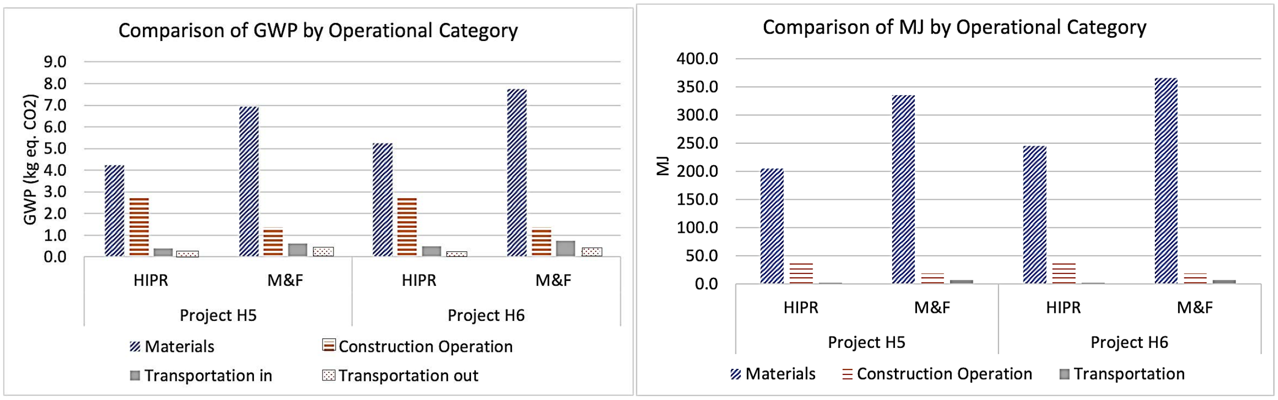


Figure 5: Breakdown of GWP and Energy Metrics (per sq yd) by Operational Categories

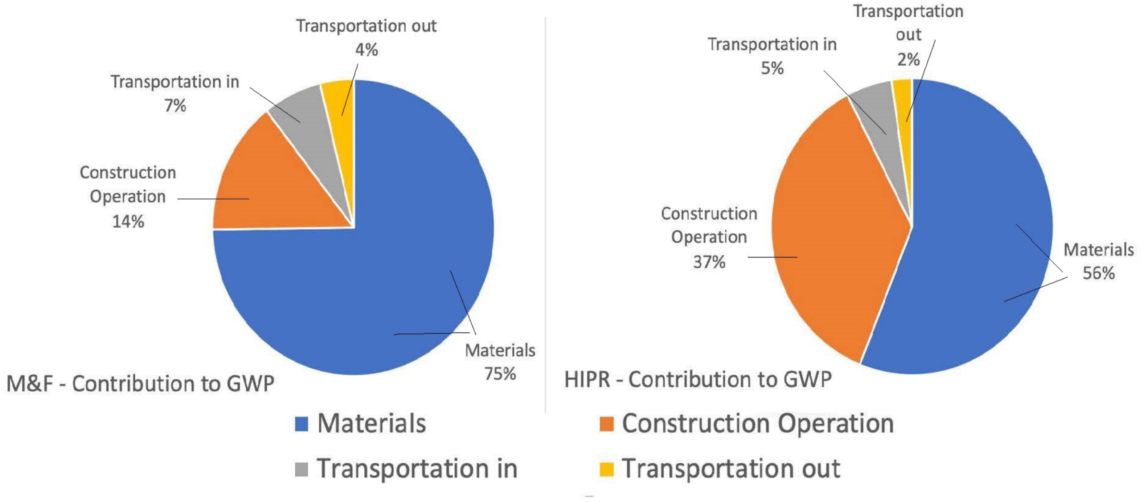


Figure 6: Breakdown of GWP for M&F and HIPR for Project H5

The analysis indicated that the M&F operation has a higher impact for both energy and GWP. From this study, the following could be concluded by the researchers:

1. While the construction operations for HIPR have a higher impact than M&F, likely due to the energy intensive processes of heating and scarifying the existing pavement, overall the increased tonnage of new asphalt mixture used in the M&F operation makes it a more energy intensive operation with a higher GWP.
2. Transportation of the asphalt millings away from site in the M&F operation has a slightly higher impact than in HIPR, but it is not a driving factor in determining overall impact.
3. Though the operation that recycles the pavement in situ uses a more energy intensive process, it has an overall lower environmental impact than an operation that uses new asphalt mixture.
4. The impact of the new material is significantly higher than the energy used in heating and scarifying the existing pavement, which highlights the benefit of recycling the pavement.

Limitations of this study are the data gap associated with the use of rejuvenators and emulsion, and absence of upstream impacts from the production and manufacturing of the construction equipment.

The results are specific to this case study and should not be generalized.

PROCESS DEFINITION

The next question is how a decision-maker can use the LCA metrics and outcomes when selecting between comparable operations.

The organizational question identifies the specific context in the decision-making process where the LCA information is introduced. Figure 7 was developed in collaboration with ADOT and identifies three distinct decision points in the pavement management process.

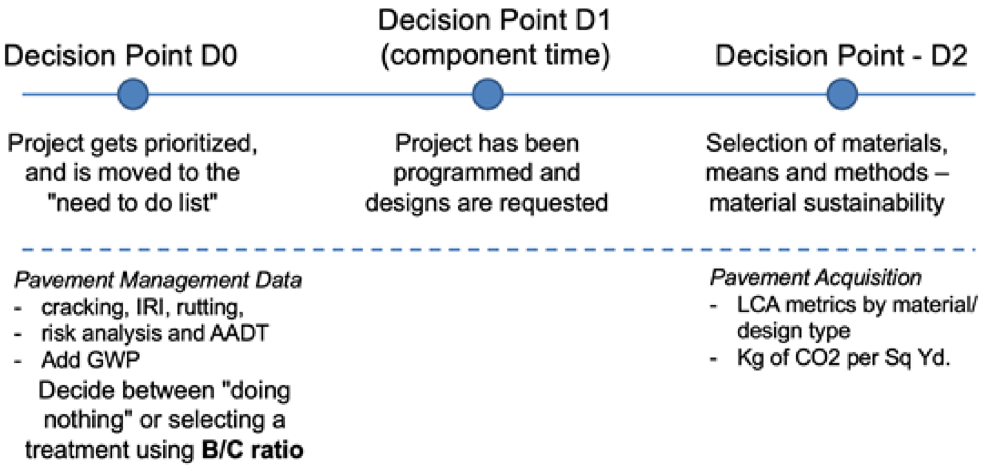


Figure 7: Relevant Decision Contexts in Pavement Management

Decision Point D0 initiates the process from when a project is nominated for pavement preservation treatment. Pavement management data describe the condition of the pavement, as well as the trajectory that the pavement is likely to take based on pavement degradation models. Benefit/Cost (B/C) ratio-informed calculations are used to consider alternative treatments or to justify a do-nothing option. As with cost, GWP can be used either as an additional variable in the B/C calculations or considered in conjunction with B/C when selecting between alternative treatments.

A firm intervention selection is made in the next decision context, D1. The third decision context under consideration, identified as D2, leads directly into the pavement acquisition phase, bordering on project procurement. It allows the engineer to focus on specific choices of materials and construction practices that can reduce the GWP and energy intensity of the project. An example could be to select an asphalt mixture design that uses more reclaimed asphalt pavement (RAP) and is procured from a plant within a limited mile radius. As observed from this case study, in an M&F operation where a significant majority of the environmental impact is from the newly produced asphalt mixture, such an approach can reduce the impact of the intervention.

The technical question of interest to this study is at the D0 point: What process should be used to identify a long-term benefit in selecting between two alternative treatments, given the difference in environmental impact between the two?

This study used the service life extension (SLE) associated with each comparable treatment. In this case, the SLE for the HIPR and M&F interventions are as follows:

- HIPR: SLE of 10 years when the intervention is at 15 years, and for an additional 8 years when the intervention is at 25 years
- M&F: SLE of 10 years when the intervention is at 15 years, and for an additional 8 years when the intervention is at 25 years

A selection decision between the two interventions can be made by weighing in balance the B/C ratio, the SLE, and the GWP associated with HIPR and M&F operations. The net GWP per year of SLE for H5 at the end of 15 years are:

- HIPR is (7.55 kg of CO_2 Eq.)/(10 years) = 0.755 kg of CO_2 Eq./year of SLE
- M&F is (9.29 kg of CO_2 Eq.)/(10 years) = 0.929 kg of CO_2 Eq./year of SLE

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The net GWP per years of SLE for H5 at the end of 25 years are:

- HIPR is (7.55 kg of CO_2 Eq.)/(8 years) = 0.944 kg of CO_2 Eq./year of SLE
- M&F is (9.29 kg of CO_2 Eq.)/(8 years) = 1.161 kg of CO_2 Eq./year of SLE

Similarly, for H6, the net GWP per years of SLE for H5 at the end of 15 years are:

- HIPR is (8.47 kg of CO_2 Eq.)/(10 years) = 0.847 kg of CO_2 Eq./year of SLE
- M&F is (9.61kg of CO_2 Eq.)/(10 years) = 0.961 kg of CO_2 Eq./year of SLE

The net GWP per years of SLE for H5 at the end of 25 years are:

- HIPR is (8.47 kg of CO2 Eq.)/(8 years) = 1.059 kg of CO2 Eq./year of SLE
- M&F is (9.61 kg of CO2 Eq.)/(8 years) = 1.201 kg of CO2 Eq./year of SLE

A selection decision can be made when considering the above metrics in conjunction with the B/C ratio and context-specific priorities for each. In this case, the SLE offered by each treatment is the same. However, in all cases, the context of the projects should be accounted for when making a decision. In addition:

- Consider multiple aspects such as cost, service expectations, and environmental impacts while analyzing the relative suitability of the alternative treatments within the context of the entire pavement life cycle.
- Learn from the insights of the study and generalize with caution. For example, it would be inappropriate to conclude that an HIPR treatment is always a better choice than an M&F treatment. Instead, select treatments that overall emphasize in-situ recycling and reduce the use of new asphalt mixture and find ways to reduce the energy intensiveness of in-situ processes.

In this discussion, traffic was not considered because the growth in Average Annual Daily Traffic (AADT) and Vehicle Operating Costs (VOC) were considered separately in the B/C calculation. In addition, for asset managers, the impacts discussed in this study can provide insights for reducing an agency's environmental impacts from maintenance and rehabilitation operations.

SUMMARY

This study outlined the process to generate LCA based metrics for two comparable ADOT removal and replacement pavement preservation treatment operations. That process was to:

1. Develop a representative foreground data set for the construction operations included in a maintenance/rehabilitation intervention using project data acquired from drawings, equipment data and bid tabs to estimate quantities of material used and fuel used in construction activities. Express all material and energy flows using a unit that is in line with the project pay item.
2. Develop a complete cradle-to-gate life cycle inventory for the project under consideration in open source LCA tool using the FHWA background data sets and the process models. Identify data gaps as necessary.
3. Report GWP and energy metrics by conducting an LCA using the FEDEFL compatible TRACI 2.1 and NREL USLCI's CED impact assessment methods. Analyze the LCA metrics of GWP and energy in sub-categories of materials, construction operations and transportation to develop deeper insights into factors driving the GWP and energy impacts.

ADOT indicated the study was helpful and plans to pursue an in-depth examination through a transportation pooled fund project.

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CONTACT

Federal Highway Administration (FHWA)
Office of Preconstruction, Construction, and Pavements, Migdalia Carrion
(Migdalia.Carrion@dot.gov)

RESEARCHER

This case study was developed by Amlan Mukherjee, PhD, PE, Professor at Michigan Tech, his students Chaitanya Bhat, (Graduate Research Assistant), Erik Oshaben (Undergraduate Research Scholar), and Joep Meijer of the Right Environment, under FHWA's Technical Support for the Infrastructure Analysis and Construction Team Program (FHWA-DTFH61-17-D-00005). ESCINC served as the contractor to FHWA.

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KEY WORDS

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