NOVEMBER 2023

Carbon Reduction Strategy

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Michigan Department of Transportation

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1.0 Background

1.1 Overview of Legislation

1.1.1 Bipartisan Infrastructure Law

The Bipartisan Infrastructure Law, also known as the Infrastructure Investment and Jobs Act, was passed in 2021 and established the Carbon Reduction Program (23 U.S.C. 175 § 11403). The Carbon Reduction Program provides just under $169 million of funding for Michigan to implement cutting edge projects to reduce transportation-sector carbon emissions (i.e., carbon dioxide (CO_2) emissions). Program funds for carbon reduction projects are to be provided to both urban and rural areas based on the relative share of the population.

The Bipartisan Infrastructure Law also requires states to develop a Carbon Reduction Strategy by November 15, 2023. This Carbon Reduction Strategy was developed by the Michigan Department of Transportation (MDOT), in collaboration with statewide and regional stakeholders, to explore initiatives to reduce statewide transportation sector carbon emissions that reflect the carbon reduction needs and preferences of Michigan's diverse communities. Per the U.S. Department of Transportation's guidance, the strategy must be updated at least once every four years as discussed further in **Section 4 Roadmap For Integration**.

1.1.2 Justice40 Initiative

The Justice40 Initiative was signed in 2021 under Executive Order 14008. Per section 223, eligible agencies, such as MDOT, must work toward the goal of having 40% of the overall benefits of federal investments flow to disadvantaged communities. Disadvantaged communities are defined by the U.S. Department of Transportation based on six impact categories: transportation, health, environment, economy, resilience, and equity. The study team identified best management practices (BMPs) and procedures to facilitate equitable benefits of carbon reduction initiatives in alignment with Justice40 during the development of this strategy. This Carbon Reduction Strategy provides Michigan's transportation partners with opportunities to lead in benefitting these communities.

1.1.3 Michigan Governor's Executive Directive 2020 – 10

In September 2020, Governor Gretchen Whitmer signed Executive Directive 2020-10. Under this directive, Michigan will aim to achieve economy-wide carbon neutrality no later than 2050, and to maintain net negative greenhouse gas (GHG) emissions thereafter. In the interim, by 2025 Michigan will aim to achieve a 28% reduction in carbon emissions below 2005 levels. As part of achieving carbon neutrality, all new and renovated state-owned buildings and facilities (including MDOT facilities) must be carbon neutral by 2040; all existing buildings and facilities must reduce energy use 40% by 2040. This directive also required the Department of Environment, Great Lakes, and Energy (ELGE), through its Office of Climate and Energy, to develop and issue the Michigan Healthy Climate Plan (see **Appendix D**).

1.2 Purpose of the Carbon Reduction Strategy

The purpose of this Carbon Reduction Strategy is to identify and evaluate initiatives to reduce carbon emissions generated from the transportation sector in the state of Michigan, an important step in fighting climate change. Reducing transportation-sector emissions aligns with Governor Whitmer's Executive Directive 2020 – 10 which commits to accelerating new and existing policies to reduce carbon pollution and promotes clean energy deployment. **Section 4 Roadmap for Integration** outlines how this Carbon Reduction Strategy aligns with existing MDOT transportation and programs as well as guided an analysis of how the initiatives can be further woven into MDOT's transportation planning process.

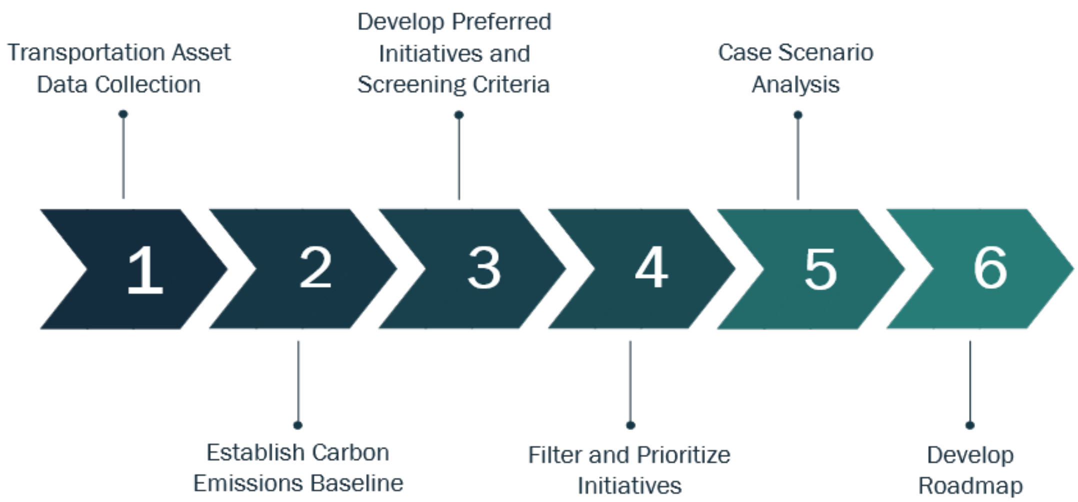
The strategy focuses on three areas: (1) Use of Systems (e.g., vehicle tailpipe emissions); (2) Capital Projects (e.g., carbon emissions of infrastructure construction); and (3) Roadway Maintenance, as shown in **Figure 1**. Reducing transportation sector carbon emissions is needed to improve the state of the environment, improve public health, and improve the resilience of the Michigan economy. This Carbon Reduction Strategy can be used to support metropolitan and regional planning organizations in their carbon reduction planning efforts and serve as an educational tool for the public to understand efforts to reduce transportation-sector carbon emissions.

Figure 1. Carbon Reduction Strategy Areas

1.3 Overview of the Carbon Reduction Strategy Process

This Carbon Reduction Strategy was developed using a six-step process (**Figure 2**) that: (1) collected transportation asset data; (2) established the state's baseline transportation system carbon emissions; (3) developed preferred initiatives and initial screening criteria; (4) screened initiatives for applicability in Michigan; (5) assessed the overall sustainability of selected initiatives through a case scenario analysis; and (6) aligned the overarching strategy with other MDOT plans through a planning roadmap for integration.

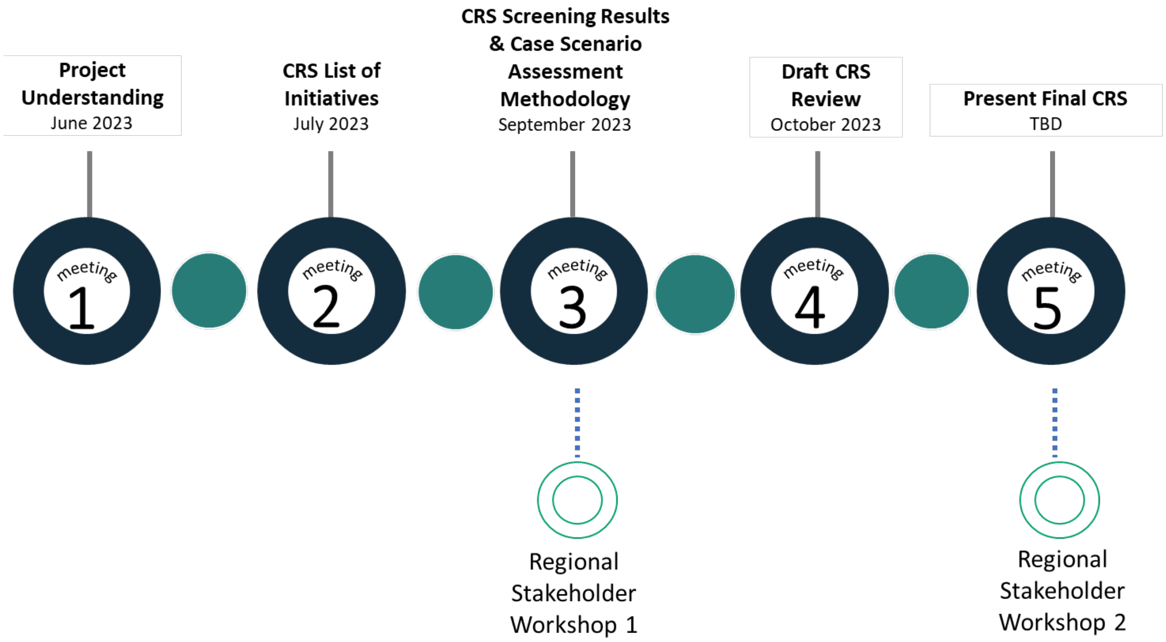
Figure 2. Carbon Reduction Strategy Development Process



1.4 Stakeholder and Agency Involvement

MDOT worked with stakeholders from across the state to inform the development of this Carbon Reduction Strategy. Input from stakeholders was crucial to developing a strategy that considers Michigan's existing carbon reduction efforts and is implementable across the diverse communities in the state. MDOT collaborated with stakeholders through two groups: the Internal Advisory Committee and the Regional Stakeholder Workshop Group. The Internal Advisory Committee included representatives across MDOT, State of Michigan agencies, and the Federal Highway Administration. The Regional Stakeholder Working Group consisted of larger groups of representatives across the state, including metropolitan planning organizations, regional planning commissions, transportation agencies, and councils of government, among others. Input gathered from stakeholders was incorporated into this Carbon Reduction Strategy after each meeting to ensure the diverse needs across Michigan were considered. The final stakeholder meeting focuses on a path forward for Carbon Reduction Strategy implementation, including how implementation strategies may vary across the state, how this Carbon Reduction Strategy can be used as a tool to educate the public, and how public outreach will occur to further emissions reductions efforts. **Figure 3** presents the Carbon Reduction Strategy milestones in which stakeholders were involved.

Figure 3. Meetings with Stakeholders



2.0 Understanding Existing Carbon Emissions

2.1 Carbon Emissions (CO_2e) Baseline

A statewide carbon emissions baseline was developed to understand primary sources of carbon emissions from the transportation sector in Michigan. The baseline analyzes carbon dioxide equivalent (CO_2e) emissions across the following three areas: (1) Use of Systems, (2) Capital Projects, and (3) Roadway Maintenance. Emissions from the Use of Systems far outweigh CO_2e emissions associated with construction of Capital Projects and performance of Roadway Maintenance.

2.1.1 Use of Systems

The Use of Systems baseline established the estimated CO_2e emissions in 2015 as a direct result of statewide vehicle use, measured in tailpipe emission, and estimated using vehicle miles traveled (VMT). It's worth mentioning that MDOT attempted to use 2005 as its baseline year (i.e., in alignment with the MI Healthy Climate Plan), but is unable to obtain the county level data that's necessary to generate emissions for this analysis.

Figure 4 depicts VMT and CO_2e emissions by county. In 2015, vehicles traveled 97 billion miles and emitted 48 million metric tons of CO_2e. **Figure 5** and **Figure 6** depict the distribution of VMT (billion)and CO_2e (million) across urban and rural counties in Michigan. Urban counties have been defined as having a population of 50,000 or above; rural counties have been defined as having a population of under 50,000. The four counties with the highest overall VMT, and therefore highest CO_2e emissions, in 2015 were Wayne, Oakland, Macomb, and Kent which relate to the largest metropolitan areas in the state. However, when considering VMT and CO_2e emissions per capita in 2015 (**Figure 7** and **Figure 8**), the highest emitting counties were Mackinac, Crawford, Schoolcraft, and Arenac which are rural. This emphasizes that reducing carbon emissions is primarily a function of VMT and is important in both urban and rural areas.

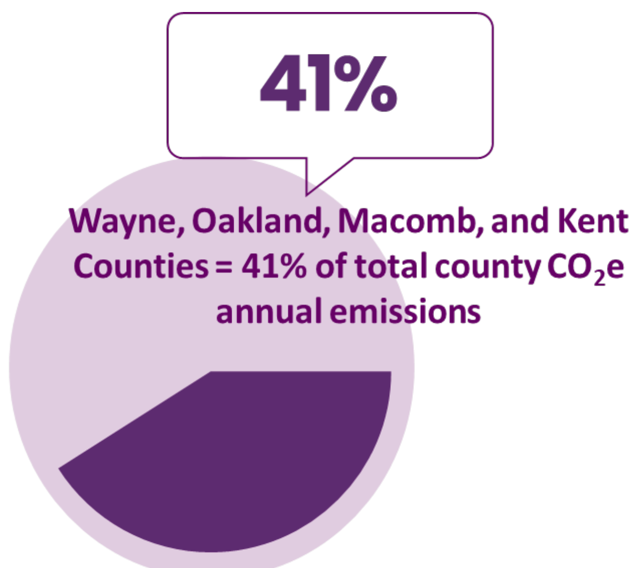


Figure 4. Map Of Michigan VMT And CO_2e By County in 2015

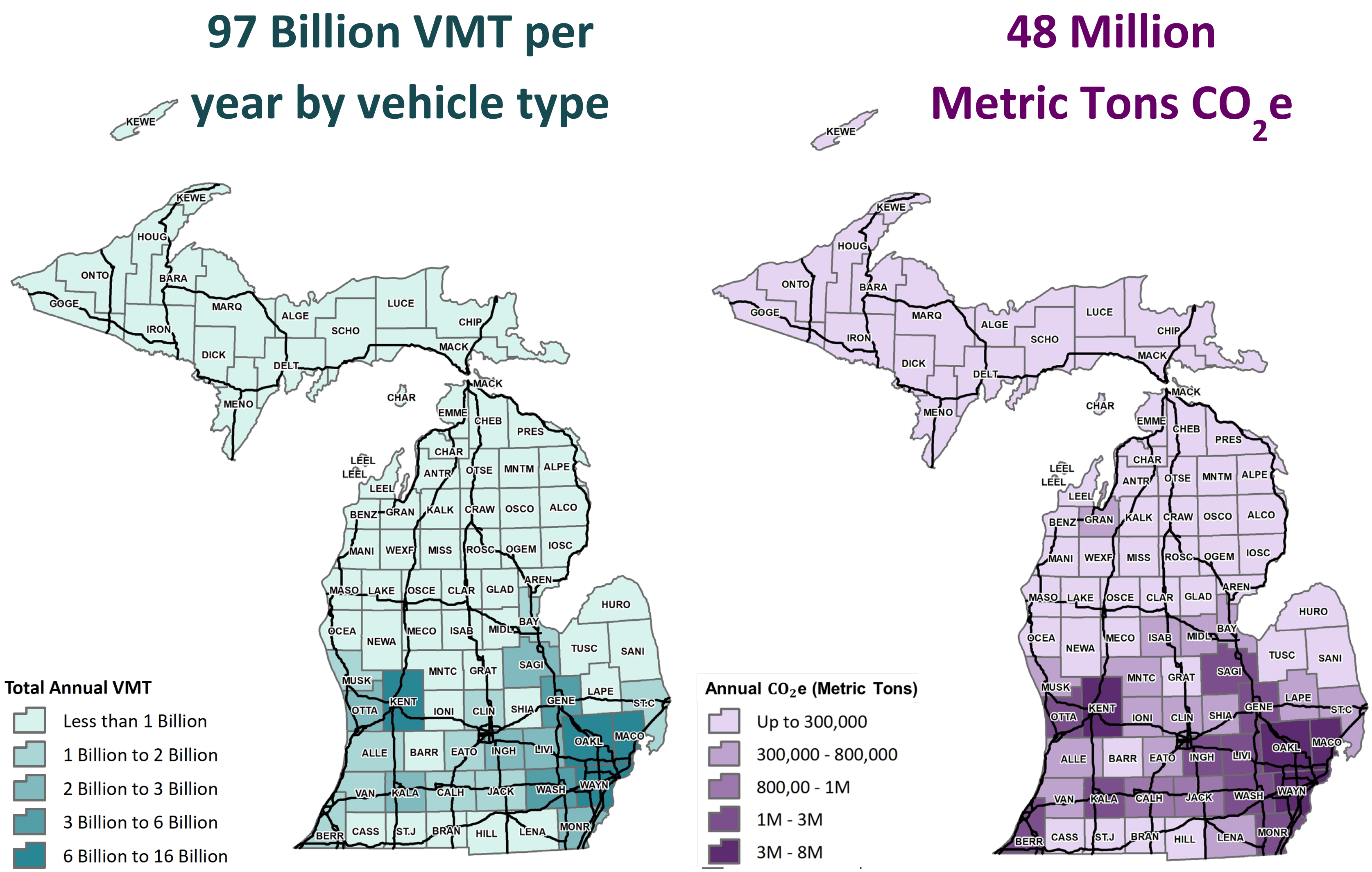


Figure 5. Chart of Michigan VMT (Billions VMT/year) and CO_2e (Millions MT/year) by Urban County in 2015

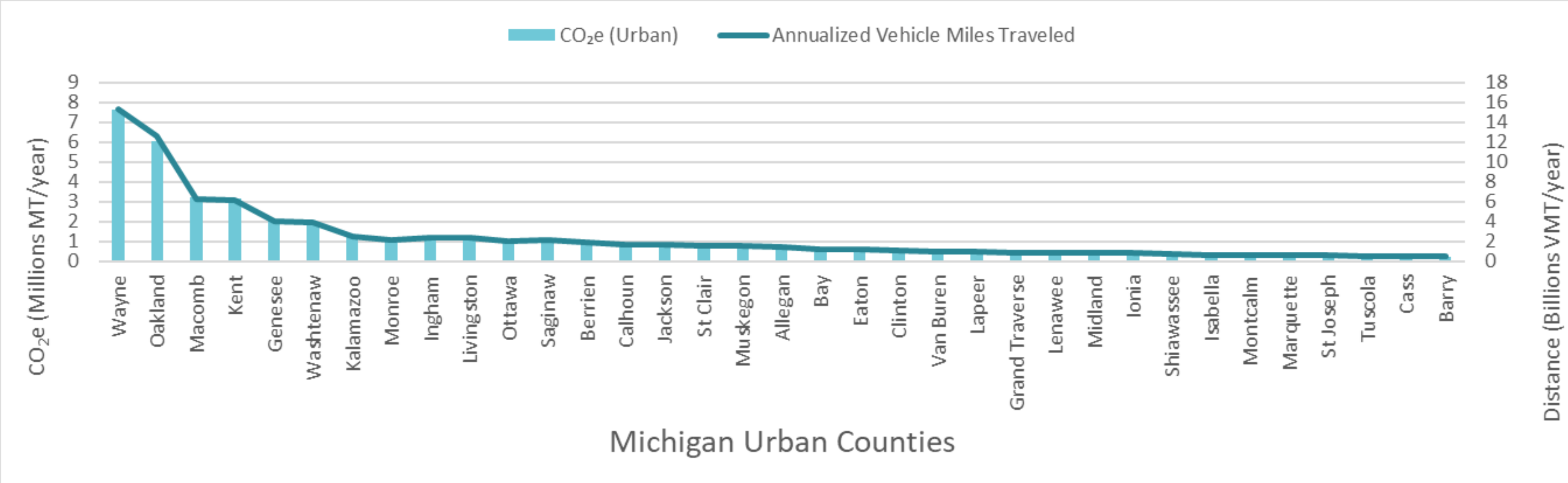


Figure 6. Chart of Michigan VMT (Millions VMT/year) and CO_2e (Thousands MT/year) by Rural County in 2015

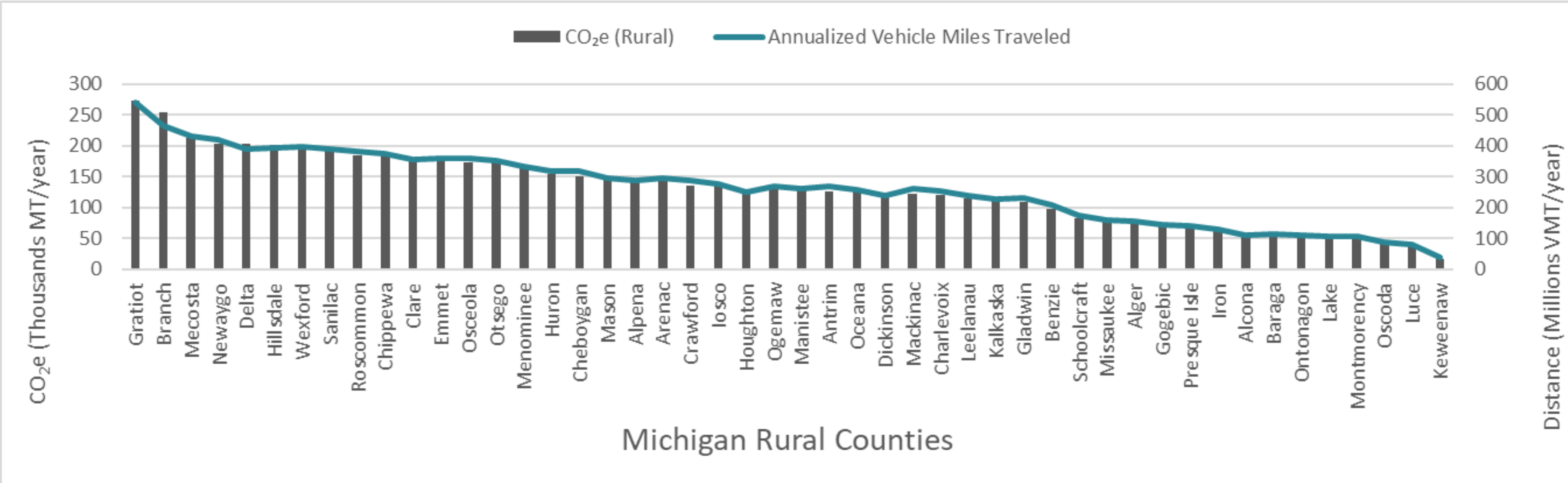


Figure 7. Chart of Michigan's County Annual VMT and CO2e Per Capita in 2015- Highest Values

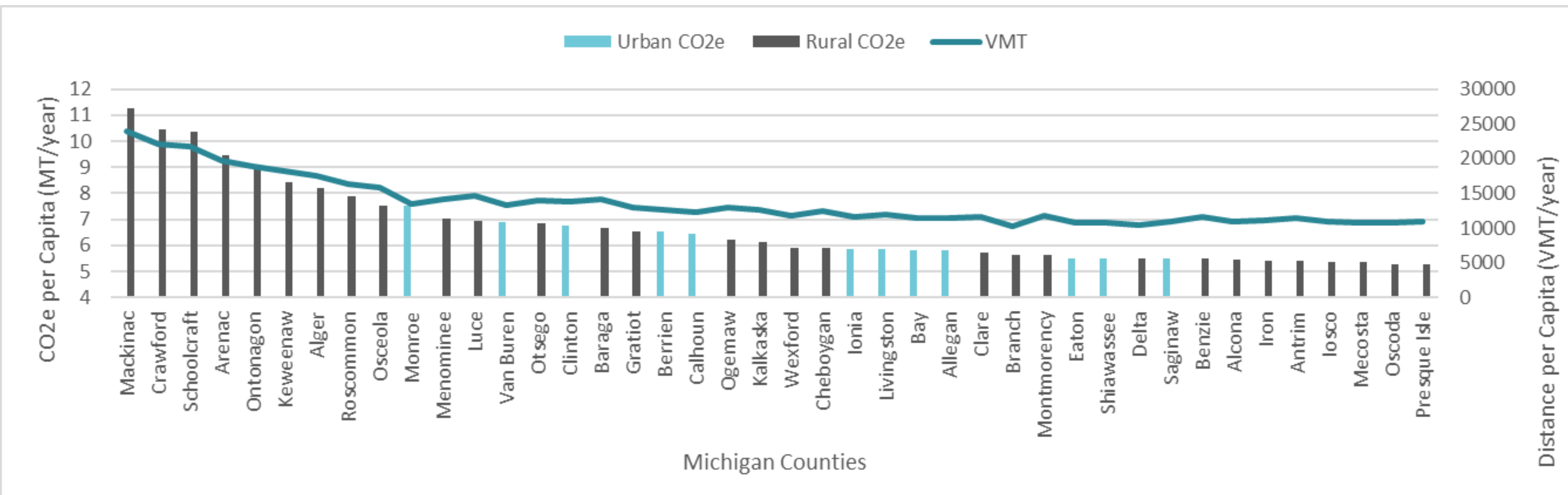


Figure 8.Chart of Michigan's County Annual VMT and CO2e Per Capita in 2015 – Lesser Values

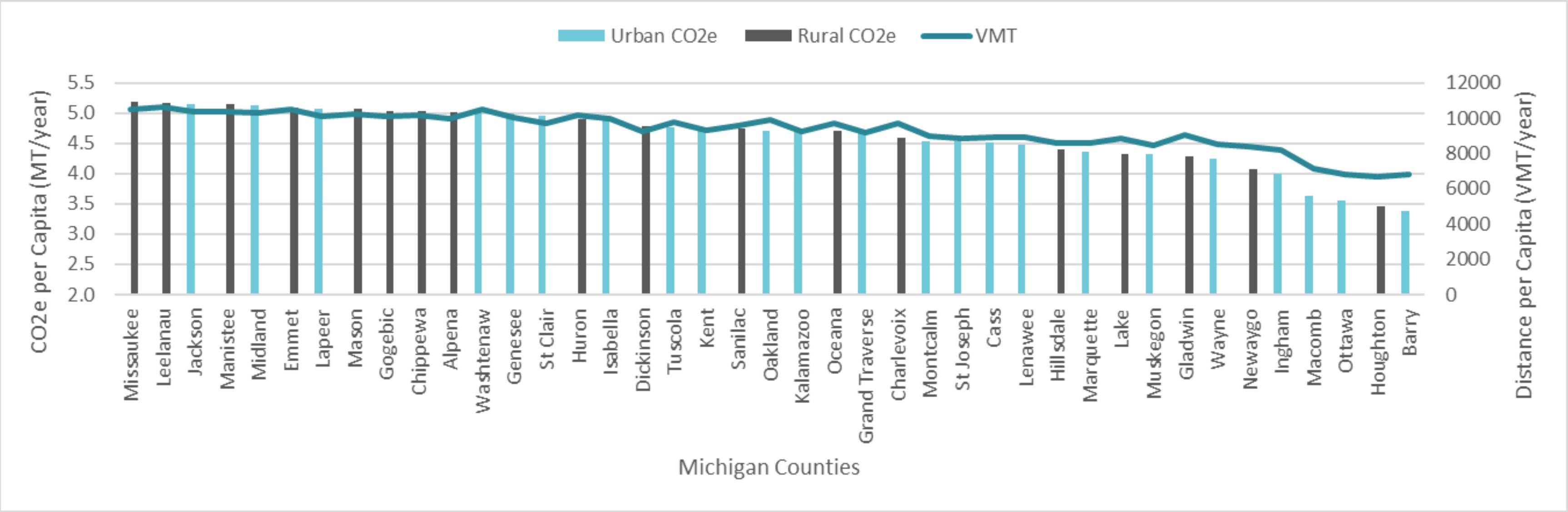
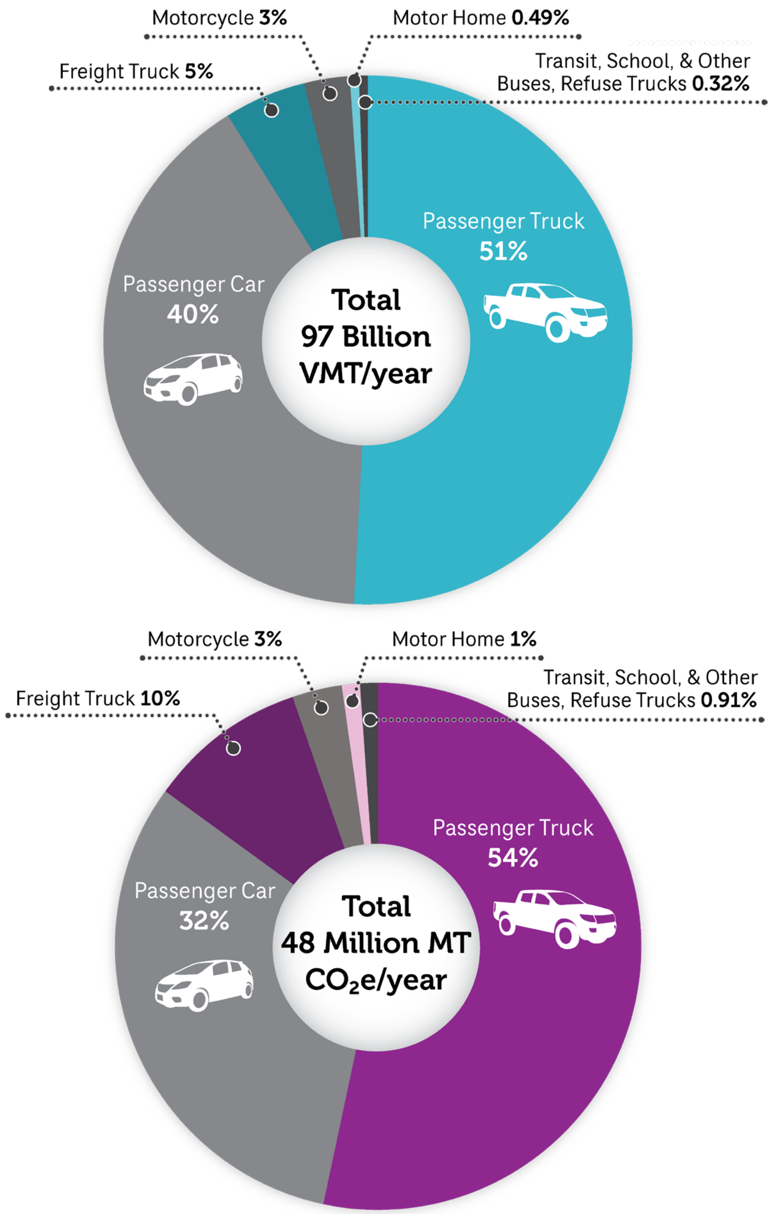


Figure 9 shows the distribution of registered vehicle types with the greatest VMT and CO_2e emission within the state. The Motor Vehicle Emission Simulator (MOVES) model used for **Figure 9** generated emissions based on number and type of vehicles registered in the state. This means that VMT and associated CO_2e emissions calculations distributed by vehicle type do not include vehicles passing through the state that are not registered in Michigan, including trucks using major inter-state and United States-to-Canada truck routes. Passenger vehicles (cars and trucks) represent 91% of state-registered vehicle VMT in Michigan and 86% of emissions associated with the use of systems.

Figure 9. Distribution of VMT and CO_2e by Vehicle Type



2.1.2 Capital Projects

The construction of Capital Projects baseline included estimated CO_2e emissions using the Federal Highway Administration's Infrastructure Carbon Estimator (version 2.1) tool. Emissions were estimated for material use and construction activities (i.e., carbon footprint) of one lane-mile for the following four modes of transportation infrastructure: (1) roadway, (2) rail, (3) bus rapid transit, and (4) bicycle and pedestrian facilities. The assessment found that rail had the highest capital projects carbon footprint (resulting from the greater use of cement and steel) followed by bus rapid transit, roadways, and bicycle/pedestrian pathways. The higher-speed and longer-distance travel road types, such as interstates and principal arterials, have higher carbon footprints than lower-speed and volume roads such as minor arterials and collector roads. **Table 1** summarizes the results of the assessment**.** When considering emissions per passenger mile, single-occupancy vehicles are the highest emitting mode of transportation, followed by bus rapid transit, commuter rail, and biking/walking. Capital projects carbon emission footprint is significantly below Use of System annual emissions of 48 Million Metric Tons CO_2e. Across all infrastructure and construction types, the materials with the highest contributions to the emissions baseline are steel, cement, and construction equipment fuel (for earthmoving equipment, etc.).

Table 1. Summary of Capital Projects Construction Baseline CO_2e Emissions

Capital Projects Transportation Infrastructure Mode	CO_2e Emissions
Roadways – Interstate[1]	291 MT CO_2e per lane mile
Roadways – Principal Arterial[1]	235 MT CO_2e per lane mile
Roadways – Minor Arterial and Collector[1]	216 MT CO_2e per lane mile
Commuter Rail – Aboveground[2]	2,890 MT CO_2e per track mile
Commuter Rail – Underground[2]	171,000 MT CO_2e per track mile
Bus Rapid Transit[3]	335 MT CO_2e per lane mile
Bike/Pedestrian Path[4]	25 MT CO_2e per lane mile

Key: MT – metric tons

Notes:

1. Values presented for Roadways are averages of urban and rural projects for each road type.
2. Aboveground Rail is an average of at-grade and elevated track baseline values for both heavy and light rail, and Underground Rail is an average of soft soil and hard rock baseline values for both heavy and light rail.
3. Bus Rapid Transit values are averages of new lanes or right of way and converted or upgraded lanes/facilities.
4. Bike/Pedestrian values are averages of off-street bike lanes and sidewalk, on-street bike lanes and sidewalks.

Figure 10 and **Figure 11** depict the capital projects emissions breakdown by construction materials for new roadway construction and bus rapid transit. Figures presenting a similar breakdown for all modes are available in **Appendix A.** In addition, **Appendix A** presents the total emissions for new construction of roadways and additional lane construction for roadways by road type (e.g., rural interstate versus urban interstate).

Figure 10. Emissions Baseline of Roadway, New Construction, by Material

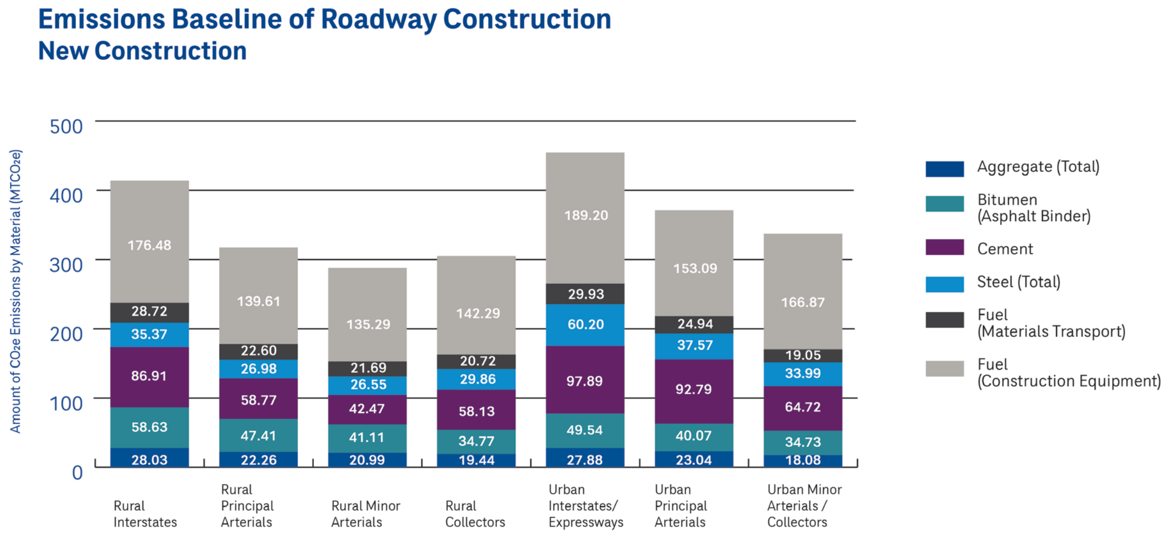
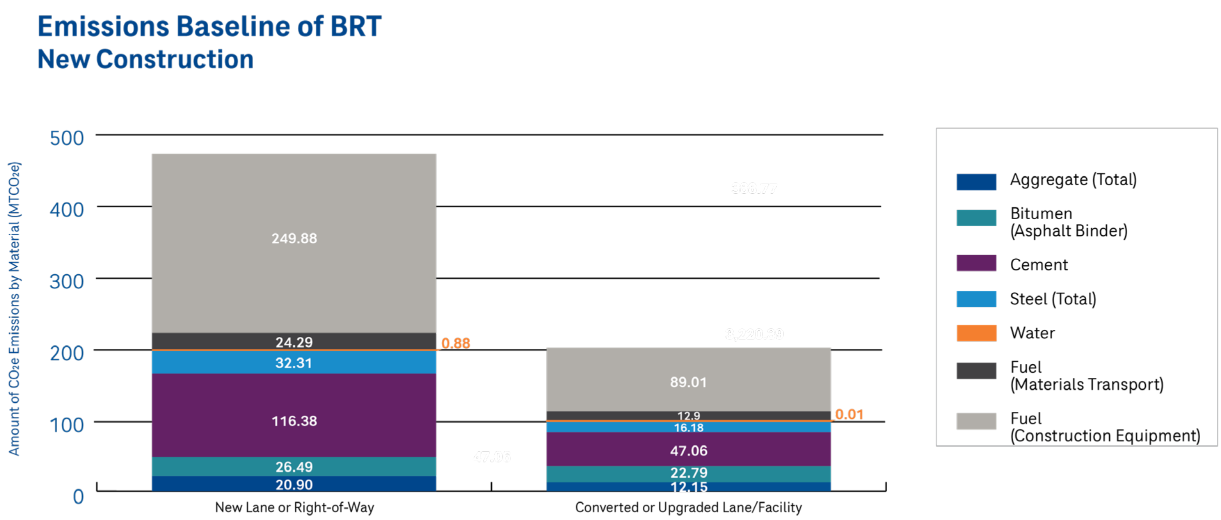
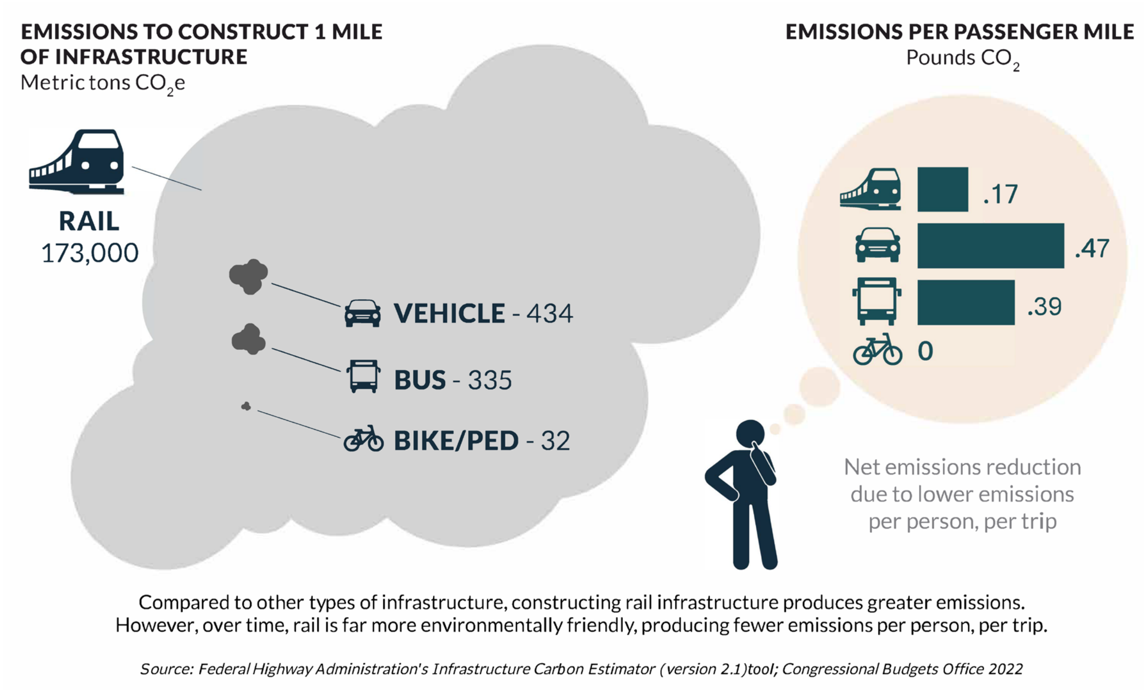


Figure 11. Emissions Baseline of Bus Rapid Transit, New Construction, by Material



The initial construction of public and multi-modal infrastructure (i.e., rail and bus rapid transit) has a higher emission footprint than roadway construction. However, once constructed rail and bus rapid transit can carry a higher number of passengers. Availability and access to public transportation can support a mode shift away from single-occupancy vehicles thereby reducing carbon emissions associated with the Use of Systems, see **Figure 12**. This is an important consideration because 73% of Michiganders travel alone in a vehicle.[1] In the long term, the initial carbon emission of new rail and bus rapid transit projects can be offset by the lower carbon emissions associated with the increased use of public transportation and decrease in single-occupancy vehicles.

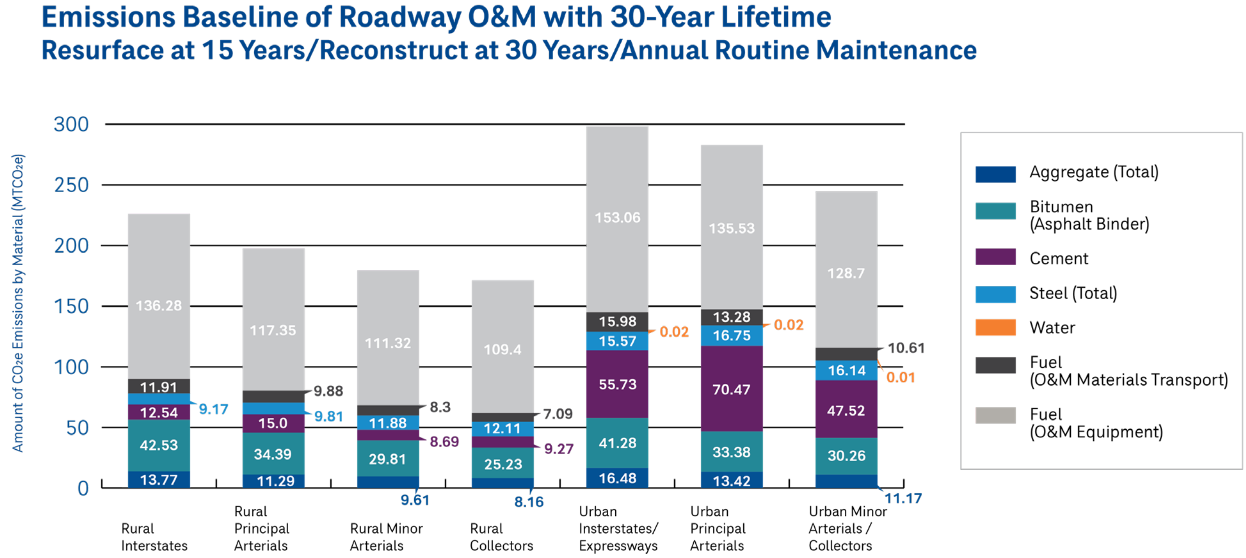
Figure 12. Comparison of Construction Versus Use Emissions, By Mode[2]



2.1.3 Maintenance of Roadways

The baseline also includes estimated CO_2e emissions associated with the maintenance of roadways. The baseline maintenance schedule includes annual routine maintenance (snow removal, vegetation management, sweeping, striping, bridge deck repair, and litter pickup), a resurfacing event at 15 years, and reconstruction at 30 years. Averaging all road types, the emissions baseline for road maintenance is 229 MT CO_2e per lane mile, or 7.62 MT CO_2e per lane mile per year across the 30-year road lifespan. Fuel use by construction equipment is the primary source of emissions in maintenance of roadways, followed by asphalt and cement consumption; see **Figure 13**. Resurfacing and reconstruction events have a high impact on the overall carbon baseline of roadway maintenance. Significant emissions savings can be obtained by delaying the need for resurfacing and reconstruction through pavement preservation activities (i.e., chip and crack sealing) and maintaining roadways in a state of good repair.

Figure 13. Emissions Baseline for Roadway Maintenance



2.1.4 Baseline Key Findings

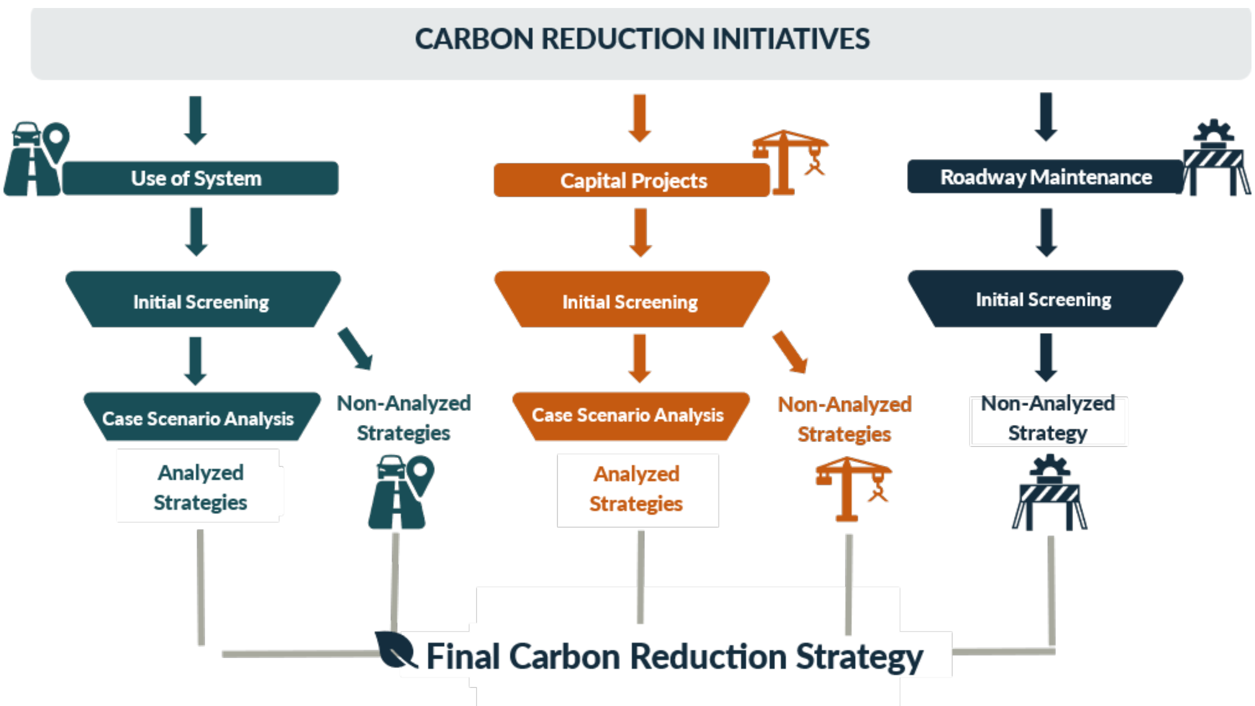
- Use of Systems – CO_2e emissions associated with passenger vehicles are the dominant source of carbon emissions in Michigan's transportation sector. The majority of Michiganders travel in single-occupancy vehicles.
- Use of Systems – The number of trucks registered in Michigan is low yet there are major truck routes throughout the state. Carbon reduction initiatives will consider both pass-through and state-registered trucks.
- Capital Projects – Rail is the highest emitting per-mile type of new construction project, followed by roadways/bus rapid transit, and bicycle/pedestrian projects. However, when considering post-construction use of systems emissions by transportation mode, roadways are the highest emitting per passenger mile, followed by bus rapid transit, rail, and biking/walking.
- Capital Projects – Based on the estimated carbon footprint of differing transportation capital projects, steel and cement materials, and equipment fuel use were identified as dominant sources of carbon emissions during construction.
- Roadway Maintenance – Fuel use by construction equipment, followed by asphalt and cement use are the primary driver of CO_2e emissions in maintenance activities.

3.0 Carbon Reduction Initiatives Evaluation

3.1 Initiative Evaluation Overview

A three-step process was used to identify and evaluate carbon reduction initiatives within the three key strategy areas (1) Use of Systems, (2) Capital Projects, and (3) Roadway Maintenance. This three-step process consisted of initiative identification, initial screening, and performing a case scenario analysis. This process is depicted in **Figure 14**. The findings of the case scenario analysis are presented in **Section 5**.

Figure 14. Carbon Reduction Initiative Evaluation Process



3.2 Initial Initiative Screening

Sixteen carbon reduction initiatives were identified through review of existing literature and identified best practices. The initiatives are described in **Table 2**.

Table 2. Carbon Reduction Initiatives and Description

Carbon Reduction Strategy Area	Initiative	Description
Use of Systems	Charging infrastructure for electric vehicles for on-road and private/public fleet vehicles (buses, trucks, and cars)	Direct current fast-charging stations allow owners of electric vehicles to recharge quickly on the go, encouraging wider adoption.
Use of Systems	Charging infrastructure for electric vehicles for off-road vehicles (maritime, aviation)	Adoption of electric vehicle support (off-road) vehicles, including charging infrastructure, for both maritime and aviation facilities.
Use of Systems	Low-carbon fuel infrastructure for light and heavy vehicles	Low-carbon fuel infrastructure includes fueling stations and associated infrastructure for low-carbon fuels (e.g., hydrogen fuel, renewable natural gas, low-carbon biofuel) that allow owners of light and heavy vehicles utilizing these low-carbon fuels to recharge quickly on the go, encouraging wider adoption.
Use of Systems	Encourage modal shift from personal vehicle usage to shared mobility and public transit	Improving availability to/of public transit (e.g., dedicated bus lanes; multimodal access to public transit; high-volume fixed-route transit services such as bus rapid transit; park and ride facilities; transit signal priority)
Use of Systems	Reduce freight-related congestion and support freight route efficiency on the network	Lessening stop-and-go movement of freight vehicles and improving traffic flow, thus reducing CO_2 emissions from use of systems (e.g., intermodal exchange, AI-based operations streamlining, curb management)
Use of Systems	Prioritize transportation infrastructure efficiencies	Improving design to decrease congestion and improve traffic flow thus, reducing emissions (e.g., roundabouts, interconnected/coordinated traffic signals, update timings and coordination of traffic signals, added lanes for left turns, weigh station bypass options such as PrePass and DriveWyze)
Use of Systems	Energy-efficiency projects for street lighting and traffic control devices	Switching to LED lights can reduce carbon emissions associated with the use of this infrastructure. Such projects reduce the amount of purchased electricity required to operate these devices.
Use of Systems	Connected and autonomous vehicle technology	Incorporating vehicle-to-vehicle technology and vehicle to infrastructure technology to improve traffic flow and reduce accidents.
Use of Systems	Intelligent transportation systems	Electronic toll collection, traffic signal optimization/retiming, ramp metering, and traffic incident management will lessen stop-and-go traffic and congestion, improving traffic flow and thus, reducing CO_2 emissions from use of the system.
Use of Systems	Micromobility, pedestrian, and bicycle infrastructure	The installation of active transportation infrastructure (e.g., bike, pedestrian, scooters) to improve accessibility, decrease traffic congestion, and encourage a shift from single user passenger vehicles to carbon-neutral modes of transport.
Use of Systems	Fuel standards	Adjusting fuel standards to require more efficient vehicles and/or alternative fuels to gas/diesel.
Use of Systems	Incentives for transportation efficiency	Providing incentives for carpooling, increased vehicle occupancy rates, and electric or zero-emission vehicles such as through dedicated lanes.
Use of Systems	Pricing adjustments for vehicle use	Encouraging carpool and public transit through higher parking rates, congestion pricing, road usage charging, pay-as-you-drive insurance, and mileage-based charging

Carbon Reduction Strategy Area	Initiative	Description
Capital Projects	Sustainable design	Implement efficient and environmentally beneficial strategies from the planning stage through the project's lifetime. Examples include using low-carbon, recycled, or reclaimed construction materials, low-carbon emissions equipment, staging construction to reduce congestion, incorporating urban greenways, or establishing project-specific sustainable performance metrics.
Capital Projects	Sustainable purchasing	Reducing carbon footprint of construction materials through local purchasing and procurement and purchasing of zero emission construction and/or maintenance vehicles.
Roadway Maintenance	Pavement preservation	Extends the life of infrastructure, thereby preventing rebuilds and associated emissions.

Each of the 16 initiatives went through the initial screening process which considered six criteria in which an initiative could pass or not pass. If special conditions were required for an initiative to pass the criterion, a conditionally-passed rating was used. An example condition required to pass a criterion is coordination with non-MDOT transportation partners, such as metropolitan planning organizations or regional transit authorities, for the initiative to be implementable statewide.

The six screening criteria were developed in coordination with MDOT and stakeholders (Internal Advisory Committee and Regional Stakeholder Workgroup). Stakeholders informed the factors each criterion would consider and assisted in categorizing criteria as either required (must pass the criteria to move forward in analysis) or desired (preferred to pass the criteria to move forward in analysis). The required and desired criteria are shown in **Figure 15**. The initial screening process was used to determine the applicability of initiatives in Michigan and narrow the range of initiatives that would be analyzed in the use case scenario analysis.

Notably, the initial screening process did not quantify the carbon reductions for these 16 initiatives. The initial screening process was qualitative in nature, and it screened for social, operational, or policy-related impacts or conditions. Carbon reduction is later quantified for four carbon reduction initiatives in the case scenario analysis; see **Section 5** for further information.

In general, carbon reduction initiatives that focus on the Use of System strategy area will have the greatest carbon reduction potential, followed by construction of capital projects and roadway maintenance activities.[3] High VMT from internal combustion engine (ICE) vehicles, which in turn use the most fuel, is the primary driver of Use of System carbon emissions. In the short term, initiatives that focus on reducing VMT of ICE vehicles, such as electrification of vehicles and other modes of transport, mode shift from single occupancy vehicles to public transportation and shared mobility, and improved congestion management have high carbon reduction potential. Other initiatives play an important role in carbon reduction, however, may still require large amounts of vehicle fuel consumption and produce carbon emissions, such as alternative and low-carbon fuels, fuel standards, and pricing adjustments. Due to relatively low electricity consumption compared to state-wide fuel consumption and renewable energy sources supporting the electrical grid, energy-efficiency projects for street lighting and traffic control devices will have the lowest overall carbon reductions for Use of System. Initiatives with the highest carbon reduction potential for capital projects and roadway maintenance strategy areas focus on electrification of construction and maintenance equipment followed by the procurement of low-carbon construction materials.

Figure 15. Initial Screening Criteria

Required Criteria (must pass to move forward)	Desired Criteria (preferred to pass to move forward)
Social Equity Considerations Avoiding disproportionate burdens to surrounding communities either during construction or operation (e.g., increased localized air emissions, requires temporary displacement).	**Environmental Justice** Providing benefits to disadvantaged communities either during construction or operation in alignment with the Justice40 Initiative
Community Safety and System Operations Improving or maintaining the level of safety and risk profile of the transportation system once operational.	**Internal Policy Synergies** Support existing MDOT internal agency/departmental policies such as the MI Healthy Climate Plan and the Michigan Mobility 2045 long range transportation plan.
Regulatory Conflict Avoiding conflicts with Federal or Michigan regulations.	**Jurisdictional Ability to Implement** Does MDOT or its transportation partners have jurisdictional ability to adequately plan and implement the strategy, project, or program?

3.2.1 Findings of the Initial Screening

All 16 initiatives passed the initial screening, are considered applicable to Michigan, and would result in a reduction of transportation sector carbon emissions. **Appendix B** presents the initial screening results, additional consideration for implementation, and best practices to facilitate sustainable implementation of initiatives.

The initial screening results identified four initiatives that passed all criteria: (1) charging infrastructure for electric vehicles for on-road vehicles, (2) encourage modal shift from personal vehicle usage to shared mobility and public transit, (3) micromobility, pedestrian, and bicycle infrastructure, and (4) sustainable purchasing.

The remaining 11 initiatives passed the initial screening with conditional-pass ratings. Conditionally passed initiatives require additional consideration during the process of implementation to facilitate meeting that criterion (refer to **Appendix B**). Examples of additional considerations for implementation include needing revisions to existing MDOT policy or guidance documents, project-level impact analyses to avoid disproportionate burdens to and/or ensure project benefits disadvantaged communities, and needing coordination among transportation partners. The findings of the initial screening process were reviewed and vetted with the Internal Advisory Committee and Regional Stakeholder Working Group. The results of the initial screening are presented in **Table 3.**

Table 3. Initial Screening Results

	Required Criteria		Desired Criteria	
Initiative	Screening Results	Conditionally Passed Criteria	Screening Results	Conditionally Passed Criteria
Charging infrastructure for electric vehicles for on-road vehicles	Pass	-	Pass	-
Charging infrastructure for electric vehicles for off-road vehicles	Pass	-	Conditional Pass	Jurisdictional Ability to Implement
Low-carbon fuel infrastructure for light and heavy vehicles	Conditional Pass	Social Equity Considerations; Community Safety and System Operation	Conditional Pass	Environmental Justice Considerations
Encourage modal shift from personal vehicle usage to shared mobility and public transit	Pass	-	Pass	-
Reduce freight-related congestion and support freight route efficiency on the network	Conditional Pass	Social Equity Considerations; Regulatory Conflicts	Conditional Pass	Environmental Justice Considerations; Jurisdictional Ability to Implement
Prioritize transportation infrastructure efficiencies	Pass	-	Conditional Pass	Environmental Justice Considerations
Energy-efficiency projects for street lighting and traffic control devices	Pass	-	Conditional Pass	MDOT Internal Policy Synergies
Connected and autonomous vehicle technology (CAV)	Conditional Pass	Social Equity Considerations; Community Safety and System Operation	Conditional Pass	Environmental Justice Considerations
Intelligent transportation systems	Conditional Pass	Social Equity Considerations; Regulatory Conflicts	Conditional Pass	Environmental Justice Considerations
Micromobility, pedestrian, and bicycle infrastructure	Pass	-	Pass	-
Fuel standards	Conditional Pass	Social Equity Considerations	Conditional Pass	Environmental Justice Considerations; Jurisdictional Ability to Implement
Incentives for transportation efficiency	Pass	-	Conditional Pass	Jurisdictional Ability to Implement
Pricing adjustments for vehicle use	Conditional Pass	Social Equity Considerations	Conditional Pass	Environmental Justice Considerations; Jurisdictional Ability to Implement
Sustainable design	Pass	-	Conditional Pass	MDOT Internal Policy Synergies; Jurisdictional Ability to Implement
Sustainable purchasing	Pass	-	Pass	-

	Required Criteria		Desired Criteria	
Initiative	Screening Results	Conditionally Passed Criteria	Screening Results	Conditionally Passed Criteria
Pavement Preservation	Conditional Pass	Social Equity Considerations	Conditional Pass	Environmental Justice Considerations

4.0 Roadmap for Integration

Michigan has developed ambitious goals to address climate change and reduce carbon emissions. The Governor signed Executive Directive 2020-10, as discussed in **Section 1.1.3**, which charges Michigan to pursue a 26-28% reduction below 2005 levels in GHG emissions by 2025 and achieve economy-wide carbon neutrality by 2050. In addition, Michigan is a member of the U.S. Climate Alliance, aiming to achieve a 52% reduction in GHG emissions by 2030.

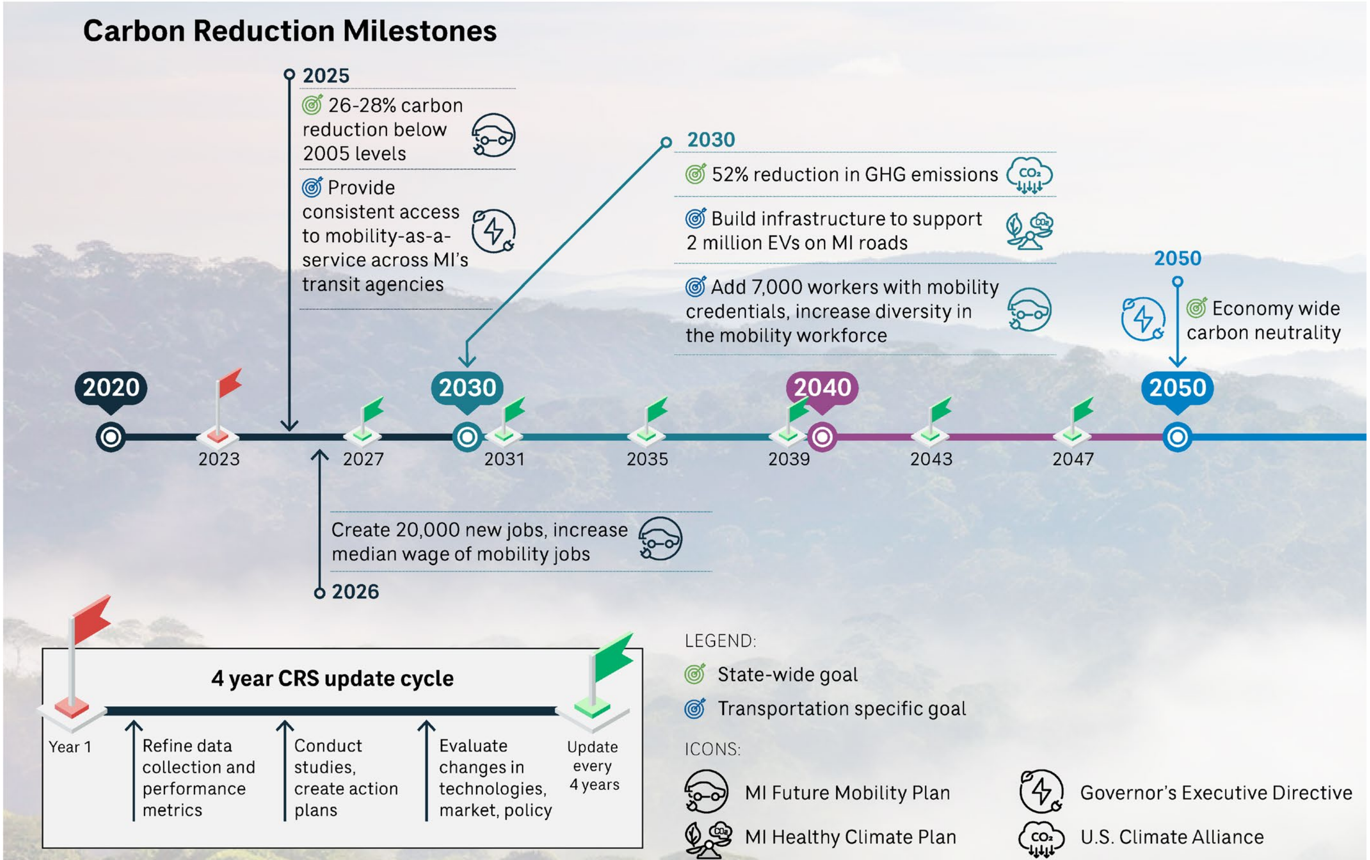
To achieve these climate goals, the MI Health Climate Plan identifies the following transportation related goals:

- **Commit to Environmental Justice and Pursue a Just Transition:** Ensure that at least 40% of state funding for climate-related and water infrastructure initiatives benefit Michigan's disadvantaged communities
- **Clean the Electric Grid:** Generate 60% of the state's electricity from renewable resources and phase out remaining coal-fired power plants by 2030
- **Electrify Vehicles and Increase Public Transit:** Build the infrastructure necessary to support 2 million electric vehicles on Michigan roads by 2030. Increase access to clean transportation options – including public transit – by 15% each year

Achieving these ambitious goals will require deliberate coordination with state agencies, stakeholders, and the public. This Carbon Reduction Strategy is a tool for MDOT to pursue these climate goals and associated coordination. As described in **Section 1.2**, the purpose of this Carbon Reduction Strategy is to identify and evaluate initiatives to reduce carbon emissions generated from the transportation sector in the state of Michigan. Reducing transportation sector emissions should utilize all available funding sources and consider all applicable policy. For example, this Carbon Reduction Strategy should be implemented in concert with National Electric Vehicle Infrastructure (NEVI) projects and funding.

The U.S. Department of Transportation Carbon Reduction Strategy Guidance requires that this Carbon Reduction Strategy be updated at least once every four years (23 U.S.C. 175(d)(3) and (4)). MDOT will aim to use the data collection mechanisms presented herein to estimate carbon reduction achieved at the first 4-year update of the carbon reduction strategy in 2027. This will allow MDOT to track progress made towards its 2030 and 2050 reduction goals. The roadmap to achieve these reduction goals include alignment with MDOT's existing transportation planning process, and statewide carbon reduction goals is presented in **Figure 16**.

Figure 16. Roadmap for Implementation



NOTES:
The MDOT Carbon Reduction Program funds will be distributed on a 4-year cycle.

MDOT Carbon Reduction Strategy

Carbon Reduction Strategy will be updated every 4 years:

Inaugural CRS submittal: 2023

4-year update: 2027, 2031, 2035, 2039, 2043, 2047

This update includes the tracking and reporting of carbon reduction initiative performance metrics

The following are related climate and transportation related plans. As new metrics are identified and existing metrics are refined, they should be integrated into the related plans - see Appendix C for more details on this plan integration.

2022-2026	NEVI Formula Program Deployment, with updates every 4 years
2021-2045	MM 2045 Plan Period (Includes Long Rang Transportation Plan, Active Transportation Plan)
2021-onwards	CAV plan
2022-onwards	MI Future Mobility Plan
2023-onwards	State Transportation Implementation Plan (STIP) is updated every 4 years

4.1 Alignment with MDOT's Transportation Planning Process

Existing MDOT transportation plans were reviewed to determine alignment with existing goals, policies, and strategies for the Michigan transportation network. This assessment provided an understanding of how carbon reduction initiatives are already incorporated into MDOT plans and programs as well as guided an analysis of how the initiatives can be further woven into MDOT's transportation planning process. Plan and program summaries are provided in **Appendix D.** The analysis of plan alignment is presented in **Appendix C.**

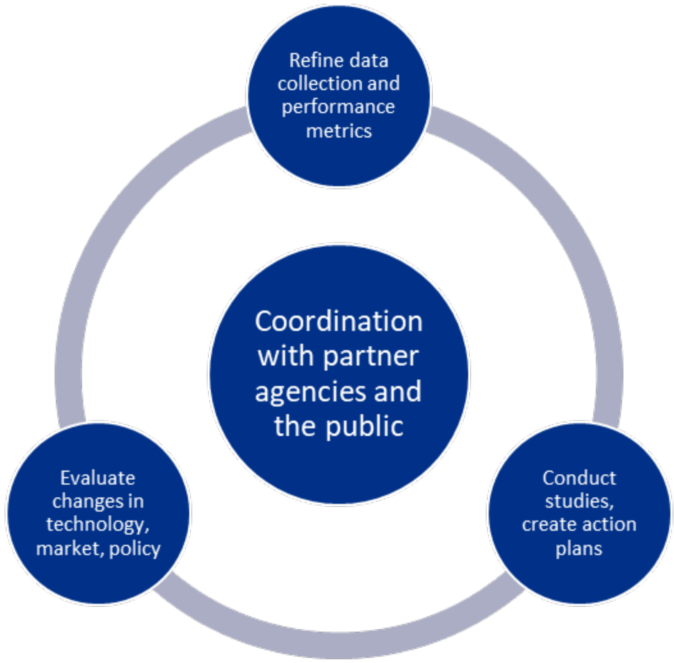
The goals, policies, and strategies identified were then used to guide the creation of performance metrics that MDOT and its transportation partners can use to quantitatively evaluate progress on implementing carbon reduction initiatives at both the planning and project-level scale to estimate reduction in carbon emissions achieved over time. These performance metrics were chosen for their specificity to the carbon reduction initiatives, such as progress towards a policy implementation compared to reductions in single occupancy vehicle hours traveled or VMT, and the feasibility of accurately gathering the data. The analysis also included a recommendation for which program the metric should be tracked in. Recommended carbon reduction performance metrics are presented in **Appendix C.**

Within the first four years of strategy implementation, MDOT will continue to refine data collection methods to assess carbon reduction strategy performance metrics. Refinement of data collection methods will be cost effective and initially focus on initiatives that result in significant carbon emission reductions. High priority performance metrics can be identified based on their ability to reflect the implementation progress of an initiative, accurately quantify emissions reductions, and MDOT's ability to reliably collect the data.

Each four-year update will include an assessment of strategies and re-evaluation of the carbon reduction initiatives. MDOT will consider results of future studies (See **Section 4.4 Additional Studies and Action Plans**), advancements in novel technologies (e.g., advancements in connected and autonomous vehicles), market availability of resources (e.g., low-carbon construction materials), developments in policies, and insight from complementary programs such as the NEVI program. The four-year updates will be made with continued coordination with stakeholders and the public.

Figure 17 illustrates the main elements of the four-year review cycle.

Figure 17. Major Elements of the 4-year Carbon Reduction Strategy Review Cycle



The next sections describe how MDOT and transportation partners can further the carbon reduction strategy roadmap implementation.

4.2 Agency Coordination

The responsibility for implementing the carbon reduction strategy initiatives will vary based on jurisdiction. Successful implementation of initiatives will therefore require strong coordination across agencies. In addition to this, MDOT must partner with regional planning organizations and other transportation partners to maintain sensitivities to local differences and leverage the knowledge and benefit of local best practices. Local jurisdictions and partner agencies may have opportunities to implement the initiatives in ways that are outside of MDOT's authority. For example, local governments may be able to tax parking structures or remove parking minimums in zoning ordinances as pricing adjustments for vehicles use; however, this is outside of MDOT's jurisdiction.

Agency Coordination Example: MDOT will further implementation of electric vehicle charging stations in coordination with partner agencies, such as was done through the development of the NEVI Plan. Partner agencies for the NEVI Plan included Michigan Department of Environment, Great Lakes, and Energy, the Michigan Department of Labor and Economic Opportunity, the Office of Future Mobility and Electrification (OFME), and the Michigan Public Service Commission (MPSC), with support from many other agencies.

One method to facilitate this partnership is to create a Carbon Reduction Strategy Working Group – a regularly scheduled gathering of representatives from partner agencies. MDOT can use these meetings to build relationships with the local agencies facilitate consistency in program implementation, and adjust programs to local needs. These meetings can be used to inform how this Carbon Reduction Strategy can be incorporated into metropolitan planning organization's plans and programs, the State Transportation Improvement Program, and state long-range transportation plans.

Development of a toolkit can be a useful resource that compiles educational resources, funding opportunities, and analytical tools tailored to different stakeholder groups with the goal of helping them plan their carbon reduction pathway, implement programs efficiently, and effectively measure process.

4.3 Public Outreach

MDOT's relationship with the public is critical for successful implementation of the carbon reduction initiatives. A stronger relationship with the public can enable better input regarding public needs, and improved information on the effectiveness and equity of actions taken. In addition, this relationship can foster a sense of participation in the public, encouraging communities to get involved in local solutions and stay informed in broader policies. To reach a variety of people, the format of public engagement must be diverse (face-to-face engagement, informational website, advertisements). The goal of public engagement is both to educate as well as gather feedback.

Education (informational booths, website, flyers/billboards, radio/TV advertisements): A best practice is for MDOT to be proactive in exposing the public to new technologies and ideas, educating to avoid common misconceptions, and spreading the word on tax incentives and pilot programs. Education is especially important for carbon reduction initiatives that are related to new technologies (e.g., electric vehicles, connected and autonomous vehicles technology), or are more likely to face pushback (e.g., incentives for transportation efficiency). It is important to explain the components of the different initiatives and be clear in communicating the environmental impacts and how the initiatives contribute to Michigan and MDOT's climate goals. Where applicable, MDOT can increase public engagement by communicating how each individual's participation contributes to climate impacts (e.g., "each time you choose to take the bus instead of a car, the quantity of CO_2 you avoid is equivalent to what a tree sequesters in nearly four months").

Gathering feedback (town halls, onsite surveys, website): Another best practice is for MDOT to regularly solicit feedback from the public to understand the effectiveness of its initiatives, identify confusing elements, and remain conscious of local and cultural sensitivities that require tailored approaches. Public constituents are likely to have insights that can improve program adoption or accuracy in data collection. MDOT can benefit from gathering public feedback both directly as well as secondhand from local agencies.

One idea to bolster a sense of community involvement is for MDOT and transportation partners to create carbon reduction challenges in which communities compete to increase participation in a certain carbon reduction initiative over a set time period (e.g., the community with the largest number of self-reported trips switching from single passenger vehicle to public transit would win). This challenge could leverage friendly competition to aid in education and spread the word about feedback mechanisms.

4.4 Recommended Studies and Action Plans

Additional studies and an action plan have been identified to further the initiatives identified in this plan and efforts to reduce transportation sector carbon emissions.

MDOT must implement its carbon reduction initiatives in coordination with the interconnected elements of its economy. A first step of this coordination is to conduct studies on the state's capacity for supporting certain changes to its transportation system. It is important that MDOT perform an evaluation of its energy capacity to understand how much more energy is needed to support vehicle electrification, and how to meet those needs with clean energy sources. It is important to quantify the portion of the future electrical capacity needs that can be supported by the grid, and what will need a grid independent solution. This study can be supported by a life cycle assessment to more comprehensively evaluate the embodied carbon emissions associated with electrical grid use and/or electric vehicle manufacturing and supporting infrastructure construction.

It is also important for MDOT to pursue an analysis of its workforce needs – understanding the current expertise of workers in the state (e.g., workers in the automotive industry are mostly focused on vehicles with internal combustion engines), and how the needs for different skills will change in response to decarbonization efforts and evolution of technology (e.g., an increase in EVs will drive a need for skills related to maintenance of vehicle charging stations). The workforce analysis should also include recommendations on how to support industries in upskilling the existing workforce, and partner with educational institutions to create a pipeline of workers that can support novel technologies.

MDOT can demonstrate potential local air quality benefits of a given carbon reduction initiative by conducting an air quality analysis. For example, the US Environmental Protection Agency MOVES model (currently MOVES4) can be used to determine emissions of CAP from motor vehicle engine exhaust, tire wear and brake wear. Several key pollutants from these sources include ozone-related pollutants (volatile organic compounds and nitrogen oxides) as well as fine particulate matter (PM2.5). The analysis approach would be to use MOVES to estimate these emissions prior to implementation of the initiative using known traffic activity data (volumes, VMT, and vehicles hours traveled) for the area. The post-implementation analysis could initially be performed on the anticipated reductions in the traffic activity levels, and/or could be conducted on traffic activity data collected after implementation of a specific carbon reduction project for the area.

Freight is an important element of MDOT's economy. An action plan to reduce freight-related carbon emissions would further reduce emissions associated with the transportation system. Currently, planning related to the reduction of freight-related carbon emissions are interspersed throughout MDOT's current plans. The Michigan Mobility 2045 Plan outlines major strategies and is supplemented by a State Rail Plan focused on both passenger rail and freight rail. Creating a freight specific carbon reduction action plan would give MDOT a dedicated space to document current efforts and identify opportunities for improvements to the freight network that support carbon reduction.

4.5 Alignment with MDOT Project Funding Frameworks

MDOT project funding frameworks, such as the State Transportation Improvement Program, can be updated to include criteria that prioritizes projects that align with the carbon reduction initiatives. It could be implemented in the form of a screening checklist or scoring method. The project funding frameworks can also give priority to carbon reduction related pilot projects that focus on new technologies or new geographies, since projects operating in new markets and locales often face unique site-specific barriers. Language can be included in request for proposals that makes it clear to bidders that projects showing coordination with this Carbon Reduction Strategy will receive points for this alignment. These changes can be reflected in MDOT's Mobility Planning Platform.

One idea to foster community creativity while targeting project alignment with this Carbon Reduction Strategy is for MDOT to host a competition for carbon reduction pilot projects or those that meet carbon reduction criteria. Projects could be evaluated by quantity of carbon reduction or level of creativity. A competition like this could help encourage consideration of these types of projects and foster innovation. The prize for these challenges and competitions could be special access to grants in partnership with MDOT.

4.6 Funding Allocations

MDOT intends to implement the Carbon Reduction Strategy into its transportation planning processes in two proactive ways. However, prior to Fiscal Year (FY) 2027, MDOT's trunkline program is established, and any additional projects will have a negative impact on an already inflated program. Therefore, to be fiscally responsible in implementing the Carbon Reduction Strategy, MDOT will use FYs 2022-2026 Carbon Reduction Program funding on existing Five-Year Transportation Program projects. Please see **Appendix F** for projects that are programmed to use this funding, as well as other currently programmed projects that align with this strategy but use other funding sources. The funding sources for projects in **Appendix F** are subject to change. Beginning in FY 2027, new projects could be selected to use these funds; however, this would require continued analysis of MDOT's overall financial constraint as the funds increase the Department's program by approximately $20 million annually.

For FY 2027 program funding, the first way that MDOT will implement the Carbon Reduction Strategy is by holding a Carbon Reduction Program (CRP) and Congestion Mitigation and Air Quality (CMAQ) Program Call for Projects next year to select trunkline projects to be obligated in 2027. This joint CRP and CMAQ Call for Projects will specifically solicit projects that align with the decarbonization strategies listed within this Carbon Reduction Strategy.

The second way MDOT intends to implement the Carbon Reduction Strategy is by integrating into the subcommittee reviews the consideration of decarbonization strategies as a project element during the annual Call for Projects process. This includes examining the potential of including identified decarbonization strategies into future trunkline projects so that the MDOT's highway program, in general, works toward decarbonization (i.e., not just relying upon the limited reach of the Carbon Reduction Program to achieve system decarbonization). Finally, for FYs 2022-2026, MDOT plans to follow this three-step process:

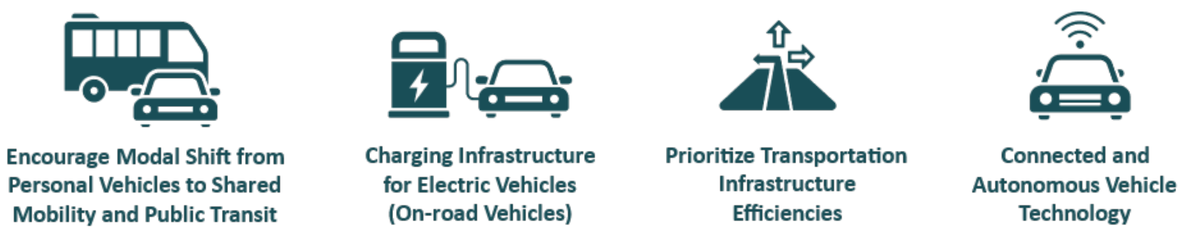
1. Transfer funds that cannot be spent on the Trunkline network to the Office of Passenger Transportation (OPT) to support transit operations.
2. Program some small new projects for the Trunkline network. This may have a small impact the effort to reduce overprogramming. As an example, these funds could be used on non-motorized projects, as this is an eligible CRP activity.
3. Provide funds that cannot be spent on the Trunkline network to the Local Program. This will require adjustments to other programs to maintain the 75% MDOT/25% Local split for Federal Aid.

5.0 Use Case Scenarios

Further analysis through use case scenarios was performed for four initiatives: (1) encourage modal shift from personal vehicle usage to shared mobility and public transit, (2) charging infrastructure for electric vehicles for on-road vehicles, (3) prioritize transportation infrastructure efficiencies, and (4) connected and autonomous vehicle technology, see **Figure 18**. The purpose of the use case scenarios is to further explore carbon reduction potential, implementation best practices to maximize carbon reduction, and considerations of disadvantaged communities and Justice40 Initiative policy to facilitate sustainable implementation.

The case scenario analysis provides a more detailed understanding of the selected initiatives using eight criteria to inform implementation best practices. The quantitative criteria describe an initiative's ability to reduce carbon emissions and air pollutants. The methodologies to quantify GHG and criteria air pollutant (CAP) emission reductions are compiled in **Appendix E**. The qualitative criteria analyze factors such as the initiative's associated job creation, climate resilience, and changes to the necessary infrastructure and operation of the transportation system. The eight criteria described in **Table 4** were reviewed and vetted with the Internal Advisory Committee and Regional Stakeholder Working Group.

Figure 18. Four Initiatives Identified for Case Scenario Analysis



These four use of system initiatives were selected to represent a diverse selection of MDOT carbon reduction initiatives currently underway that either had no conditional passes, conditionally pass desired criteria, or conditionally passed required and desired criteria during initial testing (refer to **Section 3**). These selected initiatives are not meant to suggest that MDOT will only be considering these four initiatives when implementing this Carbon Reduction Strategy. Rather, these four were simply selected for deeper exploration and carbon reduction quantification. The case scenarios presented herein provide best practices to implement state-wide carbon reduction projects and policies in a manner that maximizes carbon reduction potential, equitable implementation, and sustainable co-benefits to the environment and society.

The other 12 initiatives remain valuable to MDOT and will also be considered as MDOT begins to implement this Carbon Reduction Strategy into transportation planning processes.

Table 4. Case Scenario Analysis Criteria

Criteria	Description
Qualitative Criteria	
Agency Coordination	Does the initiative require partnership and/or coordination with State of Michigan agencies or other transportation partners?
Electrification Potential	Does the initiative have the potential to increase vehicle electrification?
Environmental Stewardship	Does the initiative provide co-benefits related to land use, climate resilience, and alignment with stakeholder objectives?
Access to Low-Carbon Public Transit	Does the initiative provide the opportunity to improve access to public transit options, clean energy and transportation accessibility?
Operational Infrastructure Impacts	When implementing the initiative, how can it change how the system and supporting infrastructure currently operates? How does the operation of the system change?
Job Creation	Is there a potential for long-term agency/operational jobs and/or localized economic development surrounding implementation of projects associated with the initiative?
Quantitative Criteria	
Carbon Emissions	What is the net change in carbon emissions or embodied carbon as a result of this initiative?
Criteria Air Pollutant (CAP) Emissions	What is the net change in CAPs emissions (I.e., net change in $PM_{2.5}$, VOC, NO_X) as a result of this initiative?

5.1 Findings of the Case Scenario Analysis

5.1.1 Encourage Modal Shift From Personal Vehicle Usage to Shared Mobility and Public Transit

Improvement and expansion of public transportation availability can lead to the displacement of emissions from personal vehicles.

Agency Coordination

Implementation of modal shift across the state will be most effective if coordinated and implemented in partnership with Michigan Planning Regions, rural and urban transit agencies, and ferry boat service agencies. MDOT's Office of Passenger Transportation will be vital in this coordination. Alignment of this initiative with existing transport plans include: the MI Healthy Climate Plan's key strategy to increase access to clean transport options (which encompasses public transit) by 15% each year, and the Michigan Mobility 2045 Plan's strategy to reduce the proportion of single occupancy passenger vehicle trips by enabling alternative modes of travel that are convenient, comfortable, and affordable.

Electrification Potential

Shared mobility and public transportation options can be electrified, including van pool, bus, rail, ferry, and more. Fleet electrification of public transit assets will not only improve air quality and reduce GHG emissions, but also reduce operational expenses related to fleet maintenance and fueling. To support this effort, the U.S. Department of Energy has compiled a blueprint for fleet electrification, which outlines key activities and technical resources that are publicly available.[4] Fleet electrification is already occurring in several of Michigan's transportation agencies, and MDOT's efforts should align and expand upon the work which is already underway.[5] [6] It is important to note that stakeholder engagement efforts related to the electrification of public transportation assets should engage not only current and potential riders, but also fleet managers, mechanics, drivers, and other support staff.

Environmental Stewardship

The improvement and expansion of public transportation can introduce a variety of environmental co-benefits beyond just GHG and CAP reductions. Transit stations and stops can include climate resilient features such as green stormwater infrastructure, shade and canopy cover, green roofs, urban wildlife and pollinator habitats, permeable and cool pavements, and natural ventilation and cooling.[7] Robust transit systems also make cities more resilient to major climatic or public health disruptions which leave carless people vulnerable.[8] Land use may be affected positively or negatively by this initiative, depending on the scenario by which modal shift is implemented; however, it is reasonable to assume that future improvements to multimodal access can be planned with minimal or negligible land burden associated. Where right-of-way acquisitions are necessary, they are likely to occur on land that has been previously developed or burdened, and additional burdens can be ameliorated or offset with vegetation and beautification, where practicable.

Access to Low-carbon Public Transit

Public transportation can be improved through low- or zero-carbon fuel sources and sustainable construction materials and practices, as mentioned for other criteria and initiatives. This initiative's GHG and CAP emission reduction potential are quantified and discussed in detail below, so the discussion in this criterion focuses primarily on transportation accessibility, rather than environmental benefits.

Supporting a modal shift from personal vehicle usage to shared mobility and public transit will necessitate improved access to encourage new riders. Transportation accessibility should be considered through a variety of lenses. **Table 5** provides resources and studies pertaining to several dimensions of public transportation accessibility.

Table 5. Summary of Resources to Guide Accessible Public Transportation

Type of Accessibility	Demographic Being Served	Resource(s) to Guide Implementation
Physical	Elderly and/or disabled persons; all riders	International Association of Public Transport: "How to make public transport accessible and inclusive for all" (2021) https://www.uitp.org/news/how-to-make-public-transport-accessible-and-inclusive-for-all/ National Aging and Disability Transportation Center: "Toolkit for the Assessment of Bus Stop Accessibility and Safety" (2014) https://www.nadtc.org/wp-content/uploads/NADTC-Toolkit-for-the-Assessment-of-Bus-Stop-Accessibility.pdf TRIPS: "Views of persons with disabilities on future mobility" (2021) https://trips-project.eu/wp-content/uploads/2021/06/D2.1-TRIPS-White-Paper.pdf
Lingual	People with Limited English Proficiency[1]	Jeng, E., NYU Rudin Center for Transportation: "Improving Language Access on NYC Transit" (2023) https://wagner.nyu.edu/rudincenter/2023/01/improving-language-access-nyc-transit

Type of Accessibility	Demographic Being Served	Resource(s) to Guide Implementation
Informational/ Intellectual	People with intellectual disabilities (may include difficulties in comprehension, memory, reactivity, etc.); people accessing transit information from a personal device; all riders	van Holstein, E., Wiesel, I., & Legacy, C.: "Mobility justice and accessible public transport networks for people with intellectual disability" (2022) https://www.tandfonline.com/doi/abs/10.1080/23800127.2020.1827557 Gervais, Z., Inclusive City Maker: "Public Transport: Accessibility Solutions, Also for the Intellectual Disability!" (2019) https://www.inclusivecitymaker.com/transport-accessibility-intellectual-disability/
Economic	Low-income people; frequent riders; all riders	National Aging and Disability Transportation Center: "Understanding Half Fare/Reduced Fare Requirements" (2018) https://www.nadtc.org/news/blog/understanding-half-farereduced-fare-requirements/ Massachusetts Institute of Technology, Department of Urban Studies and Planning: "How Low-income Transit Riders in Boston Respond to Discounted Fares: A Randomized Controlled Evaluation" (2019) http://equitytransit.mit.edu/
Connectivity	Elderly and/or disabled persons; people connecting from public transportation to a different mode of transportation (bike, walk, carpool, etc.)	National Association of City Transportation Officials: "Transit Street Design Guide Pedestrian Access & Networks" (2016) https://nacto.org/publication/transit-street-design-guide/transit-system-strategies/network-strategies/pedestrian-access-networks/

NOTES:
1 https://dol.ny.gov/limited-english-proficiency-and-language-access

Public transportation is most effective when it is implemented with land use and population density in mind (e.g., stops located near employment centers, businesses, and more dense residential areas). Public transportation may be most beneficial when focused in areas with higher populations and/or when focused on commuters by connecting park and ride locations to major employers. Potential projects which may broadly lead to greater public transportation accessibility include complete streets designs that connect bicycle and pedestrian infrastructure to transit, mixed-use and transit-oriented developments, buses which are accessible to bikes/strollers/mobility devices, expanded micromobility options such as bike shares and scooters, improvements to the cleanliness, safety, and appearance of transit stops, improvements to real-time route information, and additional station or vehicle amenities such as Wi-Fi and device charging. Thoughtful expansion and improvement of low-carbon public transportation also contributes to environmental goals; in fact, moving away from car-centric infrastructure can reduce city-wide transportation fuel use by approximately 25%.[9] Further, Flint Michigan has a demonstration project underway where an existing hydrogen fuel cell bus will be upgraded to be able to function as an energy source that could support a community organization's facilities in the event of a power outage. This demonstration project highlights the potential multipurpose benefits of communities investing in hydrogen fuel cell buses.

Carbon emission reductions resulting from mode shift are mostly attributed to urban areas; however, rural areas should not be excluded from the development of multimodal access to public transportation. Rural locations may have prevalent populations that would be served by transit, such as elderly or disabled persons and veterans. Rural areas may also contain non-driver attractions such as colleges or universities, retirement communities, or tourism locations. Limited fixed-route, on-demand services such as local bus routes, van pools, or interregional bus routes to urban centers could be effective in rural areas.

such as local bus routes, van pools, or interregional bus routes to urban centers could be effective in rural areas.

Operational Infrastructure Impacts

Expanded or improved public transportation systems may lead to operational changes such as the introduction of transit signal priority (TSP), bus lanes, and Bus Rapid Transit (BRT) operations, and upgraded crosswalks and pedestrian areas such as bus bulbs. Additionally, electrification of public transportation assets would also create operational changes with charging locations and electric vehicle range in mind.

Job Creation

Expansion and maintenance of public transportation is proven to create jobs and economic growth and can support job retention or improve quality of life by providing routes to job centers. Public transportation benefits local businesses by connecting people to stores, entertainment, and other organizations; promoting economic development near public transportation stops.[10] Investment in public transportation has been shown to generate 31% more jobs per dollar than construction of new roads and bridges.[11] Specifically in large cities, multimodal transit availability has been shown to provide economic benefits through reducing traffic congestion, reducing time spent commuting, and increased productivity.[12] Additionally, public transportation investment often leads to long terms jobs in the public sector, such as drivers, maintenance workers, administrative, and other transportation agency workers, and private sector jobs in parts and materials manufacturing[13] The American Public Transportation Association estimates that $1 billion spent on public transportation capital investment creates 24,000 jobs, and $1 billion spent on public transportation operations supports or creates over 41,000 jobs[14] These jobs are not limited to the transportation sector, as multi-use transit hubs can lead to economic development and new jobs in the service, security, retail, custodial, and creative industries.[15], [16] In addition to the creation of new jobs, this initiative is anticipated to require workforce development of the labor directly associated with public transportation. As the public transportation system is improved and potentially electrified, fleet managers, drivers, and technicians may be required to learn energy efficient driving behaviors, new operational strategies, and methods of repair and maintenance for electric vehicle assets. The U.S. DOE blueprint to fleet electrification provides resources for workforce development and training.[17]

Carbon Emissions

Mode shift from personal, single-occupancy vehicles to bus or rail has the potential to significantly reduce carbon emissions. Diverting gas-fueled ICE vehicles to increase bus ridership by 0.1% per year is projected to result in a statewide GHG reduction of 170.8 MT CO_2e/year. The 0.1% increase in bus ridership was obtained by averaging two bus ridership targets from relevant study areas (Ohio and the Midwest region) to obtain a reasonable, obtainable target of increased bus ridership. The emission factor used to calculate bus emissions was derived from Michigan's 2015 MOVES model, which accounts for a mixture of diesel, electric, and other alternative bus fuels. The calculation of emissions reduction accounts for both the emissions saved from diverting personal vehicle trips, as well as the additional emissions created by additional bus service. The calculation also recognizes that most buses are not full at all times, and it accounts for this by assuming 10 passengers per bus, which is average for Detroit. It is also noted that Detroit is the largest city in Michigan by population, and local bus services in other cities may experience higher or lower bus ridership, on average.

For rail, a 0.1% per year mode shift of passenger miles travelled from gas-fueled personal vehicle to diesel-fueled commuter or high-speed rail is projected to lead to GHG reduction of 31,024 MT

CO_2e/year. The 0.1% per year mode shift was derived from a study predicting mode shift in the Midwest region following investment in regional high-speed rail and improvements (e.g., to frequency or comfort) of both high-speed rail and commuter rail. Improving and investing in bus and rail networks in Michigan can lead to these mode shifts and associated GHG savings.

Carbon emissions reduction potential of mode shift can be further reduced with use of low-carbon or zero emissions fuels for transit. Nationally, bus fleets are being actively converted to run on compressed natural gas, renewable natural gas, and hydrogen fuel cells. Electrification of bus and rail transit has also been implemented.

CAP Emissions

Similar air quality benefits are attainable for CAP emissions when encouraging mode shift to bus and rail. Diverting gas-fueled ICE vehicles to increase bus ridership by 0.1% per year is projected to result in a statewide reduction of 0.211 short tons NOx/year, 0.005 short tons $PM_{2.5}$/year, and 0.264 short tons VOC/year, assuming a mixture of bus fuel sources which is realistic to Michigan's fleet at the time the MOVES data was developed. For rail, a 0.1% per year mode shift of passenger miles travelled from gas-fueled personal vehicle to diesel-fueled commuter or high-speed rail is projected to lead to a reduction of 46.5 short tons of VOC/year, and increases of 17.5 and 0.05 short tons/year of NOx and $PM_{2.5}$, respectively. The increases in NOx and $PM_{2.5}$ in spite of the mode shift to public transportation is due to the shift in fuel source; high-speed and commuter rail are commonly diesel or diesel-electric, which emit more NOx and $PM_{2.5}$ per unit burned than motor gasoline. Though the assumption of diesel-run rail is part of this calculation of CAP emissions, electrification of rail, especially light rail, is a feasible possibility which could even further reduce GHG and CAP emissions. Encouraging mode shift through the improvement and expansion of low-carbon bus and rail networks in Michigan can lead to mode shifts and associated air quality benefits.

5.1.2 Charging Infrastructure for Electric Vehicles for On-Road Vehicles

Introduce more charging stations, specifically direct current fast charging (DCFC) for this analysis, into the current infrastructure, allowing all electric vehicle owners to recharge quickly on the go, resulting in the encouragement of a wider adoption of electric vehicles and a displacement of ICE vehicles.

Agency Coordination

To further electric vehicle implementation, coordination is expected among numerous agencies including but not limited to the Michigan Infrastructure Office, Department of Environment, Great Lakes, and Energy, the Office of Future Mobility and Electrification, and the Michigan Public Service Commission. Coordination with neighboring states would also support continuity of electric vehicle infrastructure across state lines. Alignment of this initiative with existing transport plans include: the MI Healthy Climate Plan's and the Michigan Future Mobility Plan's goal to build the necessary infrastructure (100,000 electric vehicle chargers) to support 2 million electric vehicles on Michigan roads by 2030, as well as the Michigan Future Mobility Plan's initiative to build out charging infrastructure on popular routes in the state. Further, this initiative could build upon the efforts of Michigan's State Plan for Electric Vehicle Infrastructure Deployment. The plan was developed to guide Michigan's direction for successful deployment of NEVI program funds to implement electric vehicle charging infrastructure and establish an interconnected network of charging infrastructure across states.

Electrification Potential

This initiative will increase the total number of public DCFC stations, creating a more reliable travel network for electric vehicles within the state. With more fast chargers readily available to the public, more people will feel comfortable purchasing electric vehicles, as they are the most useful charger for electric vehicle users while on the go. As electric vehicle usage increases, periodic assessment of the electrical grid capacity and needs for local supporting infrastructure should be performed. MDOT implements initiatives through the Future Mobility Plan to encourage off-peak charging of electric vehicles to help mitigate burdening the electrical grid.

Environmental Stewardship

With best practices in place, this initiative can have a neutral impact on land use burden. Charging infrastructure is expected to be added to developed lands, such as parking lots, gas stations, retail centers, tourist destinations, and roadways with high demand.[18] Development of unused land may be required for more rural installation and natural areas, such as State or National Parks.[19] In this case, additional electricity infrastructure may be required, and local authorities should perform an impact analysis to ensure as minimal land impacts as possible.[20]

This endeavor offers the potential for enhancing emergency disaster readiness and response. It could enable the recharging of emergency vehicles powered by electric vehicles and harness electric vehicles as a potential backup power source during electric system outages. Additionally, it can achieve resilience through the integration of green infrastructure and the implementation of safeguards against wind, heat, and flooding. Such measures include avoiding construction in future flood-prone areas, employing lighter-colored pavement to reduce heat absorption, and establishing wind-control barriers.

Access to Low-carbon Public Transit

There are no clear indications that the implementation of charging infrastructure will have a positive or negative impact on accessibility to low-carbon public transit. One potential negative impact of expanding electric vehicle charging infrastructure includes inadvertently promoting private electric vehicle usage over public transit, potentially undermining the broader environmental, societal, and economic benefits associated with robust public transit systems. A strategy to introduce new electric vehicle charging infrastructure and bolster public transit ridership involves strategically locating electric vehicle chargers in areas already well-connected to public transit, such as park and ride facilities.[21] By placing electric vehicle chargers at these transit-accessible hubs, this will not only encourage the use of park and ride services but also facilitate seamless transitions to public transportation for commuting and accessing commercial centers.

Operational Infrastructure Impacts

There are no significant operational impacts when implementing electric vehicle charging infrastructure. A potential impact can include that the current system will gain a greater access to charging ports, as well as an increase of electric vehicles, however there will be no significant change to its current operations. Electric vehicles are acting as a replacement for ICE and behave similarly to them as a result, creating a negligible effect on the system itself.

Job Creation

The construction of charging infrastructure is expected to have a potential for both long-term employment/operational job creation and localized economic development; however, may require efforts to reskill workers. Argonne's JOBS EVSE model projected that one individual state plan could create nearly 274,000 jobs associated with charging stations over the next 10 years.[22] With a nationwide buildout goal of 500,000 electric vehicle DC fast chargers by 2030, employment opportunities will increase within multiple different work-sectors. These jobs would include electricians, general contractors, planning and design, electrical contractors, as well as sales and marketing job roles. The electrician role, which will be the primary work-sector that install/operates on these projects can acquire certifications like the Electric Vehicle Infrastructure Training Program that will compliment/better prepare an electrician to perform installation and operational maintenance on electric vehicle charging infrastructure. The data for impacts on local businesses within the immediate vicinity is limited, but there is some research indicating that the availability of electric vehicle charging at retail and commercial locations shows a positive relationship with real estate values.[23]

Carbon Emissions

The average annual amount of charging that occurs at a DCFC port directly correlates with the displacement of ICE VMT by replacing ICE VMT with electric VMT, resulting in overall tailpipe carbon emission reduction. To be NEVI compliant, a DCFC port must have a capacity of 150 kilowatts. Today, electric vehicles' average fuel economy is 0.321 kWh/mile. This means that for each DCFC port added to a system, there is 102.09 MT CO_2e reduction in tailpipe emissions based on an annual displacement of 204,673 ICE VMTs. These calculations do not account for the electricity emissions required for electric vehicle charging, therefore resulting in a decrease in emission reduction benefits.

CAP Emissions

This approach is the same as it is for CO_2e, with the ICE emission factors representing each respective CAP, instead of CO_2e. The annual tailpipe CAP emissions reduced per DCFC port is 639 pounds total CAPs. This value is the sum of NOx, VOC, and PM2.5 emissions.

5.1.3 Prioritize Transportation Infrastructure Efficiencies

Replacing intersections and interchanges with more efficient infrastructure, more specifically Diverging Diamond Interchanges (DDIs) and roundabouts, can reduce congestion, improve traffic flow, and reduce vehicle hours traveled, which could result in a reduction of carbon emissions associated with the use of system. Other efficiencies that are capable of showcasing this improvement but are not included in our analysis include interconnected signals, signal re-timings, and added lanes.

Agency Coordination

MDOT is able to prioritize transportation infrastructure efficiencies within MDOT owned right-of-way without requiring coordination with other agencies. However, prioritizing such efficiencies beyond MDOT right-of-way will be most effective in coordination with Michigan Planning Regions.

Electrification Potential

There is no indication of a positive or negative impact on the electrification potential for transportation efficient infrastructures.

Environmental Stewardship

The land use burden of this initiative is entirely dependent on the site of the proposed project. Both roundabouts and diverging diamond interchanges can have significant land impacts depending on the site-specific details of the project. Once-site specific details are identified, proposals should be reassessed and mitigate land burden wherever possible. These site-specific details include what infrastructure is already present, what infrastructure is being built, the surrounding community, and its urban or rural setting. Roundabouts have a much higher land usage than a traditional four-way intersection, however it can be offset through the reduction in idling/queuing, as well as a space for vegetation in the center island.[24] While land impact does not drastically change for diverging diamond interchanges, they may require the development of new infrastructure, such as new ramps or lanes, which could significantly impact land use burden.

By optimizing roadways for greater efficiency, this initiative offers the potential to enhance emergency disaster preparedness and response. This improved infrastructure facilitates smoother navigation for emergency responders without introducing redundancy into the transportation system. Additionally, resilience can be achieved through the inclusion of green infrastructure and the implementation of measures to mitigate wind, heat, and flooding risks. This could include green stormwater infrastructure, shade and canopy cover, and urban wildlife and pollinator habitats. Strategies can also include avoiding future construction in flood-prone areas, selecting lighter-colored pavement to reduce heat retention, and installing wind control barriers.

Access to Low-carbon Public Transit

Access to low-carbon public transportation is heavily dependent on the existing and new infrastructure, as well as the surrounding transportation network. With roundabouts being proven to be safer than traditional four-way intersections, riders may feel more comfortable taking public transportation and waiting at an intersection-adjacent station.[25] This can also be said for DDIs, as they help to reduce the number potential conflict points and reduce speeds, creating a greater comfortability to utilize low-carbon public transportation.[26] However, this willingness would be contingent upon the rider’s own perception of safety. MDOT and transportation partners can encourage high feelings of safety through public education and outreach about navigating a roundabout as a pedestrian, cyclist, or driver. For DDI construction, it was found that construction could include expanded accommodations for public transportation, such as bus shelters, pick-up and drop-off points, and nearby park-and-ride facilities, as well as expanded space for pedestrians and cyclists traversing the interchange bridge(s).[27] The reduction in time delays for both infrastructures could also benefit accessibility to low-carbon public transportation. With fewer time delays and a timelier public transit network, people may be more comfortable utilizing public transportation, creating a boost to ridership.[28]

Operational Infrastructure Impacts

Transportation efficient infrastructure can drastically change the area that it surrounds with a decrease in idling times and an improvement in traffic flow. A decrease in these delay times can create a more efficient transportation system, which will overall decrease the level of congestion within an area during peak traffic hours, as well as during peak travel months. The system will also likely see a decrease in the number of collisions that are caused by current infrastructure, improving not only the flow of traffic, but the safety of drivers who are entering the system.[29]

Job Creation

There is limited potential for long-term job creation for the prioritization of infrastructure efficiencies. While it is still a relatively new field for research, there have been a few case studies that showcase the potential benefits for local businesses that are located near these infrastructures, as improved traffic flow could attract and improve access to more businesses and new developments.[30]

Carbon Emission

DDI and roundabout infrastructure calculated the reduction in carbon based on the time improvement and decrease in idling emissions for each infrastructure. With a time improvement of nearly 23 seconds for a DDI, and 58.3 seconds for roundabouts, the total CO_2e reduction potential is 46.70 and 55.55 MT

CO2e per year, respectively, for each infrastructure that is constructed. This value is based on the percentage of peak traffic hours in a day, which for this initiative is 20%.

CAP Emissions

The same approach that was used for CO2e was used for the calculations of CAP emissions. The total CAP emissions that were reduced for a DDI was 65 pounds per year for each DDI constructed. The total CAP emission that were reduced for a roundabout was 77.84 pounds per year for each roundabout that was constructed. The CAPs that were measured include NOx, PM2.5, and VOC.

5.1.4 Connected and Autonomous Vehicle Technology

Incorporating vehicle-to-vehicle technology and vehicle to infrastructure technology to improve traffic flow and reduce accidents.

Agency Coordination

MDOT is presently spearheading CAV implementation through research and pilot projects in coordination with numerous partners such as the Michigan Office of Future Mobility and Electrification and Department of Labor and Economic Opportunity. Further CAV implementation is expected to maintain and expand these partnerships. Alignment of this initiative with existing transport plans include MDOT Connected and Autonomous Vehicle Strategic Plan's suggested actions to strategically invest in interaction upgrades for CAV, evaluate uses of data from CAV, and continuing to support the safe testing and development of CAV.

Electrification Potential

CAVs are not necessarily also electric vehicles; CAV refers to the way the vehicle is controlled, whereas electric vehicle refers to the vehicle's power source. CAVs can and do make use of traditional gas/diesel engines.[31] With this in mind, though, the implementation of CAV technology does have high potential to increase vehicle electrification. As compared to gas or diesel engines, electric vehicle engines create environmental benefits, have more stable power sources, are safer to refuel autonomously, and have lower latency and quicker engine response times. For these reasons, commercial and academic sources are proposing and anticipating that CAV deployment will rely heavily or exclusively on electric vehicles.[32] This attitude will contribute to greater market availability and price competitiveness of electric vehicle CAVs. Likewise, CAV infrastructure can also make electric vehicles more attractive. CAVs can communicate live with connected charging infrastructure, which could reduce passenger anxiety about their electric vehicle CAV's range and the availability of a charger nearby. Additionally, integrating CAVs with charging technology can provide greater information about electricity usage and demand, which can contribute to optimized grid management for a region or urban area overall.[33] These features of CAV technology may alleviate some common passenger or planner concerns about electric vehicles, creating a positive feedback loop in which CAVs and electric vehicles work harmoniously to improve the overall reliability and efficiency of the transportation system.

Environmental Stewardship

CAV technologies promote environmental stewardship by avoiding land burden and preventing tailpipe emissions that lead to climate change. Very little new land acquisition or usage will be necessitated for CAV technology. Almost all new CAV infrastructure will be installed at previously developed areas. Examples include charging stations for electric CAVs in parking lots and fueling stations, curb use designations in urban areas, and signalized intersections. CAV technologies can include the ability to allow vehicles to strategically avoid areas impacted by climate hazards such as flooding, severe storms, or other inclement conditions like fog and smog. CAV technology reduces VMT, which lowers GHG emissions and minimizes the impact of climate change.

Access to Low-carbon Public Transit

Existing connected and autonomous public transit is a new and developing technology. As fleet vehicles are more easily transitioned to alternative fuels than privately owned vehicles, pilot projects are ongoing across the country. Many of these projects are funded by the Biden Administration's BIL and IRA. One example pilot project was carried out at the University of Michigan in Ann Arbor. The Mcity Driverless Shuttle operated on a non-stop one-mile route at U-M's North Campus Research Complex (NCRC) on Plymouth Road and transported members of the college community.[34] Another self-driving bus pilot program occurred at the University of Iowa. This bus, contrary to the University of Michigan's shuttle, traveled hundreds of miles throughout rural Iowa.[35] These pilot projects will inform both urban and rural connected and autonomous public transit investments in the future.

Operational Infrastructure Impacts

CAV technology can greatly improve the operational efficiency of the transportation system. CAV technology incorporates communication and connection with the following: vehicle-to-vehicle, vehicle-to-pedestrian, vehicle-to-infrastructure, and vehicle-to-surroundings. Sending, receiving, and interpreting alerts with computer-driven autonomy allow vehicles to perform with more information about the possible hazards and adjust their paths immediately. This capability decreases the number of crashes attributed to human error, reduces VMT, lowers congestion and related delay time,[36] and increases user safety. The existing infrastructure to support CAV operation is limited. Investments in infrastructure needed to support statewide CAV deployment include designated lanes, ITS, roadside units to accommodate low-capacity onboard units, and roadside monitoring locations.

Job Creation

As the workforce transforms amid new technology such as CAVs, retraining efforts will be required to maintain the existing labor force and even create new jobs. Driverless CAV vehicles and shuttles require ambassadors onboard in the case of a technological issue or rider emergency. Therefore, the implementation of CAV technology should include the retraining of ICE vehicle operators to work with new and emerging technologies. Roadway maintenance including restriping, pavement preservation, and signage updates is paramount to ensure optimal operations of CAVs. This added maintenance frequency would introduce job opportunities.

Carbon Emissions

Within this analysis, GHG reduction from CAVs occurs due to congestion mitigation and decreased travel and idle times.[37] Connective urban technologies such as dynamic traffic lights, dynamic routing, and smart traffic junctions communicate with CAVs to provide more efficient routes and driving practices, thereby reducing carbon emissions. In this analysis, it was assumed that the aforementioned infrastructure technologies would be deployed and that there would be a 20% penetration rate of CAVs across all of Michigan. Based on a review of CAV technology performed in Iowa, 20% CAV penetration rate appears reasonable for Michigan within the short-to-medium term, given that connected infrastructure technologies are also deployed to make the CAV system robust and attractive to CAV passengers and developers.[38] Based on these two assumptions of CAV technology deployment, Michigan's estimated GHG emissions reduction is 6.24 million metric tons CO_2e/year. This figure is based upon an approximate 10-18% reduction of baseline CO_2 emissions, depending on the population of the region of deployment. In densely populated areas where congestion and idling are common problems, GHG reduction will be higher than that of less dense suburban or rural areas where idling emissions are already less prevalent. Additionally, CAV technology is more effective in reducing emissions during times of non-peak traffic; this is because CAV technologies cannot optimize performance as well during peak traffic hours when maximum road capacity is more likely to be exceeded. Refer to the methodology in **Appendix E** for further details regarding the assumptions and conditions of CAV deployment. It is notable that the methodology does not consider the fuel source of the CAVs. GHG reductions are based solely on congestion mitigation, not the potential for CAVs to be ZEVs as well.

It should be noted that as compared to other case scenarios explored above, CAV deployment in particular may be associated with complex changes in system-wide GHG emissions. CAVs are a disruptive technology, and they could transform urban environments and personal transportation. This transformation will be associated with some activities that reduce GHG emissions and other activities which add additional emissions to the system (such as induced demand from mitigating congestion). Activities which reduce emissions include encouraging shared mobility, efficient routing and driving practices, and future land use changes such as lower demand for urban parking space. Additionally, CAV deployment can heavily or exclusively utilize ZEVs, which would lead to even greater GHG reduction when coupled with CAV's congestion mitigation benefits. On the other hand, CAV deployment will also lead to additional GHG-emitting practices, such as increased trip demand, reliance on cars, construction of new infrastructure and associated land changes, and the potential for riderless cars making trips without transporting people or goods (for example, a CAV driving itself back to a parking location after delivering a passenger).[39] CAV deployment must be implemented with great consideration in order to achieve net GHG reduction over time.

CAP Emissions

Under the same assumption of 20% CAV penetration and additional urban connective technologies in place, statewide CAP emission reductions are estimated to be 9,679 short tons NOx/year, 166.3 short tons $PM_{2.5}$/year, and 6,705 short tons VOC/year, for a total of 16,550 short tons CAPs/year. Refer to methodology in **Appendix E** for further calculation details.

6.0 Key Definitions

Best practices: Measures and methods to implement a process or activity.

Bipartisan Infrastructure Law: A public law providing long-term investment in the U.S. infrastructure and economy. This may also be known as the Infrastructure Investment and Jobs Act (IIJA).

Carbon baseline: Calculation of estimated existing greenhouse gas emissions resulting from Michigan's transportation sector.

Carbon dioxide equivalent (CO_2e) emissions: A measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential, by converting amounts of other greenhouse gases to the equivalent amount of carbon dioxide with the same global warming potential.

Carbon Reduction Strategy: A plan of action or policy designed to achieve reductions in carbon emissions, in alignment with the Bipartisan Infrastructure Law.

Criteria Air Pollutants (CAP): Air pollutants for which acceptable levels of exposure can be determined and for which an ambient air quality standard has been set.

Diverging Diamond Interchange (DDI): A type of diamond interchange where the two directions of traffic on a non-highway road cross to the opposite side on both sides of a bridge.

Equity: Fairness and justice recognizing that not all people start from the same place and adjustments may be necessary to address imbalances.

Initiative: An act or series of actions intended to resolve an issue (i.e., reduce carbon emissions).

Intelligent Transportation Systems: The application of sensing, analysis, control, and communications technologies to ground transportation to improve safety, mobility, and efficiency.

Internal Combustion Engine (ICE): A heat engine that uses a fuel and air mixture to produce work.

Justice40 Initiative: An executive order requiring federal agencies to work toward the goal that 40% of the benefits of certain federal investments flow to disadvantaged communities that are marginalized, underserved, and overburdened by pollution.

Use of Systems: A carbon reduction strategy area that focuses on elements associated with the use of transportation infrastructure.

Vehicle Miles Traveled (VMT): The number of miles a vehicle traveled.

Endnotes

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[28] https://nacto.org/publication/transit-street-design-guide/introduction/why/reliability-matters/

[29] https://www.fhwa.dot.gov/publications/research/safety/07048/, https://www.fhwa.dot.gov/publications/research/safety/00067/000675.pdf

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Appendix A Capital Projects Construction Baseline Graphics

The following figures present a breakdown of CO_2e emissions for the construction of Capital Projects by the type of construction material required based on the Federal Highway Administration's Infrastructure Carbon Estimator (version 2.1) tool. In addition, the following figures present the total emissions for new construction of roadways and additional lane construction for roadways by road type (e.g., rural interstate versus urban interstate).

Figure A.1. Emissions Baseline for Roadway Construction, New Construction

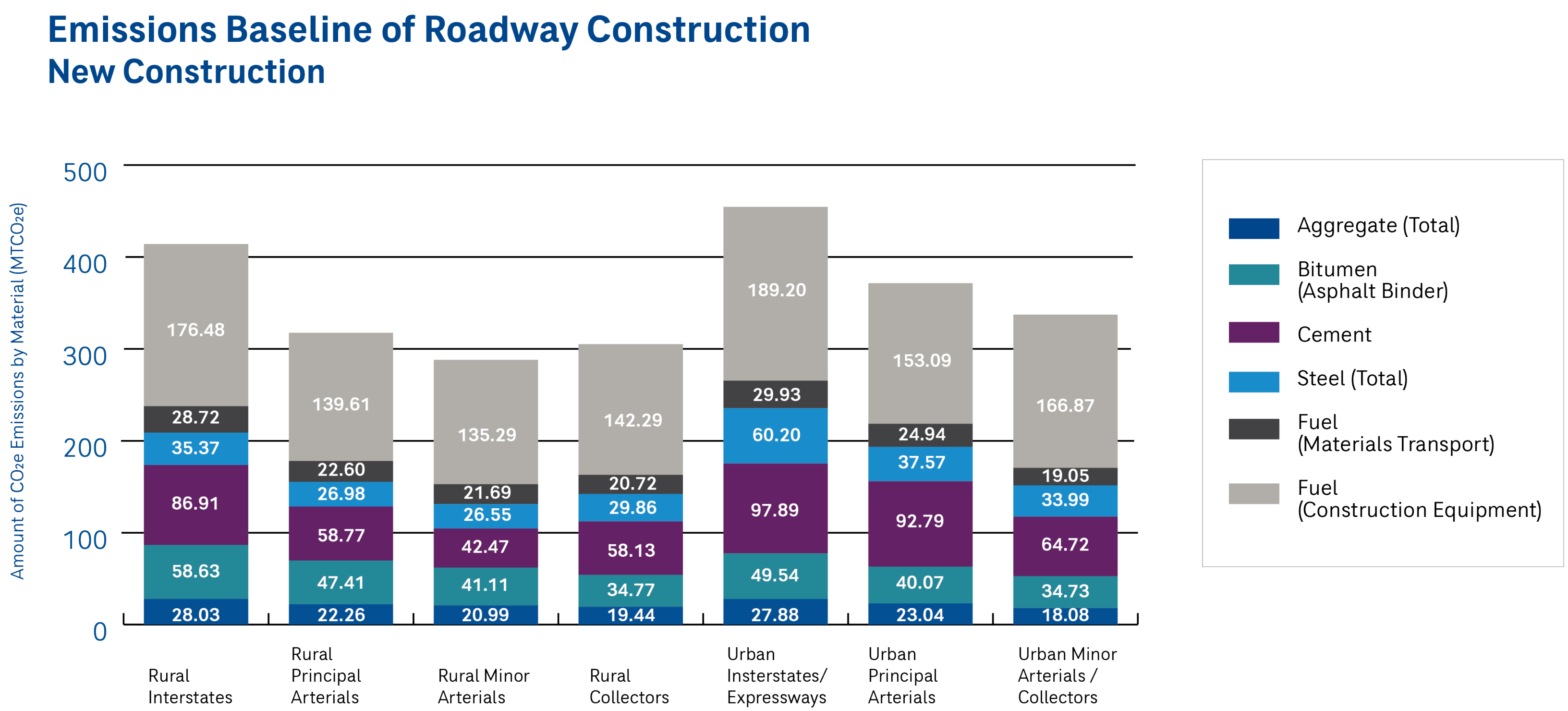


Figure A.2. Emissions Baseline for Roadway Construction, Construct Additional Lane

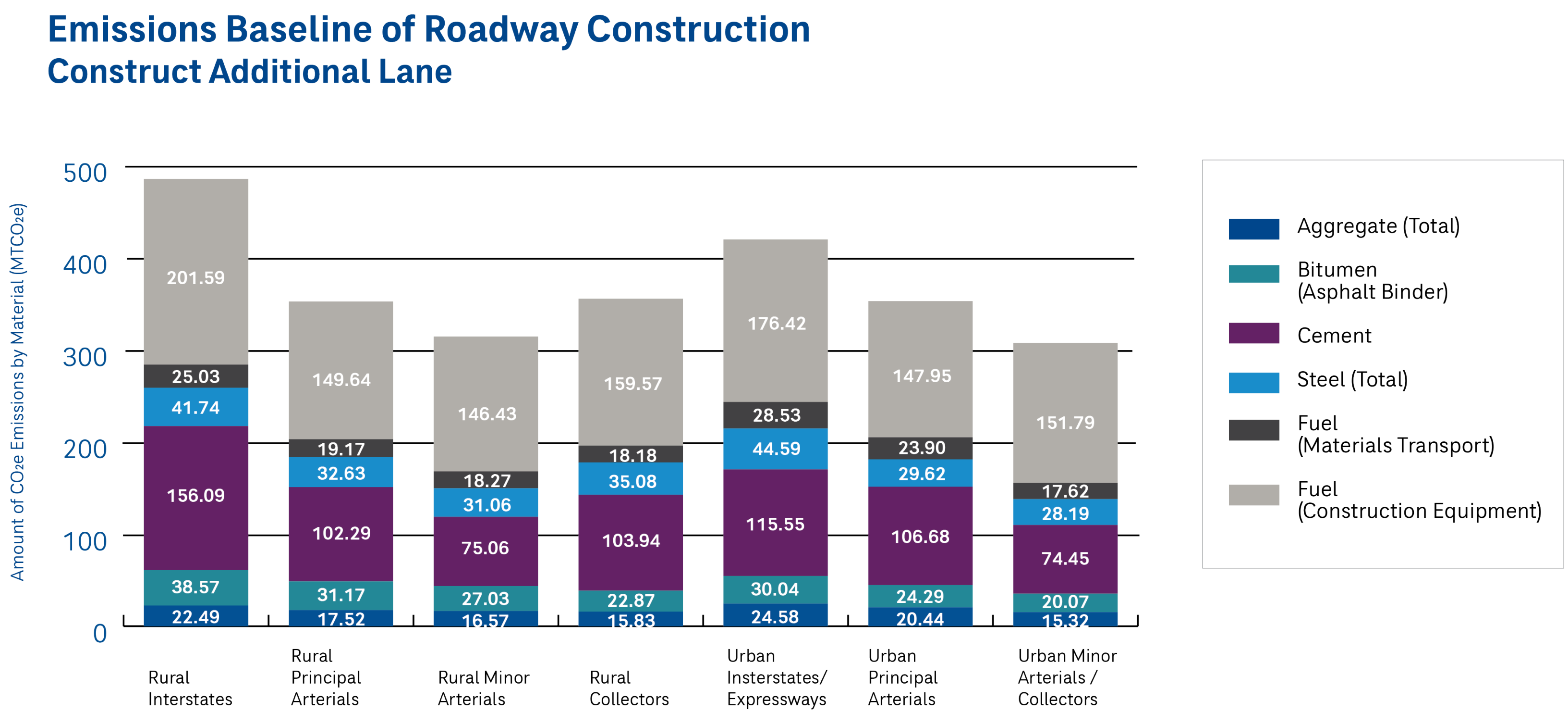


Figure A.3 Emissions Baseline for Roadway Construction, Realignment

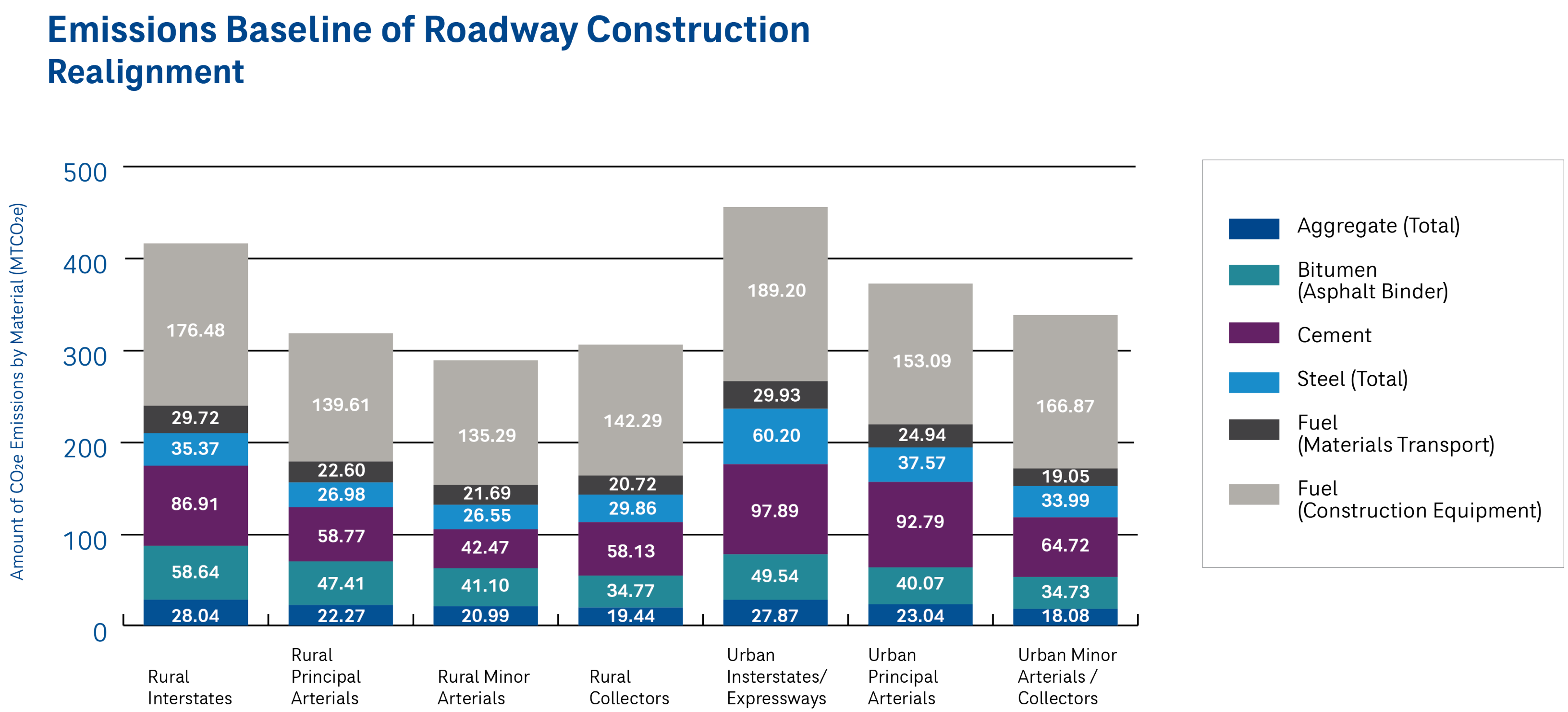


Figure A.4. Emissions Baseline for Roadway Construction, Lane Widening

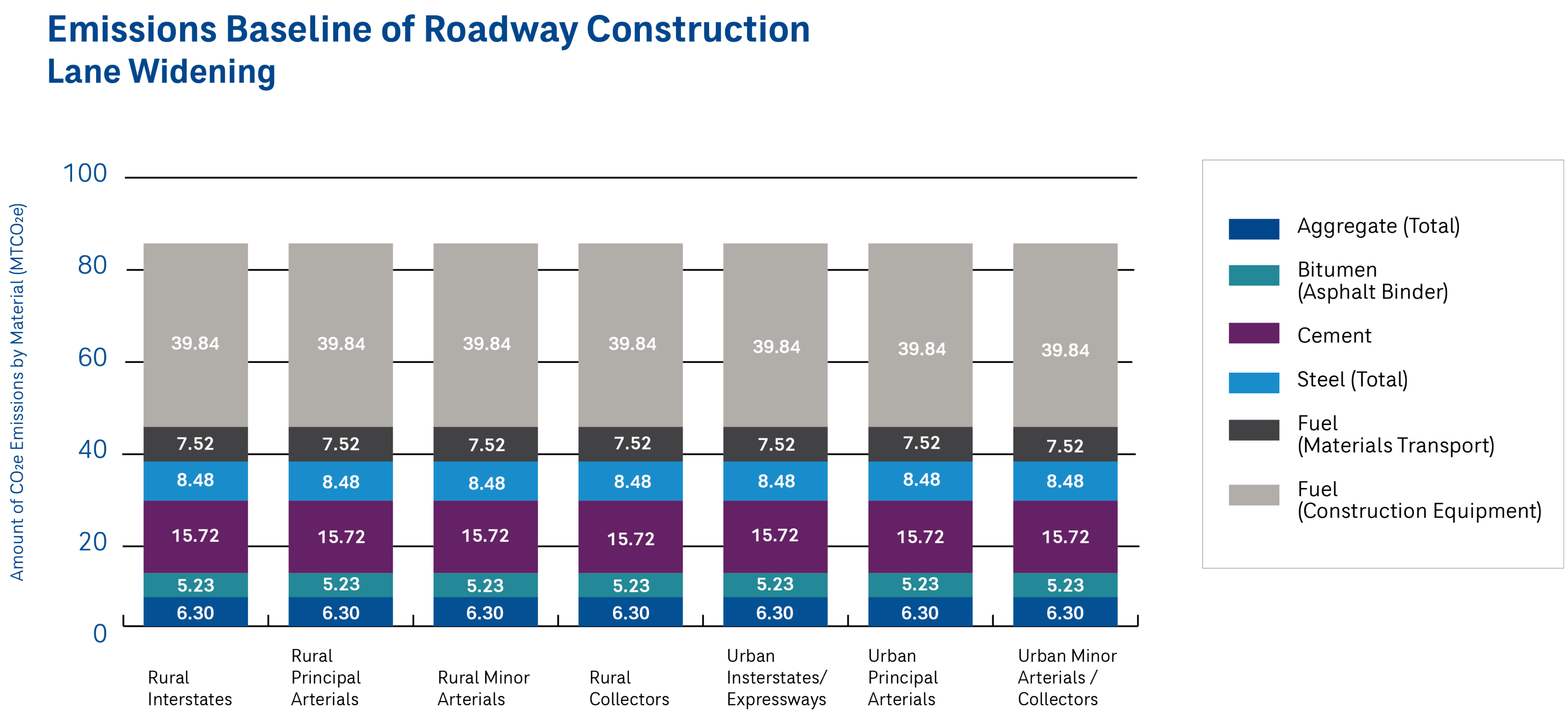


Figure A.5. Emissions Baseline for Roadway Construction, Shoulder Improvement

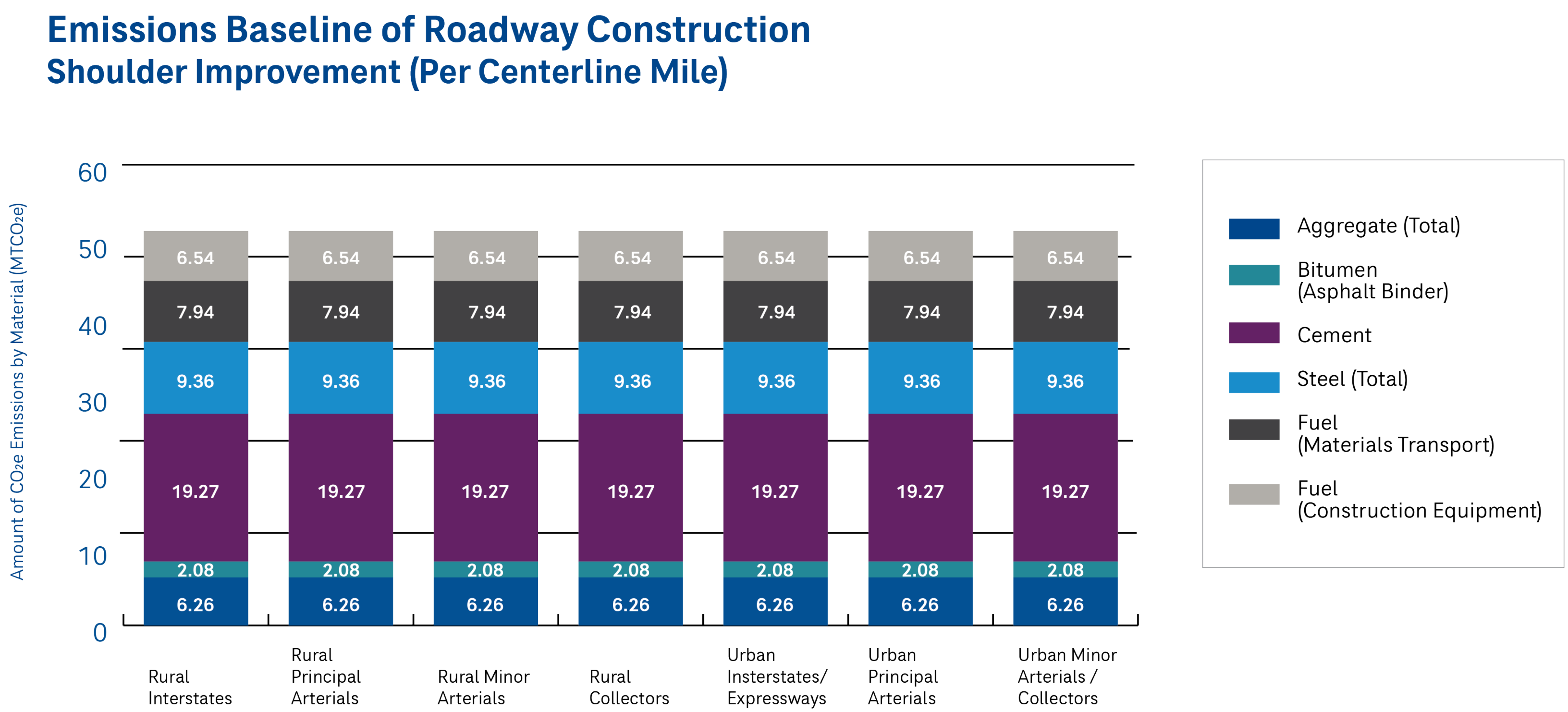


Figure A.6. Emissions Baseline for Heavy Commuter Rail Construction, New Construction

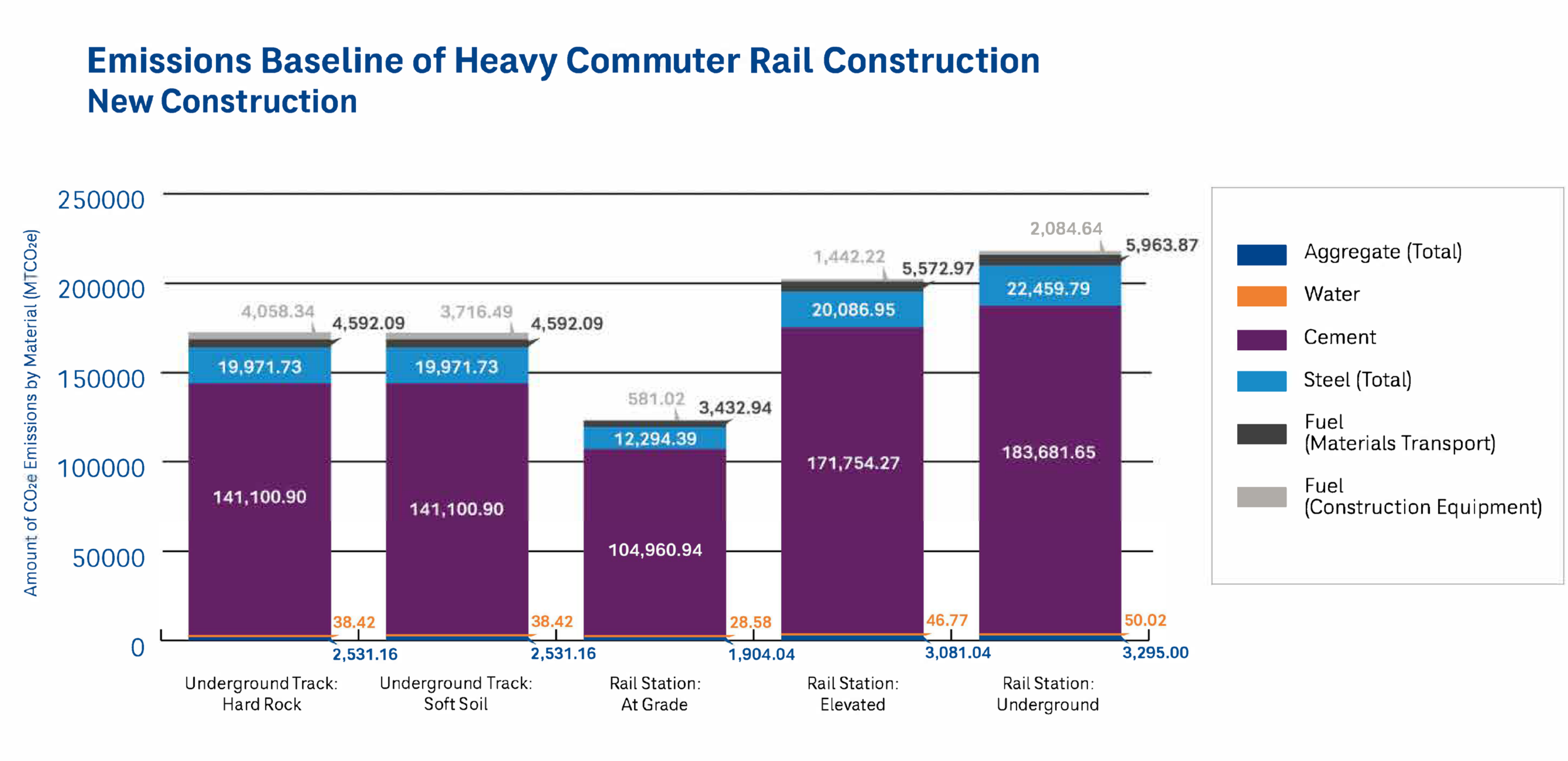


Figure A.7. Emissions Baseline for Bicycle/Pedestrian Infrastructure, New Construction and Resurfacing

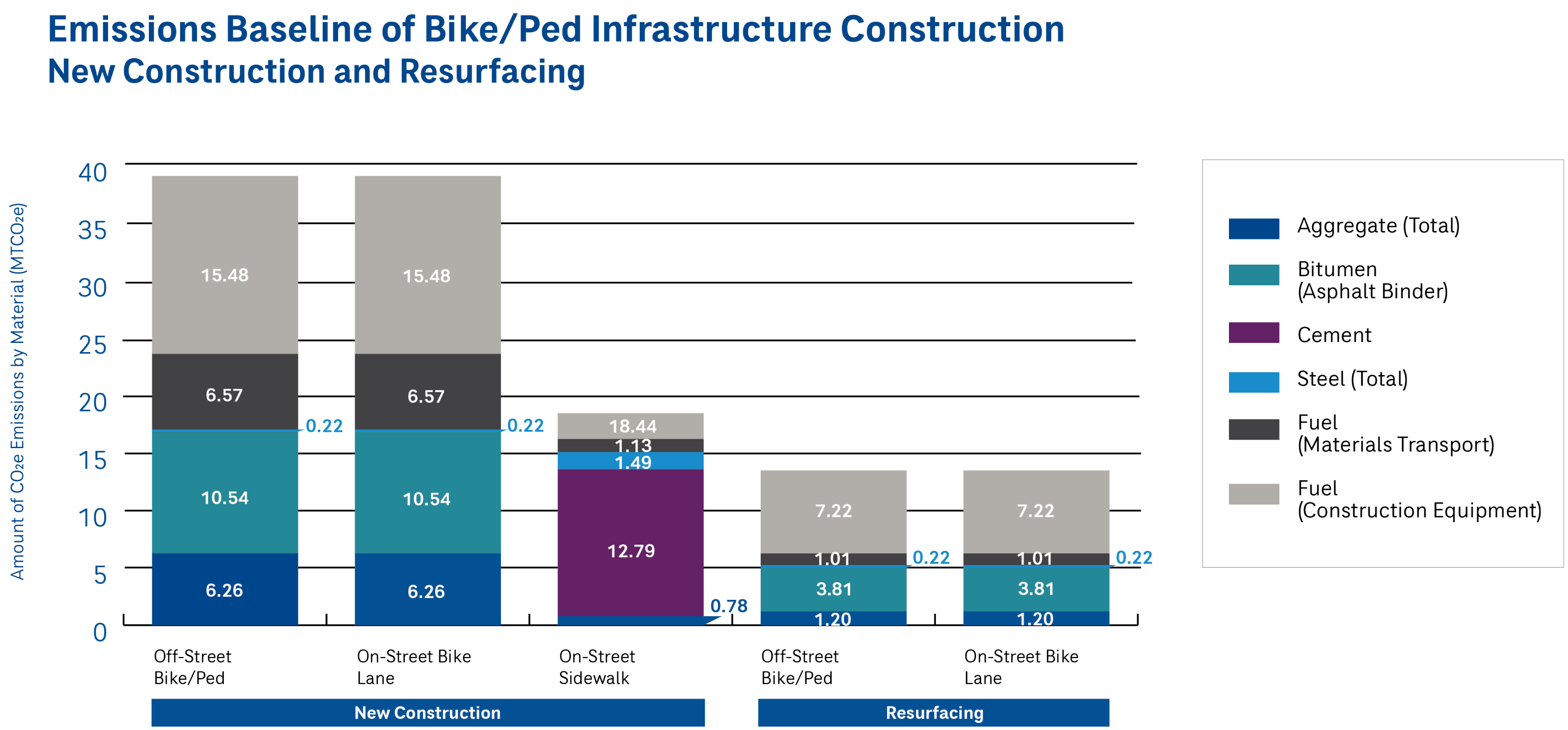


Figure A.8. Emissions Baseline for Bus Rapid Transit, New Construction

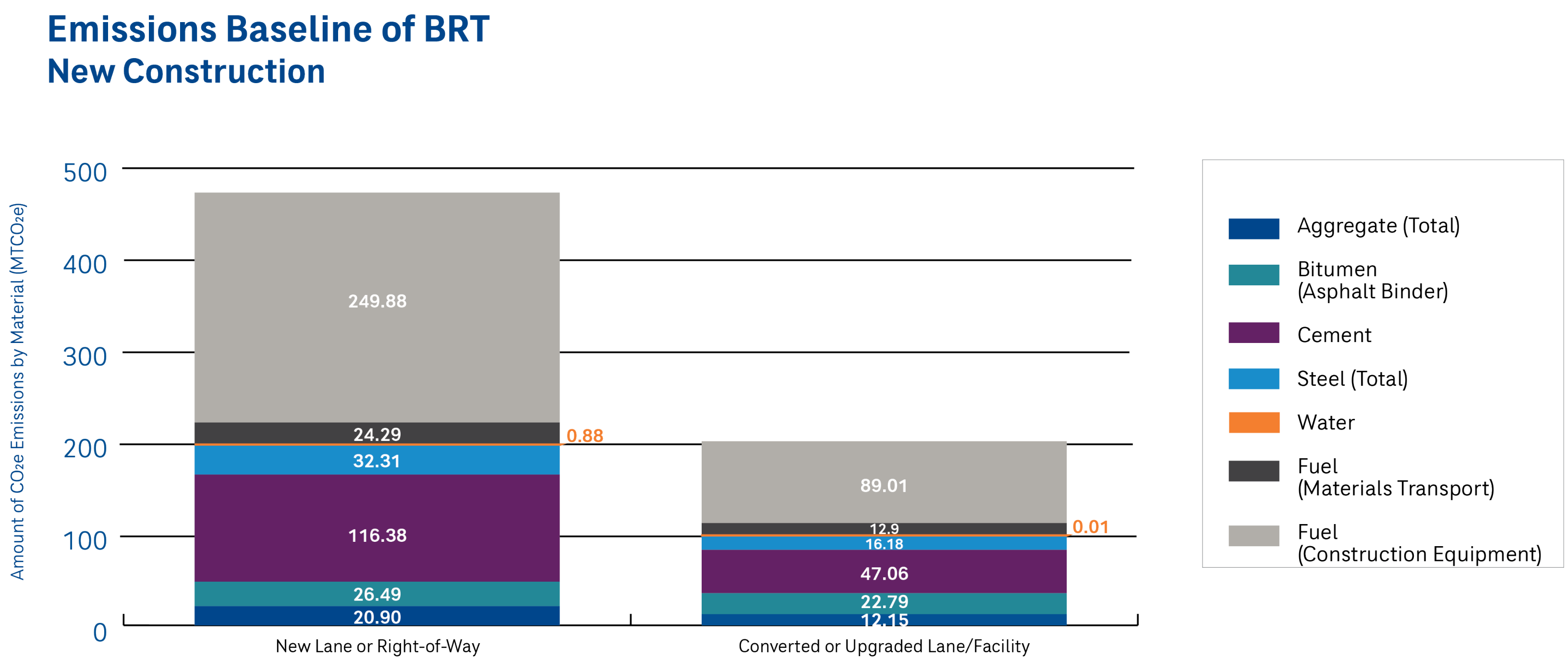


Figure A.9. Emissions Baseline for Bus Rapid Transit, New Station Construction

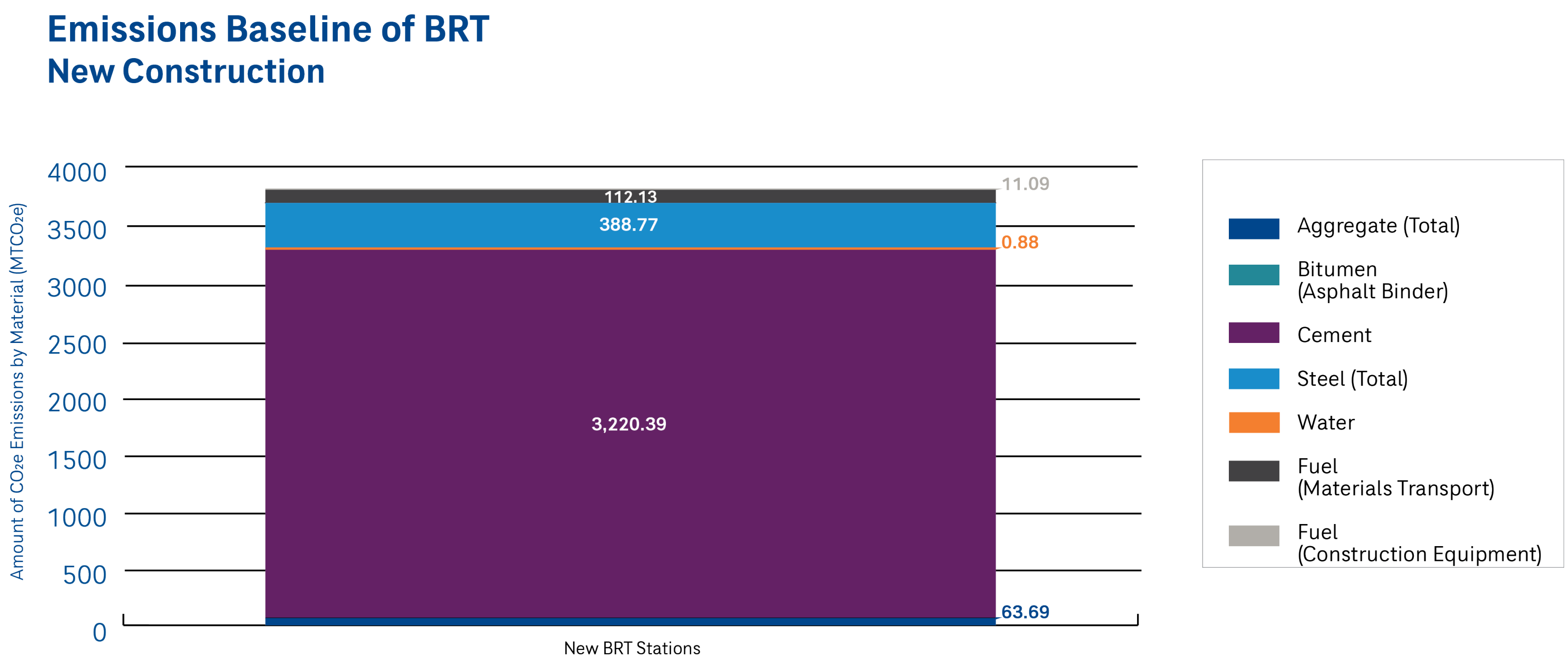


Figure A.10. Emissions Baseline for Heavy Commuter Rail Construction, New Track Construction

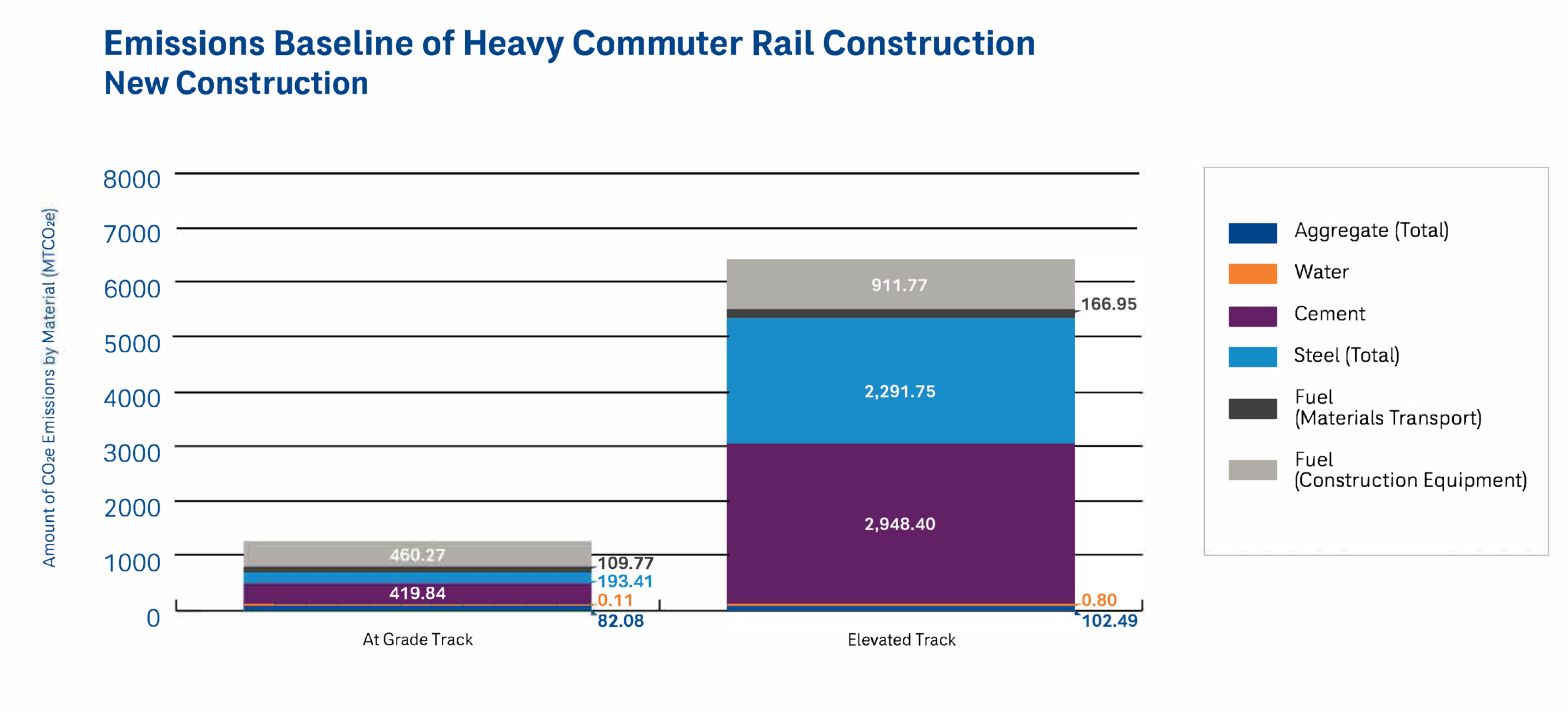


Figure A.11. Emissions Baseline for Light Commuter Rail Construction, New Construction

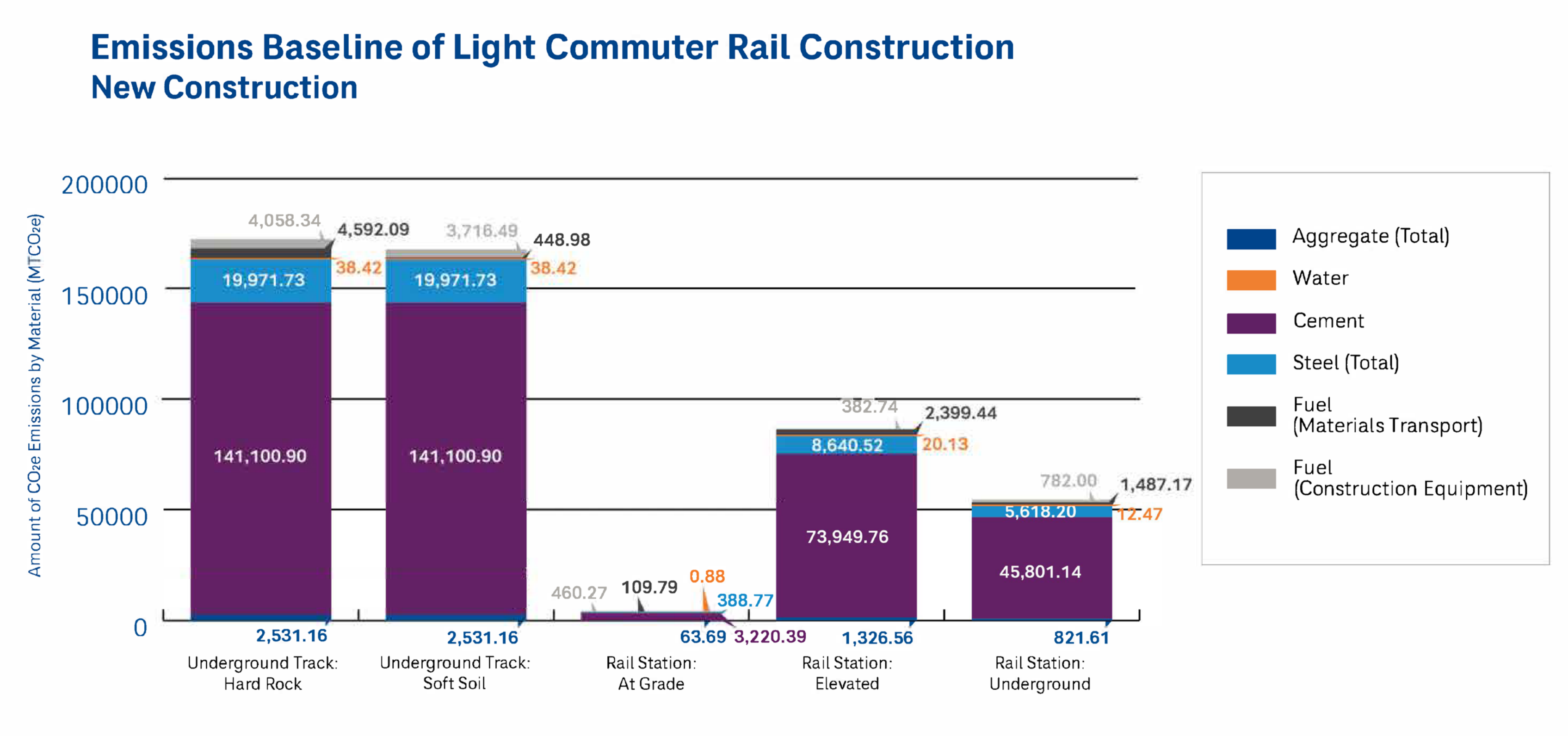


Figure A.12. Emissions Baseline for Light Commuter Rail Construction, Track Construction

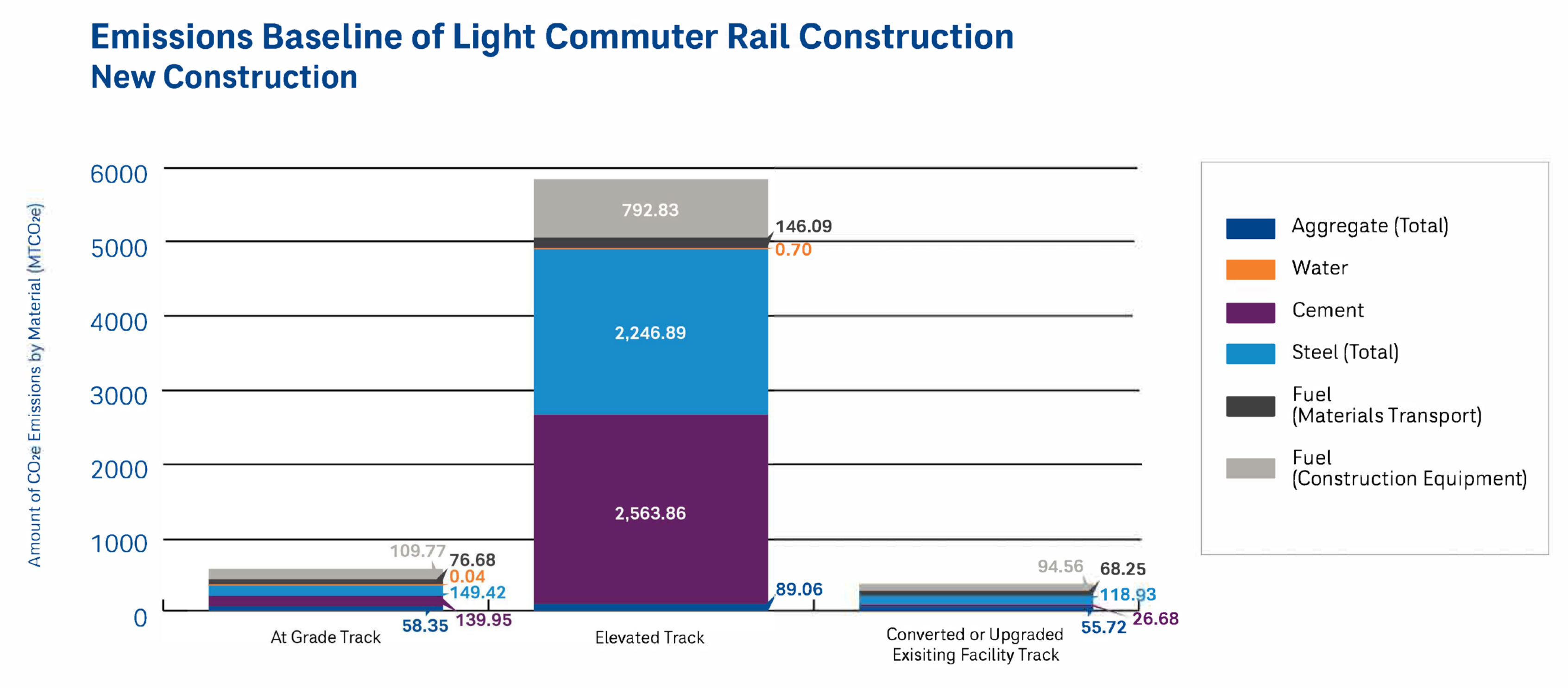


Figure A.13. Emissions Baseline for Roadway, New Construction by Road Type

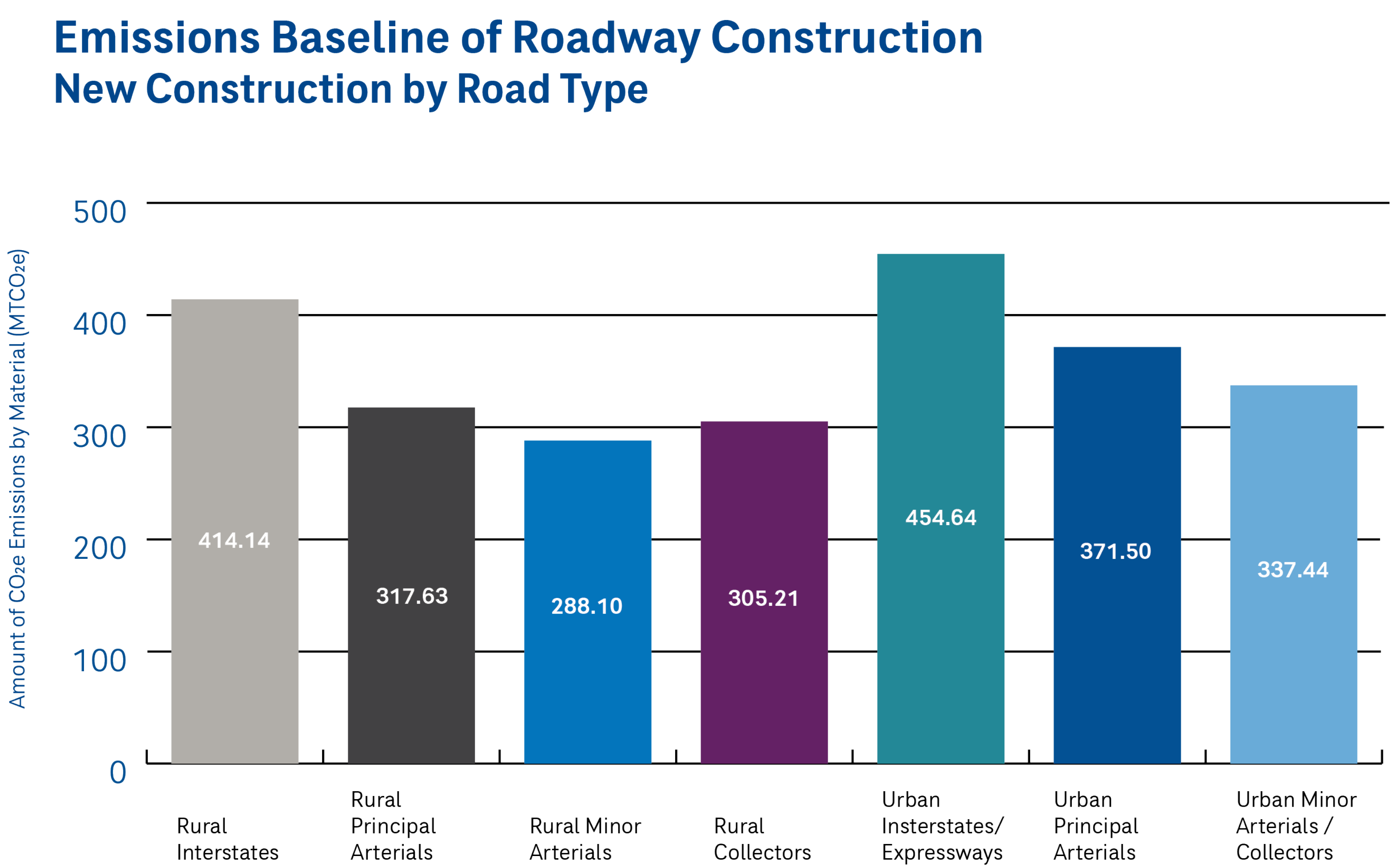
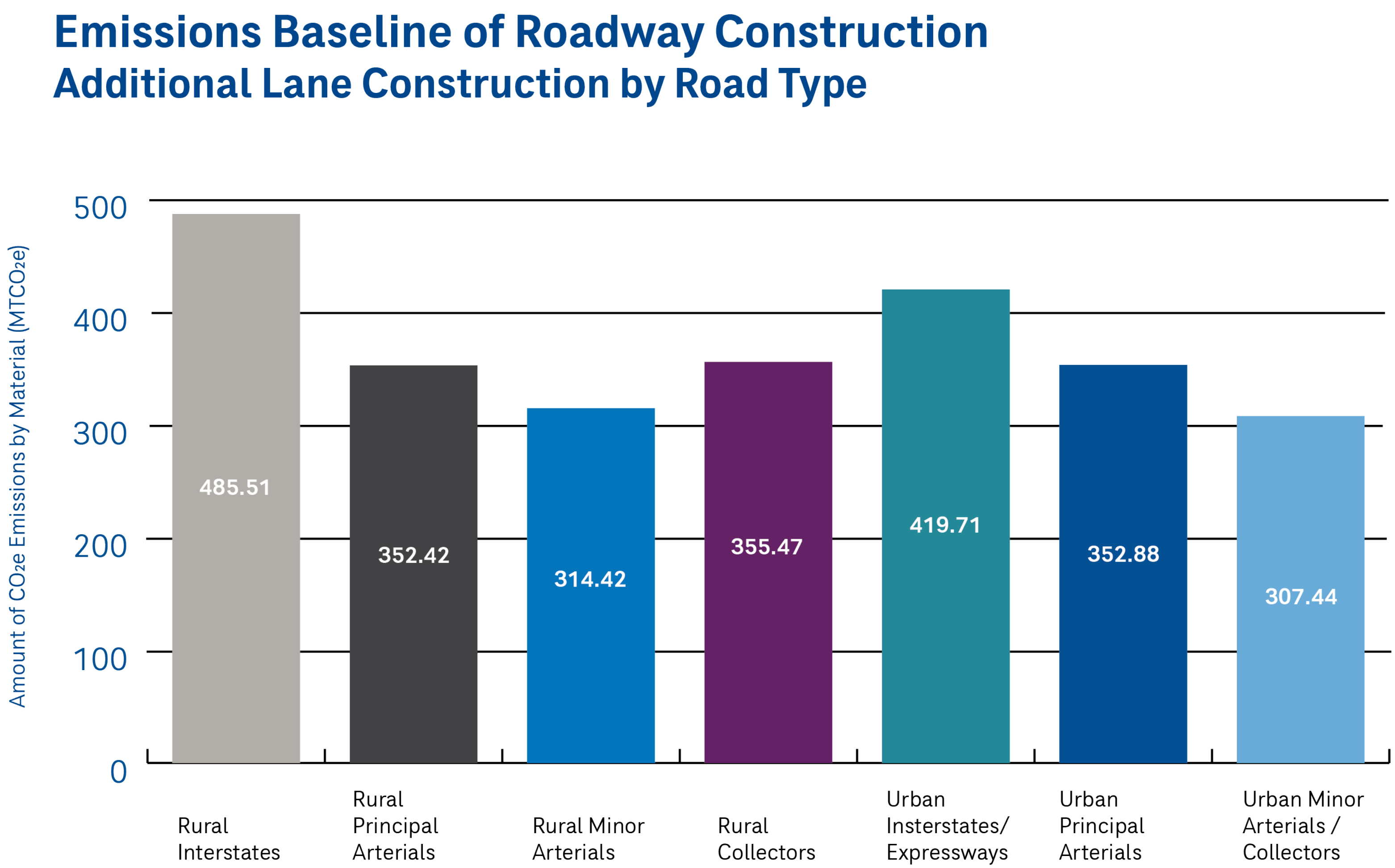


Figure A.14. Emissions Baseline for Roadway Construction, Additional Lane Construction by Road Type



Appendix B Initial Screening Results

Provided as Excel file.

Appendix C Alignment with MDOT's Transportation Planning Process and Roadmap Performance Metrics

Alignment with Existing MDOT Existing Transportation Planning Process

Existing MDOT transportation plans were reviewed to determine alignment with existing goals, policies, and strategies for the Michigan transportation network. This assessment provided an understanding of how carbon reduction initiatives are already incorporated into MDOT plans and programs as well as guided an analysis of how the initiatives can be further woven into MDOT's transportation planning process.

Table C.1 in the Appendix C excel file displays examples of how the proposed carbon reduction strategies align with MDOT's existing planning documents and transportation partnerships. The 16 carbon reduction initiatives are listed across the top (e.g., CR-01: Charging infrastructure for EVs for on-road vehicles). On the left side of the matrix are the MDOT plans and partnerships listed in Appendix D (e.g., MI Healthy Climate Plan). The cell at the intersection of each carbon reduction initiative with each MDOT plan or partnership displays goals, strategies, or performance metrics that illustrate how the topics of the carbon reduction initiatives are discussed in the MDOT plan (e.g., At the interaction of CR-01 and MI Healthy Climate Plan, the cell describes one of the MI Healthy Climate Plan's goals of building necessary infrastructure to support 2 million electric vehicles on Michigan roads by 2030).

Carbon Reduction Strategy Roadmap Performance Metrics

The existing goals, policies, and strategies identified (refer to Table C.1) were then used to guide the creation of performance metrics that MDOT and its transportation partners can use to quantitatively evaluate progress on implementing carbon reduction initiatives at both the planning and project-level scale to estimate reduction in carbon emissions achieved over time. These performance metrics were chosen for their specificity to the carbon reduction initiatives, such as progress towards a policy implementation compared to reductions in single occupancy vehicle VHT/VMT, and the feasibility of accurately gathering the data. The analysis also included a recommendation for which program the metric should be tracked in. Recommended carbon reduction performance metrics are presented in **Table C.2** in the Appendix C excel file.

The highest level of accuracy for most of the metrics is to capture data on a project level with pre- and post- installation data collection to accurately calculate carbon emission reductions and co-benefits. A pilot project is a mechanism to help collect project level data that can be used more broadly. One option to quantify emissions reductions without project level data is to utilize a different readily available metric as a proxy value to generalize changes in emissions (e.g., use changes in the quantity of purchased diesel fuel to infer impacts of freight related efficiencies). Although this option would not be able to provide information on project level success, it would facilitate insights into carbon reduction performance more generally. Data collection mechanisms need to consider potential overlaps between carbon reduction initiatives (e.g., most CAVs are also EVs) when calculating carbon emission reductions to avoid accidental double-counting of carbon reductions. As data is collected, recommended performance metrics can be further defined and used to set new goals or refining existing goals to match certain targets (e.g., reduce single occupancy vehicle trips by 20%).

Table C.2 in the Appendix C excel file contains the recommendations for future metrics that MDOT can use to track its progress in implementing the initiative and/or quantifying the resulting carbon reductions. The column on the far left of the matrix, 'Purpose of Metric', categorizes the metric purpose as being used to quantify carbon reductions or track progress of the initiative's implementation. The next column over, 'CRS Tracking Metrics', contains the recommended future metrics. The third column from the left, 'Associated Initiative for CRS Tracking Metric', designates which of the 16 carbon reduction initiatives the metric applies to.

The second part of this spreadsheet, 'MI Healthy Climate Plan' and onwards, makes recommendations for which of MDOT's planning documents the metric should be tracked in (green cells), and which planning documents would benefit from referencing the metric (yellow cells).

Appendix D Plan and Program Summaries

Existing MDOT Plans and Programs

Michigan has existing plans and programs that guide carbon reduction efforts and transportation section investments across the state.

Michigan Healthy Climate Plan

The Michigan Healthy Climate Plan (MHCP) was released in 2021[1] after a rigorous, statewide stakeholder engagement process. The MHCP underscores the urgent need for action to address climate change and identifies bold, necessary, and strategic measures to deliver a carbon neutral economy. The MHCP identifies actions to reduce GHG emissions by 50-52 percent from 2005 baselines by 2030 in an equitable manner. Actions related to transportation sector emissions include: (1) Clean the Electric Grid; and (2) Electrify Vehicles and Increase Public Transit.

Michigan NEVI Program

In August 2022, Michigan developed their state plan for electric vehicle infrastructure deployment, in alignment with the National Electric Vehicle Infrastructure (NEVI) Formula Program.[2] Through the program, Michigan will receive a total of roughly $110 million in NEVI Formula Program funding through Fiscal Year 2026. The NEVI Formula Program will complement Michigan's existing electric vehicle charging efforts such as Charge Up Michigan and the Lake Michigan Circuit. Collectively, these programs will aim to build out the infrastructure to support two million electric vehicles on Michigan roads by 2030.

State Long Range Transportation Plan: Michigan Mobility 2045

The Michigan Mobility 2045 Plan (MM2045)[3] is the state long-range transportation plan for transforming Michigan's transportation system. The plan identifies the need to invest in infrastructure for electric vehicles, safer bike and pedestrian access to transit stops, intelligent transportation systems and connected vehicles, as well as the need for policies to decarbonize Michigan's transportation system.

Active Transportation Plan

While developing MM2045, MDOT identified active transportation as an important factor in the transportation system. Active transportation is human-powered transportation, such as walking and biking, which results in minimal to no carbon emissions and can support the use of public

[1] https://www.michigan.gov/egle/about/organization/climate-and-energy/mi-healthy-climate-plan

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transportation. The MM2045 Active Transportation Plan[4] identifies the need for improved access and connectivity for active transportation and between modes of travel (e.g., transit).

State Rail Plan

The Michigan State Rail Plan[5] is a supplement to MM2045. The plan identifies needs currently being addressed by MDOT such as infrastructure condition, line signal improvements, and safety improvements. The plan also identifies future opportunities to improve the rail system. Such opportunities include improved service and faster trains, completing additional environmental studies for the separation of freight and passenger trains, as well as new Amtrak services and passenger rail services.

MDOT Connected and Autonomous Vehicle Strategic Plan

Connected and autonomous vehicles hold potential to reduce carbon emissions associated with vehicle use. MDOT's Intelligent Transportation Systems Program Office developed the Connected and Automated Vehicle (CAV) Strategic Plan[6] in 2021. The plan considers how MDOT can prepare for CAV technology, consider the challenges and opportunities of CAV, and reflect on existing CAV efforts in Michigan.

Michigan Future Mobility Plan

The Michigan Future Mobility Plan[7] envisions enabling a stronger state economy through safer, more equitable, and environmentally sound transportation. In addition to the desired outcomes of creating additional jobs, this plan calls for deploying 100,000 electric vehicles chargers to support 2 million electric vehicles by 2030 and to improve access to hydrogen fuel infrastructure. In addition, this plan aims to ensure that 80 percent of electric vehicle charging occurs during off-peak time periods to avoid burden on the electric grid.

Michigan Statewide Transportation Improvement Program

The Michigan Statewide Transportation Improvement Program[8] provides information on the programs and projects that state and local transportation agencies have committed to implementing over the next four years. It verifies that resources are available to finance the specifies programs and projects. It is updated every two years and provides an opportunity for MDOT to review alignment of committed programs and projects with the carbon reduction initiatives.

Michigan Future Mobility Plan

The Michigan Future Mobility Plan aims to create a stronger state economy through safer, more equitable, and environmentally sounds transportation. It creates clear goals to transition and grow the

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[4] https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Planning/Michigan-Mobility/Active-Transportation-Plan-Executive-Summary.pdf

[5] https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Planning/Michigan-Mobility/Michigan-State-Rail-Plan-Supplement.pdf?rev=693bf71a460744298367a0cf93c4bd4f&hash=1A2732BB48B86147748D35564B493B8A%20Non-state%20plans%20of%20note:%20Other:%20Grand%20Valley%20Metropolitan%20Council%20https://static1.squarespace.com/static/59dce13bb1ffb65b4d405588/t/64c028645a3ae6401315c12d/1690314891806/FreightAssesment_3_22_23.pdf%20Other:%20Southeast%20Michigan%20Council%20of%20Governments%20https://www.semcog.org/desktopmodules/SEMCOG.Publications/GetFile.ashx?filename=SoutheastMichiganFreightAndEconomicAnalysisJuly2012.pdf

[6] https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Travel/Mobility/Mobility-Initiatives/Connected-Vehicles/Documents/MDOT-CAV-Strategic-Plan.pdf

[7] https://www.michiganbusiness.org/4a6039/globalassets/documents/mobility/mi-future-mobility-plan-summary.pdf

[8] https://www.michigan.gov/mdot/programs/planning/state-transportation-improvement-program

mobility industry and workforce; provide safer, greener, and more accessible transportation infrastructure; and lead the world in mobility and electrification policy and innovation. This plan calls for deployment of 100,000 electric vehicles chargers to support two million electric vehicles and to maintain 80 percent of charging during off-peak time periods to minimize impacts to the electric grid. In addition, the plan calls for improved access to hydrogen fuel infrastructure.

PrePass and Drivewyze

MDOT partners with PrePass and Drivewyze. These weigh station bypass options provide opportunities for participating commercial vehicle operators to avoid stopping for weigh and tolling stations. By participating, commercial vehicles can avoid idle time, thus reducing carbon emissions.

Pavement Operations Sustainable Asphalt and Concrete Initiatives

MDOT uses several sustainable strategies for asphalt and concrete usage.

For asphalt, MDOT projects use approximately 20% reclaimed asphalt binder on average, and recycled aggregates from reclaimed asphalt pavements (RAPs) reduce the need for new aggregate material. MDOT also have permissive specifications which allow contractors to make use of recycled asphalt shingles as a substitute for new aggregate, as well as use recycled tires in asphalt. Lastly, MDOT allows Warm Mix Asphalt (WMA) technologies which lower temperatures at which the material is mixed and placed on the road. Lowering temperatures reduces the emissions generated during production and placement, as well as reduces pavement costs, extends the paving season, improves compaction, and reduces workers' exposure to emissions, fumes, and odors.

For concrete, MDOT has worked with concrete industry parties and the FHWA to transition in 2022 to the use of Portland Limestone Cements in place of conventional Portland-cement binder, a transition which can reduce cement manufacturing emissions by up to 10%. Additionally, MDOT concrete mixes contain Supplementary Cementitious Materials (SCMs), which use fly ash, slag, and other materials to reduce concrete permeability, increase concrete resistance to freeze-thaw effects, and lower the amount of cement in concrete, thereby lowering material emissions and making the resultant cements more resilient. MDOT practices aggregate optimization, a practice which uses well-graded, densely packed aggregate gradations in concrete mixtures, reducing the mixtures' overall need for cement paste and improving workability and durability. Lastly, MDOT and industry continue to work together to find ways to reuse recycled concrete on MDOT projects. Some projects now require existing concrete pavements be crushed and reused as fill materials and/or stabilized base for the new pavements being constructed.

FHWA Every Day Counts

MDOT has been engaged with the FHWA Every Day Counts Program, which is a State-based model that identifies and deploys innovations that make a transportation system adaptable, sustainable, equitable and safer for all. This program allows MDOT to attend webinars, peer exchanges, and workshops to help assist in identifying implementation of innovations that best fit the needs of their transportation system. The Every Day Counts current initiative is focused on Environmental Product Declarations (EPDs) for Sustainable Project Delivery. Every Day Counts allow for MDOT to provide an accurate reflection on a project's infrastructural burdens on the environment, as well as the potential to seek more sustainable strategies. This program also allows for MDOT to conduct research into the potential use of any tools or techniques when developing an EPD. MDOT may also work with industries on the possible development of EPDs for select hot mix asphalt (HMA) and/or concrete items, as well as perform an evaluation of progress made and determine feasibility for future steps. Further, MDOT participates in an Every Day

Counts initiative to incorporate greenhouse gas analysis into transportation planning. This allows agencies to take action toward meeting national emissions reduction goals and reducing their climate impact.

Appendix E Greenhouse Gas and Criteria Air Pollutant Reduction Methodologies

Support Modal Shift from Personal Vehicle Usage to Shared Mobility and Public Transit

Description: Improving facilities and access to increase the use of public transit (e.g., dedicated bus lanes; multimodal access to public transit; high-volume fixed-route transit services such as bus rapid transit; park and ride facilities; transit signal priority).

How Emissions are Reduced: ICE vehicle VMT is displaced by public transit VMT in the amount equal to the predicted increase in public transit trips (in passenger-miles) annually.

Bus Methodology:

1. The anticipated mode shift to bus following greater implementation and improvement of the bus system was identified. Targets from two relevant study areas were averaged to obtain a reasonable, obtainable target of increased bus rides.
    a. Ohio MPO sets goal to increase transit trips by 0.7% from 2020 to 2030[9]
    b. Study in the Midwest sets a goal of 2.4% increase in public transportation service (interpreted as trips/ridership) from 2018 to 2030[10]
    c. These figures were annualized and averaged to obtain a goal/assumption of 0.1% increase in bus trips per year, wherein investments, improvements, and best practices in the studies are applied to MDOT's system.

2. A baseline of bus ridership was developed using MDOT's 2021 Public Transit Ridership Report (x). Bus ridership for Urban Metro and Urban Large areas were used, and all smaller categories were omitted from the calculation. This is because improvements to the bus system in large urban areas with more potential riders are more representative of where investments and real benefits would likely be realized. The 2021 bus ridership in each urban area was multiplied by 0.1% to obtain a projected increase in bus passengers per year. The projected increases in passengers were summed for seven transit providers across the state to obtain a projected statewide increase in bus passengers per year. It was assumed that all of these passengers would be diverted from car to bus.

3. The projected statewide increase in bus passengers per year was divided by 1.67, the national average automobile occupancy in 2017 from FHWA's National Household Travel Survey.[11] This yielded a number of vehicle trips which would be diverted into bus trips per year. Further

[9] https://www.eneo2050.com/final-plan

[10] https://pirg.org/wisconsin/wp-content/uploads/2018/09/The-Road-to-Clean-Transportation-Aug-2018.pdf

[11] https://nhts.ornl.gov/assets/2017_nhts_summary_travel_trends.pdf

calculations assumed that all of the diverted passenger vehicles are ICE vehicles, not EVs/alternative fuel vehicles.

4. The number of diverted ICE trips was multiplied by 25.8 vehicle miles travelled (VMT), the roundtrip distance of the average workday commute in Michigan.[12] The product of this calculation was the amount of ICE vehicle VMT diverted into bus passenger miles travelled (PMT). The calculations assume that ICE VMT reductions are exactly equal to bus PMT increases.

5. To account for the additional miles travelled by buses due to increased service, the number obtained in Step 4 was divided by the average number of passengers per bus trip in Detroit.[13] This step converted the increased bus PMT into additional bus VMT that would occur due to expanding the bus system. Note that Detroit is the largest city in Michigan, and local bus services in other cities may experience higher or lower bus ridership, on average.

6. The final numbers in Steps 4 and 5 represent the VMTs diverted from ICE vehicles and added to bus service, respectively. These VMT numbers were multiplied by emission factors obtained from MDOT's 2015 MOVES model to obtain final, projected GHG and CAP emission reductions per year as bus service is improved and expanded to reach a 0.1% annual increase in ridership.

Rail Methodology:

1. The anticipated mode shift from car to rail following greater implementation and improvement of the rail system was identified. A study of the Midwest corridor (MN, WI, IL, IN, OH, and MI) projected an overall 1.5% increase in the rail (including high speed rail [HSR] and commuter rail) mode share of passenger miles travelled (PMT) across fifteen years (2013-2028) following investment in the rail system.[14] There are several conditions attached to this study and projected increase:
    a. The study projects PMT mode share from 2012 to 2050 in Figure 4.3. Projected rail mode share increases over the first fifteen years of the projection, then it appears to stay the same for the remainder of the projected period to 2050. This calculation limited the projected increase to only 15 years (2012 to 2027) in order to provide a more realistic picture of how rail mode shift might change following investment/implementation. By annualizing the 1.5% mode shift over 15 years, rather than the full study period of nearly 40 years, the resulting GHG and CAP emission reductions are more accurate to the yearly reductions that may be expected for short-to-medium-term implementation of rail.
    b. In the study, the 1.5% increase in mode share of rail is drawn from passengers choosing to use rail rather than personal vehicles and air travel. For this calculation, it was assumed that the entirety of the mode shift was derived from car passengers shifting to become rail passengers; that is, no shift from air to rail occurs. This assumption is valid for the following reasons:
        i. The predicted mode share of air travel appears to change by <0.5% across the study's projection, so a very minor shift from air to rail is projected to occur.
        ii. Any real shift from air to rail travel would be associated with even-greater emissions savings than shifts from personal vehicle to rail; thus, attributing all of

[12] https://www.michigan.gov/-/media/Project/Websites/MDOT/Programs/Planning/Mi-Travel-Counts/Characteristics-Report.pdf?rev=6c5dd0e64ef24b1d8794f630980e4a85

[13] https://www.fhwa.dot.gov/policyinformation/tables/occupancyfactors/fhwa_pl_19_048.pdf

[14] https://www.purdue.edu/discoverypark/cav/nextrans/completed-projects/docs/055PY03-%20Final%20Report.pdf

the 1.5% shift to personal vehicle-to-rail is a conservative estimate of the emissions savings resulting from greater rail service.

iii. A study of the expansion of HSR in California suggested that a 6% diversion of automobile traffic to HSR occurred, so a 1.5% shift for the Midwest Corridor appears to be reasonable.[15]

2. Michigan's 2015 VMT of personal vehicles (cars and light-duty trucks) was multiplied by 1.67 persons (the average automobile occupancy from FHWA's National Household Travel Survey) to obtain annual PMT of personal vehicles. This annual PMT of personal vehicles was multiplied by 0.1% to obtain the annual amount of PMT shifted from personal vehicles to rail.

3. The PMT shifted figure was multiplied by conversion factors obtained in the Transportation Energy Data Book to yield the additional MMBTU expended by rail serving more passenger miles per year (x, opens large PDF). These MMBTU figures underwent several unit conversions (details in spreadsheet) to obtain GHG and CAP emissions reductions for the investment and expansion of rail in the Midwest. The unit conversion calculations assumed that personal vehicles use finished gasoline/motor gasoline fuel, and rail uses diesel fuel, which appears to be accurate to the current rail system nationwide and in Michigan.[16] [17] [18] However, electrification of rail, especially light rail, is a feasible possibility which could even further reduce GHG and CAP emissions.

Charging Infrastructure for Electric Vehicles for On-Road Vehicles

Description: Introduce more charging stations into the current infrastructure, allowing all electric vehicle (EV) owners to recharge quickly on the go, resulting in the encouragement of a wider adoption of electric vehicles.

How Emissions are Reduced: Reduction in tailpipe emissions. ICE vehicles vehicle miles travelled (VMTs) are displaced by EVs VMTs in the amount equal to how much charging is occurring at an average DCFC port.

Methodology:

1. Identified the average port utilization rate for DCFC as 5 percent.[19]

2. Identified the charger capacity of a DCFC to be at least 150 kilowatts (kW) for National Electric Vehicle (NEVI) compliancy.[20]

3. Assume 24/7 access to a DCFC.

[15] https://www.sciencedirect.com/science/article/pii/S2046043016300922?ref=pdf_download&fr=RR-7&rr=810fdb666d43468f

[16] https://s3.documentcloud.org/documents/21174539/transit-matters-regionalrailelectrificationfinal.pdf

[17] https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Planning/MDOT-Fast-Facts.pdf?rev=b7e88c286ccb4d45819ba5367e6cc136&hash=433B524F82AEFE2831971211207260EC

[18] https://enginetechforum.org/rail#:~:text=Freight%20and%20passenger%20rail%20rely,nearly%20140%2C000%2Dmiles%20of%20track.

[19] https://www.pwc.com/us/en/industrial-products/publications/assets/pwc-electric-vehicles-charging-infrastructure-mindset.pdf.

[20] https://www.michigan.gov/mdot/-/media/Project/Websites/egle/Documents/Programs/MMD/Energy/NEVI/MI-Plan-for-EV-Infrastructure-Deployment.pdf?rev=b94a1a70cb264684aee612228f82a6f2&hash=9F64565DBAD9A75C5174B99011FCE7D4

4. Calculated the theoretical daily energy expenditure by multiplying the charger capacity by 24 hours in a day.

5. Calculated the annual port utilization by multiplying the theoretical daily expenditure by the port utilization rate (5 percent) by 365 days per year.

6. Identified average EV "fuel economy" as 0.321 kWh/mile considering both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) (Argonne National Laboratory 2022).

7. Assume all charging for EV miles will displace an equal amount of ICE VMT.

8. Calculate the annual ICE VMT displaced by dividing the annual port utilization calculated in Step 5 by the average EV fuel economy in Step 6.

9. Use the carbon dioxide equivalents (CO_2e) emissions factor for ICE vehicles of 498.81 grams CO_2e/VMT. Use the following CAP emission factors for overall CAP reduction: NO_x - 0.8854 grams NO_x/VMT, $PM_{2.5}$ – 0.0207 grams $PM_{2.5}$/VMT, VOC – 0.5102 grams VOC/VMT.

10. Calculate the overall CO_2e reduction potential by multiplying the annual ICE VMT displaced calculated in Step 8 by the CO_2e emission factor for ICE vehicles in Step 9. Follow this same step to calculate the overall reduction of NO_x, $PM_{2.5}$, VOC and sum these values to find the total CAP reduction.

11. Final CO_2e Unit: metric tons (MT) CO_2e reduced/1 DCFC added/year.

12. Final CAP Unit: lbs. CAPs Reduced/1 DCFC port added/year.

Prioritize Transportation Infrastructure Efficiencies

Description: Replacing traditional intersections and interchanges with more efficient infrastructure can reduce congestion, improve traffic flow, and reduce vehicle hours traveled (VHT), which could result in a reduction of carbon emissions associated with the use of the system.

How Emissions are Reduced: Idling time at intersections and interchanges (which is associated with tailpipe emissions) is reduced for all ICE vehicles passing through that specific intersection/interchange marking an improvement over one year (annually).

Methodology:

1. Resource review identified decreases in stop/stop-delay time, the time a vehicle is idle at the intersections/interchange, when switching from "inefficient" to "efficient" intersections/ interchange. Specific assumptions:
    a. Roundabouts were found to reduce stop times by 1.9 to 58.3 seconds per vehicle for vehicles that enter the intersection.[21]
        i. Simulation looked at going from a split phase traffic light and four-way stop control to a two-lane roundabout at a peak traffic volume of 2,900 vehicles per hour (veh/hr) and 1,200 veh/hr traffic volume at two intersections.

[21] Hallmark, S.L., Fitzsimmons, E.J., Isebrands, H.N. and Giese, K.L. 2010. Roundabouts in signalized corridors: evaluation of traffic flow impacts. Transportation research record, 2182(1), pp.139-147.

b. DDIs were found to reduce stop times by 0 to 23 seconds per vehicle for vehicles that enter the DDI intersections.[22]
    i. All simulations looked at converting conventional diamond interchange (CDI) to DDI
    ii. Looked at vehicle traffic flows of 1,700 to 6,100 veh/hr
    iii. The lower the vehicle flow, the lower the reduction in stop time
c. There is a lot of variability in the idling time/stop time reductions because of project specific information such as the baseline "inefficient" interchange and traffic load (vehicles/hour).
d. Stop time considers the impact of idle time when a vehicle is stationary with the engine running but does not consider acceleration and deceleration times.

2. Used a CO_2e and CAP emission factor representative of idling to correlate the reduction in idling time/stop time to CO_2e and CAP emissions. The following idling emission factors were used for the next calculations: CO_2e – 0.588 g CO_2e /s, NO_x – 0.0097 milligrams NO_x /s, $PM_{2.5}$ – 0.098 milligrams $PM_{2.5}$/s, VOC – 0.266 milligrams VOC/s.[23] Multiply CO_2e and CAP emission factors by the Stopped-Delay Time Savings.

3. Identified an average annual daily traffic per lane (AADT) number representative of all principal arterials (urban and rural) in the state of Michigan to determine potential carbon emission reduction. Principal arterials AADT value were used as opposed to freeway traffic to be consistent with the studies that delay reductions as experienced by the vehicles entering the intersection(s). The AADT value used was 5,550 vehicles/day/lane [24]
    a. Roundabouts: A factor of four was applied to the AADT/lane value to roundabouts based off an assumption of a four-legged roundabout (four entry lanes). This is a conservative value since a four-legged two-lane roundabout can typically serve a daily volume of up to approximately 45,000 vehicles according to FHWA's *Roundabouts: An Informational Guide*.
    b. DDIs: A factor of eight was applied to DDIs based off the assumption of eight entry lanes (2 on-ramp, 2 off-ramp, 4 arterial through lanes).
    c. Twenty percent of projected AADT value was used as the final calculation because typically the AM/PM peak hour traffic accounts for ~10 percent of AADT. As the stopped-delay reductions from the studies were based on peak hour traffic, a similar approach was applied to the AADT value.
    d. Adjusted Daily Traffic Volume was calculated using the following equation:
        i. Roundabout Entry Lanes: 4
        ii. DDI Entry Lanes: 8

4. Annual potential CO_2 emissions reduction was calculated by multiplying the adjusted daily traffic volume by the carbon emission factor and time improvement and converting to annual metric tons. This step can be repeated to find the CAP emission reduction potential using the NO_x, $PM_{2.5}$, and VOC emission factors and summing the total reduction. The cumulative calculations are as followed.

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[22] Sustainability Discipline - R D Sustainability Analytics (SA) Framework - Double crossover intersection and DDI Performance.pdf - All Documents (sharepoint.com)

[23] Sustainability Discipline - R D Sustainability Analytics (SA) Framework - Argonne Which is Greener.pdf - All Documents (sharepoint.com)

[24] Table HM-62 - Highway Statistics 2016 - Policy | Federal Highway Administration (dot.gov)

5. Final CO_2e unit: metric tons (MT) CO_2 reduced/year/interchange improvement (roundabout or DDI saved)

   Final CAP unit: lbs. CAPs reduced/year/interchange improvement (roundabout or DDI saved)

Connected and Autonomous Vehicle Technology

Description: Incorporating vehicle-to-vehicle technology and vehicle to infrastructure technology to improve traffic flow and reduce accidents.

How Emissions are Reduced: GHG reduction from CAVs would occur due to congestion mitigation, decreased travel times, and the likelihood for future CAVs to be low- or zero-emission vehicles. The efficiency benefits of CAVs can be more fully realized when paired with associated connective technologies, such as dynamic traffic lights, dynamic routing, and smart traffic junctions.

Methodology:

1. Within this analysis, GHG reduction from CAVs occurs due to congestion mitigation and decreased travel and idling times. This methodology is based off of the study Accelerating Safe and Sustainable Transportation: Smart Cars Communicating with Smart Roads. Study assumptions which affect this analysis are as follows:

   a. Michigan is assumed to have a statewide 20% CAV penetration rate. This level was chosen due to the availability of GHG reduction data at this level; additionally, a study in Iowa predicts approximately 20% penetration of AVs (study did not distinguish AV and CAV) between 2020-2040. Thus, 20% CAV penetration appears reasonable for the short-to-medium term in the Midwest, including Michigan (citation).
   b. Dynamic traffic lights, dynamic routing, and smart traffic junctions are deployed. Deployment of these infrastructure technologies makes 20% CAV penetration more feasible, as vehicle to infrastructure and infrastructure to vehicle (V2I and I2V) communication makes the CAV system more robust and attractive to passengers and developers.
   c. As mentioned above, the basis of GHG reduction in this study is congestion mitigation and efficient routing and driving practices. These benefits of CAV vary depending on the location of deployment. In densely populated areas where congestion and idling are common problems, GHG reduction will be higher than that of less dense suburban or rural areas where idling emissions are already less prevalent. The study accounts for this difference by designating Tier 1, 2, and 3 cities, which are defined as cities with populations greater than 500K, between 100-500K, and less than 100K, respectively. The same cut-offs were applied to Michigan's cities in this methodology. Additionally, CAV technology is more effective in reducing emissions during times of non-peak traffic; this is because CAV technologies cannot optimize performance as well during peak traffic hours when maximum road capacity is more likely to be exceeded. The description of peak/non-peak hour calculation is shown below in Step 2.
   d. The methodology does not consider the fuel source of the CAVs. GHG reductions are based solely on congestion mitigation, not the potential for CAVs to be ZEVs as well. If CAV deployment does heavily or exclusively use low- or zero-emission vehicles, then GHG reduction can be even higher than the base case scenario, which assumes a current mixture of vehicle fuels in CAV deployment.

e. With this in mind, it is also important to note that the study is based in Europe, and as such, the GHG reduction potential is based on the European fuel mix. Europe has a higher proportion of diesel-fueled personal vehicles than the U.S. (citation). Thus, the GHG reduction potential in the study may be higher than what is realistic for the U.S. This limitation is noted; Michigan has a different fuel mix than the study origin, and should expect different results.

2. Based on discussion with transportation subject matter experts, assume that peak hours generally occur for 20% of the day (10% for morning and evening commutes, respectively). Under this assumption, peak hours occur for 4.8 hours per day, and the remaining 19.2 hours are non-peak hours. This is the same assumption used in the "Prioritize Transportation Infrastructure Efficiencies" case scenario.

3. Use the emission savings percentages presented below, obtained in Accelerating Safe and Sustainable Transportation: Smart Cars Communicating with Smart Roads. Using 4.8 peak hours and 19.2 non-peak hours, calculate a weighted average of emissions savings percentages for 20% CAV penetration in Tier 1, 2, and 3 cities. For example, the weighted average emissions savings percentage for a Tier 1 city at 20% penetration is calculated as [(4.8/24)*12.75]+[(19.2/24)*17.56]. See calculation spreadsheet for greater detail regarding the calculation of emissions savings percentages.

Table 3: Emission savings for all cities in EU27

Tier	Penetration Rate (%)	CO_2 emissions savings (%)	
		Peak Hours	Off-peak Hours
1	20	12.75	17.56
	50	16.75	23.66
	80	20.18	27.09
	100	20.64	28.51
2	20	14.22	15.77
	50	22.38	22.99
	80	25.65	26.43
	100	27.97	28.34
3	20	10.00	15.59
	50	17.39	21.23
	80	20.62	22.70
	100	23.91	24.15

4. Based on publicly-available population data, determine which cities in Michigan are designated as Tier 1, 2, and 3 cities.
   a. Tier 1: Detroit
   b. Tier 2: Grand Rapids, Warren, Sterling Heights, Ann Arbor, Lansing, Dearborn
   c. Tier 3: All other cities/towns

5. Obtain baseline emissions of passenger cars and passenger trucks from MDOT's 2015 MOVES model for the *county* in which each Tier 1 or 2 city is found. For example, Detroit is found in Wayne County, so baseline emissions were obtained from MDOT MOVES for Wayne County. Though not all emissions within Wayne County are attributed to Detroit, the lack of more

granular baseline emission data necessitates that Wayne County's emissions are all treated as Tier 1. Likewise, Kent County is considered Tier 2 because it contains the Tier 2 city Grand Rapids, and so on.

6. Tier 3 baseline emissions were obtained by summing all remaining statewide baseline emissions, excluding those of the Tier 1-2 counties.
7. Multiply the baseline emissions by the appropriate Tier 1, 2, or 3 emission reduction percentage obtained in Step 3. The product of this equation is the estimated carbon/CAP reduction that would be achieved in each county under 20% CAV penetration and deployment of associated infrastructure technologies. The same reduction potentials presented in the table above for carbon reduction were used to calculate CAP reductions as well. This assumption is acceptable because the reduction potentials are derived from congestion mitigation and overall reduction of fuel use, which would reduce both GHG and CAP emissions by the same percentage.
8. Sum the carbon/CAP reductions obtained in Step 7 to obtain statewide carbon/CAP reductions.

Appendix F Carbon Reduction Strategy Project List

This appendix is provided as an excel file and identifies projects that are programmed to use fiscal year 2022-2026 Carbon Reduction Program funding, as well as other currently programmed projects that align with this strategy but use other funding sources. The funding sources for projects in are subject to change.