Fleet Electrification Strategies

Michigan Department of Transportation

Draft Report

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16. Abstract

The Michigan Department of Transportation (MDOT) relies on data to make informed decisions regarding its vehicle fleet, which totals approximately 4,800 units. Recognizing the environmental impact of its operations, MDOT is exploring alternative fuel and electric vehicle technologies to meet its diverse needs. This research, conducted by Hatch, an engineering consulting firm, involved assessing MDOT's fleet, documenting current and emerging technologies, and evaluating their operational capabilities and suitability. The study included a cost/benefit analysis and emissions impact assessments, focusing on market-available alternative fuel vehicles and electric vehicles. In addition to quantitative data provided by MDOT, Hatch conducted workshops with various MDOT groups to analyze the feasibility of these technologies. Hatch provided insights for MDOT to consider initiating a zero-emission fleet transition, including pilot projects and key performance indicators (KPIs) such as CO2 reduction, cost savings, and infrastructure needs. The report details the conversion of specific vehicle types and emphasizes the environmental, financial, and operational benefits of transitioning to an alternative-fueled fleet. This research will guide MDOT in future equipment procurement and set a precedent for similar research efforts nationwide.

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Acronyms and Abbreviations

AFV	Alternative-Fuel Vehicle
APU	Accelerated processing unit
cfm	cubic feet per minute
CO2	carbon dioxide
EV	Electric vehicle
ePTO	Electric power take-off
GHG	Greenhouse Gas
KPI	Key Performance Indicator
LPG	Liquified petroleum gas
MDOT	Michigan Department of Transportation
VAC	Volts Alternating Current

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Executive Summary

The Michigan Department of Transportation (MDOT) relies on representative data to make informed decisions regarding the agency's vehicle fleet. With a fleet inventory totaling approximately 4,800 vehicles and equipment units, MDOT recognizes the operation of this equipment has an environmental impact. Recognizing the critical role that transportation plays in contributing to air pollution, MDOT is dedicated to exploring the capabilities of today's alternative fuel and electric vehicle technologies to meet the agency's diverse needs. The outcomes of this research will not only guide MDOT in making informed decisions for future equipment procurements but also set a precedent that could influence similar efforts across the nation.

Hatch, an engineering consulting firm, was awarded a contract through a competitive solicitation process to conduct this research. The study involved an assessment of MDOT's vehicle fleet, which includes a wide range of vehicles from light-duty passenger cars to heavy-duty trucks, various equipment such as cement mixers and snow blowers, as well as highly specialized equipment including under bridge inspection units and a variety of aerial tower and lift trucks. Although MDOT has implemented emissions reduction technologies that were technically feasible in the past, this research aimed to document current and emerging technologies, evaluate their operational capabilities, and assess their suitability for MDOT's purposes. This included identifying potential technology pilots through cost/benefit analysis and emissions impact assessments.

The methodology for this project consisted of evaluating market-available vehicles that were both technically and operationally suitable for replacement. The initial step included compiling a list of light-, medium-, and heavy-duty alternative fuel vehicles (AFVs) and electric vehicles (EVs). Data was collected through peer group workshops involving various MDOT groups, such as Bridge, Construction Engineers, Electricians, Equipment Coordinators, Maintenance Superintendents, and Maintenance Workers. This data was used to analyze the operational feasibility of alternative fuel vehicles for each vehicle type within the MDOT fleet. The study also focused on the current market and industry standards for alternative fuel vehicles, exploring various technologies such as battery electric, hydrogen fuel cell, hybrid-battery electric, natural gas, renewable diesel, and biodiesel. The selection of alternative vehicle types was based on an analysis of their technical and operational viability, with a focus on emissions reduction and cost-benefit analysis.

Based on the data gathered and the analysis conducted, Hatch provided high-level insights for MDOT to consider if and when MDOT chooses to initiate a zero-emission fleet transition. These considerations include pilot projects with a representative sample of the fleet to provide an appropriate technology evaluation. Key performance indicators (KPIs) like actual annual CO2 reduction, annual operating cost savings, maintenance practices and costs, reliability, required infrastructure upgrades, and the total cost of ownership per CO2 reduction were established to effectively monitor the pilot program and gather valuable insights for MDOT’s technology selection. First, MDOT could realize the benefit of reduced carbon footprint by focusing on converting their Class 4-8 vehicles that utilize diesel conversion technology, such as idle reduction, as well as diesel aerial lift conversion technology, such as electric power take-off technology (ePTO). In addition to the MDOT’s existing idling policies, secondary priority items to convert are Class 4-6 gasoline conversion technology for idle reduction, Class 1-3 light-duty vehicle, Class 7-8 diesel aerial lift conversion technology, lawn tractors, loaders over 1.25 yards, underbridge inspection vehicles, and walk-behind snow blowers. The report details each vehicle type and its justification as a viable technology conversion for MDOT to consider in the agency’s transition to alternative fuel vehicles.

In summary, this research provides MDOT with an established set of criteria for informed decision making on transitioning to an alternative fueled vehicle fleet, emphasizing environmental benefits, financial implications, and operational feasibility of various technologies. The findings from this study will guide MDOT in making informed decisions for appropriate pilot project initiations and future equipment procurement. Notwithstanding the foregoing, the information provided in this report is for informational purposes only and is based on the unique features of the fleet as communicated by MDOT, including any assumptions made by Hatch and confirmed by MDOT.

1. Introduction

Michigan Department of Transportation (MDOT) recognizes its environmental impact as a government agency that has a fleet of over 4,000 vehicles and equipment ranging from light-duty passenger cars to heavy-duty trucks and their associated equipment. In the nascent years of vehicle electrification technology, MDOT had already strived to curb CO2 emissions through early implementation of idle reduction technologies on a portion of the agency's heavy-duty vehicles and has continued a long standing idle reduction policy to help curb its fleet's emissions. MDOT initiated this study to find additional opportunities for emissions reduction though electric and/or alternate fueled vehicle implementation. As it stands today, the MDOT fleet has a heavy reliance on petroleum-based fueled vehicles due to the agency's priority of providing the needed operational and maintenance services to Michigan roads. Currenty on the market, only petroleum-fueled vehicles allow MDOT to reliably perform its operations. However, this vehicle types contributes to greenhouse gas emissions and air pollution. To address these issues, MDOT has a goal to enter the electrification or alternative-fuel vehicle (AFV) market with educated decision-making. MDOT enlisted Hatch, an international engineering consultancy, to evaluate the capabilities of modern electric and alternative-fuel vehicle technologies. The goal was to assess the feasibility of the technologies for their fleet and to develop a set of operational and technical criteria that could help MDOT assess the suitability of newly available alternative-fuel vehicles for their fleet operations in the future. Factors considered included Michigan's harsh climate conditions such as winters in recent years with temperatures dropping below 25 degrees Fahrenheit and snowfall reaching up to 10-15 feet in some regions. Ultimately, this document serves as a customized guide to help MDOT transition its vehicle fleet to a more sustainable foundation while still maintaining its needed operations as existing assets come due for replacement.

To properly assess MDOT's fleet, it was crucial to have a comprehensive understanding of their current fleet. MDOT has a large fleet storing more than 4000 vehicles, including relevant vehicle attachments and equipment, spread across 68 depot locations across the state. According to the fleet roster provided by MDOT, these depots are spread across seven regions and multiple business areas containing a variety of light, medium, and heavy-duty vehicles with different configurations, operational hours, and staffing levels. **Figure 1** shows the locations of the maintenance garages for the seven regions. Although there are multiple bureaus, offices, and business areas providing services across the state, the focus was narrowed to the regions and offices that significantly impact MDOT's daily operations: Bay (BAY), Grand (GRD), Metro (MET), North (NTH), Superior (SUP), Southwest (SWS), and University (UNI). For the purposes of this study, the Blue Water Bridge area (BWB) is also being referred to as a separate regional fleet due to the area's specific use equipment. **Table 1** summarizes the existing MDOT fleet by vehicle type for each participating region. The color-coding highlights vehicle counts aiding the selection of certain types for analysis while excluding less impactful ones.

Throughout the study, continued findings guided the analysis toward vehicle types and regions that could contribute to the first step in MDOT's transition to electrification or other alternative-fuel vehicle options. The project's main objectives are as follows:

Key Objectives and Goals

- ### Identify commercially available AFV/EV equipment
  Conduct a comprehensive market analysis to identify and catalog commercially available alternative fuel vehicles (AFV) and electric vehicles (EV) that meet the project's criteria.
- ### Assess viability of AFV/EV equipment based on MDOT's functional requirements
  Evaluate the identified AFV/EV equipment to determine their suitability for MDOT's specific operational needs and functional requirements, including examining performance metrics, compatibility with existing infrastructure, and potential for integration into MDOT's fleet.
- ### Assess risks, rewards, costs, and benefits
  Perform a detailed analysis of the potential risks and rewards associated with adopting AFV/EV technology, including a cost-benefit analysis to understand the financial implications and the environmental impacts of carbon to evaluate the long-term sustainability benefits.
- ### Develop Pilot Project considerations
  Formulate a set of pilot projects and first steps to guide MDOT on actionable steps and strategies to implement and manage AFV/EV technology with their operations.

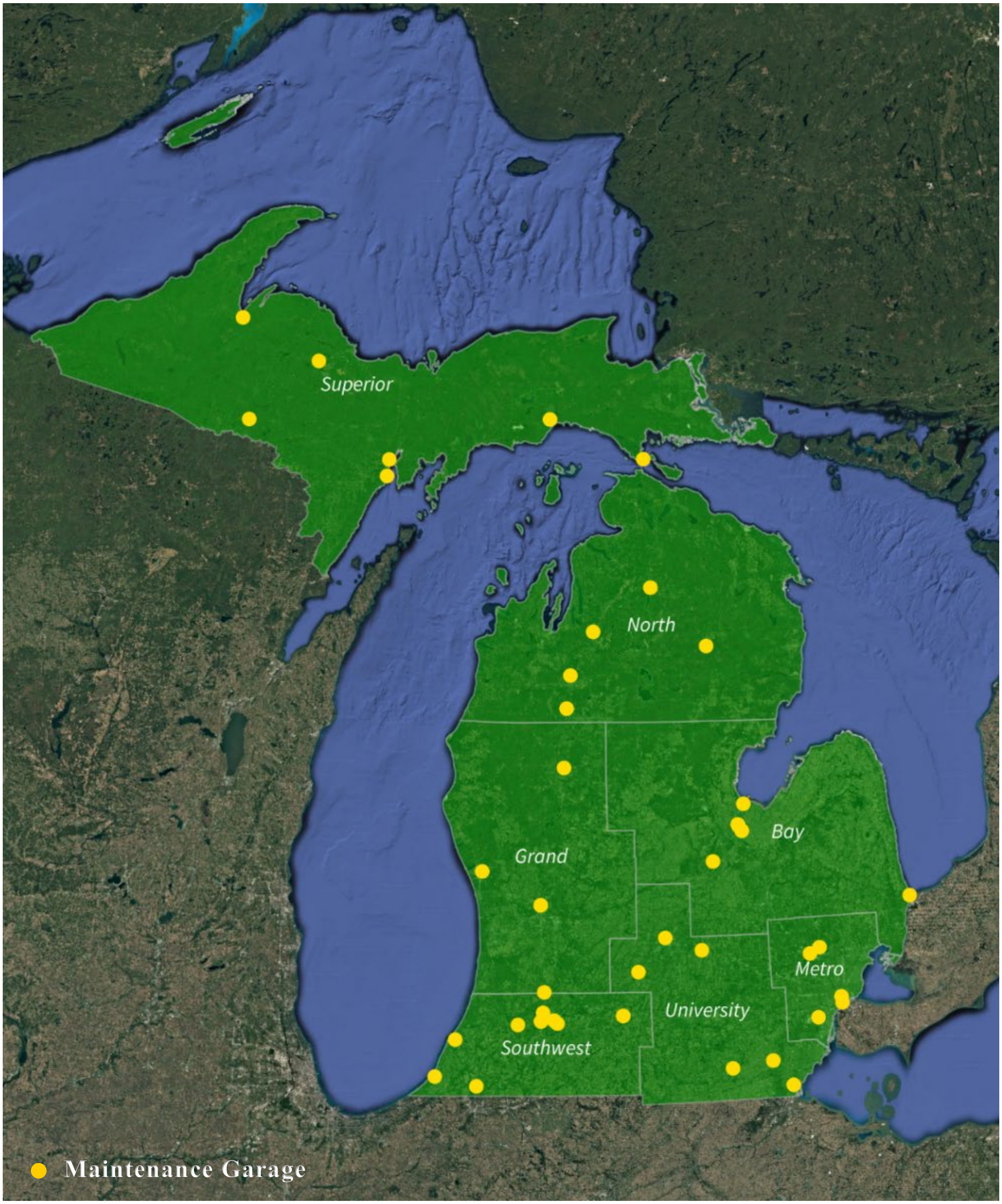


Figure 1. MDOT Maintenance Garages within Michigan regions. Locations are approximate.

Table 1. Count of Vehicle Type by Region

Vehicle Type / Region	BAY	BWB	GRD	MET	NTH	SUP	SWS	UNV
Light-Duty Vehicles (Class 1-2)	115	8	147	212	122	107	125	208
Medium-Duty Vehicles (Class 3-6)	32	9	36	23	21	30	52	81
Heavy-Duty Vehicles (Class 8)	18	4	17	17	18	16	22	28
AERIAL EQUIPMENT	11	1	9	9	6	7	12	13
ATV & SNOWMOBILES	4	1	1	2	2	0	0	1
AUGER TRUCK MOUNTED	2	0	2	2	1	1	0	1
BOATS	0	0	0	0	0	0	0	0
CHIPPER BRUSH	2	0	4	2	1	3	4	11
CHIPPER STUMP	0	0	1	0	1	1	1	3
COMPRESSOR 60-119 CFM	0	0	1	1	0	0	0	1
COMPRESSOR OVER 295	4	1	3	4	4	7	5	5
COMPRESSOR SKID 120 & UP	3	1	4	5	2	4	4	9
COMPRESSOR UNDER 295	1	1	4	1	1	1	6	6
CRANE HYDRAULIC	3	0	4	2	4	3	4	3
CUTTER FORESTRY	4	0	6	0	1	1	8	3
EXCAVATOR TRUCK MOUNTED	0	0	0	0	0	0	0	1
GENERATOR ELECTRIC	1	0	3	7	0	1	6	2
GENERATOR- OVER 100KW FED	0	0	0	2	0	0	1	0
GRADER	2	0	4	0	1	3	6	6
HEATER ASPHALT STORAGE	4	1	5	3	2	4	9	13
HEATER BITUMINOUS & RUBBER	0	0	4	2	0	0	5	9
HEATER ROADWAY PATCHING	2	0	1	0	2	2	3	8
HYDRO SEEDER	1	0	0	0	0	0	1	1
LIGHT TOWERS, FED FUNDED	1	2	2	6	1	0	1	2
LOADER 1-1.25 YARDS	6	1	10	4	4	5	13	11
LOADER FORK LIFT	4	1	4	4	3	4	1	11
LOADER OVER 1.25 YARDS	4	4	8	2	4	11	13	15
MIXER CONCRETE	0	0	2	0	1	3	2	5
PAVEMENT GRINDER	1	0	0	0	1	1	0	1
ROLLER TANDEM OVER 3	1	0	0	0	0	0	0	0
ROLLER TANDEM UNDER 3	1	0	0	0	0	0	0	0
SAND BLASTER	0	0	0	0	3	5	0	1
SAW CONCRETE	2	0	1	1	0	0	0	3
SEWER RODDER 9 & UP	3	0	0	1	1	2	1	2
SEWER, RODDER - SPR	0	0	0	0	0	0	0	0
SHOT BLASTER	0	0	0	0	0	0	0	1
SNOW BLOWER - WALK BEHIND	0	0	0	0	0	0	2	0
SNOW BLOWER-LOADER, TRACT	1	1	1	0	0	5	3	0
SPRAYER PRESSURE	8	0	4	1	1	1	6	2
SPREADER CHIP	2	0	2	0	0	0	3	1
SPREADER TOWED	1	0	1	0	0	0	1	1

SPREADER, COMBINATION MAT	2	0	0	0	0	0	0	0
SURFACE GRINDER	0	1	1	0	1	1	1	1
TRACK MOUNTED EXCAVATOR	0	0	1	0	2	1	3	0
TRACTOR BRUSH CUTTER	1	0	0	0	0	1	2	0
TRACTOR CRAWLER OVER 30	0	0	1	0	0	0	1	0
TRACTOR LAWN	1	0	5	1	5	9	9	9
TRACTOR LOADER BACKHOE	4	0	3	1	2	3	6	13
TRACTOR ROADSIDE	6	1	9	2	4	4	22	19
TRAILER DEFLECTOMETER	0	0	0	0	0	0	0	0
TRENCHER - SPR	0	0	0	0	0	0	0	0
TRUCK STREET SWEEPER	0	1	0	1	0	0	0	1
WELDER ELECTRIC	0	2	2	3	0	2	2	0

Regions with a higher quantity of vehicles will have a greater impact with alternative fuel vehicle conversions. The darker green shades represent larger quantity of vehicles signifying a greater impact on that region. The lighter yellow shades represent fewer quantity signifying less of an impact on the region if the vehicle technology was converted to an alternative fueled version.

2. Methodology

The methodology for this project was designed to evaluate the feasibility and suitability of alternative fuel and electric vehicle technologies for MDOT's diverse fleet. The approach involved several key steps: data collection via workshops and interviews with various MDOT groups, establishing operational criteria for vehicles/equipment by regions, a feasibility analysis of alternative fuel vehicles and equipment, and detailed cost-benefit and emissions analyses. This multi-faceted methodology intended to provide an assessment of the potential for transitioning MDOT's fleet to more sustainable alternatives, providing MDOT with insights and considerations for future implementation. The approach involved several key steps detailed below:

Data Collection

Data was collected by applying several data sources. First, the detailed vehicle and equipment list was extracted from the MDOT database. This list was analyzed and summarized according to the vehicle or equipment type, regional ownership, age, picture, and quantity. The vehicle and equipment list was used to facilitate the discussion with the MDOT peer groups. Then, peer group workshops involving various MDOT groups, including Bridge and Construction Engineers, Electricians, Garage Supervisors, Maintenance Workers, Regional Equipment Foremen, Regional Superintendents, Sign Crew, and Forestry Staff were conducted. These workshops gathered detailed anecdotal insights on the typical use of different vehicle types including accessory equipment usage, vehicle descriptions, operational conditions, storage locations, fueling areas, operator assignment processes, average travel speeds, shift times, average distances traveled, idling times, maximum mileages per shift, minimum operation times per shift, and the availability of electrical outlets near idling locations. Additionally, interviews and surveys of other state DOTs were conducted and their current decarbonization efforts were summarized. Further insights were collected from technology vendors such as ePTO and electric generator vendors.

Developing Alternative Fuel Vehicle (AFV) List

Once the operational requirements for MDOT fleet was established, a list of all AFV/EV vehicle and equipment was compiled, encompassing a wide range of vehicles from light-duty passenger cars to heavy-duty trucks, as well as various equipment such as air compressors and snow blowers. The list included AFV/EV equivalents for MDOT’s existing vehicle and equipment fleet if commercially available. The vehicle and equipment categories that lacked any alternative fuel propulsion were excluded during this initial step. The feasibility of the vehicles on AFV/EV list, detailed in **Appendix A**, was than evaluated for MDOT operations in the next step.

Feasibility Analysis

After an AFV list was compiled, the technical and operational performance of the AFVs and equipment were assessed for the vehicle and equipment categories where equivalent AFVs were commercially available. In this step, AFVs and equipment that did not meet the technical capabilities of MDOT's current fleet such as engine power, operating weight, and bucket capacity were eliminated. The operational feasibility of the remaining AFVs was then evaluated against MDOT's specific use cases. This evaluation approach included technical specification analysis, industry and academic reports, and vehicle modeling and simulations that mimicked the performance of vehicles under MDOT's operational scenarios. At the end of this multi-step analysis, a list of feasible AFVs and equipment was extracted for the cost-benefit analysis. Additionally, each of these vehicles was analyzed across different regions to determine their technical and operational feasibility for alternative-fueled versions or for the use of electric power takeoff (ePTO) technologies. ePTOs are zero emission technology systems that use electrical energy stored in dedicated batteries to power auxiliary equipment and functions on vehicles, rather than relying on mechanical energy from a combustion engine.

Cost-Benefit, Carbon Emissions and Risk Analyses

A cost-benefit analysis was performed to assess the carbon emission reductions and financial implications of replacing the gasoline or diesel fleet with alternative fuel vehicles (AFVs). The cost analysis considered the vehicle purchase cost differential and the fueling cost differential between conventional and alternative fuel vehicles along with each's operational cost differential. Different metrics were generated out of these calculations such as the cost of one pound of CO_2 reduction for each vehicle type in each region and total daily, annual, vehicle life of CO_2 reduction for each vehicle type in each region. At the last stage of the analysis, risk assessment of each feasible vehicle type and equipment was conducted based on several metrics such as the availability of multiple manufacturers in the market, their maturity in the industry, and the equipment's application history. The cost-benefit analysis is detailed in **Appendix B**.

Pilot Projects for MDOT's Consideration

Based on the data gathered and the analysis conducted, some vehicles were identified for potential pilot projects for MDOT to consider testing out the zero-emissions technologies and initiate their zero-emission fleet transition. These potential pilot projects are determined based on a representative sample of the fleet to provide accurate technology evaluation. Key performance indicators (KPIs) were established to monitor the pilot program and gather valuable insights for technology selection.

Assumptions and Limitations

In this fleet research on alternative fuel vehicles, the assumptions made are grounded in the accuracy of data available at the time of conducting this research. The analysis relies on current industry standards and information, acknowledging that any projections are based on data accessed at the time of the study. It is important to note that due to the lack of quantitative operational and duty cycle data, such data was collected anecdotally through stakeholder engagement such as workshops. Therefore, it is important to note that there are limitations to the accuracy of this data and further data verification may be warranted. Consequently, while the inputs reflect current industry conditions and MDOT's operational needs, they may not account for unforeseen advancements or shifts in the future or any discrepancies between established operational criteria established in this study and real life operational requirements, as well as future technological advancement and enhancement. This approach provides that the findings are relevant and applicable to the present context, but also highlights the need for ongoing updates as the industry evolves rapidly and to improve on accurate data gathering.

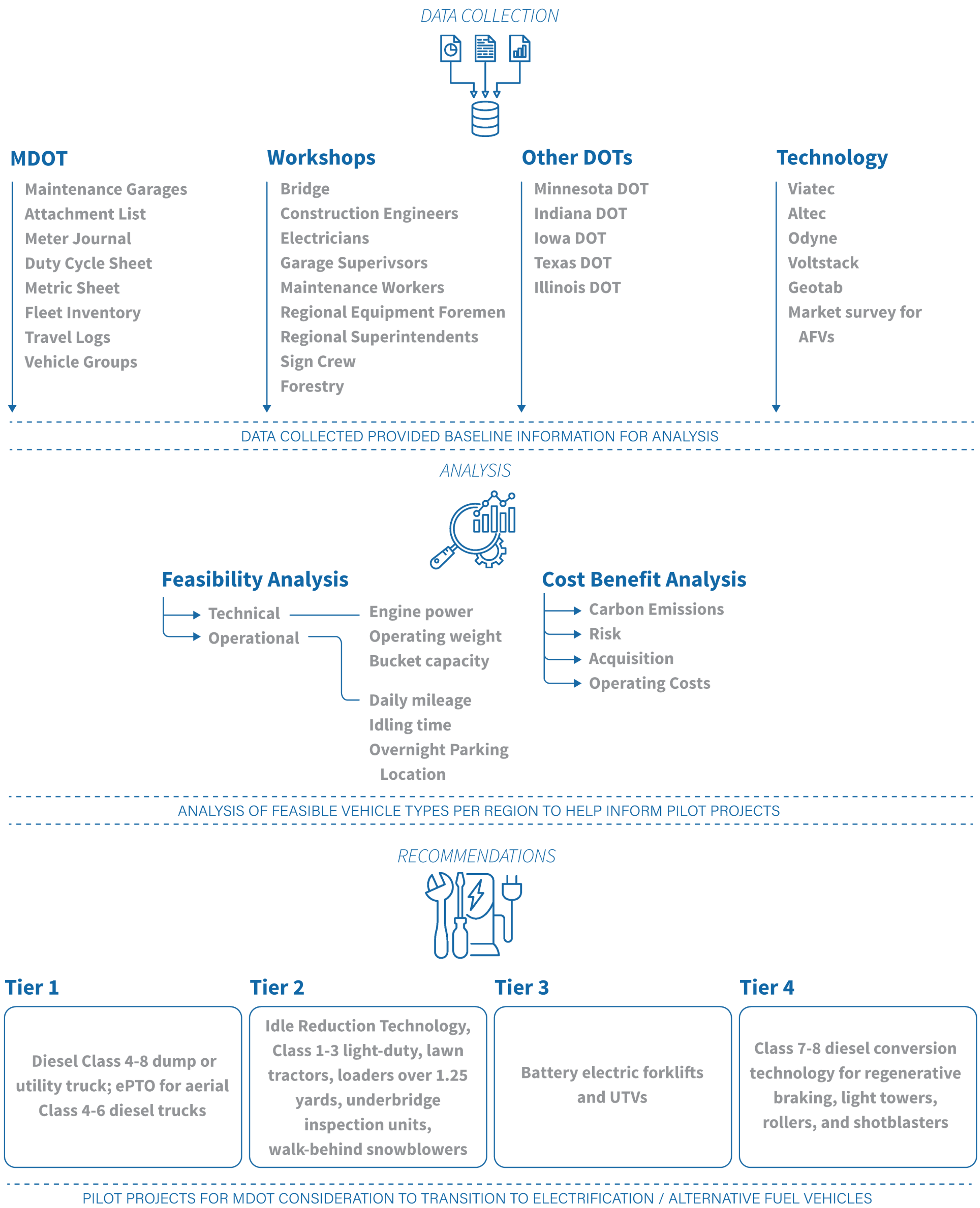


Figure 2. Methodology Diagram

3. Operational Requirements

Before a complete analysis of the MDOT fleet was conducted, the operational requirements of the current MDOT fleet for each vehicle type was assessed. This allowed for a better understanding of the day-to-day operations of each vehicle type and how it would be compared to its alternative-fuel equivalent. To determine each vehicle's daily usage, granular usage data for each vehicle in MDOT's fleet is required. While MDOT has a robust asset management system and continues to invest in fleet metrics and data collection, granularity of the data is a challenge across the board for many agencies. To address this issue, investment in KPI tracking technologies for pilot projects are later mentioned in Section 7. Despite this, a high-level operational profile view of the MDOT fleet was developed and analyses were conducted to provide insights on the fleet's diversity and usage patterns. To determine the operational requirements, multiple sources were used to gather data and establish an understanding of Michigan DOT's current vehicle fleet and its use. For medium- and heavy-duty vehicles, stakeholder interviews were conducted to gather information on the usage of each vehicle type across various regions. For light-duty vehicles, data logs were provided by MDOT. This comprehensive analysis informed the operational strategy. The operational requirements analyzed included the following factors:

+ Vehicle fleet breakdown by type (e.g. Light-, medium-, and heavy-duty fleet composition, construction equipment and attachments)
+ Fleet functions (e.g. construction, maintenance, transportation, etc.)
+ Typical operating cycles for each vehicle type
+ Endurance requirements (maximum daily mileage, maximum continuous time in service – e.g. winter snowplow duty)
+ Typical layover locations and durations
+ Fleet age and replacement schedule
+ Current fuel supply agreements and fueling methods
+ Average fuel economy and total mileage of each vehicle type in the current fleet
+ Maintenance/garage/storage facility locations and layouts
+ Staffing and capabilities
+ Current training programs
+ Funding sources and resources
+ Performance details of any existing AFVs and EVs already in the fleet

The following crews from various MDOT garages were interviewed and discussions on each of the above factors were asked for each MDOT group:

+ Bridge Crew
+ Construction Engineers
+ Electricians
+ Regional Equipment Foremen
+ Regional Superintendents
+ Sign Crew

+ Garage Supervisors
+ Maintenance Workers
+ Forestry Staff

The following groups had participated in the interviews and helped define vehicle usage per region:

+ Bay
+ Grand
+ Metro
+ North
+ Southwest
+ Superior
+ University

The baseline data gathering provided a foundational understanding of the operational requirements used for the feasibility analysis. Interviews with stakeholder groups within MDOT helped determine the actual use of each vehicle type per participating region. Having both vehicle mileage data provided by MDOT and additional context from other region's members who were familiar with the needs of different regions helped verify the operations assumed. The variance in geography based on region was critical context that allowed for more accurate analyses. For example, the North and Superior regions of Michigan have extreme winters, hilly terrain, and larger distances from garages as compared to other regions. This context is additional information that is taken into account during the technical and operational analyses. The data gathered included details on the operational use, requirements, and observations of various vehicle classes, along with region-specific notes, peer-specific notes, attachments needed for vehicles, mileage, idling, speed, garage, shift time, and the use of light-duty to heavy-duty vehicles across different regions and departments. The accumulation of information explored the potential for electrifying certain vehicle classes, the use of vehicles by different teams, and the operational analysis conducted through interviews to understand the diverse needs and uses of the fleet. This overview is crucial for informing our operational strategy and to identify suitable candidates for potential pilot projects to test zero-emissions technologies.

For instance, some regions reported consistent daily mileages averaging over 200 miles, which helped identify areas that may be less feasible for alternative fuel vehicles with lower range. This was true for the Superior region that has an average daily milage of 400 miles. Conversely, regions like Blue Water Bridge and the Metropolitan region consistently reported lower daily mileages per day, indicating a higher potential feasibility for alternative fuel vehicles depending on the vehicle type.

Key takeaways

- ### High mileages in the northern regions

  Although many of the vehicles in all regions have high daily mileages, vehicles in the northern areas consistently recorded extensive usage, indicating significant travel distances higher than the other regions due to its natural geographic differences, such as its hilly elevations, intense snowfall, and extremely harsh winters.

- Long hours for snow vehicles during the winter

  Winter storms and winter road maintenance require extensive and longer period usage of fleet equipment, therefore snow vehicles and supporting equipment operate for extended periods during the winter months, reflecting the demanding conditions they face.

- Vehicles used as pool vehicles

  Many vehicles served multiple purposes and users, functioning as shared resources within the fleet and across some regions.

- Long periods of idle times for Class 3-8 vehicles

  Engines must idle to perform PTO, power some electrical auxiliary devices, provide in-cabin heating/cooling, and power external lights for necessary operational tasks, such as snow clearing during the winter months with shift times sometimes exceeding several days.

- Commercial fueling stations

  In all regions, fuel supply is provided by commercial fuel stations available nearby work sites and MDOT garages.

- Overnight Stays/Parking

  First responders' vehicles are kept at their homes overnight, making overnight charging impractical for battery electric vehicles. Additionally, some construction equipment remains at work sites overnight, complicating electrification due to the lack of electrical infrastructure for charging.

- Electrical Infrastructure at the Garages

  Garages where vehicles and equipment are stored overnight or longer term are old with low capacity grid supply and have very limited indoor space. Therefore, building a comprehensive charging system for battery electric vehicles requires significant infrastructure upgrades for fleet-wide zero emission vehicle implementation.

- Performance requirements based on the specs of existing fossil fuel vehicles and equipment

  Alternative fuel vehicles were assessed to ensure they could meet or exceed the performance standards of current fossil fuel vehicles and equipment.

4. Technology Options and Industry Overview

4.1 Current Available Technology Options

To determine the feasible vehicles for future MDOT use, it was imperative to conduct a review on the current market and industry standards for alternative-fuel vehicles. An overview on the several types of alternative-fuel vehicles is described below:

Zero-Emissions Technology

ZE technologies consist of two propulsion technologies, battery electric and hydrogen fuel cell.

- Battery electric technology is the use of rechargeable batteries to power electric vehicles, which is a key component in the transition to zero emission transportation and is integral to the mass production of EVs. Battery energy is used to propel the vehicle and power the accessories needed to be replenished through the grid electricity. Wayside chargers are used as the interface between the battery and grid electricity to control this charging process.

Figure 3. Battery-Electric Propulsion Diagram

- Hydrogen fuel cell technology uses hydrogen as a fuel source to generate electricity through a chemical reaction in a fuel cell, providing a zero-emission alternative to traditional combustion engines. The supply of hydrogen can be provided by either on-site hydrogen production or hydrogen delivery by trucks in gas or liquid form. In both cases, hydrogen dispensers need to be installed at the fuel site. Since MDOT vehicles supply their fuels from commercial gas stations and MDOT garages are not built to support fueling stations, hydrogen fuel cell technology is not a viable solution for MDOT.

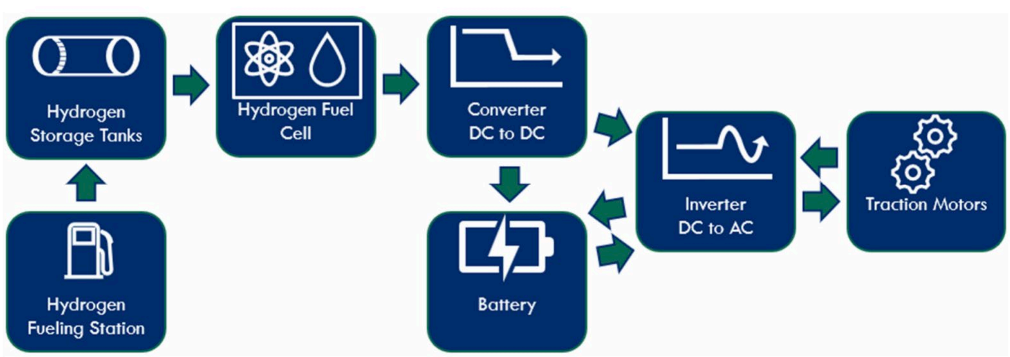


Figure 4. Hydrogen Fuel-Cell Propulsion Diagram

Emission Reduction Technologies

- Hybrid-battery electric power technology combines an internal combustion engine with an electric propulsion system, using both diesel/gasoline fuel and battery energy to improve efficiency and reduce emissions. Battery is used to capture energy from regenerative braking and to assist diesel/gasoline engine in propulsion to reduce fuel consumption.
- Natural Gas is a fossil fuel that consists primarily of methane and offers an alternative fuel which offers lower emissions than diesel fuel. Natural gas can be supplied as either liquefied natural gas (LNG) or compressed natural gas (CNG). Natural gas also requires on-site natural gas fueling stations since gas stations with natural gas are extremely limited in the state of Michigan.
- Renewable Diesel (RD) or Hydrotreated Vegetable Oil (HVO) has recently entered the transportation market. RD is similar to biodiesel in that it is a biofuel derived from fats, oils, and greases. However, the chemical process used to produce RD differs; RD is created when hydrogen is introduced into the oils, together with a catalyst, at elevated temperatures. Although this process is substantially more complex than that required to produce biodiesel, the advantage of RD is that it is chemically identical to conventional diesel, and complies with the ASTM D975 Standard Specification for Diesel Fuel. Therefore, RD can be used as a standalone fuel in diesel engines with no engine modifications, or in blends with biodiesel.
- Biodiesel is an increasingly popular alternative fossil fuel that is made from vegetable oils, animal fats, or restaurant grease. It is produced by transesterification which involves reacting fats/oils with an alcohol and catalyst creating biodiesel and glycerin.

The selection of alternative vehicle types for the project was predicated on an analysis of their technical and operational viability. The primary conclusion is that the array of alternative options is somewhat constrained due to the nascent stage of adoption for AFV technology in heavy-duty maintenance equipment. Conversely, the market for smaller equipment types offers a broader spectrum of choice, attributable to the more advanced state of electrification and AFV technologies. Subsequent sections provide a detailed exposition on the assortment of commercially accessible products viable for pilot initiatives or initial integration and replacement within the MDOT fleet.

4.2 Other Industry Initiatives

Additionally, as part of comprehensive research efforts, Hatch engaged with various other Departments of Transportation (DOTs) to gain insights into their experiences and best practices from different states. By conducting interviews with these agencies, Hatch was able to integrate their lessons learned into its findings. It was discovered that while most state DOTs are leveraging the federal National Electric Vehicle Infrastructure (NEVI) program and are optimistic about AFV technology, they do not necessarily advocate for an expedited transition to AFVs. Another common theme among some DOTs is implementation of data loggers for collection performance data on their fleet. The data is leveraged to optimize the fleet operations including accurately assessing the feasibility for transitioning to zero emissions technologies.

Minnesota Department of Transportation

The Minnesota Department of Transportation (MnDOT) has been actively implementing several alternative fuel vehicle planning projects, including their Statewide EV Infrastructure Plan supported by the NEVI grant program, the 2021 EV Assessment, and the North/West Passage Transportation Pooled Fund Study. Additionally, MnDOT is working on carbon reduction programs in coordination with local governments. Through discussions with MnDOT staff, several lessons learned and insights regarding the implementation of electric vehicles and related infrastructure were noted. MnDOT has faced significant challenges with procurement, maintenance, and facility upgrades. These challenges include difficulties in sourcing the necessary equipment, maintaining the new technology, and upgrading existing facilities to accommodate alternative fuel vehicles. Vehicle data trackers have proven to be invaluable in understanding how assets are utilized and fueled. The DOT's light-duty vehicle fleet is equipped with Geotab devices, which provide detailed insights into vehicle usage and fuel consumption. The department is considering the use of 100% Biodiesel, but a major challenge is that the fuel needs to be kept warm to remain effective. For larger vehicle applications, such as waste management, MnDOT is exploring the use of compressed natural gas (CNG). All-electric vehicles have been trialed in Minnesota metro areas where the average trip length is shorter. These trials have had mixed success; for instance, the Lightning F150 was deployed and worked well in some areas but not in others. Currently, MnDOT has no plans for the electrification of large vehicles until the market direction is more established.

Indiana Department of Transportation

The Indiana Department of Transportation (INDOT) has been proactive in exploring alternative-fuel vehicles through several initiatives, including their State EV Infrastructure Workshop on Medium- and Heavy-Duty Considerations, EV Infrastructure Deployment Plan, and EV Infrastructure Plan. Unfortunately, the electric vehicles (EVs) deployed by INDOT proved to be unreliable and incompatible with their fleet requirements. As a result, INDOT encourages other transportation departments to work towards minimizing funding restrictions for AFVs to facilitate smoother transitions. INDOT's journey into alternative fuels began as early as 2009 with the acquisition of 16 compressed natural gas (CNG) trucks. Initially, these trucks relied on public fueling stations, but INDOT later established its own station in Indianapolis, and now both public and private fueling stations are in use. Despite facing delays, INDOT has ordered three Chevy Silverado electric trucks, which boast a 400-mile advertised range, for delivery in the summer of 2024.

Iowa Department of Transportation

The Iowa Department of Transportation (Iowa DOT) is actively advancing its electric vehicle infrastructure through a comprehensive plan aimed at creating a robust charging network across the state. As part of the 2021 Infrastructure Investment and Jobs Act, Iowa's Electric Vehicle Infrastructure Deployment Plan was developed and approved in September 2022. This plan focuses on establishing EV charging stations along major transportation corridors, including Interstates 29, 35, 80, and 380, ensuring that chargers are accessible within 50 miles of each other[1]. The initiative aims to support both regional and interstate travel, promote equitable access to EV infrastructure, and reduce emissions. To support this, Iowa DOT continues to integrate public-private partnerships and leverage federal funds[2]. The Iowa DOT has been actively working on integrating electric vehicles into their fleet to reduce carbon emissions and promote sustainability. They currently own two Chevy Bolts and one Level 2 dual-port Chargepoint charging station. Additionally, the Iowa DOT has installed Optimus Technologies equipment in ten of their diesel snow plow dump trucks, allowing them to utilize B100 biodiesel. This initiative has resulted in an approximate annual reduction of 173,728 pounds of CO_2. These efforts are part of a broader strategy to transition to alternative fuel vehicles and enhance the environmental performance of their fleet.

Texas DOT and Illinois DOT

Both Texas DOT and Illinois DOT had successfully deployed data log technology through Geotab, a technology company that specializes in telematics hardware and software for fleet management, providing solutions for vehicle tracking, on-board diagnostics, route optimization, and CO_2 emissions reporting. This implementation allowed them to gain granular data, which provided valuable insights into their operations. Both departments reported positive experiences with the technology, highlighting its effectiveness in capturing detailed information that could be used to optimize fleet management and improve overall efficiency. The granular data from the loggers will also be leveraged to assess the AFV feasibility for their fleet.

[1] Iowa Electric Vehicle Plan - Iowa Department of Transportation. https://iowadot.gov/iowaevplan.
[2] Iowa Electric Vehicle Plan - Overview - Iowa Department of Transportation. https://iowadot.gov/iowaevplan/Overview-draft.

5. Feasibility Analysis

To support the evaluation, it was crucial to conduct analyses on both the technical and operational feasibilities of the vehicle types. This analysis helps determine whether the current infrastructure and technology can support the adoption of alternative fuels, such as electric or hydrogen. In the technical feasibility assessment, the availability of alternative fuel vehicles, which are in the same class or are similarly sized to each conventional vehicle or equipment in the MDOT fleet, was explored. In the operational feasibility evaluation, it was analyzed whether each technically feasible vehicle or equipment is capable of meeting MDOT specific operational requirements. Together, these analyses provide an understanding of the potential impacts, benefits, and challenges, enabling MDOT to make decisions and develop a strategic plan for a sustainable and efficient fleet transition.

5.1 Technical Feasibility Analysis

In the technical feasibility analysis, the first step explored the existence of any AFV product options for each vehicle type along with relevant attachment equipment within MDOT's fleet. The vehicle and equipment categories that do not have any alternative-fuel propulsion are eliminated from the list for further analysis. Then, the technical performance of the alternative fuel vehicles and equipment was compared to the vehicles and equipment pieces in MDOT inventory. The vehicle types, which do not have comparable options are also eliminated from the list. The remaining list is assessed for operational feasibility, which is explained in the next section.

5.1.1 Vehicle/Equipment Without Current Alternative-Fueled Options

The list below shows the vehicle and equipment categories that do not have alternative fuel versions in the market yet based on our market research.

+ Graders
+ Trucks with extended reach
+ Truck mounted excavators
+ Generators over 100 kVA
+ Brush cutters
+ Stump chippers
+ Road rakes
+ Chip spreaders
+ Hydroseeders
+ Trenchers
+ Deflectometers
+ Crawler tractors
+ Patching Heaters

Additionally, there were some vehicles that were not considered due to other factors. The Tandem rollers under 3 tons and Compressors under 295 cfm were excluded from further analysis due to MDOT's interest in higher capacity versions of these vehicles. Additionally, sand blasters and snow plowing accessories were also excluded from the list since they do not have internal combustion engines and are externally powered by pressurized air and hydraulic systems.

5.1.2 Technically Infeasible Vehicles and Attachment Equipment

This list shows infeasible vehicle types that have alternative fuel options on the market, but do not meet the technical specifications of the vehicles in MDOT's fleet.

Class 3-8 Gasoline and Diesel Engine Vehicles

There are a few battery-electric vehicles offered by various manufacturers in the market as shown in **Table 2**. But the range of these vehicles is limited compared to their internal combustion engine versions. Therefore, those battery electric vehicles are technically infeasible in meeting MDOT's daily mileage requirements.

Table 2. List of Class 3-8 Battery Electric Trucks

Manufacturer	Model Name
Mullen	Mullen Three
ZEV+	Ford Class 4-5 Conversion
Envirotech	Urban Truck
Rizon	Rizon e16L
Workhorse	Workhorse W4 CC
Lion	Lion 5, 6, 8
BYD	6F
Battle Motors	CTOS Digger, Flat and Stake Beds, Broom Bear
Freightliner	eM2
International Trucks	eMV
Kenworth	K270E and K370E
Mack	MD Electric
XOS	MDXT
Volvo	VNR

Moreover, Freightliner offers M2 112 model truck operating with CNG fuel. CNG trucks are not feasible for MDOT since the agency does not have on-site fueling infrastructure and the state of Michigan has very limited commercial CNG fueling stations.

Truck with Pumphouse Vactor

There is a battery electric driven pumphouse vactor product in Europe (ROM e-SmartCombi PRO), however, the product is not currently available for the U.S. market. Moreover, the product's tank capacity and vacuum hose diameter are smaller than the ones MDOT uses. Therefore, converting trucks with pumphouse vactor to battery electric models is not technically feasible.

Street Sweepers

There are two comparable products with CNG and LPG engines (Tymco and NiteHawk) that have similar functionality as the street sweepers in the fleet. However, Tymco's street sweepers has a smaller debris tank, hydraulic pump, and hose as compared to the street sweepers in MDOT inventory. Similarly, NiteHawk's street sweeper has a smaller hydraulic pump, debris and water tanks, and lower pressure spray water in addition to the lack of external vacuum hose. Therefore, street sweepers are not technically feasible in meeting MDOT's performance requirements.

Sewer Rodders

There are two electric driven products in the market offered by Vermeer (HDD Rig NRI 300-140TE) and Streicher (HDD45-E and HDD80-E). However, the electricity needs to be supplied by an external AC electric supply instead of a battery. Therefore, the mobility of these products is problematic due to the infeasibility of finding AC electric sources at job sites. Moreover, their pullback and motor power specifications are much larger than the sewer rodders in MDOT inventory, hence are not technically feasible.

Loaders 1-1.25 yards (Skid steers)

Bobcat and First Green have introduced battery electric skid steers. First Green's product is much smaller than the loaders in MDOT fleet in terms of operating weight. In addition to the fact that Bobcat's battery loader (T7X & S7X) is in the smaller skid steer category compared to the ones in the MDOT fleet, it also lacks the capability of working with hydraulic attachments. Since MDOT depends heavily on a wide range of Bobcat hydraulic attachments, battery electric loaders are not technically feasible for MDOT.

Roadside Tractors

There are a few battery-electric tractors offered by various manufacturers in the market as shown in
Table *3* below. However, they are designed mainly for the farming market and their motor and PTO power ratings are smaller than the ratings of the tractors in MDOT fleet. Therefore, the battery electric tractors are technically infeasible for MDOT.

Table 3. List of Battery Electric Tractors

Manufacturer	Electric Motor and PTO Power Ratings
Case Holland	74 hp, 65 hp
Solectrac	75 hp, 65 hp
Monarch	70 hp, 40 hp
Rigitrac	54 hp, 19 hp
Fendt	74 hp, not available

Track-mounted Excavators

The operating weights of track-mounted excavators in MDOT fleet vary between 13,600 lbs and 34,000 lbs. Although there are multiple battery electric excavators in the market, none are within the needed operating weight range. For example, the operating weights of battery electric excavators offered by Volvo (ECR25), Bobcat (E10 and E19e), JCB (19C-IE), and Wacker Neuron (EZ17e) are between 4000 lbs and 6000 lbs, whereas the operating weights of battery electric Volvo EC230, Caterpillar 320 (prototype), and Komatsu PC200LCE (prototype) are larger than 50,000 lbs. There is only one battery electric excavator model in the market with its operating weight of 18,739 lbs (HEVI) which is within operating weight range of MDOT fleet. However, this excavator model only has a wheeled excavator version.

Rubber & Bituminous Heater

There are LPG versions of some rubber and bituminous heaters in the market (A&A and Marathon), but their capacity is around 250 gallons, which is lower than the ones in the MDOT fleet, which is 350 gallons. Moreover, during the cold Michigan winters, LPG heaters have problems keeping the temperature at the vehicle's desired levels due to LPG's energy density.

Asphalt Paver

Although two battery electric asphalt pavers exist in the market (Dynapac and Leeboy), they are much bigger than the one MDOT's fleet regarding the paving width and operating weight. The other two battery electric asphalt pavers (BAM and CM F175) are not applicable to MDOT since those products are either in the prototype phase or available only in the European market.

Concrete Saw

There are concrete saws with similar technical specifications to those in the MDOT fleet that have EV versions powered by an external 3-phase 480 VAC electric supply (Husqvarna, Core Cut, Merit). However, since concrete saws are used at the job site, providing a consistent, reliable 3-phase 480 VAC is not practical. Moreover, diesel battery hybrid and battery generators in the market do not have the capability of providing 3-phase 480 VAC output.

5.1.3 Technically Feasible Vehicle/Equipment

This list shows the vehicle types, which have alternative fuel versions that can match the technical specifications of the vehicles in the MDOT's fleet.

Class 1-2 Gasoline and Diesel Engine Vehicles

Although Class 1-2 battery electric vehicles in the market cannot match the range of their internal combustion engine equivalents, daily mileages of many vehicles in MDOT fleet are within the range of battery electric vehicles based on the vehicle logs. Therefore, Class 1-2 battery electric vehicles are considered technically feasible in this study.

Image 1 shows a Ford 2024 F-150 Lightning.

Forklifts

Basic capacity and lifting height of the forklifts in MDOT fleet are 5,000-8,000 lbs and 118 inches, respectively. Currently there are many battery electric forklifts in the market whose basic capacity and lifting height are 5,000-5,500 lbs and 118-130 inches as shown in **Table** 4.

Table 4. Existing Battery Electric Forklifts in the Market

Forklift Brand	Basic Capacity (lbs)	Lifting Height (in)
BYD	5,400-6,000	118
Toyota	5,000-17,500	132
Hyster	5,000	133
Mitsubishi	5,500	130
Crown	5,000-7,000	116

Image 2 shows a 48V Electric Pneumatic Forklift from Toyota.

Rollers

Many battery-electric rollers from various manufacturers (Hamm, Bomag, Volvo, Ammann) match the technical specifications of the rollers in MDOT fleet in terms of motor power, drum width, and water tank capacity are available in the market.

Image 3 shows a Haam Electric Roller.

Lawn Tractors

Lawn tractors are categorized by two groups: tractors and zero-turn mowers. Battery electric tractors offered by RYOBI and Cubcadet currently in the market do not meet the requirements of the lawn tractors in MDOT fleet regarding cutting depth and target application, such as residential applications rather than commercial. However, zero-turn mower products (Gravely and EVO) match the technical specifications of the conventional zero-turn mowers in the MDOT fleet.

Image 4 shows a Gravely Pro-Turn EV Zero-Turn Electric Mower.

9’ and up Sewer Rodders

Two battery-operated sewer rodders (Pipehunter and Sharp EV4) match the technical specifications of those in the MDOT fleet in terms of water capacity, water flow rate, and pressure. While the Sharp EV4 is offered as a trailer, the Pipehunter can be both truck-mounted or trailer-based.

Image 5 shows a Pipehunter Mount Jetter.

Walk-behind Snow Blowers

MDOT only has two walk-behind snow blowers in its inventory. In the market, there are two battery-operated snow blowers offered by Greenworks with 60V and 80V battery options that can replace gasoline engine driven snow blowers.

Image 6 shows an electric Greenworks snow blower.

Surface Grinder

The surface grinders used by MDOT have electrically operated versions. These electric grinders require the supply of a single-phase AC voltage from an external power source.

Image 7 shows an electric EDCO Surface Grinder.

Asphalt Storage Heater

The asphalt storage heater's MDOT operates use diesel heaters and have an 8,800 lbs capacity. In the market, there are two asphalt storage heaters with the same capacity offered by Falcon and Marathon that operate with liquefied petroleum gas (LPG).

Image 8 shows a Falcon Asphalt Storage Heater.

Loaders over 1.25 yards

There are many battery-electric loaders currently as a final product or prototype by Volvo, Case, Komatsu, HEVI, Caterpillar, Multitone, LiuGong, and Wacker Neuson. Volvo L25, Komatsu WA70-7, Caterpillar 950 GC, Case CL36, Multitone EZ 8, and Wacker Neuson WL20e have smaller capacities in terms of operating weight, power, and bucket size than the loaders used by MDOT. Contrary to those loaders, battery-electric Volvo L120H and LiuGong 856HE are bigger than the loaders in MDOT fleet. The only battery electric loader on par to the loaders in MDOT fleet is HEVI GEL-5000.

Image 9 shows a HEVI Gel-5000 Electric Wheel Loader.

Compressors over 295 cfm

There is one electric compressor offered by Atlas Copco on the market that meets MDOT's requirement of a 450 cfm high air flow rate. An external 3-phase AC voltage supply is needed to power the compressor.

Image 10 shows an electric Atlas Copco Air Compressor.

UTVs

Although there are multiple battery electric UTVs offered by Polaris, Landmaster, Greenworks, Huntve, Intimidator, and DRR USA, none of them except the battery electric Polaris Ranger XP Kinetic can meet the technical requirements of the UTVs to operate and perform MDOT's required tasks.

Image 11 shows a Polaris Ranger XP UTV.

Underbridge Inspection/Aerial Equipment

MDOT has truck and trailer-based underbridge inspection equipment. There is only one battery electric bridge inspection equipment in the market offered by Anderson Underbridge as a trailer-based unit that can serve a purpose at MDOT.

Image 12 shows an electric Anderson underbridge.

Concrete Mixers

Concrete mixers used by MDOT have their electric versions with the same drum capacity offered by Multiquip, but they require an external single-phase AC power supply.

Image 13 shows an electric Multiquip concrete mixer.

Shot Blasters

There is only one alternative fuel LPG shot blaster offered by Blastpro which can meet the technical capabilities of shot blasters operated by MDOT.

Image 14 shows a propane Blastpro Ride-on Shot Blaster.

Light Towers

Light towers can be powered by the following alternative energy sources:

- Battery hybrid (engine generator + battery)
- Battery
- Solar + battery
- Engine generator + solar + battery

Image 15 shows an electric Generac light tower.

Light towers operated by these low-emission and zero-emission energy sources listed in **Table 5** match the performance of light towers in the MDOT inventory. While battery light towers can provide energy up to 17 hours, engine+battery light towers can provide zero emission energy between 4 and 8 hours depending on the model.

Table 5. Light towers with alternative fuel energy sources

Model Name	Energy Source	Technical Specifications
Generac MLTB	Battery	23 ft, LED, 760 W, 104 kLm
Generac VT-Hybrid	Engine + Battery	27 ft, LED, 600 W, 76.5 kLm
Wanco WLTS-M-1600H	Engine + Battery + Solar	30 ft, LED, 800 W, 128 kLm
Signal Power	Engine + Battery + Solar	30 ft, LED, 1280 W, 166 kLm
Axiom HLT-6150	Engine + Battery + Solar	28 ft, LED, 900 W, 120 kLm
Dominight	Engine + Battery + Solar	24 ft, LED, 1400 W, 200 kLm

Diesel/Gasoline Generators

The emissions coming from diesel/gasoline engine generators can be reduced by mobile battery packs, which is zero emissions, and hybrid generators where an engine is combined with a battery pack, which is low emissions. The products in the market for mobile battery packs are offered by Voltstack and Viatec with Li-Ion battery technology. The hybrid generators in the market offered by EHR and Ana provide output power in the range of 10-30 kVA, which is much more than the power levels of generators in MDOT inventory (5-6 kVA).

Image 16 shows a Voltstack 30k electric generator.

Backhoe Loader Tractor

There is only one battery electric backhoe loader tractor (Case 580) alternative to the ones used by MDOT.

Image 17 shows a CASE 580EV Backhoe Loader Tractor.

5.1.4 Class 4-8 Emission Reduction Conversion Technologies

The previous section explored alternative fuel vehicles currently available on the market as replacements for diesel or gasoline vehicles and equipment for MDOT. However, another approach for MDOT involves modifying the existing and future fleet to reduce emissions from Class 4-8 vehicles. This can be achieved by minimizing engine idle time, powering hydraulic systems with battery energy, capturing the braking energy into batteries (regenerative braking), or using alternative fuels like biodiesel. The following conversion technologies are evaluated for their feasibility in MDOT operations in this study:

Engine Idle Reduction

The fuel consumption rate is low due to the low engine loading at idle. However, if the idle duration is long, it would significantly contribute to the overall emissions of a vehicle because engine idling is the least efficient operation of an engine. The engine is kept in the idle state for various reasons. The operators in MDOT sometimes keep the engine in an idle state to provide in-cabin cooling and heating and electrical power to accessories like light sources, laptops, and small electric tools. For these occasions, battery powered auxiliary power units would eliminate the need of keeping an engine idle. There are viable field-tested products in the market offered by Viatec and Altec that can be easily integrated into the existing and future MDOT fleet with extensive idling and help achieve emission reductions.

Battery Powered Hydraulic Systems

Many trucks in MDOT fleet have hydraulically operated equipment like aerial lifts, augers, etc. The hydraulic pumps in those vehicles are driven by engines through PTO, while the truck is stationary most of the time. Viatec, Altec, and Odyne have introduced products that include a battery pack, electric motor and motor inverter called ePTO. In those systems, when the hydraulic pump needs to be activated, the electric motor drives the hydraulic pump using the battery energy while the engine is off. If the battery does not have enough energy, the engine turns on and operates the hydraulic system in the conventional way. These systems also provide optional battery operated in-cabin cooling and/or heating system to maximize engine off duration. These modular devices can be installed on the existing and new vehicles. As a result, MDOT can achieve fuel savings and emission reductions for vehicles with hydraulic systems and long idle times.

Braking Energy Saving Systems

An electric motor can be used as a motor to drive an actuator and as a generator to produce electricity. If an electric motor is connected to the drivetrain, it can behave as a generator to create vehicle drag during a braking event, called regenerative braking. The electricity generated during braking can be captured and stored in the battery, which can be used later to propel the vehicle and/or its accessories. The Odyne system integrates its electric motor with the vehicle transmission to enable regenerative braking in addition to driving hydraulic pump for accessories like ePTO.

Biodiesel

Biodiesel is an alternative fossil fuel that is made from vegetable oils, animal fats, or restaurant grease. Optimus provides biodiesel conversion kits that include an engine control unit, a heated biodiesel tank, a biodiesel filter, and a fuel pump. These devices are installed to the existing or new trucks and operate in parallel to the conventional diesel equipment. Therefore, the fuel supply to the engine can be switched between conventional diesel and biodiesel fuels. However, biodiesel conversion would not be feasible for MDOT because MDOT supplies the fuel for its vehicles and equipment from the public gas stations and biodiesel is not available at the public gas stations in Michigan.

5.2 Operational Feasibility Analysis

The operational feasibility analysis takes into account the results of the technical feasibility analysis and considers Michigan DOT's actual fleet usage based on provided data. It was important to assess if the alternative fuel vehicles and equipment meet MDOT's operational needs, especially during extreme conditions like continuous snow plowing over extended hours.

Real-life scenarios were crucial in ensuring that vehicles that perform well on paper also support Michigan DOT's operational duties. Some vehicles must operate 24 hours and require a long range, which unfortunately many currently available alternative-fuel vehicles do not offer. Recognizing that some technology may not be as advanced as desired, this analysis was further detailed in the report showcasing an alternative fuel vehicle list that considered both technical and operational feasibility. The Alternative Fuel Vehicle (AFV) list with an included feasibility analysis is detailed in **Appendix A**.

Key parameters from the Operational Feasibility Analysis include:

- ### Actual Operational Range
  It was crucial to assess the real-life operational range of the vehicles, not just their theoretical capacity. For instance, while some forklifts may have a higher range, the most suitable ones are those that best meet the weight requirements for their lifts.
- ### Extreme Conditions
  The analysis had to consider whether the current fleet could meet operational needs during extreme conditions, such as continuous snow plowing over extended hours.
- ### 24-Hour Operation
  Some vehicles need to operate over 24 hours and require a long range, which many currently available vehicles do not offer.
- ### Parking Location
  Some vehicles need to operate multiple days at a job site and do not return to their assigned garage at the end of the shift, which make overnight battery charging impractical.
- ### Technology Limitations
  Recognizing that some technology may not be as advanced as desired. This was captured in the report showcasing an alternative fuel vehicle list that considered both technical and operational feasibility.

In this section, the technically feasible alternative fuel vehicles and equipment are assessed against MDOT's operational requirements and the feasible list is determined.

5.2.1 Class 1-3 Light-duty Vehicles

To determine the operational feasibility of battery electric Class 1-3 vehicles for MDOT, a statistical analysis was conducted to understand vehicle usage patterns per each region based on current vehicle mileages.

The analysis consists of the following steps:

- Travel logs of Class 1-3 vehicles in MDOT fleet are digitized for each MDOT region
- The normal distribution of daily mileages is calculated and plotted as shown in **Figure 5**
- The range of current battery electric vehicles in the market is mapped to the normal distribution plot of daily mileages as shown as blue vertical line in **Figure 5**
- Based on the plot generated for each region it was determined the percentage of vehicles that can be converted to battery electric vehicles by calculating the area under the red curve between 0 and the blue line in **Figure 5**
- The regions are then ranked based on the battery electric conversion percentages

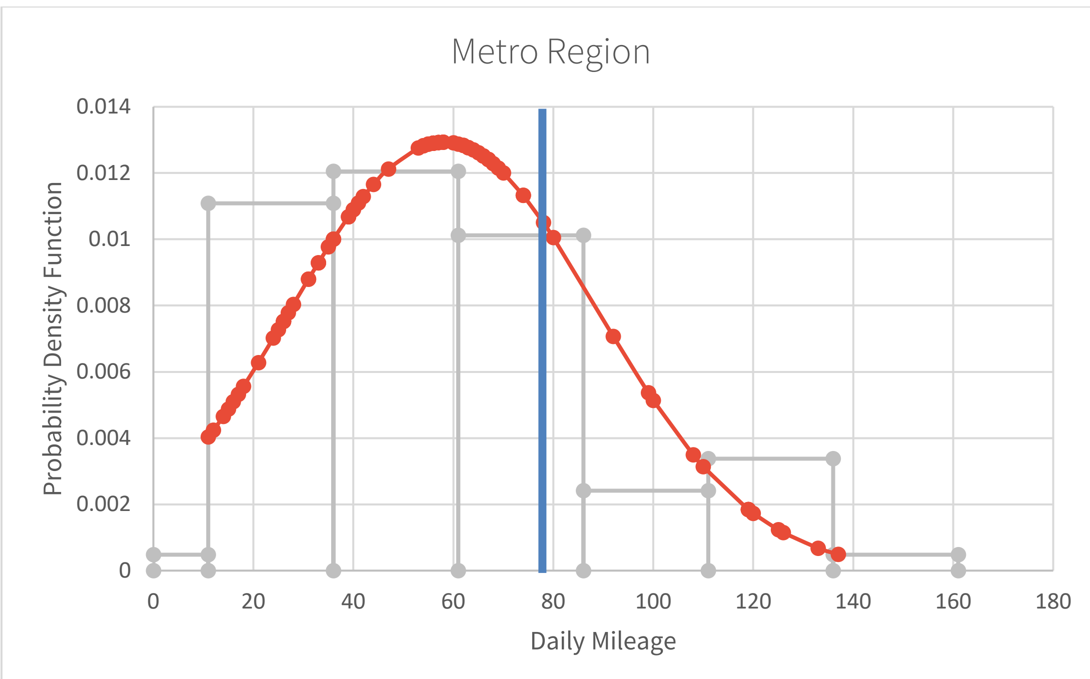


Figure 5. Probability Distribution Function of Class 1-3 Vehicle Daily Mileages (Metro Region)

Table 6 shows the result of this analysis for three different battery electric vehicle ranges that have been observed in different weather conditions. Based on this analysis, Blue Water Bridge, Metro, and Southwest are the top three regions, whose Class 1-3 vehicle fleet can be converted to battery electric vehicles at the highest percentage.

Table 6. Ranking of MDOT Regions for Class 1-3 Vehicle Operational Feasibility

Region	Probability with Various Maximum BEV Ranges		
	136 miles	**110 miles**	**89 miles**
Blue Water Bridge	100%	100%	100%
Metro	99.4%	95.4%	84.2%
Southwest	96.0%	86.0%	70.7%
University	82.3%	66.6%	51.0%
Grand Rapids	65.6%	49.4%	36.4%
Bay	57.4%	45.9%	36.8%
Superior	47.6%	32.8%	22.4%
North	43.4%	31.4%	22.9%

5.2.2 Forklifts

Three key findings were identified that affect the operational feasibility of battery electric forklifts based on our interviews with the MDOT groups:

- Forklifts typically do not leave the assigned garage
- Forklifts are generally used for 1-2 hours per shift
- Some are used outdoors, requiring pneumatic tires for traction on a wet gravel surface

For the operational feasibility analysis, it was estimated the energy consumption of a battery electric forklift in **Table** 4 through simulations in a scenario, where the forklift moves a 5000-lbs load for 100 ft and then lifts the load up by 8.5 feet. In a conservative scenario, where the battery capacity is reduced to 64% due to aging and the forklift makes this duty cycle continuously, the battery would last for 4.3 hours. Moreover, the battery electric forklifts in **Table** 4 have pneumatic tires. As a result, battery electric forklifts are deemed to be technically and operationally feasible for MDOT.

5.2.3 Rollers

Based on the interviews with the MDOT groups, rollers are not heavily used in the regions. When they are active, they are operated around 2-3 hours per day. Battery electric rollers in the market have a battery capacity varying between 20 kWh and 31.5 kWh. To estimate the energy consumption of a roller, a roller was modeled and simulated moving at its operating speed with its vibration system on. Based on energy consumption simulation results, a roller with 24 kWh battery capacity in a conservative scenario, where the battery capacity is reduced to 64% due to aging, can operate continuously for about 4.9 hours. As a result, battery electric rollers are deemed to be technically and operationally feasible for MDOT.

5.2.4 Lawn Tractors

In all MDOT regions, lawn tractors are used between three to eight hours per shift and returned to their assigned garages at the end of a shift. Based on the battery capacity of EVO battery electric lawn tractor and the battery swapping feature of Gravely battery electric lawn tractor and their technical specifications, they can operate maximum eight hours, which makes them deemed to be operationally feasible for MDOT.

5.2.5 9' and up Sewer Rodders

Sewer jetters roam among MDOT garages and are used heavily. At the end of the shift they return to a garage. The vehicle's operation duration within a shift varies and is sometimes between two to four hours, but for other tasks could operate for an entire shift of eight to ten hours. If 700 gallons of water tank capacity of Pipehunter's battery EV jetter is used just once without any refilling, the battery would last around 8.8 hours according to the power draw calculations using Pipehunter's water pressure and water flow data in its technical specifications. However, if it is assumed that the water tank is refilled in the middle of a shift to continue sewer rodder's operation, then the battery would last maximum 4.4 hours. As a result, the operational feasibility of Pipehunter sewer jetter would depend on the requirements of the task in a region and there is no guarantee of the success of its operational feasibility. Moreover, since a jetter roams from garage to garage, it would be impractical to set up a charging infrastructure at a single garage for jetters.

The Sharp EV4 includes both a jetter and a debris vacuum. Assuming the vehicle's water tank is filled once during a shift, according to the power draw calculations using Sharp EV4's water flow, water pressure, vacuum flow, and vacuum pressure data in its technical specifications, the battery would last 2.4 hours. This is less than four hours of average hydrovac operation, therefore, Sharp EV4 would not likely be operationally feasible for MDOT.

5.2.6 Walk-behind Snow Blowers

MDOT-owned snow blowers are used within the garage and facility perimeters between one and three hours. Once the job is completed, they return to the garage. The snow blowers offered by Greenworks have two swappable battery packs. Moreover, the chargers offered by Greenworks have 8A dual port charger (4A for each port) for 80V batteries and 6A charger for 60V batteries. The equipment corresponds to 75 minutes and 80 minutes charging time for 80V and 60V batteries, respectively. Since these snow blowers have portable swappable battery packs that are also charged quickly and their daily usage by MDOT is limited to one to three hours, battery electric operated snow blowers are deemed to be operationally feasible.

5.2.7 Surface Grinders

Surface grinders currently operate and stay out of a garage for a week and are typically used for three to four hours a day. Assuming four hours of operation per day, the electricity requirement for externally powered electric surface grinders can be supplied by battery-based generators in the market like Viatec's SmartPX with 12 kVA output and 21.6 kWh battery energy capacity or Voltstack battery generator with 80 kWh energy capacity, which is a trailer-based 4850 lbs heavy battery generator. Since the surface grinders typically operate at job sites up to a week, the battery capacities in battery generators are insufficient in operating the surface grinders for that duration. At the job sites, it would be extremely difficult to find an electric outlet from the grid to charge the battery pack. Moreover, the equipment would not work properly in the morning if the equipment stayed outdoor idling overnight at the jobsite in a cold climate since their minimum operating temperature is higher than the temperatures experienced in Michigan. As a result, electrical surface grinders are not likely operationally feasible.

5.2.8 Asphalt Storage Heater

Based on the interviews with MDOT groups, LPG-based storage heaters cannot keep the temperature high in the cold winter of Michigan due to the lower energy density of LPG. Moreover, propane tanks would need to be removed before storage heaters are parked indoors. Hence, storing and changing tanks create logistical issues for MDOT. As a result, LPG based asphalt storage heaters are not likely operationally feasible.

5.2.9 Loaders over 1.25 yards

At MDOT, loaders are used for various purposes. The most demanding operation is salt loading during the winter when salt is taken from large piles and loaded to the incoming trucks. Worst case scenario, tasks can last up to 24 hours depending on the severity of the storm in some regions, also include idle times during this loading operation while waiting for the empty trucks. To assess the operational feasibility of a battery electric loader, a salt loading operation was modeled and simulated, which consists of a loader moving back and forth one way empty and one way loaded for 100 ft and raises and dumps 6600 lbs of salt to a truck. Moreover, it was assumed that the loader travels 40 miles round trip to travel between salt loading barn and its assigned garage. According to this scenario, a battery electric loader with an aged 282 kWh battery capacity (assuming 64% of battery energy is available) can operate in motion for eight hours. As a result, a battery electric loader may meet some operational requirements of MDOT garages. For example, loaders in Auburn Hills Maintenance Garage in Metro region operate for no more than eight hours with 2 hours of idle time or at Blue Water Bridge, three loaders are used for salt loading, one of which can be replaced with a battery electric loader.

5.2.10 Compressors over 295 cfm

Compressors return to the garage at the end of the shift and are heavily used at the job site, running 8-10 hours each shift. The maximum power draw of the electric Atlas Copco compressor from the electric source is calculated as 42 kW. If a diesel battery hybrid generator (Ana), which can supply 3 phase 480 V is used to power the compressor, the battery of that generator would last only 20 minutes when the compressor runs at its maximum capacity. The other diesel battery hybrid generators and battery generators do not have the capability of providing three phase 480 V required for the operation of electric compressors. As a result, electric compressors are not operationally feasible for MDOT.

5.2.11 UTVs

UTVs are mostly used for spraying, litter pickup, and inspecting bike trails. During the winter, they are used for snow removal of sidewalks. They run at low speeds and have low mileage. They are towed to the jobsite and returned to the assigned garage at the end of the shift for most of the regions. For the Bluewater and Metro regions, the daily mileage is 50 miles in the summer. In Grand Rapids, UTVs stay at the job site.

Battery electric UTV's operation profile and its energy consumption are modeled and simulated for summer and winter operations. For the summer, it is assumed that a UTV moves at 8 mph for 50 miles with 200 stops. According to the simulations, Polaris UTV's 14.9 kWh and 29.8 kWh battery capacities can handle the summer operation. Since winter operation requires snow plowing, which is much more energy consuming than summer operation, Polaris UTV version with 29.9 kWh battery can meet the winter operational requirement. As a result, UTVs are deemed to be operationally feasible for MDOT.

5.2.12 Underbridge Inspection/Aerial Equipment

The battery capacity of a battery-operated underbridge inspection equipment can be customized with the smallest battery capacity of 3.2 kWh. The hydraulic operation of the equipment was modeled and simulated to estimate the battery energy consumption. According to the simulation results, eight inspections can be performed in a 10-hour shift with 3.2 kWh battery capacity. Moreover, if more battery energy is needed in actual operations, the total battery energy capacity can be easily increased with the parallel connection of multiple battery packs. However, underbridge inspection equipment fleet that belongs to Bureau of Bridges and Structures (BOBS) is shared by regions and therefore, that equipment can stay at different garages overnight depending on the job and cannot find a charging infrastructure. As a result, underbridge inspection equipment is deemed to be operationally feasible for MDOT except for at BOBS region.

5.2.13 Concrete Mixers

For all regions except Metro, the concrete mixers stay at the jobsite for multiple days and operate at a maximum of four hours per shift. The energy consumption of an electric concrete mixer is calculated as 5 kWh per shift. Portable battery generators can provide the electricity supply to the concrete mixers, but since concrete mixers stay at the job site for an extended period of time, battery generators cannot have access to the electric grid to charge its batteries once their state of charge levels get low. Therefore, concrete mixers are not likely operationally feasible for MDOT.

5.2.14 Shot Blasters
LPG fueled shot blasters can meet MDOT's operational requirements since LPG is no different from diesel engine propelled shot blasters.

5.2.15 Light Towers
In general, light towers stay on for a maximum of 8-10 hours but in the worst case, though very seldom the operations can extend up to 17 hours between 4pm and 9am. In Metro and Blue Water Bridge, the light towers return to their assigned garage, whereas in University, Superior, Grand Rapids, and Bay, the light towers stay at the job site until the job is completed. Moreover, too much luminesce is not desired as it affects the visibility of the drivers negatively. Battery light towers can provide up to 17 hours of energy but need to be charged at the end of its operation for around 13 hours. Therefore, battery light towers are operationally feasible for the regions, which return their light towers to the garage at the end of the shift, such as for the Metro region. The other regions, which keep their light towers at the job site could rely more on battery+solar+engine light towers as the engine would keep the operation of light towers for multiple days if charging through the grid is not possible or charging through solar panels is not sufficient. As a result, battery+solar and battery+solar+engine light towers are deemed to be operationally feasible for MDOT and MDOT can have a mixed inventory of battery+solar and battery+solar+engine light towers.

5.2.16 Diesel/Gasoline Generators
The output power capacity of Diesel/Gasoline generators used by MDOT are between 5-6 kW. Battery generators' battery capacities do not allow them to provide continuous energy for the entire shift. Moreover, they cannot stay at the job site for multiple days due to the inaccessibility to the electric grid for charging and low temperatures during winter in Michigan. The alternative to the battery generators can be battery+engine hybrid generators but their output power is much larger than the diesel/gasoline generators in MDOT inventory and therefore, they are bigger and heavier. As a result, battery and battery+engine generators are not likely operationally feasible for MDOT.

5.2.17 Backhoe Loader Tractors
Backhoe loaders are towed to the job site and stay at the site for multiple days for MDOT operations. Due to the unavailability of access to the electric grid, battery electric backhoe loader tractor offered by Case cannot be charged at a job site and hence is operationally infeasible for MDOT.

5.2.18 Class 4-8 Vehicle Conversion Technologies

The technically feasible conversion technologies are evaluated from the MDOT's operational requirements perspective in this section.

Engine Idle Reduction

Battery operated DC and AC voltage output APUs available in the market can provide up to 3 kW DC power and 12 kVA AC power, which is more than enough to supply energy to electronic devices, electric hand tools, and external lights. This equipment also has cabin heating and cooling functionality. The battery energy capacity ranges between 6.4 kWh and 21.6 kWh. The lowest battery capacity can provide 1 kW output for four hours continuously in a conservative scenario where 64% of battery capacity is available. The highest battery capacity can also provide 3 kW output for 4.5 hours continuously in the same conservative scenario. As a result, engine idle reduction technologies are operationally feasible.

Battery Powered Hydraulic Systems

The hydraulic systems that operate aerial lifts, augers, and sweeper brooms can be driven by electric motors energized by a battery, which are called ePTO. Aerial lift operation is modeled and simulated to estimate its battery energy consumption and how long the battery would last before being depleted. According to the simulation results, Viatec's 4.4 kWh and 12.4 kWh battery systems can perform 30 and 85 lift cycles respectively in a conservative scenario, where 64% of battery energy is available. Moreover, ePTO's hydraulic fluid flow rate and pressure can meet the aerial lift system requirements. As a result, zero emission aerial lifts are operationally feasible for Class 4-8 vehicles with aerial lifts in MDOT fleet.

The flow rate of PTO driven hydraulic pumps deployed in augers are generally between 40-50 gallons per minute (gpm), which exceeds the flow rate capability of ePTOs (20 gpm) offered by Viatec. Therefore, the application of ePTO to auger trucks should have lower priority than the aerial lift trucks. However, Odyne parallel hybrid system has options for more powerful electric motors than Viatec and Altec systems making it feasible for auger trucks.

In the hydraulically operated sweeper broom case, since a vehicle runs at low speed while operating the sweeper broom, the use of ePTO does not eliminate engine operation. Moreover, since the engine power demand is low at low vehicle speed, it is better to run the conventional PTO to drive the sweeper broom to move the engine operating point to a more fuel efficient zone. Therefore, although it is technically possible to run sweeper broom through ePTO, its benefits cannot be fully exploited. Moreover, the continuous operation of sweeper broom through ePTO would also drain the battery energy quickly, which makes ePTO application to sweeper broom operationally infeasible. In conclusion, making aerial lift systems the highest priority for MDOT in electrifying both its existing fleet and future vehicle purchases is essential.

Braking Energy Saving Systems

Odyne's parallel hybrid conversion kit, a braking energy-saving system, is available for MDOT fleet. This system is operationally feasible for MDOT as it introduces no new constraints to the trucks.

5.2.19 Summary of Technically and Operationally Feasible Technologies

The technically and operationally feasible alternative fuel vehicles and equipment, that are finalized according to the analysis described in the previous sections, are listed below in **Table 7**:

Table 7. List of Technically and Operationally Feasible Vehicles and Equipment Types

Class 1-3 Light-duty Vehicles
Class 4-8 Conversion Technologies (Idle reduction, ePTO, regenerative brake energy saving)
Lawn Tractors
UTVs
Rollers
Underbridge Inspection Equipment
Walk-behind Snow Blowers
Forklifts
Light Towers
Shot Blasters
Loaders over 1.25 yards

6. Technology Considerations for Pilot Projects

After compiling the Alternative Fuel Vehicles list and sorting through the vehicle types that are feasible based on technical and operational feasibility, those vehicles need to be ranked according to certain criteria. The following are criteria that MDOT should consider when prioritizing pilot projects:

+ Total emission reduction potential
+ Cost/Benefit ratio
+ Risks involved

The following sections showcase the detailed methodology and explanation used in ranking feasible alternative fuel vehicles. This section also explains assumptions made in the analysis of those vehicles based on information provided by MDOT, the workshops, and research.

6.1 Emissions Analysis

Since the focus of this study is to explore the reduction of MDOT's greenhouse gas (GHG) emissions through the use of alternative fuel vehicles, the most important criterion is to assess the total GHG emission reduction potential of each alternative fuel vehicle. Emissions can be analyzed by either well-to-wheels or tank-to-wheels methods. Well-to-wheels emissions method covers all emissions related to fuel production, processing, distribution, and use whereas tank-to-wheels emissions method includes emissions from combusting the fuel used to power a vehicle. Since MDOT can only control the emissions from its fleet, this analysis focused on the tank-to-wheels emissions method.

MDOT's fleet roster primarily includes gasoline and diesel engine powered equipment and vehicles as well as some LPG engine powered equipment. In the emissions analysis, the GHG emission from one gallon of diesel, gasoline, and LPG fuel is taken as inputs. Then, the daily GHG emission of each vehicle type that has a feasible alternative fuel vehicle replacement is estimated based on its operation profile and fuel consumption. At the final step, the total emission reduction potential of each alternative fuel vehicle is calculated by multiplying its corresponding conventional version's daily emissions with its quantity in MDOT's fleet. The number of conventional vehicles, whose operational requirements cannot be met by an equivalent alternative fuel vehicle is excluded in this calculation. Moreover, it should be noted that in this process the total emissions by a conventional engine operated equipment is not calculated. Instead, the emissions that will be eliminated through the deployment of an equivalent alternative fuel equipment is calculated. The overall process is shown in **Figure 6**.

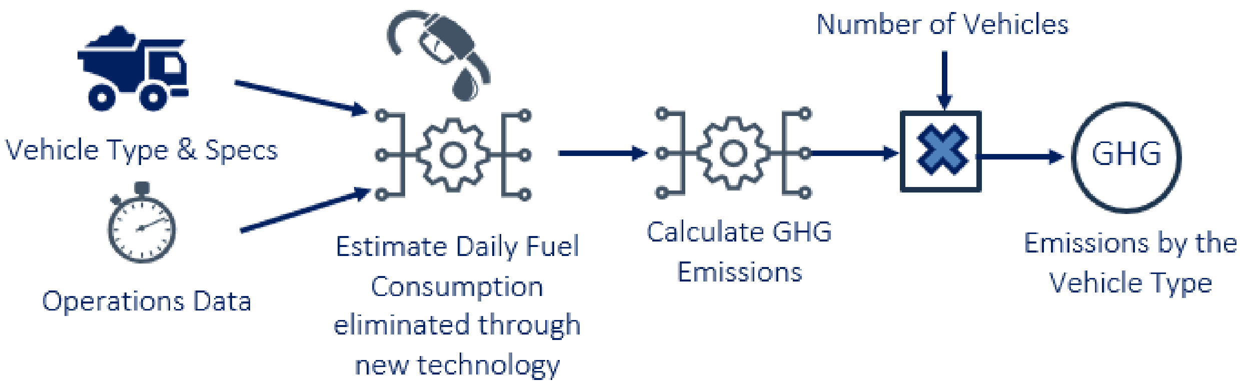


Figure 6. Emission Calculation Process

Since the way each vehicle is operated by MDOT is different, the approach to calculate each's emissions had to be tailored to each vehicle type. The different approaches are summarized in **Table 8.**

Table 8. Emission Calculation Approaches

Vehicle/Equipment Type	Fuel Consumption/Emission Calculation Method
Light-duty vehicles	Daily average mileage is divided by EPA's combined miles per gallon (mpg) rating
Class 4-6 Dump/Utility Gasoline Engine - and Class 4-8 Dump/Utility Diesel Engine Trucks	Since the battery based idle reduction technology is operationally feasible, only fuel consumption during idling is calculated by multiplying daily idle duration with idle fuel rate for some alternator load
Class 4-8 Aerial and Auger Diesel Engine Trucks, Underbridge Inspection Equipment	For the battery based idle reduction technology, only fuel consumption during idling is calculated by taking into account the time weighted average of idle fuel rate with some alternator load and idle fuel rate with the hydraulic system actuation through PTO
Class 7-8 Diesel Engine Trucks	For the battery based parallel hybrid, in addition to the idle fuel consumption approach for aerial and auger trucks, fuel consumption reduction due to the regenerative braking is also calculated.
Lawn Tractors, Walk-behind Snow Blowers, Shot Blasters	Daily operation duration of the equipment is multiplied by the fuel consumption rate (gal/hour) of the equipment engine that operates at an average load.

Vehicle/Equipment Type	Fuel Consumption/Emission Calculation Method
UTVs, Rollers	First, traction energy required to travel the daily average mileage during a shift is estimated. Then, by taking into account the average losses of transmission and engine, the consumed fuel is calculated.
Forklifts, Loaders over 1.25 yards	First, the fuel consumed to travel the daily average mileage during a shift is estimated by calculating the required traction energy and transmission and energy losses. Then, the fuel consumption due to load lifting is estimated by considering the daily idle time and the time weighted average of idle fuel rates with alternator load and hydraulic system actuation.
Light Towers	From the power rating of lights, first the required engine output power is calculated. By considering the engine and power converter efficiencies, the engine fuel rate is estimated. The daily consumed fuel is calculated by multiplying the engine fuel rate with the duration during which the equivalent battery operated light tower would stay operational.

6.2 Cost/Benefit Analysis

The previous section explored the total emissions that will be eliminated through the deployment of alternative fuel vehicles or equipment for each technically and operationally feasible vehicle or equipment. Although this metric is necessary to prioritize the alternative fuel vehicles, it is not sufficient because the financial impact of deploying those feasible alternative fuel vehicles also needs to be assessed. For this purpose, the cost/benefit ratio metric ($/lbs) used shows the cost of reducing one pound of GHG. This ratio is formulated as follows:

$$Cost\ Benefit\ Ratio\ (\$/lbs) = \frac{\Delta\ Cost\ between\ AFV\ and\ Conventional\ Vehicle}{GHG\ Reduction\ Benefit\ per\ Vehicle} \qquad \text{(Eq. 1)}$$

In (Eq. 1), GHG Reduction Benefit per Vehicle term represents the emissions calculated in the previous section. The Δ Cost term in (Eq. 1) is the total cost differential between a conventional vehicle and its equivalent alternative fuel vehicle and has two components:

- Acquisition (Capital) and Operating Costs of a Conventional Vehicle
- Acquisition (Capital) and Operating Costs of an Alternative Fuel Vehicle (AFV)

For the acquisition costs of a conventional vehicle and its equivalent alternative fuel vehicle, price quotes were obtained from the vehicle manufacturers and dealers or used Internet resources such as online price data and industry articles. Due to the significant cost differential between engine fuel prices (diesel or gasoline) and electricity rate ($/kWh), cost comparison between conventional vehicles and battery electric vehicles would be incomplete without including fueling/energy costs in the cost equation. Since the daily fuel consumption of each conventional vehicle/equipment was already calculated in the previous section, the focus in this task became only the battery electric vehicles/equipment. For this purpose, daily battery energy consumption of a battery electric vehicle or equipment was calculated based on its MDOT operation profile and then the energy cost to charge the battery back to its full state of charge. Finally, the total electricity cost to operate the battery electric vehicle/equipment throughout its useful/expected life was calculated. As a result, Δ Cost is formulated as:

$$\Delta\, Cost = (Capital\ Cost\ of\ Conventional\ Vehicle + Cost\ of\ Fuel\ replaced\ by\ the\ use\ of\ AFV) - (Capital\ Cost\ of\ AFV + Electric\ Energy\ Cost\ to\ charge\ the\ battery) \quad \text{(Eq. 2)}$$

It should be noted in (Eq.2) that fuel and electric energy costs are the total cost occurred throughout the life of an equipment or vehicle.

As a result, the feasible vehicles and equipment was organized based on highest to lowest potential of benefits and summarized below in **Table 9**. The cost-benefit analysis is further detailed in **Appendix B**.

Table 9. Results based on the Emission Benefits and Cost/Benefit Analyses

Vehicle Type	Daily CO2 Reduction Benefit per Vehicle Type (lbs)	Annual CO2 Reduction Benefit per Vehicle Type (lbs)	Cost/Benefit Ratio ($/lbs)
Dump or Utility Truck Gasoline Class 4-6 (Viatec Smart PTX)	19,436	4,858,879	33
Dump or Utility Truck Diesel Class 7-8 (Odyne Parallel Hybrid)	19,058	4,764,384	515
Light-Duty Truck (e.g. Ford F150)	15,984	3,996,116	147
Dump or Utility Truck Diesel Class 4-6 (Viatec Smart PTX)	15,144	3,785,884	5
Dump or Utility Truck Diesel Class 7-8 (Viatec Smart PTX)	13,804	3,450,885	-22
Aerial Truck Diesel Class 4-6 (Viatec Smart PTO)	9,745	2,436,249	-9
Aerial Truck Diesel Class 7-8 (Odyne Parallel Hybrid)	6,135	1,533,771	447
Aerial Truck Diesel Class 7-8 (Viatec Smart PTO)	4,574	1,143,568	-56

Vehicle Type	Daily CO2 Reduction Benefit per Vehicle Type (lbs)	Annual CO2 Reduction Benefit per Vehicle Type (lbs)	Cost/Benefit Ratio ($/lbs)
Auger Truck Diesel Class 7-8 (Odyne Parallel Hybrid)	2,923	730,833	393
Lawn Tractors (Zero Turn Mower)	2,694	673,376	-56
Loaders over 1.25 yards	2,173	543,195	-146
Forklifts	996	249,074	203
UTVs	398	99,587	132
Light Towers	338	84,564	664
Underbridge Inspection	203	50,748	-467
Roller	48	12,108	975
Walk-behind Snow Blowers	23	5,872	-212
Shot Blaster	-302	-75,575	718

6.3 Risk Assessment

In addition to the quantitative evaluation of the alternative fuel vehicles, risk ratings of Low, Medium, and High were assigned to each alternative fuel vehicle according to the following criteria:

- Is the vehicle/equipment manufacturer an established or start-up company? A start-up company is less likely to exist and support the product in the long run.
- Has the alternative fuel vehicle/equipment been in the market for an extended period of time? If the product is in the market for a certain time, it is an indication of the success of the product and/or the manufacturer of this product.
- Has the alternative fuel vehicle/equipment been proven in the field by other users? If the product is field-proven elsewhere, MDOT could be much more confident about the performance of the product according to its technical specifications.
- Do multiple vehicle/equipment manufacturers have similar products in the market? Having multiple similar products in the market is an indication of the feasibility of the technology in the field and provides additional assurance to MDOT about the availability of alternative fuel vehicles in the market.
- Does MDOT have multiple of the same type of vehicle in its fleet? If the alternative fuel vehicle does not meet MDOT's operational requirements in the field, MDOT could have alternative conventional vehicles for replacement during the initial stages until the technology is proven to be operationally reliable.

  Based on these criteria, risk ratings are assigned to each feasible alternative fuel vehicle. The risk ratings were also taken into account while developing the rankings for pilot projects.

6.4 Ranking/Prioritization of Pilot Projects

To rank the technically and operationally feasible alternative fuel vehicles and equipment, GHG emissions eliminated through their introduction, Cost/Benefit ratio, and risk level are assigned to each feasible vehicle type. Then, this vehicle list is first ranked according to the total GHG emissions that can be eliminated with alternative fuel vehicles. The vehicle types that have highest emissions per day and MDOT owns at higher numbers are ranked at the top. However, some of the top ranked vehicle types have higher cost/benefit ratio than the moderately ranked ones. As a result, at the second tier ranking, the rank order was shuffled by comparing the initially highly and moderately ranked ones to their cost/benefit ratios and risk levels. Moreover, after this reordering, the ranked vehicle types were grouped into four clusters, each of which represents the preference order for pilot implementation. This ranking process and the final ranked list with associated risks are shown in **Table 10**.

Table 10. Ranked and Clustered Operationally Feasible Vehicle/Equipment List

<table>
<tr><th>Priority Level</th><th>Ranking</th><th>Vehicle Type</th><th>Risk</th></tr>
<tr><td rowspan="3">Highest</td><td>1</td><td>Class 4-6 Diesel Conversion Technology (Idle Reduction)</td><td>Low</td></tr>
<tr><td>2</td><td>Class 7-8 Diesel Conversion Technology (Idle Reduction)</td><td>Low</td></tr>
<tr><td>3</td><td>Class 4-6 Diesel Aerial Lift Conversion Technology (ePTO)</td><td>Low</td></tr>
<tr><td rowspan="7">High</td><td>4</td><td>Class 4-6 Gasoline Conversion Technology (Idle Reduction)</td><td>Low</td></tr>
<tr><td>5</td><td>Class 1-3 Battery Electric Light-Duty Vehicles</td><td>Low</td></tr>
<tr><td>6</td><td>Class 7-8 Diesel Aerial Lift Conversion Technology (ePTO)</td><td>Low</td></tr>
<tr><td>7</td><td>Lawn Tractors</td><td>Low</td></tr>
<tr><td>8</td><td>Loaders over 1.25 yards</td><td>Medium</td></tr>
<tr><td>9</td><td>Underbridge Inspection Units</td><td>Low</td></tr>
<tr><td>10</td><td>Walk-behind Snow Blowers</td><td>Low</td></tr>
<tr><td rowspan="2">Medium</td><td>11</td><td>Forklifts</td><td>Low</td></tr>
<tr><td>12</td><td>UTVs</td><td>Low</td></tr>
<tr><td rowspan="2">Low</td><td>13</td><td>Class 7-8 Diesel Conversion Technology (Regenerative Braking)</td><td>Medium</td></tr>
<tr><td>14</td><td>Class 7-8 Diesel Aerial Lift Conversion Technology (Regenerative Braking)</td><td>Medium</td></tr>
</table>

Priority Level	Ranking	Vehicle Type	Risk
	15	Class 7-8 Diesel Auger Conversion Technology (Regenerative Braking)	Medium
	16	Light Towers	Low
	17	Rollers	Low
	18	Shot Blasters	Low

7. Conclusion

In this study, the alternative fuel vehicles and equipment in the market that can technically and operationally match the light-duty and heavy-duty vehicles and equipment in the MDOT fleet are explored and evaluated through a systematic and analytic approach.

Based on the vehicle assessment and ranking approach, the technically and operationally alternative fuel vehicles and equipment are clustered into four groups that represent the degree of priority MDOT will consider for the conversion to their alternative fuel equivalents as shown in **Table 10.** It should be noted that due to the lack of hard operational and duty cycle data, such data was collected anecdotally through stakeholder engagements such as workshops and assumptions based on previous project experience and public reports. Therefore, the results of the emission benefits and cost-benefit ratio are subject to change upon newly collected datasets from the MDOT fleet in the field.

According to our analysis, idle reduction technologies for Diesel Class 4-8 dump or utility trucks and ePTO for aerial Class 4-6 diesel trucks would have the biggest impact on the reduction of MDOT's CO2 emissions while keeping the total cost of this conversion at a minimum. MDOT has already begun the acquisition of ePTO systems for their aerial lift trucks as a pilot project. While MDOT is evaluating the ePTO technology under its unique operating conditions, the agency could start testing idle reduction technology in its Diesel Class 4-8 dump and utility trucks. Since the idle reduction and ePTO technologies are based on conventional components like electric motors and batteries and multiple suppliers of these technologies exist in the market, the risk of implementing these technologies in MDOT fleet is low.

In the second tier, MDOT could consider the acquisition of idle reduction technologies for gasoline Class 4-6 dump or utility trucks, battery electric light duty vehicles, ePTO for aerial Class 7-8 diesel trucks, battery electric lawn tractors, battery electric loaders over 1.25 yards, underbridge inspection units, and walk-behind snow blowers. Although idle reduction technologies for gasoline Class 4-6 dump or utility trucks and battery electric light duty vehicles can reduce the highest CO2 amount in the MDOT fleet, they are assigned to this second highest priority group due to the relatively higher cost/benefit ratio than the vehicle technologies in the first group. Since idle reduction technologies, battery electric vehicles, ePTO for aerial systems, and battery electric lawn tractors are offered by multiple suppliers, the risk of their acquisition and implementation is low. However, due to the stringent operational requirements of loaders over 1.25 yards and its relatively higher cost, MDOT may consider a more conservative approach for this vehicle type. For this case, only one region needs to acquire a battery electric loader as a pilot vehicle and the other regions need to evaluate the same vehicle under their specific conditions. Although GHG emissions of underbridge inspection units and walk-behind snow blowers are much lower than the other vehicles and equipment in the second tier due to their low quantity in the MDOT fleet, they are assigned to this group as well because of their lower total cost of ownership than their conventional equivalents.

This operational analysis is primarily based on the workshops conducted with MDOT's related personnel. Although the information obtained this way is sufficient to decide and start a pilot implementation, a more methodical and holistic approach is needed for the fleet-wide application of a feasible technology due to the variations in the use of a vehicle type. For this purpose, MDOT may consider installing data logger systems such as one offered by Geotab to some of the conventional vehicles in the first two highest priority groups. These data logger systems connect to the existing communication network of a vehicle and log and decode the network data traffic. From the stored data, one can extract various results such as vehicle idle time, vehicle speed, engine speed and torque with respect to time, which help MDOT understand the operational characteristics of the target vehicles at highly granular levels. Then, MDOT can obtain the wider picture of how its vehicles operate in each region and make adjustments to the implementation plan of the alternative fuel vehicles.

For the third tier, MDOT could consider battery electric forklifts and UTVs which can function in MDOT's operations without any anticipated issue. These are placed in the third tier due to having a lower CO2 reduction potential than the other vehicles. There is also a larger price differential between their conventional and battery electric versions.

Lastly, battery+engine hybrid light towers, rollers, shot blasters, and conversion technology to add regenerative braking, ePTO, and idle reduction are least considered because of the vehicle type's low CO2 reduction potential and high cost differential between their conventional and low or zero emission versions.

Furthermore, before finalizing the acquisition of alternative fuel vehicles and equipment for pilot projects, MDOT could consider starting a study to evaluate the current status of electrical infrastructure in its garages and their feasibility to accommodate battery chargers and supply electricity for battery charging.

In conclusion, MDOT has an opportunity ahead to reduce its CO2 emissions in multiple vehicle and equipment categories by using the equipment's equivalent battery electric version in the market. This report has shown the feasibility of the emission reduction through an analytical and methodical approach.

Appendices

Appendix A: AFV List with Feasibility Analysis Results

Appendix B: Cost-Benefit Analysis Results

Michigan Department of Transportation

Fleet Electrification Strategies

Operational Feasibility Analysis Results

Last updated August 21, 2024

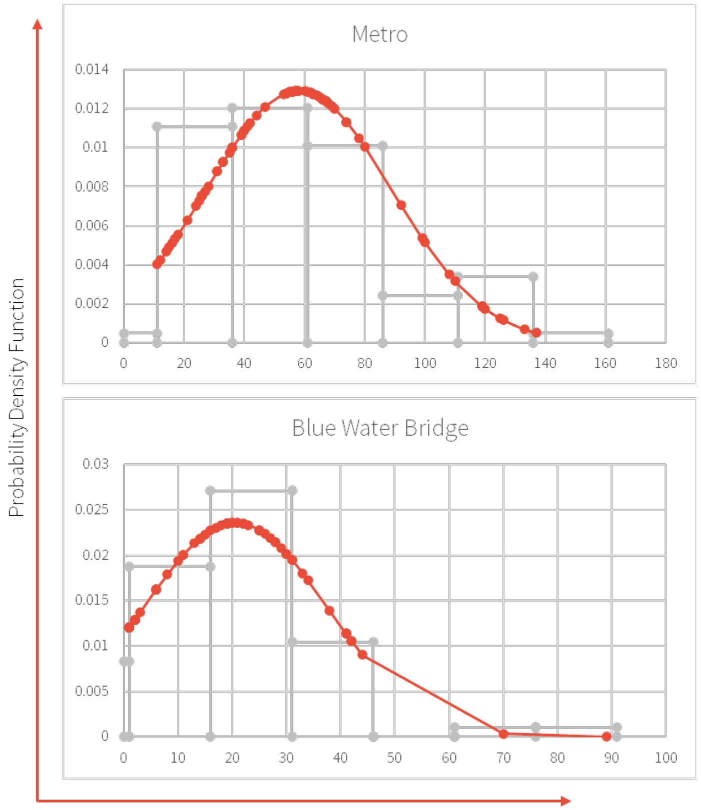
HATCH

Class 1-3 Light-duty Vehicles - Methodology

To determine the feasibility of the MDOT's light-duty vehicles (Class 1-3), a statistical analysis was conducted to understand the feasibility of alternative fueled vehicle usage for each region based on current vehicle mileages.

High-level process:

- Requested travel logs for each MDOT region
- Calculated the normal distribution of each cumulative trip mileage
- Developed gaussian plots to visually showcase the normal distribution of each region's vehicle mileages
- Compared the mileage distribution of each region to the range of current alternative fueled vehicles in the market
- Determined how many percent of the vehicles can be converted to alternative fuel vehicles using probability distribution curves and summarized and ranked the results in a table (next slide)



Caption: The image to the left shows the normal distribution for the Metro and Blue Water Bridge regions.

Class 1-3 Light-duty Vehicles - Methodology

The results show that:

- Blue Water Bridge has a 100% probability and the highest likelihood of replacing current vehicles with alternative fueled vehicles.
- Metro and Southwest region both have generally high probability to replace their current fleet with alternative fueled vehicles.
- North Region has the least likelihood of replacing current vehicles and would be an infeasible option.

Region	Probably with Various Max Ranges in Miles		
	136 miles	110 miles	89 miles
Blue Water Bridge	100%	100%	100%
Metro	99%	95%	84%
Southwest	96%	86%	71%
University	82%	67%	51%
Grand Rapids	66%	49%	36%
Bay	57%	46%	37%
Superior	48%	33%	22%
North	43%	31%	23%

Class 4-8 Conversion Technologies

Operational Feasibility	Brand	Model	Technology	Critical Specs
Aerial Lift: Yes Low voltage supply: Yes Auger: No Sweeper Broom: No	Altec	Class 4-8	Anti-idling Li-Ion based ePTO	Provides battery operated hydraulic pump for the hydraulic systems, DC voltage for powering vehicle accessories, cabin heating and cooling through vehicle's HVAC system, conventional PTO is intact and operational
Aerial Lift: Yes Low voltage supply: Yes Auger: No Sweeper Broom: No	Viatec	Class 4-8	Anti-idling Li-Ion based ePTO	Provides battery operated hydraulic pump for the hydraulic systems, DC voltage for powering vehicle accessories, cabin heating and cooling, conventional PTO is intact and operational, plug & play, 7.2-28.8 kWh, 4000 psi, 21 gpm
Aerial Lift: Yes Low voltage supply: Yes Auger: Yes Sweeper Broom: Yes	Odyne	Class 6-8	Li-Ion battery based parallel hybrid	17.7-35.4 kWh battery, 95 hp peak EM power, 1200-1600 lbs additional weight, compatible with Allison transmission, connected to vehicle PTO
No	Optimus	Class 6-8	Biodiesel	Addition of heated biodiesel tank, parallel biodiesel filter and fuel pump. Diesel and biodiesel operation can be switched. Requires biodiesel fueling stations on site. Can be used in diesel tractors and construction equipment as well.

Class 4 vehicles: Used as aerial lift or dump truck. Daily mileage varies between 70 and 200 miles (300 miles for Bay and 400 miles for Superior). It is at the job site for long hours sometimes exceeding 16 hours. For sign crew, average 1 hour spent for each sign work and 6-8 signs work per shift.

Class 5 vehicles: Used as aerial lift, auger, hauling trailers or dump truck. Daily mileage varies between 70 and 200 miles (300 miles for Bay and 400 miles for Superior). In summer, 8-10 hours at duty, in winter the shift time can exceed 24 hours.

Class 6-8: Daily mileage varies between 150 and 200 miles (300 miles for Superior region). Used mostly for aerial lift, dump truck, hauling trailers, and hydraulic crane for bridge inspection. They are parked in outdoors garages. Sometimes, they stay off garage for multiple days.

Aerial lift and auger to insert poles and hang signs. Hanging sign takes 1-2 hours and at most 6 poles are inserted per day (it takes 1 hour to auger one hole).

Aerial Lifts (Altec and Viatec)

Battery Capacity (kWh)	26 feet lift	30 feet lift	36 feet lift	43 feet lift
4.4 kWh	70 lifts	62 lifts	51 lifts	43 lifts
8.8 kWh	140 lifts	124 lifts	102 lifts	86 lifts
12.4 kWh	210 lifts	186 lifts	153 lifts	129 lifts

As seen from the estimations above, Altec, Viatec, and Odyne will be operationally feasible as long as Altec's and Viatec's ePTO hydraulic fluid flow rate and pressure (up to 21 gpm and up to 4000 psi) can meet the aerial lift requirements. Since Odyne system is a parallel hybrid electric architecture, in which an electric motor drives the existing hydraulic pump on the truck, Odyne system would not have any limitation in its deployment to an aerial lift truck.

AC (3 kW or 12 kVA) and DC (3 kW or 1 kW) output APU system of Viatec would enable to use electronic devices, electric hand tools, and lights (headlights and projector lights above cabin ceiling) without turning on the engine to turn the alternator. This product would be suitable to all sizes of trucks that haul trailers and carry toolboxes and equipment on their trunks. The battery capacity options are 6.4 kWh, 14.4 kWh, and 21,6 kWh.

Sweeper Broom: It is hydraulically operated. Since the vehicle needs to run at low speed while operating the sweeper broom, the use of ePTO does not eliminate engine operation. Moreover, since the engine power demand is low at low vehicle speed, it is better to run the conventional PTO to drive the sweeper broom to move the engine operating point to a more fuel efficient zone. Therefore, although it is technically possible to run sweeper broom through ePTO, its benefits cannot be fully utilized. If ePTO is used for sweeper broom, the battery would last around one hour, which is much shorter than MDOT's operational requirement (Maximum hydraulic motor power for sweeper broom is 13.5 kW. Assuming it runs at 50% capacity, the battery of ePTO would be discharged approximately at the rate of 9.6 kW. With the 12.4 kWh of Li-Ion battery capacity of Viatec;s ePTO system, the sweeper would run continuously for maximum one hour). As a result, the ePTO application to the sweeper broom operation should not be the high priority for MDOT.

Augers: The flow rate of PTO driven hydraulic pumps deployed in augers are generally between 40-50 gpm, which exceeds the flow rate capability of ePTOs (21 gpm). Therefore, the application of ePTO to an auger truck should have a secondary priority compared to aerial lift trucks and should be constrained to less demanding auger systems. Odyne system is a parallel hybrid electric architecture, in which an electric motor drives the existing hydraulic pump on the truck. Therefore, Odyne system can be employed to auger trucks.

Biodiesel would not be operationally feasible for MDOT because of the biodiesel availability in Michigan. MDOT fleet relies on public gas stations for refueling. If MDOT implements Optimus solution to some of the heavy-duty trucks in its fleet, those vehicles would not have access to biodiesel supply at the gas stations in Michigan.

Since Metro region has the highest stop and go driving pattern, Odyne system would be the most beneficial to Metro region by both capturing regenerative braking energy and minimizing engine idle time.

Loaders over 1.25 yards

Total Number	Regions	Critical Specs
61	Bay(4), BWB(3), GRD(8). Metro(2), North(4), SUP(11), SWS(13), UNI(15), TSMO(1)	Diesel Engine: 165-249hp, Operating Weight: 29,000-41200lb, Breakout Force: 20,000-34,000lbf, Hydraulics: 50-82gpm@3500psi, Bucket Capacity:2.5-5.5cuyd

Operational Feasibility	Brand	Technology	Critical Specs
Maybe	Volvo	Li-Ion, 237 kWh, 600V	EM: 274 hp, Operating Weight: 44500lb, Breakout Force: 38,200lbf, Hydraulics: 34gpm@1450psi, Bucket Capacity:3.3-12.4cuyd
Maybe	LiuGong	Li-Ion, 432 kWh, 618V	EM: 215 hp, Operating Weight: 46300lb, Breakout Force: 36,400lbf, Hydraulics: 3620psi, Bucket Capacity: 3.53-7.32 cuyd
Yes	HEVI	Li-Ion, 282 kWh, 618V	EM: 161 hp, Operating Weight: 39683lb, Breakout Force: 35,969lbf, Hydraulics: 47.6gpm@2610psi, Bucket Capacity: 3.9 cuyd

The battery of the EV Volvo in the slide enables up to 10 hours of operation for light applications and eight hours for heavy applications.
The other EV loaders that have smaller capacities in terms of operating weight, power, and bucket size:
1- Volvo L25 Electric, 1.17 yd3 bucket, 40 kWh
2- Komatsu WA70-7, 1.63 cuyd, 49.5 hp, 11,476 lb (prototype)
3- Caterpillar 950 GC. It is just a prototype shown at Bauma, at the end of 2022.
4- Case CL36, it is a compact loader.
5- Multitone EZ 8, compact loader.
6- Wacker Neuson, WL20e, compact loader.
Operational Analysis:
Loaders are stored indoors. During salt loading, parked outdoor. They operate in multiple cycles and each cycle lasts around 45 minutes-1 hour. During the cycle, salt is taken from the pile and loaded to the truck. After the cycle ends, it restarts 2-4 hours later. During storm, it can work continuously. Salt barns are non-heated indoors.

BWB shop is 3-4 miles away from the bridge. Bluewater Bridge also uses its front broom accessory to clean the plaza and customs area and to remove snow in plaza. Bluewater uses it to load salt during winter. 3 loaders for salt loading. At garage with the heated indoor has the least use. In summer, moving and loading in Auburn (there is infrastructure to charge batteries). Auburn and BWB garages can be target applications. In Auburn garage: no more than 8 hours. Idle times: 2 hours.

Indoor garage has limited space. Installing charger indoor might create space issues. There are two loaders assigned to Zilwaukee coming from Saginaw. It is located 1-1.5 mile away from the bridge. Other than winter, in summer used for road patching (demolition). Most times they come back to the garage but sometimes they can stay at the job location for multiple days when roads are closed for maintenance. Loaders come from Bay region's Zilwaukee Bridge, loader loads CMA (nonchloride salt) to the truck. The loading frequency is high (every 45 minutes). 16-17 trucks are loaded before the storm continuously. Then, the trucks come back for reloading depending on the route length. We can assume 10 min loading time and 45 minutes later another loading and so on. At Zilwaukee bridge, there is limited infrastructure for charging. Superior uses them as snow blowers for 24-hour operation as well.

In summer, loaders used for salt loading during winter are used to clean bridge decks and pull concrete slams. For summer work, they travel to the jobsites that are closer than 1 hour. For the longer ones, they are hauled. NCA loader in Bay area is not used during the summer.

The operational feasibility of loading road salt to the trucks is evaluated. It is assumed that the loader travels 100 ft between a truck and salt pile and loads 6600 lbs of salt in every round trip. It makes four round trips (26,400 lbs of salt) to load one truck, which takes 16 min. According to this scenario, the battery energy consumption is calculated as 1.2 kWh. Since the battery capacity of an electric loader is 282 kWh, a battery electric loader would be operationally feasible for MDOT's salt loading operation during winters.

Moreover, a loader can be driven for up to one hour to a job site during summer to perform duties like clearing bridge decks and pull concrete slams. After one hour of driving at 20 mph each way, the battery energy consumption would be 60 kWh for a round trip. Assuming energy consumption for the duties at the jobsite would be similar in nature to salt loading, a battery electric loader would be operationally feasible.

- There are Loaders used at both BWB and Zilwaukee Bridge/East Side Garage
- Loaders are NOT ONLY used for CMA
- There is a bridge crew that is stationed at Zilwaukee Bridge
- The East Side Garage does all the winter operations at their location
- Crew does not differentiate or identify which vehicle can go on the road and which cannot, since it's an expensive piece of equipment, they optimize its usage
- In the summer, the main operations is concrete patch work (cutting and pulling the road / demolition work for maintenance)
- There is no set time length the vehicle will sit out on the road, it depends on the job
- In the winter, sometimes there are heavy snow barriers on the Zilwaukee Bridge and it must be dislodged with a loader, but this is rare. The vehicle would usually come back to the garage.
- Loaders are parked at the East Side Garage, not the Zilwaukee Bridge. The East Side Garage is where everything happens, the salt loading, etc.
- East Side Garage has 480V.
- There is not enough room to park everything inside, but there is 40 acres, and around 20 acres is not used (outside).
- MDOT was built when they had smaller single axle trucks from the 1970s and would need brand new infrastructure for electrification.
- The BWB crew does the bridge and DOES NOT do road services outside the bridge. Canada does the other half of the bridge.
- The county for BWB is not a direct county, and contracts out to do roads outside of BWB.
- BWB Shop is 2-3 miles south of where they work on the bridge.
- BWB uses the loaders to clean the plaza and other areas and remove snow from the plaza and salt during the winter.
- BWB uses the loaders at a lower intensity than the other regions.
- Use at BWB:

  - Loading/unloading salt and snow
  - Use the front-end loader, or bucket, pusher, or scoop to snow plow to load into other dump trucks and dump it off the bridge
  - Use could be extensive, like having gone up to 500 tons total, but around 280 tons within the first 2 months. This would be in continuous use, 24/7, at 0 degrees or colder with the wind chill. On average it's colder climate here than in other places (around 20 degrees cooler).
  - There are 4 units:
    - 3 front end loaders
    - 1 excavator with a front end loader attachment
  - Excavator is more for summer use (e.g. removing trees, taking out trenches, putting in drain pipes, building rock gardens, planting trees, moving earth around)
  - Front-end loader is used in the heavy winter (picking up big sections of concrete, snow removal, salt loading)
  - There is a small team to move from the day shift to night shift
  - A front end loader would be used to push at the parking lots
  - The other front end loader is used in the plaza
  - We will use a snow plow to push snow, then front end loader to move snow into a big pile
- How extensively are these vehicles used?
  - Summer - 4 days/10 hrs or 5 days/8 hrs
  - Winter - Range from a few hours to 24/7, continuous days
    - At the bridge, it's really busy because they cannot have any ice on the bridge, lots of wind brings water on the bridge and turns into ice
- Where are these stored?
  - 3 are stored in the main garage near the I-94 mile marker 274 across from the Welcome Center east bound I-94
  - 1 is stored in the 10th street area near the MDOT parking lot north east garage
  - 1-2 miles from working destination for both
  - 4-5 miles round trip
  - There is one loader that stays at the salt barn where it loads salt for around 20-25 mins (around 15 mins loading and 5 mins idling) and is not being used 24/7
  - Sometimes slightly longer since they do 3 different bays
  - Summer - front end loader, jack hammer (jack hammer is used in summer may be 5-10 times in a year)
  - Winter - front end loader, pusher
  - They use a street sweeper instead of a brush attachment (even though they have one) because brush picks up a lot of dirt
  - Maintenance Garage, Plaza, 10th street parking lot, misc. properties, neighborhoods they use John Deeres side by side plow and salt spreader, 9 miles of sidewalk
  - No infrastructure, not even for light duty vehicles
  - 480V service at the facility

Target regions for a pilot project: Auburn Hills Bridge Repair Maintenance Crews and one loader at BWB

Lawn Tractors

Total Number	Regions	Critical Specs
41	Metro(1), Bay(1), BOBS(1), GRD(5), SUP(9), Uni(9), SWS(9), North(5), TSMO(1)	**Tractor:** 18-25 hp, 48-54 in. cutting depth **Zero Turn Mower:** 25-35 hp, 60-72 in cutting depth, max. speed 10-12 mph

Operational Feasibility	Brand	Technology	Critical Specs
No	RYOBI	80V Li-Ion	Tractor, 23 hp, 46 in. cutting depth, portable multiple batteries, 1hr autonomy/battery, residential product
Yes	Gravely	56V Li-Ion, 16 kWh	Zero turn mower, 60 in. cutting depth, 11mph, 6.6 acres/battery, swappable battery
Yes	EVO	35 kWh Li-Ion	Zero turn mower, 40hp, 74 in. cutting depth, 13mph, 8 hr autonomy, no swappable battery

evRYOBI: 80V, 46 inch mower. MDOT uses John Deere X380, which has 48" mower. From that perspective, it is a little bit smaller. But in terms of dimensions and motor power, it is comparable.

With one battery pack, RYOBI can mow 2.5 acres land. For 46" inch cutting depth, 2.5 acres correspond to 5.37 miles. For 5 mph average speed, it takes 65 minutes to mow 2.5 acres land. After 65 minutes, the batteries are depleted and need to swapped. The mower would operate another 65 minutes with the swapped battery. Therefore, the first set of batteries need to be fully charged in 65 minutes. However, the charge time of the depleted batteries is 2.5 hours. Therefore, 65-minute operation with one battery pack is not operationally feasible for MDOT.

Cubcadet: It has 42" mower, which is smaller than what MDOT uses (48"). Not an alternative.

RYOBI: It is equivalent (42 hp) to John Deere Z970R (35 hp) but its deficiency is forward speed of 8 mph as opposed to John Deere's Z970R's 12 mph. Its other deficiency is cutting width of 54" as opposed to John Deere Z970R (60"-72"). With full charge, it can mow 4 acres of lands. Charge time of Li-Ion battery is 5 hours but it has multiple batteries and battery can easily replaced.

Cubcadet: It has 42" mower, which is smaller than John Deere Z970R. Not an alternative.

Gravely: It is equivalent to John Deere Z970R. It has 60" deck and cutting width (Z970R is also 60"). Its forward speed is 11 mph (Z970R speed is 12 mph). Battery capacity 4 kWh Li-Ion 56V but it has four battery packs (16 kWh). Batteries are easily replaceable. It has read and side discharge options. It has Mulch kit, fast and normal charger kit.

With one battery pack, Gravely can mow 12 acres land. For 60" inch cutting depth, 12 acres correspond to 19.8 miles. For 5 mph average speed, it takes 238 minutes (~4 hours) to mow 12 acres land. After 238 minutes, the batteries are depleted and need to swapped. The mower would operate another 238 minutes (~4 hours) with the swapped battery.

The total operation time would be 8 hours. For all regions, lawn tractors return to their garages at the end of shift. In Bluewater, lawn tractor mows less than 50 miles per day. University, Grand Rapids, and Superior use lawn tractors maximum 8 hours per day. Southwest and Bay regions use lawn tractors 3-4 hours per day. Welcome Center at SW use once a week 8 hours. 0.5x0.5 miles for SW Welcome Centers (Cold Water and New Buffalo Welcome Centers).

As a result, Gravely mowers would meet the operational requirements of the aforementioned regions, especially Southwest and Bay regions. Therefore, 238x2-minute operation with one battery pack and one spare battery pack is operationally feasible for MDOT. Gravely also offers portable battery charger with 110 VAC and 220 VAC input supply to charger batteries. They can be used on the field if 110/220 VAC supply is available through a diesel battery hybrid generator or electric grid.

EVO: 35 kWh, 8 hour autonomy, 13 mph forward speed, 74" cutting width, 40 hp engine equivalent. It is on par to John Deere Z970R. Its only disadvantage is the battery is not swappable. Commercial grade mower.

EVO battery pack is not swappable but its battery capacity is the double of Gravely's battery pack and has 8 hours autonomy. Therefore, the same arguments provided for Gravely mowers are valid for EVO mowers and as a result, they are operationally feasible for MDOT.

UTVs

Total Number	Regions	Critical Specs
12	Bay(4), Metro(2), North(2), BWB(1), TSMO(1), GRD(1), UNI(1)	Engine: 54 hp, Cargo capacity: 1000 lb, Cargo dimensions: 45x12x52 inch, Towing capacity: 4000 lb, 4WD

Operational Feasibility	Brand	Technology	Critical Specs
Yes	Polaris	Li-Ion 14.9&29.8 kWh	EM: 110 hp, Cargo capacity: 1250 lb, Cargo dimensions: 37x12.5x54 inch, Towing capacity: 2500 lb, 4WD
No	Landmaster	Li-Ion 7.7 kWh	EM: 24 hp, Cargo capacity: 1000 lb, Cargo dimensions: 50x14.25x70 inch, Towing capacity: 1500 lb, 4WD

Other electric vehicles that have deficient performance:
Huntve, Intimidator, DRRUSAs
Operational Analysis:
Mostly used for spraying, litter pickup, and inspecting bike trails. In winter, in Bluewater bridge, it is used for snow removal of side walks (What are the details of snow removal cycle?: Not many miles, half a day actual usage, half a day for hauling). Metro also uses it for snow plowing in winter. Low speed, low mileage. It returns to the garage at the end of the shift. It is towed to the job site. For Bluewater and Metro regions, the daily mileage is 50 miles in summer. For Grand Rapids, they stay at the job site. It must be 4WD. It should also climb stairs (pad crossings). 20 staircase. A blade on the front of the machine to remove snow. Blades are specific to the UTV OEM.
Polaris Empty Weight = 1754 lbs
Cargo Weight for 45 gallons spray tank: 500 lbs
Two passengers: 300 lbs
For the summer, assuming a UTV moves at 8 mph for 50 miles with 200 stop and goes, the battery energy consumption would become 9.8 kWh and the total duration would be 6.7 hours. 9.8 kWh of battery energy corresponds to 66% DoD for 14.9 kWh battery capacity. Therefore, 14.9 kWh battery capacity would be operationally feasible in summer.
For the winter, snow plowing would generate much bigger friction to the atv. Therefore, for winter, it is assumed that the cargo capacity and towing capacity of atv are fully used. In this case, battery energy consumption would become 15.3 kWh. In this case, 29.8 kWh battery option is required.
According to the simulations, Landmaster ATV battery capacity would not be enough to meet the operational requirement of 50 miles during summer due to its limited battery capacity.

Rollers

Total Number	Regions	Critical Specs
6	Bay(2), Metro(1), UNI(1), North(1), GRD(1)	Diesel Engine: 24.8 hp, Drum Width: 47.2", Speed: 6.3 mph, Water tank: 47.6 gal, Weight: 5,942 lbs

Operational Feasibility	Brand	Technology	Critical Specs
Yes	Hamm	Li-Ion, 23.4 kWh, 48V	Drum Width: 47.2", Speed: 6.3 mph, Water tank: 47.6 gal, Weight: 6,068 lbs
Yes	Bomag	Li-Ion, 25 kWh, 48V	EM: 26.8 hp, Drum Width: 47.2", Speed: 6.3 mph, Water tank: 54.2 gal, Weight: 5,727 lbs
Yes	Volvo	Li-Ion, 20 kWh, 48V	EM: 33.3 hp, Drum Width: 47.2", Water tank: 69 gal, Weight: 6,195 lbs
Yes	Ammann	Li-Ion, 31.5 kWh, 48V	Drum Width: 47.2", Speed: 6.3 mph, Water tank: 50 gal, Weight: 5,815 lbs

- Based on simulations, It is estimated that 23.4 kWh Li-Ion battery with usable capacity of 15 kWh can continuously operate around 4.9 hours with an operating weight of 6,068 lbs (with 25 kN, 0.5mm, 51 Hz vibration).
- Rollers are not used heavily by the regions.
    - For Metro, roller operates 2-3 hours per day around facilities and always comes back to the garage. Therefore, battery electric roller is operationally feasible for Metro.
- Maximum battery charge rate is around 6.4 kW. The existing electrical power capacity in the garages may handle the additional battery charging load.
    - As a result, MDOT can consider to acquire battery electric rollers.

Concrete Mixer

Total Number	Regions	Critical Specs
13	UNI(5), SUP(3), GRD(2), SWS(2), North(1)	Engine: 7.9 hp, Drum Capacity: 9 cuft

Operational Feasibility	Brand	Technology	Critical Specs
No	Multiquip	Electric 1 phase 115/230 VAC	EM: 1.5 hp, Drum Capacity: 9 cuft

Operational Analysis:

For all regions except Metro, the concrete mixer can stay at the jobsite for a week but would operate maximum 4 hours per shift.

For Metro, it returns to the garage at the end of the shift.

4 hours/day corresponds to 1.5 hp*0.75*4/0.9 = 5 kWh. The required battery capacity is 5/0.64 = 7.8 kWh.

It can be mated with a portable e-generator. Voltstack portable e-generator with 6.9 kWh battery capacity and 4.8 kW output power would operate the electric mixer for 3.5 hours in the worst-case scenario when the battery is at the end of its life. Since concrete mixer is used 2-3 hours per shift in general and 3.5 hours of electric supply by the e-generator is for a battery at the end of its life, electric concrete mixer mated with an e-generator is operationally feasible for Metro region.

HATCH

Underbridge Inspection / Aerial Equipment

Total Number	Regions	Critical Specs
6	BOBS(3), BWB(1), SUP(1), SWS(1)	Max underbridge width reach: 741", Max underbridge height reach: 156" (L shape) & 811" (\ shape) Max underbridge width reach: 384", Max underbridge height reach: 216" (L shape)

Operational Feasibility	Brand	Technology	Critical Specs
Yes	Anderson Underbridge	Li-Ion, 3.2 kWh, 51.7V, 3.1 kW	Max underbridge width reach: 420", Max underbridge height reach: 209" (L shape)

MDOT has different types of aerial equipment – truck based and trailer based. We cover trailer based ones in this slide. There are two critical specs of the existing equipment. The first equipment is under underbridge inspection category and the second equipment is under aerial equipment category.

NMC Li-Ion battery, 3.2 kWh, 51.7 V, 3.1 kW, 3 hour battery charging, cold temperature functionality

MDOT's existing underbridge platform can reach the underbridge not only through L shape but also \ shape

These inspection equipment is a property shared among regions.

SW has one. Not used too much. Underutilized.

With 3.2 kWh battery, 6 bridge inspections can be performed.

The battery packs can also be connected in parallel to increase its capacity up to 32 kWh. As a result, the battery operated under bridge inspection equipment is operationally feasible for MDOT. However, since it is shared among regions, it may be difficult to find a charging spot although it can be charged by a standard 120 VAC outlet with 15A capacity.

Walk-behind Snow Blowers

Total Number	Regions	Critical Specs
2	SWS(2)	

Operational Feasibility	Brand	Technology	Critical Specs
Yes	Greenworks	Li-Ion, 0.4 kWh, 80V	24" wide intake, up to 18" snowfall
Yes	Greenworks	Li-Ion, 0.48 kWh, 60V	24" wide intake, up to 18" snowfall

MDOT owned snow blowers are used within the garage and facility perimeters between one and three hours. Once the job is completed, they return to the garage. Good fit to the Welcome Center. Mowers can be converted to snow blowers with attachments, broom attachments for cleaning.

The snow blowers offered by Greenworks have two swappable battery packs. Moreover, the chargers offered by Greenworks have 8A dual port charger (4A for each port) for 80V batteries and 6A charger for 60V batteries. It corresponds to 75 minutes and 80 minutes charging time for 80V and 60V batteries, respectively. Since these snow blowers have portable swappable battery packs that are also charged quickly and their daily usage by MDOT is limited to one to three hours, battery electric operated snow blowers are operationally feasible.

Forklifts

Total Number	Regions	Critical Specs
44	UNI(11), Metro(4), Bay(4), GRD(4), SUP(4), BOBS(4), TSMO(4), North(3), F&A(2), BWB(1), CFS(1), OOA(1), SWS(1)	LPG Engine: 64-133hp, Basic Capacity:5000-8000 lb, Weight: 8000-12800 lb, Lifting Height: 118inch, Pneumatic tires

Operational Feasibility	Brand	Technology	Critical Specs
Yes	BYD	21.6/43.2 kWh, 80V	EM: 81hp, Basic Capacity:5400 lb, Weight: 9240 lb, Lifting Height: 118inch, Pneumatic tires
Yes	Toyota	67.2 kWh, 80V	EM: 51hp, Basic Capacity:5000 lb, Weight: 10444 lb, Lifting Height: 119inch, Pneumatic tires
Yes	Hyster	33.6 kWh, 80V	EM: 35hp, Basic Capacity:5000 lb, Weight: 9535 lb, Lifting Height: 133inch, Pneumatic tires
Yes	Mitsubishi	56 kWh, 80V	EM: 49hp, Basic Capacity:5500 lb, Weight: 10434 lb, Lifting Height: 130inch, Pneumatic tires

The battery forklifts should have pneumatic tires because cushion tires cause drivability issues on the muddy outdoor environment due to the heavy weight of the forklifts.

Operational Feasibility:

- Forklifts do not leave garage
- Generally used for 1-2 hours/shift
    - Forklifts need to have pneumatic tires because it is difficult to operate them on a rainy day on a gravel surface

At the Auburn Hills, battery electric forklifts are already used. Propane is also used by Auburn Hills. Electric ones are light duty and used in warehouse indoors. Propane ones are for outdoor use. EV ones has low ground clearance and smooth tires.

MDOT should acquire battery electric forklifts with pneumatic tires from now on since the battery forklifts in the market can meet MDOT's operational requirements because of the following reasons:

- They are used generally for 1-2 hours and maximum 4-6 hours. Current battery forklifts have enough battery energy capacity.
- They are mostly used in garages.
- Power demand to charge these batteries does not require infrastructure upgrades in the garages.
- Based on our simulations, a battery forklift with 45 kWh Li-Ion battery (usable energy: 0.64*45 = 28.8 kWh) can operate 4.3 hours if it continuously moves a 5000-lbs load for 100 ft and lifts it up 100 inches. Therefore, the battery electric forklifts are capable of meeting MDOT's operational needs.
- Bay and Metro regions have already deployed battery electric forklifts and they are satisfied with their performance.
- But the battery electric forklifts should have pneumatic tires so that they can operate on gravel surface during rainy days.
- Metro, Bluewater Bridge, and Central garages have paved surface. Therefore, they are not expected to have any drivability issue on an outdoor rough terrain.

Light Towers

Region/Office	Number of Items	Technology	Critical Specs
Metro	4	Solar and Battery	25.5 ft, LED, 63kLm
Metro, BWB, GRD	Each 2	ICE Generator	30 ft, Metal Halide, 4kW, 348kLm
BAY, North, SW, BOBS, UNI	Each 1	ICE Generator	30 ft, Metal Halide, 4kW, 348kLm
UNI	1	ICE Generator	22 ft, LED, 920W, 120kLm

Operational Feasibility	Brand	Technology	Critical Specs
Yes	Generac VT-Hybrid	Engine and Battery	27ft, LED, 600W, 76.5kLm
Yes	Wanco WLTS-M-1600H	Engine+Solar+Battery (AGM) (4-5 hrs)	30’, LED, 800W, 128kLm
Yes	Generac MLTB	Battery (17.9 hrs)	23ft, LED, 760W, 104kLm
Yes	Signal Power	Battery+Solar+Engine (8 hr battery)	30’, LED, 1280W, 166.4kLm
Yes	Axiom HLT-6150	Battery+Solar+Engine (6 hr battery)	28’, LED, 900W, 120kLm
Yes	Dominight	Battery+Solar+Engine	24’, LED, 1400W, 200kLm

HATCH

Engine+Battery models are feasible but battery only ones cannot meet the duration capability of engine driven light towers.

From now on, MDOT should acquire hybrid or battery+solar light towers.

Operational Feasibility Analysis:

8-10 hours of operation (maximum) but it can extend up to 17 hours between 4pm and 9am (very seldom).

In Superior, it stays in the truck.

In Metro, it returns to the garage at the end of the shift.

In Blue Water Bridge, it is stored for a long time. Then, if used, it is used for the entire night.

Too much luminesce is not desired because it makes drivers blind. But in certain jobs, maximum luminescence is desired to have light on a remote site.

University, Superior, Grand Rapids, Bay area keep the light towers at the job site until the job is completed.

Metro area is the most suitable since they return the light tower back to the garage at the end of the shift.

However, since the light tower can be kept on up to 17 hours, battery only light tower would be marginally operational feasible and should be returned to the garage for charging at the end of the shift.

The most appropriate ones are battery + solar + engine generators that can keep running the lights up to 8 hours with battery. If the operation requires the light tower to be on for more than 8 hours, engine would turn at the end of 8^{th} hour.

Shot Blaster

Total Number	Regions	Critical Specs
8	UNI(1), BOBS(7)	Engine: 73hp, Compressor: 13cfm, Vacuum:2280cfm, 3000-4000 sqft/h, Blast Width: 18”

Operational Feasibility	Brand	Technology	Critical Specs
Yes	Blastpro	LPG	Engine: 80hp, 3800 sqft/h, Blast Width: 20”

No battery products. Just LPG versions are available.

Infeasible ones are infeasible because their engine rating and productivity (sqft/h) are lower than the one used by MDOT.

Diesel/Gasoline Generators

Total Number	Regions	Technology	Critical Specs
21	Metro(7), Bay(1), BOBS(1), GRD(3), SUP(1), Uni(2), SWS(6)	Diesel/Gasoline	5-6 kW

Brand	Technology	Critical Specs
Voltstack	Mobile Li-Ion Battery Pack	6.9kWh, 4.8kW, 120VAC, 70 min autonomy
		80kWh, 27kW, 120/208VAC, 10.7hrs autonomy@6kW
Viatec	Li-Ion Battery Pack	14.4-21.6 kWh, 12 kVA, 120/240 VAC
EHR	Battery+Engine Hybrid	10 kVA output power, 21 kWh battery, 1.5 hrs autonomy
Ana	Battery+Engine Hybrid	30 kVA output power, 15 kWh battery

Engine+Battery models are feasible but battery only ones cannot meet the duration capability of engine driven generators.

These devices will be used to provide electricity to the electric powered equipment and charge batteries.

Asphalt Storage Heater

Total Number	Regions	Critical Specs
41	UNI(13), SWS(9), GRD(5), SUP(4), BAY(4), BWB(1), Metro(3), North(2)	Diesel heater, 4 metric tons capacity

Operational Feasibility	Brand	Technology	Critical Specs
No	Falcon	Propane	Propane heater, 4 metric tons capacity
No	Marathon	Propane	Propane heater, 4 metric tons capacity

Emission reduction in propane would come from NOx and particulate matter. Moreover, diesel produces 17% more carbon dioxide than propane.

Propane tanks need to be removed before they are parked in the indoor. Storing and changing tanks are logistical issues. Propane has less energy density and in winter, you cannot keep the temperatures high with LPG.

Rubber & Bituminous Heater

Total Number	Regions	Critical Specs
20	UNI(9), SWS(5), GRD(4), Metro(2)	Diesel Engine for hydraulics: 19 hp, Diesel heater: 324,000 BTU, Propane heated chute, 350 gal capacity

Operational Feasibility	Brand	Technology	Critical Specs
No	Marathon	Propane	Propane Engine for hydraulics: 20 hp, Propane heater: 410,000 BTU, 250 gal capacity

A&A product is not feasible because it has less carrying capacity and the only advantage is the propane heater. Diesel engine remains the same. Therefore, its emission advantage would be minimal.

Marathon is a Canadian company. Both engine and heaters are propane powered. But its capacity is 250 gal, which is less than the one MDOT has. Emission reduction in propane would come from NOx and particulate matter. Moreover, diesel produces 17% more carbon dioxide than propane.

Surface Grinder

Total Number	Regions	Critical Specs
6	UNI(1), SWS(1), NTH(1), SUP(1), GRD(1), BWB(1)	Product names are available but model numbers are not available. The product names: Edco and Bartell

Operational Feasibility	Brand	Technology	Critical Specs
No	Edco	Electric 115/230 VAC	Edco has an electric version of each gasoline and propane grinder.
No	Bartell	Electric 115/230 VAC	Electric version of SP8 model, which MDOT has in its inventory. EM: 1.5 kW

MDOT has Edco and Bartell surface grinders in its inventory.

Surface grinders can stay out of garage for a week and used typically for three to four hours a day. Assuming 4 hours of operation per day, the electricity consumption would be 1.5 kW*4/0.9 = 6.7 kWh. There are battery based generators in the market that can be used to power the surface grinders. One of them is Viatec's SmartPX with 12 kVA output and 14.4 kWh and 21.6 kWh battery energy capacities. 14.4 kWh and 21.6 kWh battery packs can provide 5.5 hours and 13 hours of energy, respectively. But since the surface grinders can stay at the job site up to a week, the battery energy capacities are not enough to operate the surface grinders for a week. At the job sites, it would be extremely difficult to find an electric outlet from the grid to charge the battery pack. Moreover, although these battery packs can operate between -13 degF and 115 degF, they would not work properly if they stay idle outdoor overnight at the jobsite in a cold climate. There is a product in the market from Voltstack with higher battery capacity of 80 kWh and backup generator. But this product is heavy (4850 lbs) and needs to be transported by a trailer to the job site. Moreover, its operating temperature range is limited between 14F and 122F and if it stays idle outdoor overnight at the jobsite in a cold climate, it could not function during day time.

Compressors over 295 cfm

Total Number	Regions	Critical Specs
34	SUP(7), UNI(5), SWS(5), BAY(4), MET(4), NTH(4), GRD(3), BWB(1), BOBS(1),	400-440 cfm, 100-150 psi, 135 hp diesel engine, 4,555 lbs, 161x71.5x70 inch

Operational Feasibility	Brand	Technology	Critical Specs
No	Atlas Copco	Electric 3phase 380/460 VAC	EM: 100 hp, Air Flow: 324-454 cfm, Pressure: 72-188 psi, Weight: 2,643 lbs, 148x62.7x62 inch
No	Sullair	Electric 3phase 460 VAC	EM: 250 hp, Air Flow: 414-1035 cfm, Pressure: 100-150 psi, Weight: 10,500 lbs, 189x84x97 inch

No battery operation, 3-phase AC supplied compressors are available.

Sullair is oversized.

They return to the garage at the end of shift. It runs 8-10 hours in each shift. They are heavily used at the jobsite. The maximum power draw of the electric Atlas Copco compressor from the electric source is calculated as 42 kW. If diesel battery hybrid generator (Ana), which can supply 3 phase 480 V is used to power the compressor, the battery of that generator would last only 20 minutes (15 kWh*0.9/42kW*60) when the compressor runs at its maximum capacity. The other diesel battery hybrid generators and battery e-generators do not have the capability of providing three phase 460 V required for the operation of electric compressors. As a result, electric compressors would not be operationally feasible for MDOT.

Sewer Rodder 9' and up

Total Number	Regions	Critical Specs
10	Metro(1), Bay(3), Uni(2), SUP(2), SWS(1)	Trailer mounted jetter, Engine: 56hp, Water Capacity: 700 gal, Max Hose Capacity: 1000', Hose size:0.5-1", 40 gpm, 2000 psi Truck Mounted Vachunter: 600 gal. water, 600 gal. debris tank, 600' hose reel, water 40gpm, 3000psi

Operational Feasibility	Brand	Technology	Critical Specs
No	Pipehunter	Battery 120 kWh	Jetter, 700 gal capacity, 0.5"-25gpm@4000psi, 0.75"-30gpm@3000psi
No	Sharp EV4	Battery 40 kWh	Trailer Hydrovac, 800 gal. debris tank, 270 gal. water tank, 40gpm, 3000psi

Kaiser truck is a European truck. Therefore, it is not feasible to use in Michigan.

Sewer jetters roam among MDOT garages and hence they are used heavily. At the end of the shift, they return to a garage. Its operation duration within a shift varies. Sometimes it is between two and four hours and for some other tasks it can last up to the entire shift (8-10 hours).. Pipehunter's battery EV jetter has 700 gallons of water capacity, which is the same as its engine driven equivalent. Assuming a jetter operates 4 hours per shift, gpm would be 700/(60*4) = 2.9 gpm. At 4000psi, the battery power draw would be 8.7 kW. At that power draw, 120 kWh battery would last 8.8 hours. As a result, Pipehunter's battery jetter with 120 kWh battery would meet MDOT's operational requirement unless the jetter is used very heavily and its water tank depletes in the middle of shift and is refilled at the garage. Assuming the jetter's tank is refilled in the middle of the shift, power draw would double to 17.4 kW and the battery would last for 4.4 hours, which is less than 8 hours. In this case, battery EV jetter would not be operationally feasible. As a result, the operational feasibility would depend on the task of a region and there is no guarantee of its operational feasibility. Moreover, since a jetter roams among garages, it would be difficult for a pilot project to set up a charging infrastructure for each garage.

Sharp EV4 has both a jetter and a debris vacuum. Assuming its water tank is used filled once during a shift, the total power draw from the battery would be 10.85 kW. With that power draw, the battery would last 2.4 hours, which is less than four hours of average hydrovac operation. Therefore, Sharp EV4 would not be operationally feasible due to the insufficient battery capacity and limited water tank capacity.

Concrete Saw

Total Number	Regions	Critical Specs
9	Metro(1), Bay(2), GRD(1), Uni(3), BTP(2)	Engine: 37hp, Blade diameter: 30”, Cutting Depth: 12.25” Engine: 74hp, Blade diameter: 42”, Cutting Depth: 17.5”

Operational Feasibility	Brand	Technology	Critical Specs
No	Husqvarna	Electric Cable (480V3ph)	EM: 30hp, Blade diameter: 30”, Cutting Depth: 12.37”
No	Core Cut	Electric Cable (480V3ph)	EM: 40hp, Blade diameter: 30-42”, Cutting Depth: 11.75-17.75”
No	Merit	Electric Cable (480V3ph)	EM: 30 hp, Blade diameter: 30”, Cutting Depth: 13”
No	Core Cut	Propane	Engine: 35hp, Blade diameter: 30”, Cutting Depth: 12.37”

It returns to the garage at the end of the shift. Mostly used in summer.

Superior, Metro use 1-2 hours per shift.

Grand Rapids use 4 hours per shift.

Southwest and Bay use it heavily 8-10 hours per shift.

If diesel battery hybrid generator (Ana), which can supply 3 phase 480 V is used to power the concrete saw in Metro and Superior regions, the battery of that generator would last only 27 and 36 minutes when the concrete saw runs at its maximum capacity. The other diesel battery hybrid generators and battery e-generators do not have the capability of providing three phase 480 V required for the operation of electric concrete saw. As a result, electric concrete saws would not be operationally feasible for MDOT.

Asphalt Paver

Total Number	Regions	Critical Specs
1	SWS(1)	Engine: 20 hp, 8' paving width, Weight: 5,240 lbs

Operational Feasibility	Brand	Technology	Critical Specs
No	Dynapac	Li-Ion battery, 88 kWh	4 hrs operation, EM: 55 kW, 40 min charging with DC charger, 3 hrs charging with AC Level II charger, 350 tph, 13.7' paving width, Weight: 22,690lbs
No	Leeboy	Li-Ion battery, 48 kWh	300 tons on a single charge, EM: 155 kW, 15' paving width, Weight: 22,000 lbs

These pavers are bigger than Gilcrast 413 paver used by MDOT.

CM F175 is a product for EU. In terms of size, CM F175 is the right size for MDOT.

BAM is developed in EU and it is a prototype. Not available in the US.

MDOT has only one old asphalt paver in its inventory. Battery electric asphalt pavers are overpowered compared to the one in MDOT inventory.

Backhoe Loader Tractor

Total Number	Regions	Critical Specs
32	Metro(1), Bay(4), GRD(3), North(2), SUP(2), Uni(13), SWS(6), BWB(1)	Tractor: 116 hp, Digging Depth: 15’11”, Operating Weight: 17,582 lb (John Deere 410)

Operational Feasibility	Brand	Technology	Critical Specs
No	Case 580	480V, 90 kWh Li-Ion	Max. 8 hours autonomy, 8 hrs charging, 14’5” digging depth

Recent MDOT purchases are John Deere 410. Moreover, most of MDOT backhoes are John Deere 410L or equivalent (13 out of 31). Therefore, 310X would be underpowered. 310X specs are not out yet. Case 580EV (dig depth of 14’) seems to be equivalent to John Deere 310, which is smaller than 410L in terms of engine power and dig depth (MDOT has 410Ls). Approximately, 8 of MDOT can be an equivalent to Case 580 EV. But those were acquired long time ago (before 2005).

Used for ditching in summer. Towed to the jobsite. Stays at the job site for multiple days until the job is completed.

Stays in garage during winter. Used as a backup salt loader during winter.

Superior Region: Infrequent use. Runs for a few hours per day.

Metro: Used 4-5 hours per day.

Bridge crew uses heavily for 8-10 hours.

Region Equipment Foremen in Bay, North, Bluewater Bridge: 8-10 hours per day.

Battery electric backhoe loader tractor in the market is not operationally feasible due to two reasons:

1- Backhoe loaders stay at the jobsite for multiple days without returning to the garage. Therefore, there won’t be opportunity to charge the vehicle offsite unless there is electric grid. Diesel-battery hybrid generator cannot be a solution since they have small battery capacities and cannot provide electrical energy to charge the batteries for multiple days through the generator’s batteries.

2- At peak hydraulic operations (max flow rate and pressure), the power draw from the battery would be 97 kW. Since the backhoe loader is used heavily at the jobsite, assuming 1 hour of digging would consume 97 kWh of battery, which exceeds the useable battery capacity of Case 580EV.

Track mounted Excavators

Total Number	Regions	Critical Specs
7	SWS(3), GRD(1). North(2), SUP(1)	Diesel Engine: 53-108hp, Operating Weight: 13,600-34,000lb, Bucket Breakout Force: 9,200-22,200lbf, Hydraulics: 38-73gpm, Speed: 3 mph, Swing Speed: 9.5-13 rpm

Operational Feasibility	Brand	Technology	Critical Specs
No	HEVI	Li-Ion, 141 kWh, 618 V	EM: 81 hp, Operating Weight: 18,739lb, Bucket Breakout Force: 11240lbf, Hydraulics: 42.3gpm, Speed: 12 mph, **Wheeled** Excavator

The following EV excavators that have smaller capacities in terms of operating weight and power:
1- Bobcat E10e and E19e are smaller than Bobcat 88, which MDOT has.
2- Volvo ECR25, Operating Weight: 6000 lb, breakout force: 5000 lbf, 15.3 gpm hydraulics, EM: 24 hp, 20 kWh, 48V
3- JCB 19C-IE, Operating Weight: 4193 lb
4- Wacker Neuson EZ17e, Operating Weight: 4295 lb, 22.1 hp
The following EV excavators that have bigger capacities in terms of operating weight and power than the excavators MDOT has:
1- Volvo EC230, Operating Weight: 54,000 lb
2- Caterpillar 320, Operating Weight: 50,000 lb (Prototype)
3- Komatsu PC200LCE, Operating Weight: 52,000 lb (Prototype)
Used for ditching and with accessories like brush heads, for forestry work and cleaning after a tornado. It has various attachments like auger, hydrogen cutter, log claws, First responders use them often.
Towed to the jobsite. Stays at the job site for multiple days until the job is completed.
It is used heavily for 8-10 hours per day.
Battery electric excavators are not operationally feasible due to two reasons:
1- Excavators stay at the jobsite for multiple days without returning to the garage. Therefore, there won't be opportunity to charge the vehicle offsite unless there is electric grid. Diesel-battery hybrid generator cannot be a solution since they have small battery capacities and cannot provide electrical energy to charge the batteries for multiple days through the generator's batteries. Moreover, it is used by first responders and they cannot take the risk of batteries being depleted and not being able to charge them.
2- Battery electric excavator in the market does not offer attachments, which MDOT uses with conventional excavators in its fleet.

Class 1

Total Number	Technology	Critical Specs
576	Majority Gas; Some Diesel	Passenger Vehicles

Brand	Model	Technology	Critical Specs
Tesla	Model 3	Li-Ion Battery, 75 kWh	1020 hp; 341 mi; AWD
Hyundai	Ioniq 6	Li-Ion Battery, 74 kWh	239 kW; 273 mi; AWD
Kia	EV 6	Li-Ion Battery, 77.4 kWh	320 hp; 282 mi; AWD
Hyundai	Ioniq 5	Li-Ion Battery, 74 kWh	320 hp; 260 mi; AWD
Tesla	Model Y	Li-Ion Battery, 81 kWh	425 hp; 310 mi; AWD
Rivian	R1S	Li-Ion Battery, 135 kWh	665 hp; 352-400 mi; AWD
VW	ID.4	Li-Ion Battery, 77 kWh	330 hp; 263 mi; AWD

None of the EVs can meet the range performance of equivalent conventional vehicles.

Class 2

Total Number	Technology	Critical Specs
657	Majority Gas; Some Diesel	Pickup truck; Towing

Brand	Model	Technology	Critical Specs
Ford	F-150 Lightning	Li-Ion Battery, 131 kWh	580 hp; 300 mi; 8,500 lbs towing capacity
Tesla	Cyber Truck	Li-Ion Battery, 123 kWh	500 hp; 340 mi; 11,000 lbs towing capacity
Rivian	R1T	Li-Ion Battery, 180 kWh	835 hp; 500 mi; 11,000 lbs towing capacity

These vehicles are primarily used by supervisors and first responders. The daily mileage is high at the level of 200-300 miles. Some of these vehicles stay at the homes of supervisors and first responders. In emergency cases, they may stay off-garage more than 72 hours. Due to the high daily mileage and high probability of staying off-garage multiple days, battery electric trucks are not operationally feasible. However, the alternator of these types of vehicles are used by Metro region and electricians to power spot lights and arrow boards. Anti-idling technologies like DC voltage output APU system of Viatec would eliminate engine idling by powering the external electrical loads through a battery system.

None of the EVs can meet the range performance of equivalent conventional vehicles.

Class 3

Total #	Regions	Technology	Critical Specs
166	Bay (10), BOBS (16), BTP (7), BWB (4), GRD (14), MET (8), NTH (7), OOA (2), SUP (18), SWS (20), TSMO (20), UNV (38)	Gas, Diesel	Dumping

Brand	Model	Technology	Critical Specs
Blue Arc	Class 3 EV	Li-Ion Battery, 240 kWh	322 hp; 200 mi
Mullen	Class 3 Urban Utility Low Cab Forward	Li-Ion Battery, 89 kWh	160 hp; 125 mi

These vehicles are primarily used by supervisors and first responders. The vehicles are heavily loaded with the equipment, metal toolboxes, and water tanks on the truck bed. The daily mileage is high at the level of 200-300 miles. Some of these vehicles stay at the homes of supervisors and first responders. In emergency cases, they may stay off-garage more than 72 hours. Due to the high daily mileage and high probability of staying off-garage multiple days, battery electric trucks are not operationally feasible. However, the alternator of these types of vehicles are used by Metro region and electricians to power spot lights and arrow boards. Anti-idling technologies like DC voltage output APU system of Viatec would eliminate engine idling by powering the external electrical loads through a battery system.

None of the EVs can meet the range performance of equivalent conventional vehicles.

Class 4

Total #	Regions	Technology	Critical Specs
42	BAY (6), BOBS (3), BWB (2), GRD (5), MET (6), NTH (4), SWS (5), TSMO (1), UNV (10)	Gas, Diesel	9 ft dumping, stake, stake drill

Brand	Technology	Critical Specs
Envirotech Urban Truck	Li-Ion Battery, 106.2 kWh	161 hp; 170 mi
Envirotech Cutaway Van	Li-Ion Battery, 106.2 kWh	161 hp; 170 mi
Optimal Ford E-450	Li-Ion Battery, 113 kWh	170/280 kW; 125 mi
Velocity Rizon e16L (Daimler Truck)	Li-Ion Battery, 82/123 kWh	129 kW; 110 mi
Workhorse W4 Work Truck	Li-Ion Battery, 118 kWh	150 kW; 150 mi

None of the EVs can meet the range performance of equivalent conventional vehicles.

Class 5

Total #	Regions	Technology	Critical Specs
63	BAY (13), BOBS (4), BWB (2), GRD (5), MET (8), NTH (4), SUP (8), SWS (5), TSMO (2), UNV (11)	Diesel, Gas	Dual Rear Wheel

Total #	Regions	Technology	Critical Specs
63	BAY (13), BOBS (4), BWB (2), GRD (5), MET (8), NTH (4), SUP (8), SWS (5), TSMO (2), UNV (11)	Diesel, Gas	Dual Rear Wheel

None of the EVs can meet the range performance of equivalent conventional vehicles.

Class 6-8

Total #	Regions	Technology	Critical Specs
74 in Class 6	Bay (3), BOBS (1), BWB (1), CFS (2), GRD (12), MET (1), NTH (6), SUP (4), SWS (22), UNV (22)	Diesel	Dump Lopro, Stake dumping, Utility body
73 in Class 7	BAY (5), BOBS (12), GRD (6), MET (4), NTH (9), SUP (7), SWS (14), UNV (16)	Diesel	Stake, utility with tower, Dumping, Scissors bed, Aerial
100 in Class 8	BAY (13), BOBS (16), BTP (2), BWB (4), GRD (11), MET (13), NTH (9), SUP (9), SWS (8), TSMO (3), UNV (12)	Diesel	Crane truck, Stake crane, Tower 45ft, Drill truck, Drill rig, Under bridge inspection

Brand	Model	Technology	Critical Specs
Freightliner	eM2	Li-Ion Battery; Class 6, 194 kWh; Class 7, 291 kWh	Class 6, 190 HP; Class 7, 255 HP Propulsion-Single Detroit eAxle; 180 or 250 mi; 80% in
Peterbilt	Model 520 EV	Li-Ion Battery; 400 kWh	Class 8, Right-Hand Side Loader and Rear Loader Refuse Collection, 670 hp (500 kw), 80-120 mi per charger (1,100 bin pickups)
Kenworth	T680 Fuel Cell EV	Fuel Cell; 58.8 kg hydrogen storage	Class 8, 415 hp, 450 mi, 82,000 lbs GCWR, quick refuel time, new lightweight roof fairing
Mack Trucks	MD Electric	Li-Ion Battery; 150 or 240 kWh	Class 6 and 7 -19,400 lbs, 230 mi, 185/260 hp; 19,400 lbs

None of the EVs can meet the range performance of equivalent conventional vehicles.

Roadside Tractors

Total Number	Regions	Critical Specs
71	Metro(2), Bay(6), GRD(9), North(4), SUP(4), Uni(19), SWS(22), BWB (1), OOA(4)	Engine: 102-123 hp, PTO: 85-110 hp, Hydraulic Flow Rate: 25 gpm, Operating Weight: 8800-12500 lb (JD 5100, 5125, 6120)

Operational Feasibility	Brand	Technology	Critical Specs
No	Solectrac	Li-Ion	EM: 75 hp, PTO: 65hp, 17.4 gpm, 6655 lb
No	Monarch	Autonomous Li-Ion	EM: 70 hp, PTO: 40hp
No	Case H.	Li-Ion, 110 kWh	EM: 74 hp, PTO: 65hp, 12.8 gpm, 10,800 lb
No	Rigitrac	Li-Ion, 58 kWh	EM: 54 hp, PTO: 19hp, 10.6 gpm, 4,890 lb
No	Fendt	Li-Ion, 100 kWh	EM: 74 hp

In MDOT, there are also very old tractors dating back to 1950s, 1960s, 1970s, 1980s, and 1990s. In determining reference tractor specs, we focused on the acquisitions done after 2010. There were two other tractors that were acquired after 2010, Trackless MT7 and Kubota M5-091D. We excluded them from the critical specs section since MT7 (in Metro region) is not a classical tractor and MDOT has only one vehicle in its fleet and MDOT has also just one Kubota tractor in its fleet (Southwest Region).

Electric tractors are designed for farming. Therefore, they are less powerful than the ones used by MDOT.

Sewer Rodder - SPR

Total Number	Regions	Critical Specs
1	BTP(1)	10,000 lbs pullback, Engine: 55hp, Max Flow: 9gpm, Max Pressure: 750psi

Operational Feasibility	Brand	Technology	Critical Specs
No	Vermeer	Electric	660,000lbs pullback, EM: 6x117hp
No	Streicher	Electric	100,000lbs pullback, EM: 315hp

Vermeer machine specs are much more powerful than the one MDOT has.

Streicher specs are much more powerful than the one MDOT has. Its target market is Europe.

Street Sweepers

Total Number	Regions	Critical Specs
3	Metro(1), BWB(1), UNI(1)	Aux. Diesel Engine: 74 hp, Blower: 30,000 cfm, Hose: D12”xL164”, Hydraulic Pump:16.6 gpm, Spray Water: 23 gpm, 290 psi, Debris tank: 10-13 cuyd, Water tank: 335 gal

Operational Feasibility	Brand	Technology	Critical Specs
No	Tymco	CNG	Aux. Diesel Engine: 99 hp, Hose: D8”, Hydraulic Pump: 8 gpm, Debris tank: 7.3 cuyd, Water tank: 330 gal
No	NiteHawk	CNG and LPG	No Aux. Engine, No Hose, Hydraulic Pump: 6.5 gpm, Spray Water: 2.8 gpm, Debris tank: 5 cuyd, Water tank: 100 gal

Tymco has smaller debris tank, hydraulic pump, and hose.

Nitehawk has no external vacuum hose, smaller hydraulic pump, debris and water tanks, and low pressure spray water.

HATCH

Loaders 1-1.25 yards (Skid steers)

Total Number	Regions	Critical Specs
57	Bay(6), BOBS(3), BWB(1), GRD(10). Metro(4), North(4), SUP(5), SWS(13), UNI(11)	Diesel Engine: 74-100 hp, Operating Capacity: 3500 lb, Operating Weight: 10,000 lb, Tipping Load: 8900-12000 lb, Hydraulics: 23-40gpm@3500psi, Speed: 8mph

Operational Feasibility	Brand	Technology	Critical Specs
No	Bobcat	Li-Ion, 72.6 kWh, 400V	EM: 107 hp, Operating Capacity: 2900 lb, Operating Weight: 11,970 lb, Tipping Load: 8429 lb, Speed: 7.8mph, No hydraulics
No	First Green	Li-Ion, 39 kWh	Operating Capacity: 1982 lb, Operating Weight: 7,269 lb

Hydraulic attachments won't work on the Bobcat EV.

Patching Heater

Total Number	Regions	Critical Specs
18	UNI(8), SWS(3), SUP(2), North(2), Bay(2), GRD(1)	Diesel Engine: 74 hp, Electric Heater: 1.5 kW. Emulsion Tank: 250 gal, Weight: 5500 lbs

There is no alternative product that has lower emissions since the heater is already electric in the existing product.

Equipment without any zero emission equivalent

Total Number	Number of Items in MDOT	Notes
Grader	22	
Hydroseeder	3	
Stump Cutter	24	
Road Rake	1	
Chipper Stump	7	
Chipper Brush	27	There is an electric version but it does not have wheels. It is stationary. There is also a wheeled battery version but it is much smaller than the ones MDOT uses.
Trencher	1	
Deflectometer	1	
Sprayer Pressure	27	There are battery operated (12V or 24V) pressure sprayers, where hydraulic pump is driven by an electric motor. But their tank capacity is smaller than the ones MDOT uses.
Tractor Crawler	3	
Tractor Brush Cutter	5	Tractors used brush cutting have higher power and PTO rating than the battery electric tractors have.
Spreader Chip	8	

Appendices

Appendix B: Cost-Benefit Analysis Results

MDOT Fleet Electrification Strategies Cost-Benefits Analysis Calculation Sheet

The purpose of this document is to provide a dynamic cost-benefit analysis calculation sheet for Michigan Department of Transportation (MDOT) to utilize to inform their future decision-making for future transitioning to Alternative Fueled Vehicles. This document is a supplemental document to the MDOT Fleet Electrification Strategies Final Report document and should not be utilized as a standalone document.

CO2 per gallon gasoline (lbs)	19.57	Greenhouse Gases Equivalencies Calculator - Calculations and References | US EPA
CO2 per gallon diesel (lbs)	22.42	Greenhouse Gases Equivalencies Calculator - Calculations and References | US EPA
CO2 per gallon LPG (lbs)	12.51	emission-factors_apr2021.pdf (epa.gov)
Electricity Rate ($/kWh)	0.13	https://www.eia.gov/electricity/state/michigan/
Gasoline Price ($/gal)	3.67	AAA Gas Prices
Diesel Price ($/gal)	3.88	
LPG Price ($/gal)	2.12	Weekly Michigan Propane Residential Price (Dollars per Gallon) (eia.gov)
Equipment Life (years)	6.00	
Equipment Life (years)	10.00	
Equipment Life (years)	20.00	
Number of business days per year	250.00	
Charger Efficiency	0.95	
Battery Charge Efficiency	0.98	

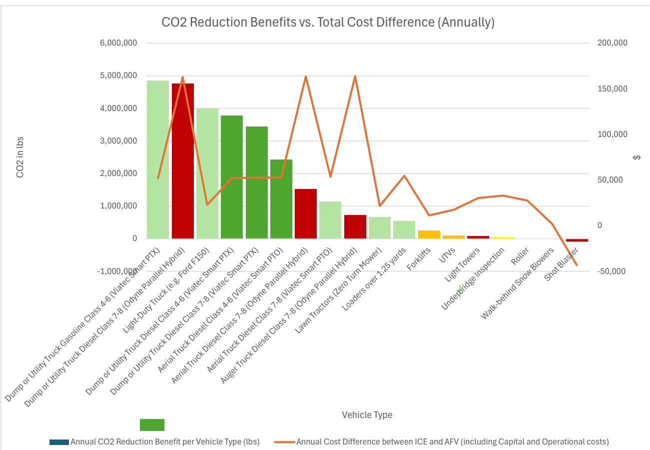
Key

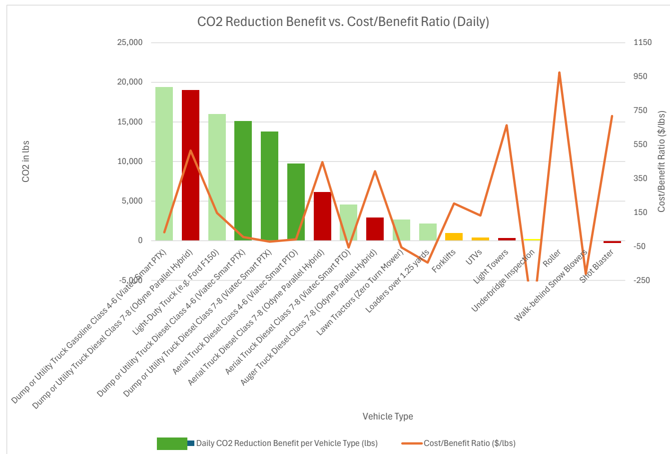
(grey)	Represents cells that purposefully contain "No Data"
(light blue)	Represents cells that include formulas

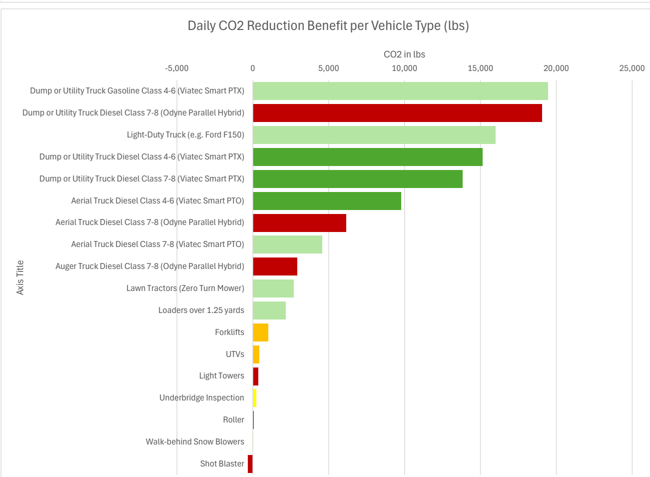
	the higher the better		the lower the better				
Vehicle Type	**Daily CO2 Reduction Benefit per Vehicle Type (lbs)**	**Annual CO2 Reduction Benefit per Vehicle Type (lbs)**	**Cost/Benefit Ratio ($/lbs)**	**Daily Operational Cost Difference between ICE and AFV**	**Annual Cost Difference between ICE and AFV (including Capital and Operational costs)**	**Risks (L/M/H)**	**Prioritization**
Dump or Utility Truck Gasoline Class 4-6 (Viatec Smart PTX)	19,436	4,858,879	33	18	52,023	L	High
Dump or Utility Truck Diesel Class 7-8 (Odyne Parallel Hybrid)	19,058	4,764,384	515	28	163,019	M	Not Feasible
Light-Duty Truck (e.g. Ford F150)	15,984	3,996,116	147	8	22,948	L	High
Dump or Utility Truck Diesel Class 4-6 (Viatec Smart PTX)	15,144	3,785,884	5	19	52,287	L	Highest
Dump or Utility Truck Diesel Class 7-8 (Viatec Smart PTX)	13,804	3,450,885	-22	20	52,615	L	Highest
Aerial Truck Diesel Class 4-6 (Viatec Smart PTO)	9,745	2,436,249	-9	20	53,051	L	Highest
Aerial Truck Diesel Class 7-8 (Odyne Parallel Hybrid)	6,135	1,533,771	447	30	163,556	M	Not Feasible
Aerial Truck Diesel Class 7-8 (Viatec Smart PTO)	4,574	1,143,568	-56	22	53,703	L	High
Auger Truck Diesel Class 7-8 (Odyne Parallel Hybrid)	2,923	730,833	393	32	163,967	M	Not Feasible
Lawn Tractors (Zero Turn Mower)	2,694	673,376	-56	21	21,720	L	High
Loaders over 1.25 yards	2,173	543,195	-146	39	54,771	M	High
Forklifts	996	249,074	203	2	11,366	L	Low
UTVs	398	99,587	132	5	17,492	L	Low
Light Towers	338	84,564	664	4	30,370	L	Not Feasible
Underbridge Inspection	203	50,748	-467	12	33,087	L	Medium
Roller	48	12,108	975	3	27,578	L	Not Feasible
Walk-behind Snow Blowers	23	5,872	-212	2	2,009	L	Medium
Shot Blaster	-302	-75,575	718	-6	-43,157	L	Not Feasible

Preference Order
Highest
High
Medium
Low
Not Feasible

***Note: This chart reflects an aggregate view of feasible vehicles developed during the analysis for all regions per vehicle type.**







Vehicle Type	Number of Vehicles in current MDOT fleet	EV Feasible Percent *Light-duty Only	Number of Technically and Operationally Feasible Vehicles	Region	Miles Travelled	Idling Time per day (hours)	Idle Fuel Rate (gal/h)	mpg	Daily Fuel Consumption Saving per Vehicle (gallons)	Daily Electrical Energy Consumed to charge battery per Vehicle (kWh)	Daily Operational Cost Difference between ICE and AFV	Operational Cost Difference between ICE and AFV over Equipment Life	Annual Total Cost Difference between ICE and AFV (including Capital and Operational costs)	Cost of ICE Vehicle	Cost of Electric Vehicle (non-inclusive of infrastructure costs)	Daily CO2 Reduction Benefit per region(lbs) [the higher the better]	Daily CO2 Reduction Benefit per region per vehicle (lbs) [the higher the better]	Cost/Benefit Ratio ($/lbs) [the lower the better]	Additional Inputs to Calculations
Light-Duty Truck (e.g. Ford F150)	3	100%	3	BWB	20.6			20	1.03	12.2	2.2	3258	21.543	44.000	65.000	60.49	20.16	879.96	Usable Battery Capacity (kWh)
	92	84%	77	Metro	58.1			20	2.905	34.4	6.1	9189	22.532	44.000	65.000	4378.61	56.87	207.70	98
	47	71%	33	Southwest	67.8			20	3.39	40.1	7.1	10723	22.787	44.000	65.000	2189.84	66.36	154.87	BEV Range (miles)
	82	51%	41	University	87.7			20	4.385	51.9	9.2	13871	23.312	44.000	65.000	3519.27	85.84	83.06	89
	68	36%	24	Grand	89.0			20	4.45	52.6	9.4	14076	23.346	44.000	65.000	2090.60	87.11	79.49	
	59	37%	21	Bay	89.0			20	4.45	52.6	9.4	14076	23.346	44.000	65.000	1829.27	87.11	79.49	
	41	22%	9	Superior	89.0			20	4.45	52.6	9.4	14076	23.346	44.000	65.000	783.97	87.11	79.49	
	58	23%	13	North	89.0			20	4.45	52.6	9.4	14076	23.346	44.000	65.000	1132.41	87.11	79.49	
											7.79		22947.96			15984.46		146.94	
															Viatec SmartPX 14.4 kWh				
Dump or Utility Truck Diesel Class 4-6			3	BWB	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	339.03	113.01	5.45	Alternator Load (kW)
			11	Metro	150	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	1243.13	113.01	5.45	0.90
			23	Southwest	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	2599.26	113.01	5.45	
			34	University	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	3842.39	113.01	5.45	
			15	Grand	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	1695.17	113.01	5.45	
			5	Bay	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	565.06	113.01	5.45	
			13	Superior	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	1469.15	113.01	5.45	
			6	North	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	678.07	113.01	5.45	
			10	BOBS	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	1130.11	113.01	5.45	
			4	TSMO	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	452.05	113.01	5.45	
			10	BFS	200	6	0.84		5.04	5.8	18.8	46974	52.287		47.590	1130.11	113.01	5.45	
											18.79		52287.39			15143.53		5.45	
															Viatec SmartPTO 14.4 kWh				
Aerial Truck Diesel Class 4-6			1	BWB	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	118.84	118.84	-8.78	No Load Idle Fuel Rate (gal/h)
			9	Metro	150	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	1069.57	118.84	-8.78	0.84
			12	Southwest	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	1426.10	118.84	-8.78	No Load Idle Duration (hours)
			13	University	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	1544.94	118.84	-8.78	5
			9	Grand	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	1069.57	118.84	-8.78	Idle Fuel Rate with Load (gal/h)
			11	Bay	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	1307.26	118.84	-8.78	1.10
			7	Superior	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	831.89	118.84	-8.78	Idle with Load Duration (hours)
			6	North	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	713.05	118.84	-8.78	1
			12	BOBS	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	1426.10	118.84	-8.78	Battery Energy Consumption during no-load idling (kWh)
			1	TSMO	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	118.84	118.84	-8.78	4.50
			1	BFS	200	6	0.88		5.3	6.8	19.7	49177	53.051		48.133	118.84	118.84	-8.78	Battery Energy Consumption for lifting (kWh)
											19.67		53050.69			9745.00		-8.78	1.80