Sustainable Pavements

U.S. road transportation accounts for 83% of greenhouse gas (GHG) emissions from the transportation sector and 27% of all GHG emissions in the U.S. The road system requires 350 million tons of materials annually for maintenance. It gets a grade of D from the American Society of Civil Engineers, which reports that congested highways cost roughly $101 billion in wasted time and fuel annually.

For the foreseeable future, U.S. infrastructure funding will remain significantly below what is required to improve conditions and performance. Because of the environmental impact of pavements and the economic challenge of building and maintaining them, there is a growing need to better quantify performance and cost over pavements’ entire life cycle.

To meet that need, the MIT Concrete Sustainability Hub (CSHub) is developing tools and data for decision makers to evaluate pavement designs and make choices that are both cost-effective and environmentally responsible. The CSHub’s results are peer-reviewed.

PAVEMENT-VEHICLE INTERACTION (PVI)

The CSHub has quantified excess fuel consumption due to PVI—primarily associated with road stiffness and roughness—and has demonstrated that the environmental impacts are significant for pavements over time. As roads age, the impact of PVI on GHG emissions worsens. PVI is thus essential to the analysis of the lifetime environmental impacts of road projects.

- The CSHub’s models shed light on the key drivers of PVI. The models have been used to predict that stiffer pavements could reduce fuel consumption up to 3 percent for the U.S. road network—a savings that could add up to 273 million barrels of crude oil per year. This would result in an accompanying annual decrease in GHG emissions of 46.5 million metric tons.

- The CSHub found that flexible pavement designs must be 25% to 60% thicker to achieve the fuel consumption savings associated with the stiffness of rigid pavements.

- PVI also includes the impact of pavement roughness on fuel consumption. A sample CSHub case study showed a significant impact on fuel consumption due to roughness—an increase of 30,000 gallons of fuel per mile over a 14-year test period.

Numerous outside experimental studies have demonstrated that there is additional fuel consumption due to PVI.

- One of the most recent studies focused on pavement stiffness was conducted by Florida International University.

- The University of California Pavement Research Center is leading a new collaborative effort to review existing models of PVI related to pavement stiffness, including MIT’s.
• MIT is collaborating with several departments of transportation in the U.S. to evaluate environmental impacts due to PVI at the pavement network level.

TOOLS FOR SMARTER PAVEMENT DESIGN, CONSTRUCTION & MAINTENANCE

Researchers are examining the cost and environmental impacts for the full life of pavements. They have created life-cycle assessment (LCA) and life-cycle cost analysis (LCCA) tools that thoroughly account for the use and maintenance phase of pavements—not just the costs and GHG emissions that occur at initial construction. The ultimate goal is to create tools that will be embedded in the pavement design process.

• The CSHub evaluates different types of pavement designs under various contexts (climate and traffic levels) and framing conditions (design life, rehabilitation schedule, and analysis period).

• Researchers developed a comprehensive methodology outlining the best-practice concepts for any pavement LCA or LCCA, including accounting for uncertainty in the data used in the analyses. When properly designed, the inputs to both LCA and LCCA models can be taken directly from Pavement-ME—the current standard of pavement design software.

• The scope in the LCAs includes the maintenance and use phases, including factors such as excess fuel consumption due to PVI. Analyses of a range of scenarios showed that the contribution of the use phase to the life-cycle GHG emissions of a pavement ranges from 25% to nearly 60%. Higher traffic volumes generally lead to higher use-phase impacts. More specifically, the degree to which PVI contributes to the use phase depends upon both traffic volume and climate.

• The LCCA accounts for uncertainty in initial costs, future price projections, and the timing of maintenance activities. Analyses of a range of scenarios indicate that a life-cycle perspective is important when making pavement design decisions and that the uncertainty in initial cost is the largest driver of uncertainty in overall LCCA results. Better understanding of the variation in initial cost could significantly improve pavement decision-making.

• Scenario analyses also showed that the cost of maintenance and rehabilitation (even when discounted into today’s value) represented as much as 45% of the life-cycle cost of a pavement. Thus, ignoring life-cycle costs such as M&R can lead to unwise long-term spending.

IMPROVING CONCRETE PAVEMENTS

CSHub researchers developed a cost-effective analysis to determine whether or not a given environmental reduction strategy made economic sense for concrete pavements. Among the strategies evaluated, two significantly reduced embodied energy: increased fly ash and optimized design. They were found to decrease GHG emissions by approximately 10% and 17%, respectively, while also lowering initial construction costs.