LIFE CYCLE ANALYSIS USING FHWA'S CONSTRUCTION AND MAINTENANCE GREENHOUSE GAS EMISSIONS ESTIMATOR

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ABSTRACT

Greenhouse gas (GHG) emissions from construction and maintenance of transportation infrastructure are an often-overlooked component of the overall carbon footprint from transportation. Construction materials, construction equipment, and ongoing maintenance all contribute to the GHG emissions load from the transportation system. This paper introduces a new FHWA tool to estimate life cycle GHG emissions and energy consumption from highway and transit construction and maintenance activities. This tool can be used by Metropolitan Planning Organizations (MPOs) and state Departments of Transportation (DOTs) to develop simplified estimates of GHG emissions from implementing long-range transportation plans. It could also be used to compare overall GHG emissions from projects being evaluated in an environmental impact statement, or to estimate the construction emissions consequences of strategies being proposed as part of a climate action plan. The paper also provides two example applications of the tool to assess life cycle construction and maintenance emissions from hypothetical transportation projects. The first example is a hypothetical port access project, with roadway improvements and truck parking. The second example is a hypothetical truck climbing lane. While the tool can be used either at the planning or project scale, project-level examples are used in this paper as a means of providing simple illustrations of the tool's capabilities. In both cases, the tool is used to estimate life cycle construction and maintenance emissions, and EPA's Motor Vehicle Emissions Simulator (*MOVES*) model is used to estimate changes in operational emissions due to the projects.

INTRODUCTION

Several tools are available to calculate transportation construction and maintenance greenhouse gas (GHG) emissions, but they are generally designed for use when the details related to construction activity are already known. For example, the *GreenDOT* model developed under National Cooperative Highway Research Program (NCHRP) 25-25/Task 58 requires very detailed inputs related to construction of individual projects *(1)*. The Sacramento Air Quality Management District Roadway Construction

Emissions Model *(2)* is another potential tool, but even this model requires inputs unlikely to be available at the planning level, including acres of land disturbed and cubic yards of soil moved for each project. The New York State Department of Transportation (NYSDOT) uses energy factors in its GHG analysis procedures that were developed by the US Department of Energy in the 1990s. These factors are expressed in terms of energy and emissions per lane mile of construction, which provides emissions factors in units that planners can work with, but the underlying data are very old. The introduction to the *Final Report and Users Guide* for the project describes its relationship to other similar tools in more detail.

Current research by the Federal Highway Administration (FHWA) has produced a similar, updated set of factors, based on the most up-to-date information on GHG emissions and energy consumption. The emissions factors have been incorporated into a spreadsheet tool requiring inputs that transportation planners have readily available (lane-miles of new roadway construction, track-miles of new rail transit, miles of new bike path, etc.). This tool also has capabilities not found in its predecessors, including greater differentiation among road and transit facility types, impact of geography and climate on emissions, adjustments for work zone delay and pavement smoothness, and GHG benefits of alternative construction and maintenance techniques. FHWA envisions the following potential contexts for use of this tool:

Regional transportation planning: Many MPOs now conduct GHG emissions analysis as part of the development of long-range transportation plans. However, with the exception of New York, most MPOs do not account for the construction and maintenance emissions associated with new and expanded roadways, transit projects, or bicycle networks. This tool will enable MPOs to account for these emissions and evaluate the overall carbon impact of a proposed transportation plan.

State climate action plans: Many of the roughly 40 state climate action plans include new infrastructure (typically, transit and bike/pedestrian facilities) to help reduce transportation GHG emissions. However, none of the plans that FHWA has reviewed account for the emissions from constructing and maintaining this infrastructure. This tool will allow climate planners to evaluate the construction and maintenance burdens of new infrastructure proposed for GHG reduction purposes, to calculate the “payback” periods from these projects (when the operational improvements or VMT reductions will be sufficient to offset the construction emissions associated with achieving them), and to improve the likelihood that projects will provide a net reduction in emissions by the target year in the climate plan.

Analysis of the benefits of alternative construction/maintenance techniques: There is widespread interest in the emissions/energy reduction potential of alternative construction materials and techniques that reduce GHG emissions compared to “standard” practice. These include use of warm mix asphalt, recycling strategies (including in-place recycling and full-depth reclamation), reuse of old pavements as road base, biofuels in construction equipment, hybridization of construction equipment and vehicles, etc. This tool will enable planners to quantify the benefits of these strategies at a statewide or regional scale.

National Environmental Policy Act (NEPA) analysis: Some states require analysis of construction and maintenance GHG emissions and energy consumption for the alternatives evaluated in a NEPA document (e.g., an environmental impact statement), and NEPA GHG analysis may be required more broadly under pending Council on Environmental Quality guidance *(3)*. This tool will provide an easy way to estimate these emissions; it could also potentially be used for evaluating the effectiveness of alternative construction and maintenance techniques being considered for mitigation.

CONCEPTUAL DESIGN

Figure 1 illustrates the scope of emissions-producing activities covered by the tool. The tool generates simplified, pavement neutral estimates of energy and emissions for construction and maintenance of infrastructure, and also quantifies the energy and emissions benefits of using alternative construction materials and techniques. It will not estimate energy and emissions for vehicles using the roadway network; these estimates can be generated separately, as they are now, using travel demand models and EPA's Motor Vehicle Emissions Simulator (*MOVES*) model *(4)*. However, the model will generate simple estimates of energy consumption and emissions from 1) traffic delay during construction, and 2) reduced energy use attributable to smoother pavements (as deteriorating pavements are rehabilitated, the resulting improvement in pavement smoothness has benefits for vehicle fuel efficiency).

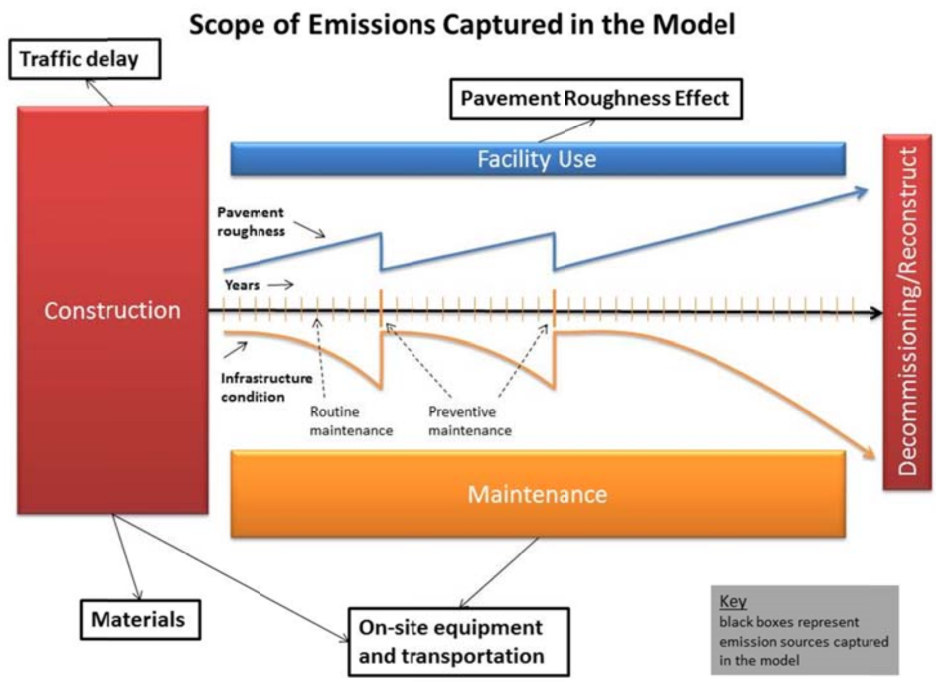

Figure 1: Conceptual model.

ACTIVITY TYPES AND DATA SOURCES

The tool provides estimates for the following types of transportation infrastructure and related activities:

1. New roadway construction, roadway widening, resurfacing and reconstructing pavements, on multiple roadway functional classes (e.g., interstates, arterials, collectors)
2. Bridge construction, reconstruction, and widening
3. Light and heavy rail transit construction, including stations
4. Bus rapid transit construction
5. Bicycle and pedestrian facility construction
6. Maintenance of highway and transit infrastructure, and
7. Use of alternative construction and maintenance techniques

FHWA and its contractor, ICF, conducted a thorough literature search to identify the most recent data on emissions and energy consumption from construction and maintenance activities. We were assisted by an expert panel made up of practitioners from FHWA, the Federal Transit Administration, state DOTs and MPOs. For roadways and bridges, we are relying on data from Oman Company's BidTabs database (detailed contracting data for over 14,000 highway projects in the last five years), along with materials data from the Highway Economic Requirements System (HERS) model developed for FHWA by Battelle, Inc. *(5)*. In response to concerns that the estimator would be inappropriately used to inform pavement selection decisions, the HERS and Batelle data were aggregated across pavement categories to produce "pavement neutral" estimates of material inputs. Fuel consumption data come from the recently updated NCHRP Fuel Factors study *(6)*, which provides information on the amount of fuel consumed during various activities associated with roadway construction. Finally, energy and CO_2 emissions estimates are generated using data from EPA and from the NCHRP *GreenDOT* model.

For transit, the primary source of data is Mikhail Chester's *Life-Cycle Environmental Inventory of Passenger Transportation in the United States (7)*, which is based on well-researched estimates of the materials and inputs used to construct various types of transit infrastructure. Estimates for some types of transit, including bus rapid transit and bike lanes, are derived from the information for roadway projects, because of the similarities between the two. Estimates for underground and elevated rail transit infrastructure have been developed through engineering analysis by the ICF contracting team.

Finally, the tool has the capability to evaluate the environmental and energy benefits of preservation strategies and/or "fix it first" policies. Roads, bridges and transit infrastructure that are kept in a state of good repair under a robust asset management program require less energy to maintain and less frequent reconstruction. Roadway maintenance fuel usage estimates, along with weather-related adjustment factors, are based on maintenance records obtained from state DOTs. Transit maintenance estimates are based on data from the National Transit Database *(8)* and the Los Angeles County Metropolitan Transportation Authority, along with data developed for roadways for those modes that are similar to roadway infrastructure.

In addition to the ability to analyze specific project examples, the tool also uses adjustment factors ("toggles") to account for external factors that might affect activity or emissions across multiple categories of transportation infrastructure. Examples of these include adjustments for rolling or mountainous terrain, addition of sidewalks, and lane widening. The tool includes an estimate of operational energy savings related to improved pavement surfaces from construction projects. Smoother pavements on reconstructed and resurfaced roadways improve the fuel economy of vehicles travelling on those roadways. The user supplies average daily traffic counts in the project area to estimate total fuel savings related to smoother surfaces. The initial version of the tool only estimates emissions of carbon dioxide, and not other GHGs, due to the limited availability of data for emissions of other GHGs.

With respect to data quality and uncertainties, the data sources and their limitations are more fully described in the Final Report and User s Guide for the tool. The ICF team estimates, based on anecdotal experience that the quantities of materials and fuels used in resurfacing projects can vary by approximately 15% above or below the estimates developed for this research product. More intensive projects, such as reconstruction, lane addition, or new construction, likely have wider ranges of requirements – as much as 40% above or below average quantities. Also, it is important to note that this is a planning-level tool intended for comparing different alternatives of a transportation plan network, or comparing project alternatives in an environmental document. For many types of project comparisons (e.g., different alignments of a new roadway), uncertainties would be likely to affect all scenarios in the same way. In a 20-year transportation planning context, uncertainties about funding levels and regional economic growth (and thus, land use and the infrastructure that will be needed to serve that land use) probably introduce an equivalent or greater amount of uncertainty.

STRUCTURE OF THE TOOL

The spreadsheet-based tool consists of three modules:
1. Roadway
2. Rail, bus, bicycle, and pedestrian
3. Bridge

Each module consists of three elements:
1. User-entered **inputs** that describe the amount of existing and new facilities. For ease of use, the tool has a single inputs page in which users enter inputs for new construction, maintenance of existing infrastructure, and parameters to calculate construction delay. The input tables specify the units for which the user must enter data (e.g., lane-miles or right-of-way (centerline) miles of roadway, track-miles of rail, number of parking spaces, etc.). A separate inputs page allows the user to specify GHG mitigation strategies.
2. **Factors** that describe the amount of materials, fuel, and electricity used per year to construct and maintain new facilities on a per-unit basis. Each module has a separate factors page, and for the most part no inputs are needed with respect to these factors. (Factor tabs are currently hidden, but can be unhidden by the user.)
3. **Results** that summarize total annual materials/fuel/electricity use, energy use, and GHG emissions. The tool presents both unmitigated energy use and GHG results that do not account for energy/GHG reduction strategies and mitigated results that do account for these strategies. Each module has a separate results page that summarizes total results and results by project type, and the summary results tab shows results across all three modules.

EXAMPLE APPLICATIONS OF THE TOOL

The remainder of this paper provides two freight-related example applications of the tool. The first example is a hypothetical port access project, with roadway improvements and truck parking. The second example is a hypothetical truck climbing lane. While the tool can be used either at the planning or project scale, project-level examples are used in this paper as a means of providing simple illustrations of the tool's capabilities. In both cases, the tool is used to estimate construction and maintenance emissions, and EPA's *MOVES* model is used to estimate changes in operational emissions due to the projects.

Example #1: Hypothetical Port Access Project

This project would improve truck access to a small, recently expanded port. The existing access route is not direct, and requires 500 trucks per day to travel through a community. A more direct roadway access from the Interstate highway to the port exists, but cannot be used by trucks because of weight limits on structurally deficient bridges. In addition, trucks waiting to pick up or drop off freight currently wait (and idle) along the shoulder of the existing street access, due to a lack of parking at the port facility itself. The existing access route is illustrated in Figure 2.

Figure 2: Existing conditions (No Build).

The proposed project would create a new truck access route by widening the existing southern access roadway, and rebuilding two bridges. The project would also create 100 spaces of truck parking. This would require relocation and extension of the final half-mile of the rail access line (see Figure 3).

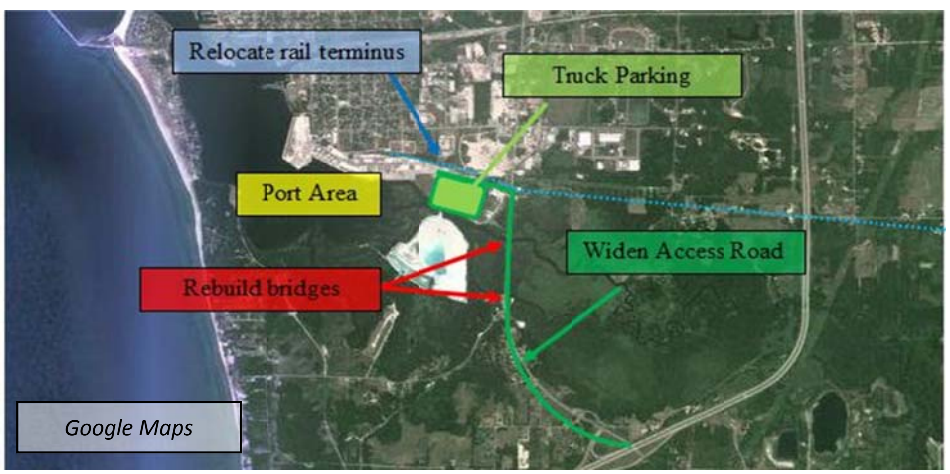

Figure 3: Proposed project.

In this example, FHWA's spreadsheet tool was used to estimate the roadway, bridge and rail construction emissions, and maintenance emissions; *MOVES* was used to estimate the reductions in operational emissions on the shorter access route, and was also used to account for a reduction in idle emissions (since trucks can park and wait, instead of having to creep along the shoulder).

<u>*MOVES* Analysis</u>

*MOVES*2010b was used at the Project scale to estimate CO_2 emissions for the Build and No Build roadway networks. Fifty combination long-haul trucks per hour are assumed to use the roadway links; 100 trucks per hour are assumed to use the parking area, with 50% of these (50 trucks) starting their engine and leaving during the hour. Annual average meteorology and national default fuel inputs were used. The project has a nominal design lifetime of 20 years and will open to traffic in 2020; to estimate average emissions over that 20-year period, each scenario was modeled for 2020 and 2040, and the results averaged. (Since *MOVES*2010b does not include the most recent GHG emissions standards applicable to heavy-duty trucks, adjusted Fuel Type and Technology inputs were used to simulate the effect of these standards.) The truck volume is assumed to be constant at 50 trucks per hour over the life of the project (for 10 operating hours per day) due to capacity constraints at the port.

Table 1 provides the results of the *MOVES* runs:

Table 1: *MOVES* Results for Example 1

	2020	**2040**	**Annual Average**
No Action CO_2 (tonnes)	5063	4764	4913
Build CO_2 (tonnes)	746	702	723

<u>Construction and Maintenance Analysis</u>
The construction and maintenance spreadsheet tool was used twice. The existing roadway and port rail facility were entered in the Roadway Maintenance section of the spreadsheet's Roadway module to estimate annual maintenance emissions of the existing system. Then, the additional roadway lanes and rail track, along with the truck parking lot, were entered to estimate the construction emissions of the new infrastructure, along with the maintenance emissions of the existing and new infrastructure. As mentioned above, the tool can also estimate the benefits of various construction and maintenance-related mitigation strategies. The Build scenario was analyzed with and without all possible mitigation strategies. Because the project does not involve any significant resurfacing of pavements, the pavement smoothness calculations were not conducted; also, due to the relatively small scale of the project and the currently low volumes on the roadway being widened, construction delay was not calculated.

Figure 4 presents a screenshot of the results. In the No Build scenario, maintenance of 28 lane miles of roadway and 1 mile of heavy rail generates 56 metric tons of CO_2 emissions per year. In the Build scenario, the construction emissions, annualized over the 20 year life of the project, amount to 165 metric tons of CO_2 per year; maintenance emissions increase to 58 metric tons per year (due to the additional roadway and rail infrastructure). The net difference between the two project scenarios is 167 metric tons of CO_2 per year. Use of all possible mitigation strategies in the Build scenario reduces the construction-related emissions by 38 tons, or approximately 23%; maintenance-related emissions are also reduced by 25 tons, or 43%

With information on construction and maintenance emissions, one can calculate the payback period of the proposed project in terms of CO_2 reductions (the point in time at which the accumulated operational emissions reductions are sufficient to offset the construction and maintenance emissions required to achieve those reductions). The total unmitigated construction and maintenance impact of the project is 167 tons per year, times 20 years, or 3,340 tons. However, the project reduces truck operational emissions by 4,190 tons per year. Thus, it would only take 10 months of operational energy savings to offset the entire construction and maintenance impact of the project.

	Annual GHG emissions (MT CO2e), per year over 20 years							
	Unmitigated				Mitigated			
	Roadways	Bridges	Rail, bus, bicycle, ped.	Total	Roadways	Bridges	Rail, bus, bicycle, ped.	Total
Materials	55	6	35	**96**	39	6	35	**80**
Construction	39	3	27	**69**	25	2	20	**47**
Maintenance	53	0	5	**58**	29	0	4	**33**
Total	**147**	**9**	**67**	**223**	**93**	**8**	**59**	**160**

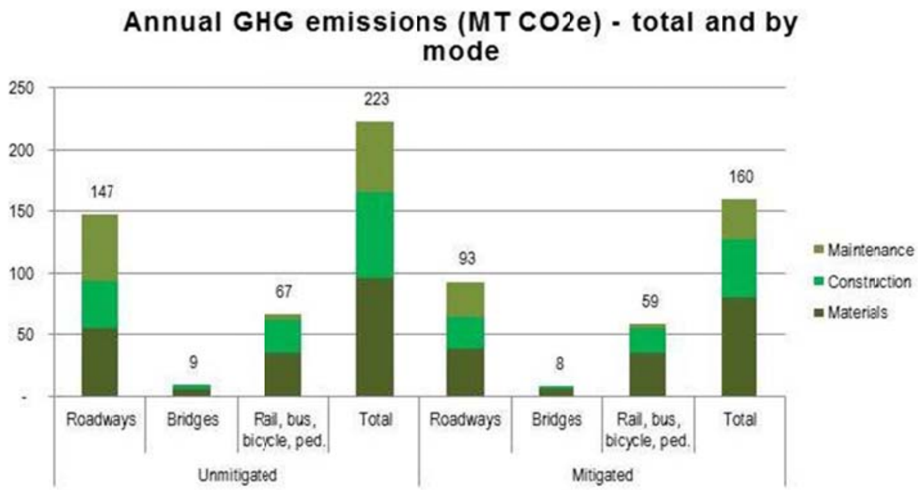

Figure 4: Spreadsheet tool tabular and graphical outputs.

Example Project #2: Hypothetical Truck Climbing Lane

This project would construct a truck climbing lane on westbound I-70 near Denver (Figure 5). Westbound I-70 has three lanes for the length of the project area. Most vehicles travel at or near the speed limit of 65 mph, but trucks in the far right line often travel as slowly as 5 mph. This creates occasional congestion and accidents as vehicles attempt to pass trucks, or attempt to pass slower vehicles passing trucks. (This is a strictly hypothetical project to provide another example of construction/operations emissions tradeoffs; to our knowledge, the Colorado Department of Transportation is not planning such a project.

Figure 5: Hypothetical truck climbing lane project.

For the *MOVES* portion of the analysis, capacity/speed relationships developed by the Texas Transportation Institute were used along with estimated 2020 and 2040 traffic volumes to estimate the congestion benefit of adding an extra lane of capacity. Travel speeds for vehicles other than trucks are estimated to increase by 13 mph in 2020 and 24 mph in 2040 if the truck lane is constructed; because of the 6% grade, speeds for single-unit and combination trucks are expected to average 40 mph in either scenario. *MOVES* was again run at the Project scale, with links representing the truck climbing lane (with single-unit and combination trucks) and the general purpose lanes (with all other vehicles). Annual and national average inputs were used; the 6% grade was included in the inputs. The No Build scenario is expected to generate 136,164 tons per year of CO_2 emissions, on average between 2020 and 2040; the Build scenario was estimated to generate 135,839 tons per year, a difference of 325 tons (a very slight reduction).

As with the port example above, the construction and maintenance spreadsheet tool was used to estimate construction emissions and the change in maintenance emissions. In the example, the construction activity consists of four lane-miles of highway widening, one widened bridge and one reconstructed bridge. The primary difference in inputs is that the selection for construction in mountainous terrain was used. The No Build scenario generates 39 tons per year of maintenance-related CO_2 emissions; the Build scenario results in 126 tons per year of combined construction and maintenance emissions (with the construction emissions annualized over 20 years, as before).

Again, the payback period of the proposed project in terms of CO_2 reductions can be calculated using the *MOVES* results and the estimates of construction and maintenance emissions. The total construction and maintenance impact of the project is 87 tons per year, times 20 years, or 1,740 tons; the project reduces operational emissions by 325 tons per year. Thus, it would take over 5 years of operational energy savings to offset the entire construction and maintenance impact of the project. If the project's additional lane was completed in 2020, it would not begin producing a net reduction in GHG emissions until sometime in 2025. Thus, while this hypothetical project would have congestion (and probably safety) benefits, it would not be an ideal GHG mitigation project if near-term reductions in GHGs were considered important.

SUMMARY AND NEXT STEPS

Pilot testing of the tool, with three MPOs and three state DOTs was completed in late 2013. The draft tool was also provided to interested academic researchers for their review and feedback. FHWA and ICF revised the tool in response to the feedback we have received, and a final version of the tool was released in August 2014, along with a final report and a webinar outreach and training session. The tool is posted on FHWA's website at www.fhwa.dot.gov/environment/climate_change/index.cfm. FHWA hopes that this tool and the accompanying information will make it easier for the transportation community to both quantify and reduce the energy consumption and emissions associated with construction and maintenance, and that planners examining GHG reduction strategies will begin to account for the emissions generated in the process of constructing infrastructure.

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