Electric Vehicle Technologies and Alternative Fuels for Winter Road Operations

Synthesis Report

CLEAR ROADS
research for winter highway maintenance

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The goal of this project is to provide transportation agencies who operate heavy-duty fleets in support of winter highway maintenance with research on fleet electrification and alternative fuel options. Research will cover the challenges of transitioning to a green fleet including engine and component power, torque, and durability, infrastructure and staffing support, energy resources and availability, and operating conditions.

The project team compiled a current profile of the winter operations fleet and conducted interviews with the 13 DOTs who agreed to participate in the study. These organizations shared their limited experience with alternative fuel vehicles (AFVs). Due to negligible use of AFVs, interviews focused on best practice areas that will support the future use of alternative fuels. Barriers to AFV adoption and the conditions for a successful transition were also explored.

Significant fuel shifts in society are rare but lessons from the shift to diesel, propane and natural gas were reviewed to determine their relevance for the future shift to electricity. The importance of infrastructure in successful fuel transitions was recognized.

The project team also looked outside the participating DOTs to other levels of government experimenting with AFVs. From these interviews additional information on biodiesel and renewable options were recorded and compared.

Finally, the team interviewed vehicle and fuel system manufacturers to learn about existing and emerging AFV and fueling options. The research, findings and recommendations are summarized in a synthesis report.</td></tr>
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FINAL REPORT

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Additional abbreviations to aid in understanding the report:

AFV - Alternative Fueled Vehicle

BEV – Battery Electric Vehicle

CNG - Compressed Natural Gas

DGE – Diesel Gallon Equivalent

DOT – Department of Transportation

DPF – Diesel Particulate Filter

ePTO – Electric Power Take-Off

FMIS - Fleet Management Information System

GHG - Greenhouse Gas

HFCEV – Hydrogen Fuel Cell Electric Vehicle

HICE – Hydrogen Internal Combustion Engine

ICE - Internal Combustion Engine

LCFS – Low Carbon Fuel Standard

LPG - Liquefied Petroleum Gas (propane)

NG – Natural Gas

OEM – Original Equipment Manufacturer

PM - Preventive Maintenance

PTO – Power Take-Off

RD - Renewable Diesel

rLPG - Renewable Liquefied Petroleum Gas (propane)

RNG - Renewable Natural Gas

TAC - Technical Advisory Committee

TCO - Total Cost of Ownership

VEU - Vehicle Equivalency Unit

CHAPTER 1: EXECUTIVE SUMMARY

Matrix Consulting Group was engaged to conduct an Evaluation of Electric Vehicle (EV) Technologies and Alternative Fuels for Winter Road Operations. This report covers the research, analysis, findings and recommendations developed between July 2022 and January 2023.

1.1 STUDY DESCRIPTION

Starting with a profile of the winter maintenance equipment and practices of thirteen DOT participants, the study involved comparing the fleet practices of the study participants to industry best practices. Next, we compared participating DOTs in a benchmarking review. Research into historical fuel transitions, current case studies and manufacturer offerings and future plans round out the study.

1.2 FINDINGS AND RECOMMENDATIONS

Overall, we discovered that the use of alternative fuels in winter roads maintenance operations was quite limited and the use of electrification virtually non-existent. DOT managers hold healthy skepticism about their future uses due to the rigorous requirements of the vehicles and equipment. Ultimately, they need to be shown proof (through actual trials) that alternative fuel vehicles (AFVs) can do the job. The step-by-step research and analysis demonstrate the current situation, best practices and benchmarking results, research into historical fuel shifts, case studies of practical use applications and discussions with manufacturers.

1.3 WINTER MAINTENANCE OPERATIONS FLEET PROFILE

The 13 DOTs who participated in the project held almost 19,000 assets engaged in winter roads maintenance operations. Alternative fuel use amongst the participants included limited use of natural gas and some biodiesel. The natural gas in use by two fleets is being phased out due to fuel availability and excessive maintenance. Biodiesel is used in several fleets but is unpopular due to the need for pre-warming and loss of power. The only potential use of electric vehicles is a pending order of F-150 Lightnings to serve as crew trucks.

1.4 BENCHMARKING

Participants were asked to describe the aspects of the operating environment, maintenance, shop and training that would impede the introduction of AFVs, including EVs, as well as the conditions that would have to be met to follow this path. Operating environment top concerns included the temperature and corrosive environment as well as 24/7 nature of the operations. The primary maintenance concern is that so much is unknown, especially battery life and recyclability. Likewise, the needs for shop adjustment and mechanic training are uncertain.

To be acceptable and gain widespread implementation, AFVs need to have the power and range to move snow 24/7. Training and infrastructure (shop and charging) would have to be in place prior to their deployment. Overall, respondents want to see trials with good data to prove the vehicles and equipment can perform effectively before they would be willing to make any transition.

1.5 BEST PRACTICES

With the limited use of alternative fuels amongst participants, best practices focused on wider fleet management issues that should be considered to enable the use of AFVs in the future. Fleet governance, usage, inventory, maintenance, costs, technology and sustainability were all considered. The DOTs were at different points in terms of adherence to industry best practices. In general, best practices for DOT fleets would include having the right mix of equipment, personnel, budget and technological support.

Equipment should be procured in a way to minimize costs and should follow a multi-year replacement plan based on optimum lifecycles calculated using Total Cost of Ownership (TCO). Staffing needs are determined using Vehicle Equivalency Unit (VEU) methodology and mechanics have a formal training plan to keep skills current. Funding should be adequate to support the multi-year replacement plan and sustainability initiatives. Technology such as a Fleet Management Information System (FMIS), fuel system and telematics should be in place to allow for performance tracking and reporting. All of these initiatives should be supported by a policy framework.

1.6 HISTORIC FUEL SHIFTS

The project team documented several historic fuel shifts on order to identify lessons for any future shifts. Major fuel shifts are complex transitions where energy supply, delivery platforms and consumer behaviors all play significant roles. As such, they are rare and require planning. These transitions will only take place successfully when it is financially viable and when the fuel, infrastructure and vehicles are widely available. Training and education in advance of a major fuel transition is a key success factor.

1.7 PRACTICE SURVEY

Many fleets focused on one alternative fuel for simplicity and best fuel prices. Biodiesel blends (up to B20) were the most common. But other fuels included B100 and compressed natural gas (CNG). Conducting a pilot vehicle program is recommended to collect and analyze data to understand the impacts of a fuel change. Understanding and following the preventative maintenance schedule for each fuel is critical. Staying current on practice updates is also critical. Maintenance technician and operator training is key to properly operate, fuel, and maintain vehicles. Manufacturer demonstrations and training are a great resource, when available.

On-premises depot fueling infrastructure (storage and dispensing) for liquid fuels (i.e., diesel, biodiesel, gasoline, and LPG) is cost-effective and provides fuel certainty. Outdoor aboveground storage tanks for biodiesel blends (e.g., B20) require cold flow additives to maintain flow properties. B100 is a viable option (with one system) but requires tank heating to maintain flow properties. Several fleets mentioned the importance of regular liquid fuel tank cleaning. Biodiesel fuel costs in regions where fuel is produced tends to be a similar price as diesel fuel.

1.8 ORIGINAL EQUIPMENT MANUFACTURER (OEM) DISCUSSIONS

Current widely available lower or no-greenhouse gas (GHG) fuel options with medium and heavy-duty truck applications include biodiesel, natural gas (NG), liquefied petroleum gas (LPG) and electric. Other fuels that are available, but not yet widely available in all service areas, include renewable diesel (RD), renewable natural gas (RNG), and renewable LPG (rLPG). Hydrogen is a developing fuel.

Current widely available lower-GHG or no-GHG vehicle fueling system options with medium and heavy-duty truck applications include biodiesel, CNG/RNG, LPG/rLPG, and battery electric vehicle (BEV). Developing options include hydrogen fuel cell electric vehicles (HFCEVs) or hydrogen internal combustion engines (HICE).

CHAPTER 2: INTRODUCTION

2.1 PROJECT DELIVERABLES

The “Evaluation of Electric Vehicle Technologies and Alternative Fuels for Winter Road Operations” project has ten tasks. The following list illustrates these tasks:

Task 1: Project Kick-off, Work Plan Structure, and Status Updates

Task 2: Current Profile of DOT Winter Operation Fleet

Task 3: National and International Industry Best Practices

Task 4: Historical Fuel Transition Report

Task 5: Alternative Fuel Use Practices Survey Report

Task 6: Alternative Fuel OEM Suppliers List and Questions

Task 7: Documented OEM Interviews and Future Expansion Report

Task 8: Consolidated Research and Findings Synthesis Report

Task 9: PowerPoint Presentation of Synthesis Report

Task 10: Webinar Presentation of Synthesis Report

2.2 STUDY METHODOLOGY

The project team, working closely with the Technical Advisory Committee (TAC) conducted interviews and research into the past, current and potential future use of alternative fuels for winter roads maintenance operations. For each deliverable, our team developed questionnaires for TAC approval, completed the necessary interviews, and prepared draft reports for TAC review. All requested edits were made as each deliverable was finalized.

This synthesis report contains the study materials previously submitted with an Executive Summary and a conclusion with implementation and conversion options.

2.3 DEFINITIONS

The main alternative fuels used in vehicles are:

Ethanol is a renewable resource that burns more cleanly than petroleum and produces less CO_2. It is derived from a renewable source (crops). Limiting factors include the facts that it takes many acres of land to produce and current engines require modification to use fuels with high percentages of ethanol (e.g., 85%, or E85). Many domestic light-duty vehicles, however, are compatible with E85.

Biodiesel is another renewable resource that is derived from (crops) that is less polluting than diesel fueled ICEs. It can be blended with petroleum diesel and used in existing diesel engines without modification (up to the manufacturer's recommended limit). Biodiesel has a lower lifecycle greenhouse gas emissions than diesel because of the carbon uptake in the plants' growth. It is slightly more expensive than conventional diesel and gels in cold weather. Additives and tank heating are used to mitigate gelling.

Compressed natural gas (CNG) produces fewer pollutants in the combustion process than petroleum or diesel and vehicles using CNG have lower maintenance costs. Unfortunately, CNG results in reduced power and impacts the performance of the vehicle. It also requires a lot of storage space in the vehicle and comes from a non-renewable energy source.

Propane (also called liquified petroleum gas (LPG) or propane autogas) is a by-product of natural gas processing and crude oil refining. Propane is used as a fuel for cooking and heating and is also an alternative fuel for vehicles. Propane produces lower GHG emissions than gasoline and diesel, and there is established infrastructure for propane transport, storage, and distribution. On the other hand, natural gas production creates methane, a greenhouse gas that is 21 times worse for global warming than CO2.

Electric vehicles (EVs) are rapidly gaining traction in the AFV space as they produce lower or zero tailpipe emissions, are associated with lower maintenance and fuel costs and are safe and relatively noise-free. Manufacturers are producing a variety of light-duty vehicle options to meet many needs and starting to offer medium- and heavy-duty vehicles. Some barriers, however, still exist in terms of price and driving range. There are three levels of electrification.

A hybrid-electric vehicle (HEV) uses both a conventional combustion engine (gasoline) and an electric drive system. Regenerative braking charges the battery so no plug is needed for charging. HEVs increase fuel economy by capturing/reusing braking energy but are solely fueled by a conventional fuel. HEVs are popular for light-duty vehicles but are not available for medium-/heavy-duty vehicles.

A plug-in hybrid electric vehicle (PHEV) is an evolution of HEVs and includes both a conventional combustion engine (gasoline) and an electric drive system. Light-duty PHEVs use a much larger capacity battery pack than an HEV (approximately 10-20 times) as and can power the vehicle 10-50 miles. PHEVs' battery packs are recharged by plugging them into an electrical outlet/charging station. Regenerative braking charges the pack during use. PHEVs are available for light-duty vehicles but are not available for medium-/heavy-duty vehicles.

A battery electric vehicle (EV or BEV) uses only an electric drive system powered by a battery pack. Medium- and heavy-duty EV options are in limited initial commercialization, with projections for large growth in vehicle manufacturers, vehicle options, and number of vehicles. Current real-world driving range is approximately 150 miles and is expected to increase quickly with battery technology improvements, cost decreases, and increasing sales volumes.

CHAPTER 3: CURRENT STATE OF WINTER ROAD MAINTENANCE

3.1 PURPOSE

The purpose of Task 2 - Current Profile of DOT Winter Operations Fleet is to create an understanding of the key issues impacting and shaping the current state of operations, including the operating environment and challenges of weather. The project team collected data on the winter road maintenance fleet inventory and conducted interviews with DOT winter roads maintenance and fleet management staffs in order to understand processes and practices, seasonal peak issues, maintenance struggles and infrastructure challenges.

To accomplish this task, we provided a structured data collection list to stakeholders with detailed instructions to simplify the collection process. Most DOTs reported that they could not provide the requested information in a timely manner. In order fulfill the task requirements, the project team relied on annual survey data published by Clear Roads at Annual Survey of State Winter Maintenance Data | Clear Roads and virtual interviews with the thirteen participating DOTs. The data used was that available as of 1 October 2022.

This chapter documents the current state of operations of the participating DOTs. The descriptive profile will be used as the framework for our understanding of the current situation and foundation for future research.

3.2 INVENTORY

The inventory of the winter roads maintenance fleets represented in the interviewed states appears below. In most cases, the number of plows held by the state is determined by the lane miles of roadway they are responsible for. The number of plows is sub-divided into owned and contracted. No details on the breakdown of towed plows were available for Indiana.

Inventory	**CO**	**CT**	**IA**	**ID**	**IL**	**IN**	**MI**	**ND**	**NE**	**OH**	**RI**	**SD**	**WV**
Plows (Owned)	1,081	634	902	458	1,756	1,116	352	368	704	1,584	168	483	1,138
Plows (Contracted)	0	250	0	0	0	0	0	0	0	0	0	0	0
Graders	88	2	43	40	92		22	16	125	43	0	23	212
Blowers	31	17	11	23	15		12	14	26	0	5	14	27
Tow Plows	33	15	27	2	0		15	36	34	3	0	4	0

Inventory	CO	CT	IA	ID	IL	IN	MI	ND	NE	OH	RI	SD	WV
Wing Plows	506	171	902	238	488		348	368	604	273	103	515	20
Belly Plows	0	8	902	3	131		352	368	0	126	0	251	0

The totals for the equipment held by these thirteen states are shown below:

Inventory	Totals
Plows (Owned)	10,744
Plows (Contracted)	250
Graders	706
Blowers	195
Tow Plows	169
Wing Plows	4,536
Belly Plows	2,141
Grand Total	**18,741**

Within this fleet are only a few examples of the use of alternative fueled vehicles (AFVs):

- **Colorado**. Dual-fuel trucks (diesel/natural gas) are in use but being phased out due to natural gas availability.
- **Iowa.** The state is operating 20 biodiesel trucks but are finding them to be underpowered, slow to fuel and costly due to the need to be kept warm.
- **Illinois**. Has a state mandate to use 5% biodiesel but it is not uniformly followed.

- **Indiana.** There are eight natural gas trucks that are being phased out due to excessive downtime and onerous maintenance requirements.
- **South Dakota**. A 20% biodiesel blend is in use.

In terms of plans to move to the use of alternative fuels for the winter roads maintenance fleet, only Colorado has orders in place. This order is for 50 Ford Lightning pick-up trucks. There are no trials planned for any heavy-duty applications.

3.3 CHALLENGES OF THE OPERATING ENVIRONMENT

States were asked to describe their concerns with using alternative fuel vehicles (AFVs) for winter operations. Specifically, they were asked what parts of the operating environment that they feel would be challenging for AFVs. Their responses included the following:

- **Truck Power.** Non-diesel vehicles and equipment operating in winter conditions may have insufficient power.
- **Temperature**. Extreme cold could be detrimental to AFVs, especially electric vehicles EVs.
- **Altitude.** The need to scale heights and operate at higher altitudes in some areas of the country could impact performance.
- **Add-ons.** Winter road maintenance vehicles and equipment need to carry a range of materials to deal with the environment. There could be limited space on a AFV, or the weight of add-ons could impact performance.
- **Operators.** To date, winter road maintenance operators have shown reluctance to try new technologies and have a strong preference to stay with proven methodologies.
- **24/7 operations.** Snow response cannot be scheduled and must be continuous throughout the event. Prolonged breaks to travel to fueling locations and complete fueling would hamper operational response.
- **Infrastructure.** Consideration has to be made to install all necessary infrastructure prior to acquiring AFVs.
- **Power outages.** Losing power is often a biproduct of winter storm events. Contingency plans must account for this if electric vehicles are used.
- **Area.** States are often responsible for extended geographical areas and must have convenient access to refueling throughout their areas of responsibility.
- **Corrosion.** Winter road maintenance operations use a variety of materials including salt and brine. The effect of these materials on electric vehicles is unknown.

The states involved in the survey named the following factors as important considerations in their adoption of AFVs for winter roads maintenance operations.

	CO	**CT**	**IA**	**ID**	**IL**	**IN**	**MI**	**ND**	**NE**	**OH**	**SD**	**RI**	**WV**	**Tot**
Truck Power	X						X	X	X		X	X		6
Temperature	X	X				X					X	X		5
Altitude	X													1
Add-ons		X		X										2
Operators			X											1
24/7 ops			X	X	X		X		X	X				6
Infrastructure			X		X		X		X	X				5
Power Outages					X			X					X	3
Area					X						X			2
Corrosion							X				X	X		3

These concerns are already being addressed by manufacturers, at least in the light-duty vehicle market. Manufacturers realize that batteries do not achieve peak performance in the cold and operate best at temperatures between 40 to 114 degrees Fahrenheit. Some strategies to improve performance at low temperatures include:

- Pre-heat the cabin and vehicle while still charging.
- Do not allow the battery pack to get below 15 to 20% remaining.
- Warm the battery by accelerating hard, then braking hard. This engages regenerative breaking and creates additional heat from the motor.

3.4 MAINTENANCE CONCERNS OF ALTERNATIVE FUEL VEHICLES (AFVS)

The states named a variety of concerns related to the maintenance of AFVs. These concerns included the following:

- **Unknown**. Many of the respondents mentioned that it was far too early to know what maintenance concerns could come with the introduction of AFVs.
- **Battery safety**. The safety and stability of the battery in storage, during maintenance or in case of a crash could pose a danger to staff.
- **Battery – Life.** The endurance of batteries in winter roads maintenance operations may be less than in other applications.
- **Battery – Cost.** The costs of replacement batteries may be a determining factor in calculating the optimum lifecycle of winter road maintenance vehicles and equipment.
- **Impact of brine.** State personnel have a very good understanding of the impact of chemicals (salt and brine) on ICE vehicle components but their impact on electric components is largely unknown.
- **Spares.** Most fleets have a spare ratio for their diesel road maintenance fleet that ensures operations continue along with routine maintenance. The spare ratio for AFVs is unknown.
- **Resale value**. There is little information on resale values on even light-duty vehicles so this is another unknown.
- **Infrastructure care.** Installation and ongoing maintenance of infrastructure for alternative fuels will have to be part of the maintenance plan.
- **Mechanic retention.** The recruiting and retention of mechanics is a challenge for most organizations and current staff may not want to retrain on AFVs.
- **None.** Due to the reduced requirements for maintenance of EVs, some people believe that maintenance will not pose additional challenges

	CO	**CT**	**IA**	**ID**	**IL**	**IN**	**MI**	**ND**	**NE**	**OH**	**SD**	**RI**	**WV**	**Tot**
Unknown	X	X	X		X	X					X			6
Safety of battery	X									X		X		3
Battery - Life		X	X					X			X	X		5

	CO	CT	IA	ID	IL	IN	MI	ND	NE	OH	SD	RI	WV	Tot
Battery - Cost		X					X							2
Impact of brine		X										X	X	3
Spares			X											1
Resale value			X											1
Infrastructure care							X							1
Mech retention									X					1
None				X										1

It has been established that, for light-duty application, EVs can be expected to have fewer maintenance and repair issues. In fact, one fleet survey estimates that the maintenance costs associated with EVs are 70% lower than for internal combustion engine (ICE) vehicles. Some tips to keep maintenance costs low include:

- Maintain the battery level between 20% and 80
- On a long trip, fully charge the battery ahead of time and run it until it is nearly depleted.
- On a short trip charge up to 80% to maintain good battery life.
- Brake components need to be checked for wear and the fluid changed to prevent moisture in the brake fluid from corroding the brake system.
- Coolant replacement is needed.
- Tire tread wear, balancing, alignment and air pressure are critical to monitor and maintain as vehicle weight may cause rapid wear.

3.5 SHOP ADJUSTMENTS FOR ALTERNATIVE FUEL VEHICLES (AFVS)

While the full range of accommodations to shops in unknown, changes to tools and room to install charging infrastructure are likely. The full range of replies about shop challenges include:

- **Unknown.** Respondents felt it is too early to understand what shop changes may be needed.

- **None.** The similarities between ICE and AFVs mean that no shop adjustment is needed.
- **Minimal.** The similarities between ICE and AFVs mean that little shop adjustment is needed.
- **Charging.** The shop will have to accommodate the charging of EVs.
- **Time to adjust.** The conversion plan will have to leave sufficient time to make any accommodations needed to the shop.
- **Parts.** Shop space will need to be allocated to parts specific to AFVs, even while retaining parts for ICE vehicles.
- **Tools.** Tools specific to AFVs will be needed.
- **Lifts.** Lifts may be needed that are specific to AFVs.

Our respondents had the following replies to the need to adjust shops to accommodate AFVs.

	CO	**CT**	**IA**	**ID**	**IL**	**IN**	**MI**	**ND**	**NE**	**OH**	**SD**	**RI**	**WV**	**Tot**
Unknown											X			1
None				X										1
Minimal	X							X						2
Charging		X	X			X			X	X				5
Time to adjust			X											1
Parts					X									1
Tools/Diagnostics							X					X	X	3
Lifts										X				1

The best course for organizations planning for a future that includes EVs is to accommodate future charging needs when new facilities are being built or existing facilities are renovated. In addition to charging, organizations should consider safety of battery work and the need for insulated tools and an insulated, well-ventilated work area. Current lifts may not be capable of lifting the heavier EVs. Taking these factors into account well in advance will ensure an easier transition in the future.

3.6 MECHANIC TRAINING

With the pace of technology increasing, ensuring mechanics are up to date in their skills must be a consideration for fleet organizations. The introduction of AFVs is an opportune time to update training.

The respondents varied in their assessments of training requirements. Several felt that is was too early to estimate and others felt that the changes would require minimal training. The majority, however, felt that training requirements would be significant, specifically in high voltage, batteries and the impact of brine. The specific results appear below:

	CO	**CT**	**IA**	**ID**	**Il**	**IN**	**MI**	**ND**	**NE**	**OH**	**SD**	**RI**	**WV**	**Tot**
Unknown		X	X				X							3
Minimal									X	X				2
Significant	X	X		X	X	X		X			X	X	X	9
Topics	High Voltage, batteries, impact of brine													

As light-duty EVs become more prevalent, there is an increasing amount of external training available to help smooth the transition to electrified fleets. One such resource is the National Institute for Automotive Service Excellence (ASE) certification directed specifically at the maintenance and repair of EVs. Known as the Light Duty Hybrid/Electric Vehicle Specialist Test (L3), the advanced level test offered by ASE is designed to measure a technician's knowledge of the skills needed to diagnose both high- and low-voltage electrical/electronic problems, as well as other supporting system problems, on hybrid vehicles and EVs. This certification is available to technicians who have passed both the Automobile Electrical Systems (A6) and Engine Performance (A8) tests[1].

The EV Champion Training Series developed by the US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) and described in the Sustainability Report would be a potentially valuable resource to consider for fleet vehicle drivers and maintenance staff alike[2]. There are also several Technical Colleges, Vocational Training Centers, and Community Colleges in the greater Seattle region that offer automotive training courses. Exploring options for EV-specific training through

1 National Institute for Automotive Service Excellence (ASE). ASE Certification Tests, https://www.ase.com/ase-certification-tests.
2 US Dept. of Energy, Office of Energy Efficiency and Renewable Energy (EERE). EV Champion Training Series, https://www.energy.gov/eere/femp/electric-vehicle-training.

these resources may provide a more cost-effective alternative to the various privately available training courses. Heavy-duty courses are not yet available.

3.7 OPPORTUNITIES FOR ALTERNATIVE FUEL VEHICLES (AFVS)

Most organizations feel there is an application for AFVs but perhaps not in winter roads maintenance operations and definitely not yet. Their replies to the question on future opportunities in winter roads maintenance are:

	CO	CT	IA	ID	IL	IN	MI	ND	NE	OH	SD	RI	WV	Tot
Yes	X	X		X				X	X	X			X	7
No			X								X	X		3
Maybe					X	X	X							3

Those who replied “yes” felt that these opportunities are far in the future. The “no” respondents felt that winter road maintenance is the last area for EV applicability and that states should focus on other areas that make more sense.

3.8 CONDITIONS FOR SUCCESSFUL ADOPTION OF ALTERNATIVE FUEL VEHICLES (AFVS)

Survey participants had a healthy level of skepticism for the use of AFVs in winter road maintenance operations. Most want to see the results of use cases and analyze the data of successful implementations before they would undertake their use. When asked what conditions would have to be met, responses included:

- **Reliability.** The AFVs need to do their job for the duration of the weather event.
- **Ability to perform the job.** The vehicles must be fully capable of all aspects of the job, including 24/7 operations.
- **Range.** State highway systems cover long distances with little infrastructure available between urban centers and vehicles must be capable of operating these distances.
- **Load.** Winter road maintenance vehicles need to carry a full load of equipment and supplies and still be able to push snow.
- **Budget.** States must plan for the increased acquisition costs of AFVs as well as infrastructure and training.

- **Training.** Mechanics and operators must be trained in advance of the deployment of AFVs for winter roads maintenance operations.
- **Infrastructure.** Infrastructure must be installed and operational in advance of the deployment of winter roads maintenance vehicles and equipment.
- **OEM Support.** There are a lot of unknowns and OEM support will be vital through the transformation.

Our respondents named the following criteria as essential in making the transition to AFVs:

	CO	**CT**	**IA**	**ID**	**IL**	**IN**	**MI**	**ND**	**NE**	**OH**	**SD**	**RI**	**WV**	**Tot**
Reliability	X													1
Ability to do job	X					X	X		X			X		5
Range		X		X				X			X	X		5
Load Capacity		X	X											2
Budget			X		X									2
Training			X		X						X			3
Infrastructure					X					X			X	3
OEM Support										X				1

Overall, respondents want to see trials with good data to prove the vehicles and equipment can perform effectively before they would be willing to make any transition.

CHAPTER 4: INDUSTRY BEST PRACTICES

4.1 PURPOSE

This section addresses **Task 3 – National and International Industry Best Practices** and reflects data research, current literature review and interviews with Department of Transportation (DOT) stakeholders regarding current best practices in fleet alternative fuel options and electrification. The following functional areas were reviewed:

1. Governance
2. Utilization
3. Inventory
4. Maintenance
5. Fleet Infrastructure and Staffing Support
6. Financial
7. Sustainability
8. Technology
9. Fuel

This research demonstrates the degree to which participating DOT organizations conducting winter operations follow recognized industry fleet best practices and prepare for opportunities to use alternative fuels and fleet electrification in harsh winter environments. The best practice checklist was vetted and approved by the Project Steering Committee.

As an overall assessment, the fleet and maintenance services provided by DOT fleets interviewed exhibit a number of best practices. All organizations are familiar with and comply with legislative safety requirements and many procurement practices such as including manuals and training in vehicle purchase contracts. This report, however, concentrates on areas of improvement, rather than what organizations are doing well.

In compliance with the Request for Proposal, the project team sought to identify best practices in the use of alternative fuels in winter roads maintenance. As such use is extremely limited, the scope was broadened to include general fleet management best practices which, if in place, would prepare the organizations to transition to alternative fuels when practical to do so.

Each of the topics is addressed in the summary best practices table found in the Appendix. The best practice in each area for each DOT is shown in column one and assessed in the middle column. A ✓ indicates that the organization complies with best practice and a ~ indicates partial compliance with room for improvement. An X in the column means that the practice is not met. Criteria needing improvement are discussed in the narrative below. A fleet that meets industry best practice is in the best position to transition to alternative fuels when viable solutions are offered.

4.2 GOVERNANCE

Fleet governance includes the policy framework of the fleet organization as well as regulatory compliance. Best practice fleets communicate regularly with their customers and have a robust policy framework to facilitate decision making. They also ensure that knowledge of the regulatory environment is up to date. Key practices are outlined below:

1. Governance
1.1 Agency has fleet management and winter road operations policies.
1.2 Agency adheres to all mandated safety regulations related to fleet maintenance and winter road operations.
1.3 Agency adheres to all environmental regulations (EPA, DOT, FTA).
1.4 Agency adheres to all reporting requirements (EPA, DOT, FTA).

4.2.1 Policy Framework (BP 1.1)

State organizations benefit from a robust fleet policy framework comprised of a Fleet Policy Manual, a Driver's Handbook and Service Level Agreements with all customers.

The Policy Manual provides a reference for managers and staff to refer to as different situations arise and serves as a baseline for all employees to understand the mission, requirements, and constraints of the fleet management program. Without a policy manual, departments are left to exercise their own judgment on a range of important fleet issues such as the type of vehicles that will be purchased, when vehicles will be replaced, and whether replaced vehicles are sold or kept in service to meet other program needs. This situation inevitably leads to wide variations in fleet practices among end users and limits the ability of the fleet manager to implement best management practices.

A typical fleet management policy manual would have chapters on:

- Fleet organization and responsibilities
- Acquisition responsibilities and procedures
- Replacement planning lifecycles and authorities
- Utilization thresholds and annual review

- Maintenance standards and procedures
- Fuel sources, procedures and sustainability
- Performance metrics and reporting

A Driver's Handbook is a supporting document that contains the information that needs to be readily available to drivers. It should include a signatory page indicating that a driver is aware of and will comply with its contents. Drivers should be required to review and sign the document annually, and their signature should also allow management to access their Motor Vehicle Record (MVR). Information in this document should include detailed instructions and requirements for pre- and post-trip inspections, service and fuel procedures, actions in case of collision and driver obligations to report all driving infractions on a timely basis.

SLAs are written agreements between fleet and each of their customers that specify the responsibilities of each party. In a typical SLA, fleet may be responsible to ensure a specific availability of vehicles, accomplish repairs in a specified timeframe and have final sign-off on vehicle acquisitions. Each fleet customer, on the other hand, will be responsible to make vehicles available for scheduled preventative maintenance (PM), keep vehicles in a clean state, and pay for at-fault vehicle collision repair or abuse.

Many of the states interviewed are missing these elements. Creating a policy framework would have the following advantages:

- Require Districts to designate a point of contact for fleet-related matters.
- Require each designee to review utilization with the Fleet Manager on an annual basis.
- Report on Preventative Maintenance compliance.
- Track vehicle availability and repair timeliness.
- Review vehicle incidents and other safety-related matters.
- Provide a process for end users to make complaints.
- Ensure DOT inspection and reporting standards are adhered to.

Good policies enable decisions to be made in a timely fashion as all parties understand their responsibilities.

4.2.2 Regulatory Compliance (BP 1.2, 1.3, and 1.4)

All States reported that they are aware of and in compliance with Environmental Protection Agency, Department of Transportation, Federal Protection Agency and safety.

4.3 UTILIZATION

Utilization reviews call for organizations to have a mobility mindset. When a transportation requirement is identified, the default should not be to purchase an additional resource; management and users should first ask whether that requirement can be met more efficiently by other means such as leasing, renting, public transportation, employee reimbursement or loaner pools. Vehicle ownership should be the last resort. Where ownership is the best option, care should be taken in matching the asset to the requirement in a way that promotes efficiency and sustainability. In winter maintenance operations, the emergency nature of the work and the lack of rental assets means ownership is often the only way to fully meet requirements.

Utilization should be studied annually and assets not meeting utilization thresholds for that vehicle class should be subject to close review. Miles travelled, however, is not the only metric to evaluate utilization. Units may show low annual mileage but the fact that the units are used daily means they would be considered highly utilized. Asset criticality must also be considered in studying emergency fleet utilization. A specialized pumper truck, for example, may be used only once a month, however, if it is the only asset of its type and is critical to operations, it cannot be eliminated.

With this in mind, organizations should conduct annual reviews and recommend a disposition for all lightly used assets:

Retain	Keep current unit in service and replace according to a multi-year replacement plan based on optimum lifecycles.
Replace	Asset is overdue for replacement and should be replaced immediately.
Right-Type	The current asset is not the best or most economical for the job. It should be replaced with a different asset at the end of the current lifecycle.
Right-Fuel	The asset should be replaced with an alternative fuel or electric vehicle at the end of the current lifecycle.
Eliminate	Utilization does not justify retention of the asset. The asset should be sent to auction and not replaced.
Other	The asset is a good candidate for pooling or rental.

Key practices are outlined below:

2. Utilization
2.1 Asset utilization policies and guidelines are clearly defined to ensure that vehicles are allocated properly based on job requirements.
2.3 Processes are in place to capture, validate and analyze utilization data. Annual reviews are conducted, and vehicles are replaced, eliminated, pooled or rotated as needed.

2.5 Vehicles that are replaced are disposed of immediately.
2.6 Fleet users are proactive in identifying vehicles with low utilization.

4.3.1 Asset Policies (BP 2.1)

Most organizations base the number of primary winter road vehicles on lane-miles, or the amount of road surfaces that need to be cleared. While this makes sense for plows, other metrics may be more applicable for supporting vehicles and equipment. Most organizations do not currently have formal fleet utilization policies to govern the use of these other winter road maintenance vehicles or standards for justifying an asset based on its use and its job requirements. As a result, the determination of which vehicles are under-utilized and which are justified can be viewed as subjective, since it is left up to the judgement of the departments and the fleet manager.

To address this, organizations should develop a fleet utilization policy which establishes criteria necessary to justify a vehicle. These should include:

- Alignment with job descriptions and necessary specifications. Vehicles specifications should be developed by the department and the fleet division to match the needs of the job to which they are assigned. Vehicles not suited to the job assigned should be right-typed.
- Frequency and volume of utilization. Vehicles should be used regularly enough and for long enough periods that the mobility need associated with the work being done cannot be met with an alternative such as renting or borrowing a pooled asset.
- Emergency need. If a particular unit needs to be constantly available to respond to emergencies, it may be necessary even if its frequency or volume of utilization would not otherwise justify it.

The asset utilization policy should be added to the organization's other fleet policies and should be reviewed annually during the Utilization Review as described in the following subsection.

4.3.2 Utilization Review (BP 2.2)

Vehicle utilization should be reviewed on an annual basis. Vehicles with utilization well below the average for their vehicle class should be pooled or eliminated as appropriate to ensure that the size and composition of the fleet are optimized. Regular reviews of asset utilization also provide an opportunity to consider the organization's progress toward converting to alternative fuels and electric fleet assets. As new vehicles arrive to market and new charging technology becomes widely available, utilization reviews are a good time to consider which units are candidates for right-fueling.

- The approach used to assess fleet utilization should include the following steps:
- Review vehicle utilization data for each asset.

- Identify averages of usage by vehicle classification.
- Establish utilization thresholds (for example, 70% of the average for that class).
- Interview users of low-usage assets.

Interviews with fleet users are key as the odometer reading may not fully reflect utilization. A work truck, for example, may drive only a short distance to a job site but remain there all day. It is fully utilized even though it only travelled a short distance. The process for conducting this annual utilization review should be included in the Fleet Asset Utilization Policy.

4.3.3 One-for-one Replacement (BP 2.3)

When vehicles are replaced, the replaced asset should be disposed of in a timely manner. There are two aspects to timely disposal. First, older assets should not be retained as spares or extra vehicles as this creates a 'shadow' fleet that is beyond approved resource levels. Shadow fleets are not included in the vehicle count for an organization and maintenance staffing is not sufficient to deal with these ageing, retained assets.

The second general issue with asset disposal is that it should be completed as quickly as possible. Assets sitting in the yard continue to depreciate. Those assets should be immediately scheduled for virtual or on-site auction.

In many organizations, this is not always the case. Winter road maintenance vehicles are often retained even after their replacement has arrived and been added to the fleet. In select cases, such as retention of a vehicle to meet peak requirements, this can be justified. Careful review on a case-by-case basis is needed to avoid the growth of a shadow fleet.

4.3.4 Proactive Fleet Users (BP 2.4)

Fleet users should be encouraged to be proactive in identifying units which are under-utilized. The point of contact in each department should be provided with monthly utilization data, or given access to the fleet system, so that they can review, comment, and make recommendations with greater frequency than the annual review process enables.

4.4 INVENTORY

Establishing optimal lifecycles and a corresponding multi-year replacement plan are fundamentals of fleet management. The theory of effective capital asset management is well established in the fleet industry and is based on these principles.

- The failure to replace vehicles on time costs an organization more money, both in hard dollars and in indirect costs, than replacing them according to schedule.
- An old fleet has a negative impact on staff productivity, as unreliable vehicles are frequently in the shop and not available for work.

- If a fleet is old, departments seek to keep extra vehicles to act as backups and spares, so they can survive the increased unreliability of front-line vehicles. As a result, there are often more vehicles in service than are needed.
- The older vehicles in a fleet use more fuel and emit more pollution than newer vehicle, because standards for emissions and fuel economy were lower in the past than they are now.
- Older vehicles are not as safe as new ones as they lack many of the advanced safety features that are standard with new cars (such as cameras, sensors, lane departure warning, collision avoidance systems, side curtain air bags, etc.).

Key practices are outlined below:

3. Inventory
3.1 Winter road vehicles are procured to meet specific customer job requirements.
3.2 Non-technical requirements such as parts lists, repair manuals, diagnostic tools, and training are included in vehicle specifications.
3.3 Cooperative purchasing agreements are used in order to take advantage of volume pricing.
3.4 Replacement cycles have been determined for winter road vehicles.
3.5 Replacement is based on Total Cost of Ownership (TCO) which includes the capital and operating costs of assets.
3.6 A ten-year (minimum) replacement plan exists and is updated regularly.
3.7 Funding adequately supports the ten-year replacement plan.
3.8 Sustainability is considered in the replacement decision.

4.4.1 Job Requirements (BP 3.1)

In all cases, winter road maintenance vehicles are procured to meet actual job requirements. Some DOTs specify their plows according to use case.

4.4.2 Non-technical Requirements (BP 3.2)

All DOTs adhere to the industry practice of requiring parts lists, training or manuals where necessary. Much of the information is now online, reducing some requirements. DOTs that acquire all vehicles from a single OEM and those that use prisons to upfit their vehicles may have less need for these items.

4.4.3 Use of Cooperatives (BP 3.3)

Eight of the 13 DOTs interviewed use cooperative purchasing in the procurement of winter roads maintenance vehicles and equipment. In three other cases, such use was limited due to a lack of fit with vehicles required, procurement regulations and the feeling that these contracts are more effort than following the individual contracting process. In two other cases, cooperative purchasing was banned by procurement as not being a competitive process.

Using purchasing cooperatives such as NASPRO or Sourcewell, or piggy-backing on other state contracts can save valuable time and result in savings on vehicle and equipment purchases. DOTs pursuing this option should confirm that pricing is more favorable than competitive bidding. Where cooperative purchasing is restricted due to procurement policies, states should use examples from other DOTs to get restrictive procurement regulations updated.

4.4.4 Replacement Cycles and TCO (BP 3.4 and 3.5)

Vehicles should be replaced at the point which will minimize the total capital and operating costs (TCO) associated with vehicle and equipment ownership. The lowest TCO is usually just before the maintenance costs associated with an older vehicle start to spike.

All of the DOT organizations interviewed have policies for winter roads maintenance vehicle replacement. Few, however, have the funding to ensure that assets are replaced at the optimum time (shown by and X). Indiana received adequate funds (√), and South Dakota's replacement was on track until recently (~) The information collected in interviews demonstrates this:

	CO	CT	IA	ID	IL	IN	MI	ND	NE	OH	RI	SD	WV
Plows lifecycle (years)	12	12	12	12	11	15	17	17	10	8 to 12	7 to 8	10 to 15	10
Funding adequately supports the ten-year replacement plan	X	X	√	X	X	X	X	X	X	X	X	~	X

Replacement lifecycles have been determined by the states as being between 7 and 17 years which is a large spread. Individual characteristics such as elevation, use of brine, number of lane miles covered and availability of wash bays can influence lifecycles. The state with the lowest lifecycle selected 7-8 years after a consultant study based on TCO. At the other end of the scale, two states replace plows at 17 years but feel that the lifecycle should be shortened.

Only one agency said that their plows are replaced at the established lifecycle (12 years). This state has a standing practice of replacing 75 plows each year to ensure this happens.

In general, budget drives replacement. Most organizations know that maintenance and downtime are leading to increased costs but have to prioritize replacements within the allocated budget. This means that their fleet is costing more over time than if vehicles were replaced at the optimum time.

Matrix has developed parameters for fleet replacement that can be used when organizations do not have the data to calculate TCO. These guidelines are:

Unit Type	Replacement Lifecycle (yrs)
Equipment HD	15
Equipment MD	15
Truck HD	12
Truck MD	12

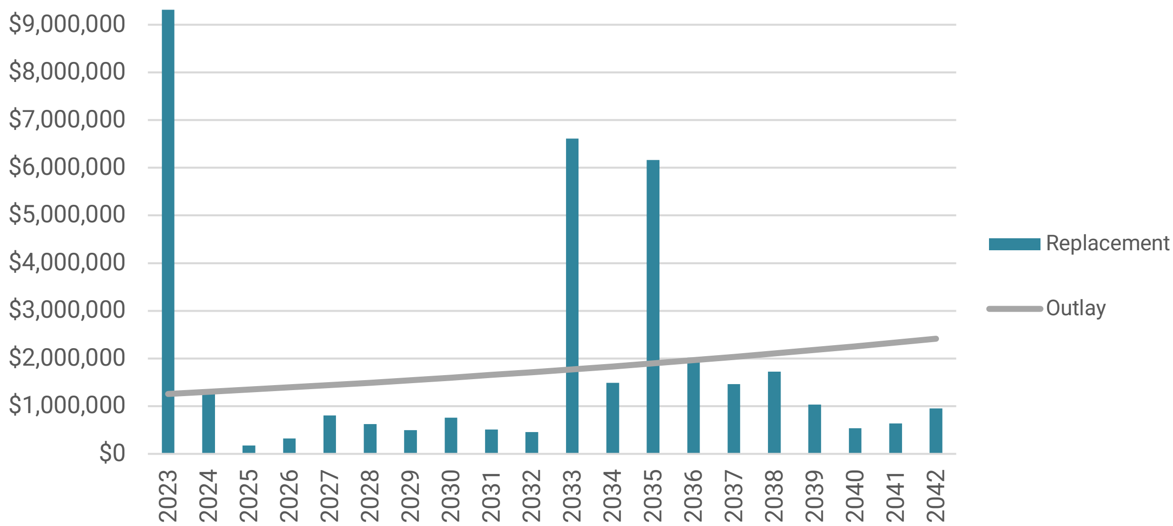
Most of the organizations interviewed endeavor to adhere to these guidelines. For the states who do not, establishing and using replacement lifecycles such as the ones shown above will allow them to benefit from a newer, safer, greener fleet at lower cost. These lifecycles can be used to develop a multi-year capital replacement plan, as described in the following subsection.

4.4.5 Fully Funded Replacement Plan (BP 3.6 and 3.7)

Organizations benefit from a predictable fleet replacement plan that covers at least ten years. Best practice is to have a draft plan that covers the longest lifecycle of an asset in the fleet. In most cases, organizations only actively manage the fleet for a three-to-five-year time period and understand that updates to the longer-term plan will be needed based on emerging requirements.

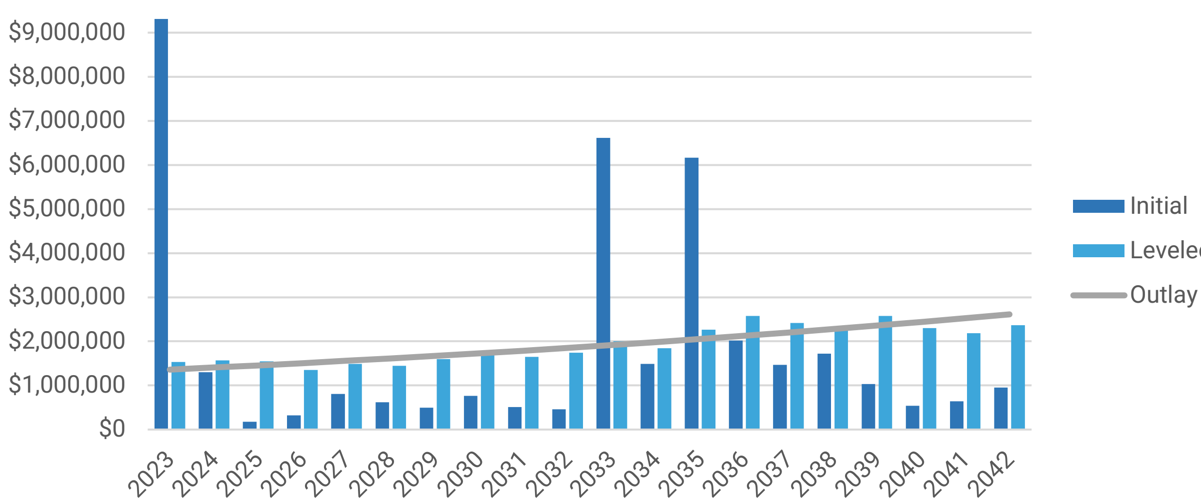
Although five DOTs have a multi-year replacement plan of at least ten years, most do not have anything that formal in place. The majority of the states have a general idea of how many, or what percentage of assets will be replaced annually, but do not designate exact unit numbers. Having a formal plan does not mean that parameters have to be strictly applied the next decade, but it provides an excellent working reference for fleet replacement.

The establishment of a replacement plan can be done in two steps. First, use the optimum lifecycle of each vehicle to determine how many vehicles are overdue for replacement. To replace all these vehicles immediately would often be cost prohibitive as in the example below.



This chart illustrates that replacing all overdue assets now would result in a large initial outlay followed by peaks and valleys. This approach of fluctuating budget requirement is unpopular with financial planners. Rather than spend $9.31 million 2023, a smoothed approach can be taken to get fleet replacement on schedule.

The next step is to calculate a more balanced and predictable annual funding requirement. After adjusting the replacement schedule the following table and chart provide an example of a replacement plan that would bring more than 50% of units in the fleet to current within the first five years, and 90% within 10 years:



This illustration is an example of a past project and is easily replicated by each DOT. Having a predictable and adequate replacement plan helps organizations deals with today’s needs and prepare for tomorrow’s challenges (such as electrification).

The replacement plan is designed to achieve the lowest TCO for the fleet over time. If the organization fails to make funds available to replace vehicles at the optimum time, the replacement plan cannot be followed and the TCO of the fleet will increase. All 13 fleets interviewed were in a challenging funding situation. This is partly being caused by unexpected inflation, but internal budget processes are also at fault for many DOTs.

4.4.6 Sustainability (BP 3.8)

Organizations were asked whether sustainability is a consideration in vehicle acquisition. Only two organizations consider sustainability as a selection factor. The others felt that it may be a future consideration but was not really being considered at this time.

4.5 MAINTENANCE

Fleet maintenance and repair processes have a significant impact on vehicle availability, reliability, safety, economy, and environmental integrity. The principal components of fleet maintenance are technician labor, facilities and equipment, parts, and commercial (i.e., sublet or outsourced) services. The objective of fleet maintenance managers is to integrate these components to maximize operating performance while minimizing costs.

The indirect costs of fleet maintenance activities are also important and can far exceed the direct costs. For example, mechanical failures that idle employees or disrupt service activities can result in productivity losses or more severe problems whose costs can often be much higher than those of repairing a vehicle.

Key practices are outlined below:

4. Maintenance
4.1 Staffing levels are consistent with the size and type of vehicles in the fleet. There are an adequate number of heavy-duty mechanics, parts and administrative support.
4.2 Staffing levels are adaptable for transition to alternative fuels.
4.3 A comprehensive preventative maintenance (PM) program is in place that complies with manufacturer recommendations. Customers receive notification of scheduled service dates and compliance is 95% or better.
4.4 A formal skills assessment and training plan has been developed to keep employees current with changes in the fleet industry.

4.5 Technicians are encouraged to keep skill levels current through financial incentives to obtain ASE and/or other certification.
4.6 Tooling is adequate to current needs.

4.5.1 Shop Staffing (BP 4.1 and 4.2)

The number of technicians and related positions required for a maintenance operation to operate effectively should be primarily driven by the size and composition of the fleet it serves. Because most fleet operations service a wide variety of vehicles and equipment, it is necessary to establish a relative measure that allows for the evaluation and comparison of staffing needs and costs.

A process known as **Vehicle Equivalent Unit (VEU)** calculation is used to equate the level of effort required to maintain dissimilar types of vehicles to a passenger car, which is given a baseline VEU of 1.0. Work with other fleet organizations has shown that a VEU of 1.0 is equal to between 10 and 15 annual maintenance labor hours, depending on factors unique to each organization. All other types of vehicles are allocated a VEU value based on their relationship to a passenger car. For example, a plow is assigned a VEU of 5. This means that a truck of this type on average requires about five times the annual maintenance hours of a passenger car.

Of the DOTs interviewed, only a few used a metric (lane miles) to determine staffing. Although they all had concerns about the number of mechanics, only one had completed a VEU analysis to determine how many mechanics were required in the District. All DOTs should complete a VEU analysis to ensure adequate support to winter road maintenance operations now and for the future.

The first step is to assign VEUs for each make and model of vehicles and miscellaneous equipment. Our assignment of VEUs in the table below Is based on industry best practice.

Unit Type	Count	VEU's / Unit	Total VEU's
Aerial Truck	1	6.5	6.5
Attachment	63	0.25	15.75
ATV/Cart	5	0.5	2.5
Bicycle	6	0.25	1.5
Equipment HD	8	5	40

Unit Type	Count	VEU's / Unit	Total VEU's
Equipment LD	37	0.5	18.5
Equipment MD	11	2.5	27.5
Forklift	1	3	3
Generator/Motor	26	0.5	13
Generator/Motor Large	22	2.5	55
Misc. N/A	4	0	0
Motorcycle	1	1	1
Mower	24	0.5	12
Mower Large	1	3	3
Patrol SUV	18	3.25	58.5
Pickup 1 Ton	20	2	40
Pickup 1/2 Ton	14	1.5	21
Pickup 3/4 Ton	12	1.25	15
Pickup Compact	8	1.25	10
Sedan	12	1	12
Small Motor	18	0.5	9
Small Tools	159	0.25	39.75

Unit Type	**Count**	**VEU's / Unit**	**Total VEU's**
SUV Small	11	1	11
Sweeper	1	12	12
Sweeper Small	1	3.5	3.5
Trailer	38	0.5	19
Truck HD	2	5	10
Truck HD Dump	6	5	30
Truck HD Tank	1	3	3
Truck HD Vac	2	8	16
Truck MD Dump	7	2.5	17.5
Truck MD Service	5	2.25	11.25
Van	6	1	6
Van 1 Ton	4	1.5	6
Van 1/2 Ton	7	1.25	8.75
Van 3/4 Ton	2	1.5	3
Grand Total	**564**		**561.5**

The next step in our analysis is to determine the number of labor hours required to maintain one VEU. The baseline is 10 hours per year, but adverse or challenging conditions can increase this while unusually good conditions can drive labor demand down. In determining the number of hours per VEU for an organization, a number of factors that are unique to each fleet are considered. These factors include fleet age and condition, usage levels, degree of outsourcing, and overall operating environment. For this example, the labor factor required to properly maintain the fleet is calculated at 12.5 hours per VEU. Our calculation for this is shown in the following table:

Calculation of Labor Hours Per VEU

Factor	Value	Explanation
Baseline hours required per VEU	10.0	Standard starting point for mixed vocational fleets.
Adjustment for fleet age	1	Fleet age exceeds industry average.
Adjustment for utilization levels	0	
Adjustment for operating environment	0	
Adjustment for facility and tools	0	
Adjustment for parts support	1	Mechanics have to find and order and sometimes get their own parts.
Adjustment for systems integration	.5	The lack of systems integration is causing scheduling to be done manually.
Adjusted hours per VEU	**12.5**	**Adjusted hours per VEU.**

With 12.5 labor hours per VEU expected, the annual maintenance and repair workload is calculated to be 7,018.75 hours (561.5 VEUs x 12.5 hours per VEU).

While a fleet mechanic's salary is based on 2,080 hours per year (52 weeks x 40 hours per week), only approximately 1,456 labor hours per year (70% of annual hours) are available to perform actual maintenance work (the remaining payroll hours are lost to vacation, sick time, holidays and indirect time such as training and meetings). Therefore, a fleet mechanic can be assigned a total of about 116 VEUs per year (1,456 hours available per year divided by 12.5 hours per VEU). When the 7,018.75 mechanic hours required to maintain the fleet are divided by the 1,456 annual labor hours available per mechanic, the result is a need for **4.8** mechanic full-time equivalents (FTEs) in this example.

Not all of this workload will be necessarily handled in-house. Depending on the types of vehicles in the fleet, the availability of warranties and favorable vendor contracts, and the strategy and approach of the organization, a portion of these hours may be outsourced. Best practice is to outsource 10-15% of maintenance, with a focus on warranty work, time-consuming repairs, or work that requires special training or tools to deal with a high degree of complexity. Outsourcing 10-15% of work would result in a need for **4.0** FTEs internally.

The following table summarizes the positions currently authorized in this fleet and the percentages of their time allocated to working on vehicles and equipment.

Position	Authorized Positions	% of Time Spent on Vehicles	Authorized Mechanic FTEs
Lead Technician	1.0	80%	.8
Heavy Duty Technician	1.0	100%	1.0
Light Duty Technician	1.0	100%	1.0
	3.0		**2.8**

The organization has 3.0 authorized technician positions. They are currently operating, however, with a staffing complement which equates to 2.8 mechanic FTEs. Since a total of 4.8 FTE are required, one mechanic should be added and the remaining work accomplished through outsourcing and improved shop processes.

This methodology can be replicated at District level to determine the appropriate staffing for DOT garages.

4.5.2 Preventative Maintenance Program (BP 4.3)

A well-designed and executed PM program is the cornerstone of effective fleet maintenance. The objective of a PM program is to minimize equipment failure by maintaining a constant awareness of the condition of equipment and correcting defects before they become serious problems. A PM program minimizes unscheduled repairs by causing most maintenance and repair activities to occur through scheduled inspections. An effective PM program pays dividends not only in improved equipment safety and reliability, but also financially by extending the life of equipment, minimizing the high cost of breakdowns, and reducing lost employee productivity resulting from equipment downtime.

Due to its importance, PMs on all classes of vehicles need to be scheduled and monitored. A Fleet Management Information System (FMIS) should be used to create a PM schedule and notify all fleet users of appointments. PM compliance should be tracked and should exceed 95%.

All states have PM programs, but they differ in their management approach and ability to meet the 95% compliance target. Many states leave compliance measurement up to Districts. Several states mentioned mechanic shortages as the reason for being behind on PMs. As an effective PM cornerstone is key in preventing unforecasted repair and minimizing maintenance costs, this should be a priority for all organizations. Although inspection parameters will change, PM compliance will remain an important Key Performance Indicator (KPI) for AFVs.

4.5.3 Technician Training (BP 4.4 and 4.5)

Fleet organizations are increasingly recognizing that adopting programs designed to ensure that technicians are well trained and technically expert is a business necessity. Vehicles and fleet equipment are becoming more complicated and increasingly expensive. Training and professional certification provide an organization with assurance that equipment will be properly maintained and, therefore, that the value of the organization's equipment investments will be preserved. Training can also act as a retention tool in areas where technicians are in high demand.

In the past, fleet organizations relied almost entirely on training that was provided by vehicle and equipment manufacturers free of charge. While these programs are still available, organizations can no longer make them the centerpiece of their training efforts. This is due to the increasing demand for these programs, which has severely reduced their availability to government fleet technicians. Moreover, manufacturer-training programs have become increasingly complex with strict prerequisites that make it nearly impossible for an organization to rely on these programs to provide technicians with well-rounded training.

Consequently, fleet organizations today are having to develop training programs that tap a variety of sources to provide technicians with the technical knowledge and updated skill sets that are required to maintain modern fleet equipment. In our view, investing in technician training today is a business necessity and should be a high priority for all DOTs.

In terms of winter road equipment training for the future, it is possible that not all operators and mechanics will embrace electrification, however, employees will be more receptive if they are prepared in advance. A robust education and training program will be key. Training on heavy-duty vehicles and equipment is not readily available. There is an increasing amount of training available for light-duty vehicles. The National Institute for Automotive Service Excellence (ASE) offers a *Light Duty Hybrid/Electric Vehicle Specialist Test (L3)* to measure a technician's ability to diagnose high- and low-voltage electrical/electronic problems, as well as system problems on hybrid vehicles and EVs. The Automobile Electrical/Electronic Systems (A6) and Engine Performance (A8) tests[3] are pre-requisites.

Another option is the EV Champion Training Series developed by the US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE)[4]. There are also several Colleges and online programs that offer EV training courses.

4.5.4 Tools (BP 4.6)

Having adequate tools available in convenient locations is a key to shop productivity. Government shops are divided on who is responsible for providing tools. All shops provide specialty tools and equipment like diagnostic equipment and heavy lifts. Some provide all tools while others require mechanics to provide their own in exchange for an annual allowance.

The benefits of employee-provided are that mechanics get exactly what they prefer and tend to take better care of their tools. They spend less time looking for tools as they are always at hand and locked

3 National Institute for Automotive Service Excellence (ASE). ASE Certification Tests, https://www.ase.com/ase-certification-tests.
4 US Dept. of Energy, Office of Energy Efficiency and Renewable Energy (EERE). EV Champion Training Series, https://www.energy.gov/eere/femp/electric-vehicle-training.

up when they are not in attendance. The downside is that it is expensive for the mechanic. A complete tool set, and proper storage compartment can cost in the range of $30,000 to $50,000[5] which may be out of the reach of a starting mechanic. Where hiring and retention are issues, employer-provided arrangements may be preferred.

Agency-provided tools can involve significant cost for the organization. There also tends to be a higher rate of loss and diminished productivity as mechanics search for tools. On the other hand, a mechanic may prefer this to having to provide their tools and therefore be more likely to choose an organization providing this option.

The DOTs interviewed were equally divided on this issue. Those that require their mechanics to have their own tools paid annual allowances of $300 to $1,000.

As winter road maintenance fleets move towards alternative fuels and/or electrification, the tool debate becomes increasingly important. Some of the questions to address include:

- What additional common tools will need to be added?
- What additions will mechanics who provide their own tools be responsible for?
- Will tool allowances need to increase? By how much?
- Will requiring these additional tools be a barrier to hiring? Retention?

Any plan for alternative fuels will have to contain a tooling strategy that addresses these questions.

4.6 FINANCIAL PLANNING

State DOTs have the challenging task of budgeting for winter roads maintenance operations, including fleet operations and fleet replacement. There are several models used by governments for fleet replacement. Most organizations use either a general fund, an internal service fund, or a combination of the two to cover the operating (fuel and maintenance) and replacement costs of fleet. Any of these models can be effective, what is important is that the funding model is seen as being transparent and equitable across departments.

Key practices are outlined below:

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[5] Providing Technician Tools vs. Offering a Tool Allowance - Maintenance - Government Fleet (government-fleet.com)

5. Financial Planning
5.1 Rates have a capital equipment replacement as well as an operating component.
5.2 The capital budget meets capital replacement needs.
5.3 Consideration is given to the possible increased capital requirements of ATF vehicles.

4.6.1 Rates (BP 5.1)

Many Organizations use a rate model to enable the fleet organization to recover funds from other departments, or Districts for the use of fleet vehicles. These rates cover the replacement of all assets as well as their operating costs.

Only one DOT uses chargeback rates to cover the cost of winter roads maintenance assets. The others use general funds, with a separation for capital and operating costs.

4.6.2 Capital Budget Meets Needs (BP 5.2)

Once a fleet has established optimum replacement cycles, they can create a multi-year replacement plan with funding requirements. Where budgeted funds do not meet requirements, organizations must prioritize the assets to be replaced. This creates a backlog of vehicles overdue for replacement and the increased costs of operating older vehicles quickly escalate the TCO of fleet ownership.

Of the fleets interviewed, almost all are in the position where budget is insufficient for fleet replacement. Even those fleets who were keeping up with replacement, have encountered hurdles in the past year due to inflation and vehicle availability. When this happens, it is important to adjust replacement plans and have a formal system to prioritize replacement.

Without the expected access to new vehicles, many fleet organizations need to be selective regarding which vehicles get replaced. Systems to prioritize replacement no longer rely on simply age and odometer but combine factors in a point system to ensure scarce replacement dollars are spent wisely.

Point systems for fleet replacement can take into account the traditional measures of age and mileage but often include downtime, maintenance costs (lifetime and last 12-months), condition and even driver preference. Many Fleet Management Information Systems have integrated tools to do this assessment but fleet managers can also create a simple spreadsheet in excel to track priorities for replacement. It is best to start with age and mileage:

Asset Age - Points Calculation		
% Life Left	Gen Wear	Points
75-100%	Very Good	1
50-75%	Good	2
25-50%	Fair	3
0-25%	At Risk	4
≤ 0%	High Risk	5

Asset Mileage - Points Calculation		
% Life Left	Description	Points
75-100%	Miles/hrs less than 25%	1
50-75%	Miles/hrs 25-50%	2
25-50%	Miles/hrs 50-75%	3
0-25%	Miles/hrs more than 75%	4
≤ 0%	Miles/hrs more than 100%	5

From these, move to more refined measures:

Lifetime Maintenance Costs - Points Calculation		
% Life Left	Main Costs	Points
91-100%	Under 10% of purchase	1
81-90%	10-19% of purchase	2
71-80%	20-29% of purchase	3
61-70%	30-39% of purchase	4
51-60%	40-49% of purchase	5
41-50%	50-59% of purchase	6
31-40%	60-69% of purchase	7
21-30%	70-79% of purchase	8
11-20%	80-89% of purchase	9
≤ 10%	More than 90% of purchase	10

12-month Maintenance Costs	
≤ 10%	0
More than 10%	2

All of the factors shown above are data driven and can be calculated using data that most fleets track. There may be other factors that require additional input:

Condition - Points Calculation		
Condition	Definition	Points
Excellent	Body and Drivetrain working perfectly	-2
Very Good	No rust, good drivetrain and engine	-1
Good	Expected wear and tear for age	0
Fair	Minor imperfections, drivetrain working	1
Poor	Deterioration in body, signs of imminent failure	2

Condition Assessments require a hands-on, slightly subjective evaluation of the asset. Increasingly, fleet organizations start including a condition assessment as part of the annual preventative maintenance schedule as assets near the end of their lifecycles. Bringing all of this information together enables the organization to quickly identify priorities for replacement. Naturally, the higher the score, the higher the priority and each organization can set limits or thresholds that trigger immediate replacement.

4.6.3 Increased Funds Needed for AFVs (BP 5.3)

Although TCO of AFVs in many applications is favorable over the life of the asset, acquisition costs may be more that the ICE equivalent. Organizations need to budget accordingly. They should also plan for one-time conversion costs such as the initial investments in infrastructure, tools and training.

4.7 TECHNOLOGY

Comprehensive, accurate, and readily accessible records regarding fleet operations are essential to optimize performance and manage costs. In the past, fleet maintenance records were kept on paper orders, vendor invoices, and handwritten notes. However, as with all business activities, fleet maintenance shops have evolved to use management information systems to document operations and produce management reports. Having all maintenance and other data available in a computerized system and accessible by all fleet program stakeholders is effective in managing shop operations and provides an efficient way to retrieve and report key information.

Key practices are outlined below:

6. Technology

6.1 A fleet management information system (FMIS) is in place that uses modern technology and provides up to date functionality for asset management, maintenance management, performance measurement, and cost reporting.
6.2 A fuel management system is in place.
6.3 A telematics system is in place to improve routing and scheduling of services, identify driver training issues, and provide timely fleet data.
6.4 Information produced by systems are routinely used to make management decisions and reports are provided to customer departments.
6.5 A formal performance measurement system is in place to track the effectiveness of service outcomes, and that performance levels compare reasonably well to industry benchmarks.

4.7.1 Fleet Management Information System (FMIS) (BP 6.1)

A number of options exist for organizations looking to meet fleet information management needs. These include:

- **Maintenance Management Systems.** These systems help maintenance staff optimize their daily maintenance duties including assigning and completing work orders, performing preventive maintenance tasks and inspections, and managing spare parts inventory and labor resources to maximize equipment availability. Leading systems include Dossier and eMaint.
- **Fleet Management Information Systems.** These systems encompass maintenance management functions and automate additional aspects of fleet management including replacement planning, budgeting and capital expense tracking and contract management. Leading systems include Assetworks FA and M5, RTA Fleet Management, Collective Data, Agile Fleet, Faster and Fleetio.
- **Enterprise Asset Management Systems.** These systems focus on the entire lifecycle of an asset from design and installation through ongoing maintenance through to retirement or replacement and are usually more suited to facilities and fixed assets than rolling stock. IBM Maximo, NexGen and Sage Fixed Asset are examples.
- Some fleets have systems that have been built in-house and correspond with one of the models described above.

The best practice in system selection is to have a fully integrated FMIS to manage all aspects of a fleet operation through a single interface and toolkit. Having all pertinent transactional and management data consolidated in a single system and available to all fleet users provides an effective tool for day-today operational management, a basis for timely management decisions, and an efficient information retrieval and reporting platform.

Any system acquired for this purpose should have the following capabilities:

- Complete vehicle equipment life-cycle management including
  - Budgeting and forecasting
  - Acquisition and upfitting capital costs
  - Capital improvements
  - Disposal management
- Comprehensive work order functionality
  - Repair status
  - Repair type
  - Repair labor hours & costs by asset
  - Repair parts expense by asset
- Shop repair scheduling and workflow assessments
- Preventive maintenance scheduling
- Regulatory safety inspection scheduling
- Labor tracking and management
- Productivity monitoring (KPIs)
- Inventory control and parts room management
- Cost reporting and billing
- Fuel tracking
- Warranty and claims tracking

Of the DOTs interviewed the majority had, or were transitioning to, a fit for purpose FMIS. Two of the organizations were unsatisfied with their existing FMIS due to data immaturity of the failure to properly train and implement the system. Organizations that are using in-house or maintenance specific systems recognize the weaknesses of the systems.

4.7.2 Fuel Management System (BP 6.2)

Organizations benefit from a fuel system that is linked to the FMIS. The fuel system is usually the source of odometer readings (either automated or manually entered). Odometer readings are important data to analyze fleet utilization.

All DOTs interviewed have an automated fuel system for in-house pumps as well as fuel cards for commercial fuel purchase.

4.7.3 Telematics (BP 6.3)

A telematics system can collect information on vehicles and operations. Fleet management information that can be collected includes:

- Location
- Odometer readings
- Maintenance issues
- Fuel consumption
- Idling time
- Driver behavior (speeding, fast accelerations, etc.)
- Suitability for alternative fuel conversion

A wide range of winter road maintenance operational data can also be tracked.

Eleven of thirteen DOTs have telematics systems that measure aspects of winter road maintenance operations. Two of these DOTs also have telematics to measure fleet performance. The remaining two DOTs do not see the value in telematics systems.

Telematics has become essential for organizations to track or monitor essential fleet data. Traditional uses include the tracking of vehicle locations, utilization fuel and driver behavior. The use of telematics has expanded to include the identification of vehicles that are ideal for EV conversion based on their domicile and usage.

The sustainability benefits of telematics come from accurate and precise vehicle performance tracking that allows for efficient analysis of individual vehicle and overall fleet data. A telematics system improves data reliability by eliminating the potential for error associated with driver submitted odometer readings or other information on vehicle performance. Most telematics systems provide fleet managers with the ability to view the activity of fleet vehicles using an intuitive online dashboard. This allows fleet managers to make better decisions about switching to alternative fueled vehicles and the required fueling/charging infrastructure by accurately knowing the actual use of the vehicle, including the average and maximum daily mileage, along with where it regularly travels.

The use of telematics by fleets around the globe is expected to increase by 25% per year according to The Gartner 2021 Market Guide. This increase will come as more fleets adopt telematics for traditional uses such as monitoring vehicle location, mileage and idling and driver behavior, as well as emerging uses like identifying candidates for and tracking the results of fleet electrification.

The adoption of telematics is increasing because the technology is proven and the Return on Investment (ROI) is almost assured. In a 2021 market research report of the transportation and services industries, Bobit reported that fleets experienced an average 8% decrease in fuel costs, 11% reduction in accident costs, and a 10% decrease in labor costs.

The top benefits of telematics in traditional roles include:

- **Monitoring vehicle location to prevent theft and ensure productivity**. Vehicle tracking is a two-edged sword. Organizations naturally want to know where their assets are at all times. At the same time, employees are resistant to the notion of being under constant surveillance. Vehicle monitoring is not a problem when employees are where they are supposed to be, performing work functions. Organizations need to emphasize the considerable advantages of vehicle tracking for employee safety and vehicle recovery in case of theft.

- **Tracking vehicle utilization to right-size the fleet**. One of the quickest ways to improve fleet productivity is through a formal utilization analysis. Telematics provides the data on vehicle movements, not just odometer readings, but how many trips the vehicle takes and how many hours it is away from its home location. This informs the decision to retain, rotate, pool or eliminate an asset.

- **Reducing fuel costs due to idling, traffic, driver behavior and poor maintenance**. Conventional fuels are usually the fleet's biggest expense after depreciation. As such, its consumption should be closely monitored and reduced where possible. Telematics can help organizations understand their fuel spend and whether savings are possible due to excessive idling, poor routing, driver behavior, or even maintenance issues. With telematics, fleet managers have a tool to help determine the reasons behind high fuel consumption and take corrective actions.

- **Enhancing driver safety**. The most important resource an organization has is their employees. They must be protected with a commitment to vehicle safety, supported by telematics. Drivers are protected when the organization knows where they are, identifies when they are involved in risky behavior, and takes formal steps to correct that behavior.

- **Improving eco-driving habits**. Eco-driving describes the driver behaviors that prioritize safety and sustainability. All drivers should seek to maximize fuel efficiency by selecting the best routes, avoiding hard stops or fast accelerations and driving at a speed appropriate for conditions. Telematics can identify driver behavior that need improvement and provide surveillance and data to help drivers improve.

- **Scheduling preventive and reactive maintenance at optimal times**. Well-maintained vehicles are more fuel-efficient and safer. Regular preventive maintenance (PM) is necessary to minimize the cost of downtime and potentially hazardous breakdowns on the road. Telematics can allow you to set custom parameters for PM inspections, so the organization complies with industry best practices.

- **Providing better customer service**. Customer service is of importance to both corporate and government fleets. Fleets only exist to support the primary operations of the organization. That organization cannot be supported if fleet vehicles are lost, inefficient or poorly maintained. Since telematics can help prevent this, it is a vital tool in ensuring high levels of customer service.

There are clear benefits to using telematics for a variety of traditional fleet functions. As organizations seek to meet greenhouse gas emissions reduction targets, telematics have an all-new purpose. In the quest to convert fleets to electric vehicles (EVs), telematics can be used to assess current fleet performance, identify candidates for EV conversion and monitor and assess results.

- **Assessment of current performance.** Fleet EV conversion cannot be undertaken without a thorough understanding of current fleet systems, polices, utilization, operations and costs. In this stage, telematics can assist in vehicle monitoring, mileage tracking, fuel tracking and establishing an emissions baseline. A utilization study should always be done prior to electrifying a fleet to ensure the fleet is the right-size before conversion efforts start.

- **Identification of EV conversion candidates.** An analytical approach to EV conversion will have the best opportunity to decrease emissions while ensuring support to operations. Analysis should start with the existing fleet replacement plan and always consider when units are due for replacement. Telematics can provide a range of data to identity and prioritize vehicles for conversion. The data would include:

  - Domiciles of all vehicles
  - Frequency and length of trips
  - Time spent at work locations
  - Total fuel spend
  - Idling time

- Scheduling of EV charging or petrol vehicle refueling for optimal advantage

- Route optimization

- Total carbon emissions

Priority for electrification should be those vehicles that are due for replacement and those that will make the most difference – high mileage or frequent idle assets where an EV option currently exists.

Monitoring and assessing results. Telematics play an important role in the ongoing assessment of fuel and emissions reduction and compliance with net zero targets. A baseline should be set prior to an electrification plan being put in place so progress can be tracked and adjustments made if targets are not being met.

Sometimes sustainable planning is done with the best intentions but gets sidetracked. To avoid this, creating a measurement framework from the start will ensure that sustainable improvements (or degradation) are tracked and reported to senior management at approved intervals.

Overall, telematics can help in every step of fleet electrification from the initial suitability assessment to goal attainment. Telematics are a powerful tool in both traditional and emerging rolls and their use will continue to grow.

4.7.4 Performance Measurement Framework (BP 4.5)

Performance measurement is a valuable management tool that can be used to increase efficiency and accountability within an organization. The use of year-to-year historical data and industry benchmarks to measure performance can provide management with the data necessary to recognize and diagnose potential problem areas as well as opportunities for improvement. Performance measures also provide the organization with the information necessary to communicate the value of the services it provides. It is not possible for an organization to optimize its performance without establishing concrete, measurable, and challenging goals.

Organizations should track a number of performance measures such as:

- **Average Fleet Age:** This measure tracks the average age of the fleet in comparison to average replacement cycles. Major classes of vehicles and data for different customer groups should be tracked separately. Trends should be presented for multiple years and associated with other Key Performance Indicators (KPIs) as the age of the fleet has a fundamental impact on program performance.

- **Fleet Availability**: This measure tracks the percentage of the fleet that is available for work each day. The calculation is simply the total number of vehicles and pieces of equipment in the fleet divided by the number of vehicles out of service for repair (i.e., in the shop, waiting in the deadline to come into the shop, or at a vendor). The target of performance for this KPI is 95%.

- **Service Turnaround Time**: This measure tracks the percentage of repairs that are completed within 24 and 48 hours. A good target of performance for this KPI is 70% of repairs and services completed in 24 hours and 90% in 48 hours.

- **Scheduled Repairs:** This measure tracks the percentage of workorders resulting from scheduled activities (such as preventative maintenance (PM), inspections, work discovered during PMs and inspections, recalls, etc.) versus unscheduled activities (such as breakdowns and road calls). The standard of performance for this KPI is at least 60% scheduled.

- **Downtime:** This measure tracks segments of downtime while vehicles are down for repair. The entire lifecycle of a work order should be tracked including waiting for a mechanic or shop bay, waiting for customer approval, under repair, waiting for parts, at a vendor, waiting for validation and closure, waiting for customer pickup, etc. Tracking of this measure enables a fleet organization to understand what activities are causing downtime and delays so they can be managed.

- **PM Compliance**: This KPI measures the percentage of PMs and scheduled inspections that are completed before they are overdue. The target of performance for this KPI is 90%.

- **Billable Hours:** This KPI tracks how productive mechanics are in terms of the annual number of hours billed to work orders. The target for this KPI is 70% of annual regular payroll hours (1,456 of 2,080 hours per year).

All DOTs should begin tracking the KPIs listed above and develop a reporting matrix that describes who should receive what information at what frequency. A carefully developed reporting matrix is an excellent tool to demonstrate what information should be collected and reported to what level of management and at what frequency. An example appears below:

Information	**From**	**To**	**Time**	**Means**
Preventive Maintenance Compliance	Equipment Manager	Divisions	Monthly	FMIS alert
	Equipment Manager	Divisions	Quarterly	Fleet Report
Downtime	Equipment Manager	Divisions	Monthly	FMIS alert
Fuel Usage	Equipment Manager	Divisions	Monthly	Email

4.8 FUEL AND SUSTAINABILITY

As the purpose of this project is to identify the current state and future for the use of alternative fuels in winter roads maintenance operations, fuel use and sustainability are important areas of study. The alternative fuel (especially EV) landscape is evolving quickly and options for various use cases are increasingly available. To be successful in introducing any AFVs in an organization, however, requires acknowledgement of the shortcomings and a realistic long-term plan.

Key practices are outlined below:

7. Fuel
7.1 Fuel types used by the fleet are readily available.
7.2 The agency is aware of options for alternatives to conventional fuels.
8. Sustainability
8.1 Agency has AFV in winter maintenance fleet
8.2 Agency has plans to include AFVs in winter maintenance fleet
8.3 Agency has AFV outside of winter maintenance fleet.
8.4 AFV have been successful.
8.5 There have been challenges associated with AFV use.
8.6 Vehicles are replaced on time.
8.7 Agency has a Strategic Plan on Sustainability.
8.8 Agency has set GHG reduction targets.
8.9 Agency has discussed AFV with OEMs.
8.10 Agency has placed orders for AFV with OEMs.

4.8.1 Fuel Availability (BP 7.1)

In order for fleet operations to run smoothly, fuel has to be available in the type, location and quantities required. All DOTs reported this to be the case for gasoline and diesel. Problems have been encountered, however, with alternative fuel, specifically compressed natural gas (CNG) availability in rural areas. In two cases, this led the state to abandon CNG and return to conventional fuels.

This is a valuable lesson for any future introduction of AFVs, including EVs. The ability to conveniently fuel fleet vehicles is an important determinant in their successful implementation.

4.8.2 Awareness of Alternative Fuel Options (BP 7.2)

Staying up to date on emerging technologies and options in alternative fuels is a challenging task. Winter operations and fleet personnel have a role to play but DOT sustainability offices should be providing information as it becomes available.

Most DOTs reported that they were aware of emerging technologies but would like more detailed information as it becomes available.

4.8.3 Current and Future Use of AFVs in Winter Operations (BP 8.1 to 8.3)

Due to the job requirements and lack of equipment options and fueling infrastructure there is almost no use of alternative fuels in winter roads maintenance. Several states mentioned mandatory biodiesel use or limited trials with CNG, but these examples were few and largely deemed unsuccessful.

The only reported planned introduction of EVs is in the form of crew pick-up trucks (Ford Lightnings) scheduled to arrive this year.

4.8.4 Success and Challenges of AFVs (BP 8.4 and 8.5)

Most organizations reported very little use of alternative fuels, even in light-duty applications. The few examples cited of light-duty EVs for administrative purposes were too new to have detailed utilization and cost data to determine their effectiveness.

In terms of challenges, organizations reported that there are presently no vehicles available capable of performing winter roads maintenance. Their availability in the future will depend on power, battery life (range) and supporting infrastructure. Much more information is needed to assess the impact on shops and mechanic training.

4.8.5 Strategic Sustainability Plan and Reduction Targets (BP 8.7 and 8.8)

All organizations should have a Sustainability Plan that is nested in the overall Strategic Plan. The Sustainability Plan should emphasize the organization's commitment to environmentally friendly practices in purchasing, operations and disposal. It should acknowledge the regulatory framework at the federal and state levels and contain specific Greenhouse Gas (GHG) reduction targets where applicable.

Of the states interviewed, only Colorado has a specific plan that meets these requirements (Colorado Electric Vehicle Plan 2020).

4.8.6 Discussions or Orders with OEMs (BP 8.9 and 8.10)

One way to stay current with evolving technology is to schedule regular discussions with OEMs on existing offerings and their future plans. Trade journals and linkedin can also provide insight on new AFV options.

Most of the participants in the survey reported that they engage in informal conversations on upcoming tech

4.9 RECOMMENDATIONS

The following recommendations stem from the interviews and research into the extent to which the DOT participants comply with industry best practices.

1. Create a robust policy framework including a Fleet Policy Manual, a Driver's Handbook and Service Level Agreements with supported departments.
2. Develop a policy on fleet utilization detailing usage thresholds and the need and process for an annual review.
3. Ensure that the replacement of older vehicles is done on a one-for-one basis to prevent the creation of a shadow fleet.
4. Encourage all winter roads maintenance fleet operators to be proactive about identifying assets that can be eliminated or that require replacement.
5. Use cooperatives for the purchase of winter roads maintenance equipment where available for favorable pricing and a reduction in administration.
6. Calculate and respect optimum lifecycles based on the Total Cost of Ownership of the asset.
7. Create a multi-year replacement plan and ensure funds are available to replace vehicles at the optimum point.
8. Consider sustainability as a criterion in fleet replacement.
9. Establish mechanic positions according to a Vehicle Equivalency Unit (VEU) analysis.
10. Create a formal preventative maintenance (PM) program and ensure 95% compliance is observed.
11. Develop a formal training plan for mechanics to retain and improve their skills on internal combustion engine (ICE) and alternative fueled vehicles (AFVs).
12. Create fleet funds that have a separation between operating and capital replacement funds.
13. Assess the condition of assets due for replacement where funding is insufficient to replace all vehicles that are due.
14. Plan for the increased costs of AFVs and supporting infrastructure in the future.
15. Acquire and use a Fleet Management Information System (FMIS) to monitor fleet acquisition, utilization, maintenance, fuel and replacement.

16. Acquire and use a Fuel Management System that is integrated into the FMIS.
17. Install telematics to monitor vehicle performance, utilization and driver behavior.
18. Create a performance measurement framework that details what information needs to be reported, to what level, and at what frequency.
19. Keep informed on advancements in AFVs by staying connected with other DOT fleets and OEMs.
20. Draft a Sustainable strategy for the organization with realistic targets for AFV introduction and GHG emissions reduction.

CHAPTER 5: HISTORICAL FUEL COMMODITY TRANSITIONS

5.1 PURPOSE

This section documents research for Task 4 – Historical Fuel Transition Report. These historical shifts from one fuel source to another can identify lessons that may be applied in converting winter road maintenance fleets to alternative fueled vehicles as they become available in the future. Research has been augmented by interviews with two DOTs who made significant shifts in the types of fuel used in their fleets.

The traditional fuels used in internal combustion engine (ICE) vehicles are gasoline and diesel. All other fuels are considered alternative fuels and the vehicles they power are referred to as alternative fuel vehicles (AFVs).

Changes in energy use involve far more than a shift in fuels. They are complex transitions where energy supply, delivery platforms, and consumer behaviors all play significant roles. There are many examples of simple shifts in fuel use, but wholescale energy conversions are rarer and much more complex.

This section cites one widespread fuel shift (gasoline to diesel) as well as two examples of localized fleet transitions (gasoline to propane and gasoline to CNG). It also provides a look at the use of CNG in a small snowplow fleet in Canada to illustrate small successes in that application.

5.2 GASOLINE TO DIESEL (1950S)

By the late 1880s, gasoline or electric batteries were the preferred energy sources for on road transportation. The limited driving range and high cost of early battery electric vehicles (BEVs) along with the discovery of easily accessible crude petroleum with its high energy density, and relatively low cost led to widespread acceptance of gasoline for all modes of on-road transport.

Diesel started to become a viable fuel source with the creation of a compression ignition engine by Rudolf Diesel in 1885. Over the next twenty years, he refined his efficient, slow-burning, compression ignition, internal combustion engine. Despite the development of the diesel engine, most on-road vehicles (cars, trucks, and buses) operated on gasoline until after World War II.

5.2.1 Shift to diesel

Although implementation was initially slow, a widespread shift for medium- and heavy-duty on-road vehicles from gasoline to diesel followed. This shift can be attributed to the availability of the fuel, the properties of the fuel, engine energy efficiency, technological improvements, and the requirements of the specific point in time.

Diesel fuel was readily available by the late 1880s as it was derived from a similar process as used to produce gasoline. Both diesel and gasoline are derived from crude oil, extracted from the ground through wells and offshore rigs. Crude oil is refined into gasoline, diesel, kerosene, and other products.

As the oil is heated, vapors are captured in a tank to condense into a new liquid. Vapors heated at different temperatures are trapped in different tanks and become different types of fuel. As refineries were built to create gasoline starting in 1851, the ability to produce diesel already existed.

In terms of the properties of the fuel, diesel fuel has a higher energy density (BTU/gallon) than gasoline. Diesel currently has about 147,000 BTU/gallon while gasoline has about 125,000 BTU/gallon. The diesel combustion cycle is also more efficient than the gasoline cycle. These factors mean that less diesel fuel volume is needed to do the same work.

Diesel fuel was considered a technological improvement as it did not need to be externally ignited. Instead, the diesel engine compresses the fuel to extreme pressures to cause it to ignite. Another technological advantage was that diesel engines could run for longer periods of time before requiring maintenance.

Economic and societal needs also drove the transition to diesel for medium- and heavy-duty applications. Diesel replaced coal in trains before becoming popular for on road applications. As trains developed, they got bigger and faster, and required locomotives with higher power, fuel efficiency, and operating range temperatures which diesel provided. The post-industrial revolution populations embraced technological improvement and by the end of World War II, conditions were set for a major systemic shift from gasoline to diesel for medium- and heavy-duty applications.

Diesel is still the dominant fuel for medium- and heavy-duty applications throughout North America and worldwide. In 2020, diesel fuel consumption in the U.S. transportation sector was approximately 44.61 billion gallons, an average of about 122 million gallons per day according to the U.S. Energy Information Administration.

5.2.2 Challenges associated with the shift

As previously described, conditions were overall favorable for this shift. Still, there were a number of early infrastructure and cost hurdles to overcome that can provide lessons for today.

One of the reasons for diesel’s success is the relative lack of additional infrastructure needed. In moving from gasoline to diesel in the mid-1900s, fuel stations were already in place and only had to offer a new liquid using the same delivery, storage, and dispensing technology.

Cost was another potential obstacle. Diesel engines were more fuel efficient and the fuel was initially cheaper to acquire which encouraged its adoption. Government taxes, however, can change the difference in price between gasoline and diesel and effect its popularity.

5.3 GASOLINE TO LPG (PROPANE)

LPG, also known as propane autogas, was discovered in the early 1900s and used largely in homes. In the 1950s, it saw more widespread use in fleets as Chicago Transit Authority ordered 1,000 propane buses and Milwaukee converted 270 taxis to run on LPG.

Fleets have adopted propane largely due to four reasons.

- Cost Savings
- Lower emissions
- Safety
- Grants

5.3.1 Use of LPG

According to the U.S. Department of Energy's Alternative Fuels Data Center (AFDC), propane accounts for just 2% of the energy used in the United States and only 3% of that is used for transportation. It is estimated that there are around 60,000 LPG-certified vehicles on the road today, nearly all fleet vehicles. There are approximately 35 LPG-only (dedicated fuel) vehicles currently available for purchase. Only the Freightliner Custom Chassis S2G Truck, Ford Medium Duty Chassis Cab F650/F750 and Ford Super Duty Chassis Cab F550 are likely fits for Winter Roads applications.

There are 1,849 LPG full-service fueling stations across the U.S. and Canada. If partial-service stations are included (where fuel is available without the ability to serve customers) that number increases to 3,191.

The AFDC describes some benefits of LPG. Despite a higher vehicle acquisition/conversion cost, fuel costs are much less than gasoline, offsetting higher acquisition costs. Converting a gasoline-powered vehicle to run on propane is fairly simple from a technical standpoint, but the availability, quality and prices of the systems vary. In general, the expense of conversion can be recovered in as little as 10,000 miles from fuel cost savings.

Propane use reduces engine-out particulate matter by up to 99% and engine-out NOx emissions by as much as 50% when compared to diesel powered vehicles.

5.3.2 Challenges

The main challenges in the switch from gasoline to propane are vehicle acquisition costs, reliability of after-market conversions and training operators on the use of hybrids. On cost, the conversion kit to run a vehicle on LPG runs between $6,000-12,000.

Another issue faced by those looking to convert their fleet to run on LPG is the reliability of after-market conversion kits. The quality varies greatly and will be a key factor in the success of the conversion.

A final issue is training. Many fleets use bi-fuel propane systems. This means that vehicles have two fuel tanks (one LPG and one gasoline). Drivers often use the fuel they are most comfortable with, so fill only the gasoline tank; losing any advantage afforded by the propane option.

5.4 GASOLINE TO COMPRESSED NATURAL GAS (CNG)

Natural gas has been used to power engines going as far back as World War I. Due to fuel energy density and engine efficiency limitations, vehicles initially required a large tank in order to operate at the same range as gas/diesel vehicles. Compressed storage technology had not yet been developed, so the solution was to mount an atmospheric pressure 'gas bag' to the roof of the vehicle. These took the form of giant bags of uncompressed natural gas that sat on the roof racks of cars and buses.

It was not until the latter half of the twentieth century that CNG began to see more widespread use as an alternative fuel. A major driver of this shift to the use of CNG was the increased convenience afforded by the advent of compressed and liquified natural gas storage technologies.

5.4.1 Natural Gas Use

Natural gas can be stored either as compressed natural gas (CNG) or as liquified natural gas (LNG). Natural gas is domestically produced, low-priced, and readily available. Natural gas consists mostly of methane. CNG is produced by compressing natural gas to 3,600 psig, less than 1% of its ambient volume at standard atmospheric pressure. LNG is cryogenically stored as a liquid to increase the energy storage density compared to CNG. Natural gas can be used in light-, medium-, and heavy-duty applications. The three types of natural gas vehicles are:

- Dedicated – Spark-ignited engine operates solely on natural gas; CNG or LNG.
- Bi-fuel – Spark-ignited engine operates on natural gas or gasoline, independently. The fuels are never used at the same time.
- Dual-fuel – Compression-ignition engine operates on a combination of natural gas (primary fuel) with another fuel (e.g., diesel) used at a low level for ignition. The engine can typically also operate solely on the non-natural gas fuel as a backup.

Natural gas vehicles are similar to gasoline or diesel vehicles in power, torque, acceleration, and cruising speed. They may have less driving range than comparable vehicles, because less overall energy content can be stored in the same size tank. For larger vehicles, extra storage tanks can help increase driving range.

Natural gas has cost and advantages over gasoline and diesel. Maintenance costs are lower, as natural gas prolongs engine life and regular preventive maintenance intervals are further apart. Natural gas prices are consistent and may provide a much less expensive options when gas and diesel prices spike.

Natural gas is the cleanest fossil fuel with a lower carbon content than diesel and gasoline per equivalent gallon. Natural gas produces 20-30% fewer tailpipe greenhouse gas emissions, 95% fewer tailpipe emissions, and zero evaporative emissions.

Fuel independence is also a factor. 93% of natural gas used in the United States is produced there and the remainder comes from Canada. The supply of natural gas is estimated to be sufficient to last for one hundred years.

Regarding refueling, there are currently 1,500 CNG fueling stations in the U.S., which include public service stations and private depot-based stations.

5.4.2 Challenges

The first challenge is the cost of purchasing new vehicles or retrofitting existing fleet vehicles. Retrofitting is likely never a cost-effective option since the fleet would have paid for both a diesel engine and a NG engine/fueling system.

The second challenge is that natural gas fuel station availability is very limited in certain parts of the country. Organizations must construct their own natural gas fueling stations at significant investment if they choose to use CNG as part of their sustainable strategy. Many partner with fuel providers (Trillium, Clean Energy, etc.) to build/operate the infrastructure after a guaranteed fuel amount is determined. This puts the burden on those companies for construction, maintenance, and operation.

5.5 CASE STUDIES

5.5.1 Interview with Assistant Director of Fleet Services, Chris Perry – Newport News, Virginia

In 2012, the City of Newport News, VA (City) fleet converted 22 of their fleet vehicles to bi-fuel propane autogas and gasoline. The change was spurred by a few key factors:

- Cost (the fleet expected to save $22,000 annually in fuel costs)
- A desire to reduce their carbon footprint
- Technological availability

The City investigated switching to LPG and CNG in the 1980s and 1990s, but the conversion requirements were determined to be too onerous. By 2012, the City felt that the change would have a relatively small impact on their fueling and maintenance infrastructure. Senior management was informed of the change but did not have much input in the process.

It took six weeks to convert the original 22 vehicles to run on LPG. Changes to existing vehicles involved installing an LPG tank and new fuel lines as well as the bi-fuel system controller. This work was performed in-house, requiring three to four days for each vehicle. To support refueling, Phillips Energy, a Virginia fuel supplier, was contracted to install a 1,000-gallon fuel tank and dispenser pump.

This number of bi-fueled vehicles has grown to 73 LPG/gasoline vehicles, ranging from sedans to heavy-duty trucks. The City also runs 126 propane transit buses managed by a separate program. The refueling infrastructure has been upgraded to contain 2,000 gallons and a second dispenser pump.

Training requirements in support of this change were minimal and included:

- Vehicle operators were taught how to fuel the LPG vehicles
- Vehicle operators receive frequent reminders to top off the propane tank instead of only using gasoline
- Technicians were trained to service the vehicles
- Specialized maintenance software was acquired

Training materials, software, and third-party technicians can sometimes be hard to secure due to LPG not being in as widespread use as gasoline and diesel.

5.5.2 Interview with Oxford County, Canada

The project team spoke to James Wagner, Fleet Technician for Oxford County, Ontario to discuss questions regarding the fleet's switch to CNG-powered snowplow trucks.

The winter road maintenance fleet consisted of only four diesel plows. As part of Oxford County's Green Fleet Plan to reduce emissions, the organization researched CNG snowplows. The CNG snowplows were projected to reduce CO_2 emissions by 5 tons per year, per truck. The County found that the fuel cost savings over the 10-year lifecycle of the truck would be enough to pay back the initial investment of retrofitting the existing vehicles to CNG.

The county converted two of the four plows in the Woodstock yard to CNG and have orders in place to convert the other two trucks. The fleet also provided employee training on fuel filling procedures and basic CNG system component identification.

Overall, the main challenges in this conversion were the availability of CNG filling stations and operators have noted that the CNG trucks have marginally less power than diesel which has minimal impact on winter road operations.

5.6 LESSONS IDENTIFIED FROM FUEL TRANSITIONS

The purpose of looking at historic and more recent fuel transitions is to identify any lessons that may apply to a future transition to electricity for winter roads maintenance vehicles. There are so few examples of alternative fuels being used for winter roads maintenance that it is too early to gather meaningful data. However, it is not too early to start thinking about the vehicle and infrastructure lessons from the past that may allow a fleet to be better prepared for change in the future.

- **Holistic view**. The major fuel shifts in history are complex transitions where energy supply, delivery platforms and consumer behaviors all play significant roles. There are many examples of simple shifts in fuel use (fleet level), but wholescale (industry wide) energy conversions are rare and much more complex.

- **Costs.** To be attractive to fleets, alternative fuel shifts need to be at least cost neutral and preferably result in savings. Costs should not be calculated based on simply vehicle acquisition but include Total Costs of Ownership (TCO). TCO includes the capital cost of the vehicle as well as the operating costs (fuel and maintenance) over the life of the vehicle.

- **Training**. Employees tend to avoid new technologies if they do not understand it and are not convinced it will perform the job functions it is intended for. A familiarization and training program for fleet operators, supervisors, vehicle operators, and mechanics is essential.

- **Infrastructure**. The lack of fueling infrastructure is one of the biggest causes of implementation failure in fuel shifts or transitions. Advance planning must ensure infrastructure is available as alternative fueled vehicles are acquired and fuel operations must be safe and simple.

- **Vehicle Availability.** The vehicles available must be fit for purpose and able to perform the job required. As soon as a vehicle is labelled as underpowered, it loses the confidence of users and will not be used. Ensure the vehicles or equipment selected as alternative fueled replacements are fully capable of accomplishing the mission.

- **Fuel availability.** Separate from the infrastructure, the fuel itself must be available in sufficient quantity to meet current and future needs. Joint plans and partnerships with electricity providers will be key in the future.

5.7 RECOMMENDATIONS

21. Evaluate the affordability of AFVs based on TCO and not the acquisition costs of vehicles.

22. Educate stakeholders on the use and benefits of AFVs to eliminate barriers to introduction.

23. Ensure fuel and infrastructure availability in advance of any alternative fuel transition.

CHAPTER 6: ALTERNATIVE FUELS PRACTICE SURVEY RESULTS

6.1 PURPOSE

This section summarizes the process to conduct, and the results of, a benchmark study on alternative fuel practices, use, and experiences in State DOT's winter road operations. The goal was to increase knowledge in these areas:

1. Motivation and decision process for using alternative fuels.
2. Which portion of the winter roads fleet was transitioned to alternative fuel.
3. What criteria had to be met to switch to an alternative fuel.
4. Fuel cost and availability.
5. Experience and challenges (e.g., vehicle operation, drivers, vehicle maintenance, manufacturer support, maintenance facilities, fueling infrastructure, training, compliance, and weather-/temperature-related).

The project team reviewed data/information gathered in the Request for Information and other previous tasks to identify the candidate State DOTs that use/have used alternative fuels to consider engaging as benchmarking partners for this task. Few State DOTs with this experience were identified. To increase potential fleets to interview the team broadened the search to include municipal truck fleets that include similar trucks and operations (ideally winter maintenance) to State DOTs' winter roads maintenance fleets.

The following organizations were contacted with a brief summary of the project, the ideal candidate fleets, project team contact info, and request for them to share with their stakeholder/member network. The organizations included:

- Transportation Research Board, Standing Committee on Winter Maintenance,
- AASHTO - Winter Maintenance Technical Service Program – Snow and Ice Pooled Fund Cooperative Program (SICOP),
- AASHTO - Committee on Maintenance,
- Professional Snowfighters Association,
- PIARC (formerly World Road Association),
- American Public Works Association (APWA) group on winter maintenance, and
- Norwegian Public Roads Administration.

Additional potential fleets were identified via discussions with truck, engine, and fuel providers. (Interviews with these organization are discussed in a different section of this report.)

Once potential organizations were identified, Energetics emailed the identified contacts with an interview request. Interviews were scheduled and held virtually, each with two technical staff present. The primary information collection method was via phone/web conference interviews using the Clear Roads project Technical Advisory Committee-approved interview guide.

The interview questions that were discussed are listed below. They were used to guide the conversation, rather than a formal sequential list of questions.

1. What alternative fuels did the fleet evaluate? Why was the chosen fuel(s) selected?
2. Who were the main stakeholders involved in planning and executing this change?
3. Which portion of the winter roads fleet were transitioned to alternative fuel? What criteria had to be met to switch to alternative fuels?
4. Is the alternative fuel readily available in your area? Is the fueling infrastructure installed on-property?
5. Is manufacturer support for the alternative fuel systems (engine, on-vehicle fuel system, etc.) readily available in your area?
6. What was the impact on fueling infrastructure (fuel storage, pumps, etc.)?
7. What was the impact on vehicle maintenance and storage infrastructure (shop requirements, parts, storage, etc.)?
8. Were DOT staff mechanics trained to maintain the vehicles? Or are alternative fuel related maintenance done by the dealer?
9. Have there been any alternative fuel vehicle maintenance challenges?
10. Did you encounter any operational issues with your winter maintenance vehicles due to weather, route length, driver error, fuel availability, driving range/operating time, vehicle reliability, etc.?
11. Did you encounter any issues in attaching/using any winter maintenance implements/equipment to your vehicles?
12. Did you encounter any safety issues related to the alternative fuel vehicles or driver operation?
13. What were your lessons learned?

A summary was developed for each interview. The initial draft of each was shared with the interviewee(s) to ensure accuracy. The interview summary for each fleet is included as a separate section. A summary of the conclusions/key lessons learned is located at the end of this report section.

The table below lists the fleets that were interviewed.

Organization	State	Alternative Fuels Experience
Iowa Department of Transportation	Iowa	B20 in warmer months; B5-B10 during the winter months and B100 (in properly equipped vehicles)
Ohio Department of Transportation	Ohio	CNG and B20
City of Ames	Iowa	B20 for roughly eight months a year; B5-B10 during the winter months.
Hennepin County	Minnesota	B20 in warmer months; B10 during the winter months
Washington D.C., Department of Public Works	District of Columbia	CNG, B20 in warmer months; B10 during the winter months, and B100 (in properly equipped vehicles)
Forest Preserve District of DuPage County	Illinois	B20 in warmer months; B11 during the winter months, and LPG

6.2 IOWA DEPARTMENT OF TRANSPORTATION

<u>Fleet contact:</u> Todd Cogdill, Fleet Manager

6.2.1 Fleet Description

The Iowa Department of Transportation (DOT) was an early adopter of alternate/carbon reducing fuels, especially in support of biodiesel. For the past five years all new vehicle purchases containing diesel engines must be capable of operation with B20 biodiesel fuel. The DOT operates 120 maintenance garages across the state.

6.2.2 Alternative fuel selection and conversion criteria

Past and current state Governors have supported directives for the use of biodiesel by Iowa State agencies in diesel engine vehicles and equipment. For approximately five years all new purchased diesel engines have had to be capable of using B20. This included trucks and tractors, which are both used by DOT for highway snow removal. The introduction of biodiesel was a challenge for the DOT because not all tractor manufacturers had a stated allowance to use biodiesel blends. The DOT worked with its manufacturer partners to document the allowance to use biodiesel blends up to B20.

6.2.3 Alternative fuel experience

The DOT currently uses B5, B10, B20, and B100 blends of biodiesel in its fleet.

Most vehicles and equipment use a B20 biodiesel blend during the warmer months. The biodiesel blend during the winter season ranges between B5 and B10. The exception is 10 trucks that use the Optimus Technologies Vector (fuel) System that enables using B100 during normal operations (described in the *OEM Interviews* section). Currently these trucks consume 90,000 gallons of B100 per year. For the B20 biodiesel program, the fleet has had minimal issues with operations and no fuel flow problems with the vehicles or fueling infrastructure. B20 is used across the diesel fleet in many applications.

For the B100 biodiesel program, five trucks (2010-2017 model years) were retrofitted with an early generation of the Vector System in 2020. The system allows use of B100 through the application of heated fuel tanks and fuel system components. Several problems were encountered with this first pilot program. Low power complaints resulted in Optimus determining that the batch of fuel did not have the correct properties and the fuel pump pressure and flow rate needed to be increased. Optimus addressed the issues to solve the problem.

The fueling infrastructure operation has been good after an early fuel supply cabinet insulation issue was solved with a remotely-monitored temperature and better insulated the door.

Since these issues were solved, the DOT has been satisfied with the Optimus-equipped truck operation and has purchased five additional International brand trucks with the Optimus system installed by the truck dealer. All Most of the trucks have Cummins engines, though some were International MaxxForce engines. All 10 of the B100 trucks are used for snow plowing.

The fleet noted that its trucks are equipped differently than its neighbor City of Ames fleet, due to the higher speed operation and much higher body hydraulics loads.

6.2.4 Vehicle maintenance, training, and storage

The B20 trucks follow the same as diesel preventative maintenance schedules. The fleet stated that no maintenance issues with B5-B20 usage occur if proper preventive maintenance practices are followed. The fleet had three mechanics specially trained by Optimus to service the B100 trucks.

6.2.5 Fuel and fueling infrastructure

Onsite bulk fuel storage and dispensing infrastructure is located at 57 maintenance garage sites. All of the fuel tanks are owned by the DOT. All of the tanks have B20 in summer and approximately B10 in the winter months. The fleet stated no issues with fuel gelling (cold flow additives) in the vehicles and in the fuel tanks/dispensers. The fleet uses different dispenser filters in summer and winter.

Twice a year, all tanks are cleaned, polished and have new filters installed. Fuel samples are recorded before and after each cleaning. The fleet felt this process was a necessity for maintaining fuel infrastructure performance.

The Des Moines, IA garage leases a 12,000-gallon B100 tank. The fleet stated that the required heating to maintain the fuel flow properties can be expensive during colder months.

6.2.6 Costs

Historically the B20 price has been comparable to diesel. During the past several years the spot price of B100 has been approximately 50% higher than diesel. At the time of this writing, the B100 on the fleet's contract was approximately $6.90/gallon vs. approximately $2.90/gallon for No. 2 diesel.

6.2.7 Future Plans

A research project with the Iowa State University at Ames will study different biodiesel blends (up to B100) in IA DOT's vehicles and equipment to define/analyze emissions, maintenance, fuel consumption, and performance to identify an optimal fuel blend for the fleet.

6.3 OHIO DEPARTMENT OF TRANSPORTATION

<u>Fleet contacts:</u> Scott Lucas and Douglas Burke

6.3.1 Fleet Description

The Ohio DOT has experience with several alternative fuels across the fleet (light- to heavy-duty) including compressed natural gas (CNG), biodiesel blends, and E85. The fleet includes 7,000 total vehicles and 16,000 pieces of equipment. The fleet includes 1,600 Class 8 snowplows which are mostly International brand trucks that have a 60/40 ratio of tandem- to single-axle chassis.

6.3.2 Alternative fuel selection and conversion criteria

In the late 1990s the Ohio DOT was an early adopter of CNG with retrofitted vehicles. All of the trucks operated out of the same district garage. This program had many problems. Although the use of OEM-equipped CNG fuel systems solved the vehicle issues, the CNG program was expensive since the cost of chassis doubled (compared to diesel). The CNG fuel tank packaging also reduced the salt/brine volume which was not acceptable. The decision was made 10 years ago to not pursue CNG further.

Around 2010, and for a period of approximately eight years, the State of Ohio required the DOT's diesel fleet to use B20 biodiesel. This directive also required an increase in B20 consumption by 10% on an annual basis.

The DOT has studied the potential use of battery electric trucks for snow plowing operation but concluded that they will be a difficult case for the DOT's operations. This is due, in large part, because many of the DOT's rural maintenance facilities do not have the required electric infrastructure for fast charging 12-15 trucks at one time between shifts (following current operations practices).

6.3.3 Alternative fuel experience

For the B20 biodiesel program, the fleet had bad experiences. The fleet found that biodiesel fuel quality and consistency of the improperly (splash) blended fuel resulted in stratification in the storage tank which in turn plugged vehicle and fuel dispenser fuel filters. These problems resulted in the stoppage of snowplow operations.

The requirement to use B20 expired approximately 10 years ago, but the fleet has not trialed B20 after the ASTM D7467 specification was approved. Additionally, natural gas operations were discontinued due to the vehicle and infrastructure expenses, compared to diesel. Furthermore, their practice of storing vehicles inside each night presented a natural gas fuel leakage risk.

6.3.4 Vehicle maintenance, training, and storage

The DOT fleet operates 88 county garages. All garages are heated (approximately 50° F) and most garages store 12-15 vehicles. The heating systems use radiant heat, so storing CNG vehicles would have required upgrades to explosion-proof heating (and other) equipment.

6.3.5 Fueling infrastructure

The DOT operates 200 fueling stations across the state. The fleet representative mentioned that cleaning the fuel tanks is important. It was also stated that switching back-and-forth between biodiesel blends and diesel is not recommended.

6.3.6 Costs

Fuel prices were not discussed.

6.3.7 Future Plans

The DOT is interested in the potential of hydrogen fuel for fuel cell electric vehicles (FCEVs). The fleet met with the Stark Area Regional Transit Authority (SARTA) in Canton, OH and observed the fleet's six FCEV buses. The DOT felt that FCEV technology could provide the required driving range/operating time for DOT winter maintenance duty cycles.

6.4 CITY OF AMES, IA

Fleet contact: Rich Iverson, Fleet Support Manager

6.4.1 Fleet Description

The City of Ames, Iowa is a progressive community regarding sustainability initiatives. The City's Public Works fleet consists of 40 Class 5, 6 and 7 trucks, many of which are called on for snow plowing duty during the winter and dump truck duties otherwise. Currently, 12 Class 6 and 7 trucks have the Optimus Technologies Vector System (described in the *OEM Interviews* section) installed that allow the trucks to operate on 100% biodiesel (for most of the operation) year-round, even in subzero temperatures. All of the trucks running B100 are International brand trucks; 10 with Cummins L9 diesel engines and two with Navistar N9 diesel engines.

6.4.2 Alternative fuel selection and conversion criteria

The City has operated its medium-duty diesel trucks on 20% biodiesel (B20) since 1997. Biodiesel became readily available to the City in 1997 via the Iowa DOT in part due to a state mandate requiring government-owned diesel vehicles to utilize B20 biodiesel blends. The City's fleet uses B20 for roughly eight months a year, while using B5-B10 during the winter months.

Since 2020 the City has operated trucks with the Optimus Technologies fuel system. Initially a pilot study, five trucks equipped with Optimus Technologies year-round showed tremendous promise. Since then, the fleet has added seven more trucks for a total of 12 operating on B100 year-round.

6.4.3 Alternative fuel experience

The fleet stated that they do not observe a difference in operations for biodiesel blends up to B20 compared to diesel. A lower-level biodiesel blend (averaging B8) is used in the winter to ensure cold flow properties.

The Optimus Technologies B100 system is viewed as a significant success by the City of Ames Public Works Department. The first five trucks had no downtime in the first year, which contributed to the decision to add seven more B100 trucks. The B100 trucks have operated very well and use between 80-90% biodiesel year-round. No work time has been lost due to B100 operation; no warranty issues have been observed, no new engine error codes; and soot in the particulate filter needs to be regenerated less frequently. B100 has a slightly lower energy content, so the fleet has experienced approximately an 7% mpg penalty compared to diesel fuel. This is a negative impact during long snow removal events.

The lower winter biodiesel blends have operated down to -30° F. The Optimus system warms the B100 up to approximately 100° F, so there are likely same or less issues in very cold weather.

Overall, the fleet stated that the Optimus-equipped B100 system is its preferred alternative for diesel trucks.

6.4.4 Vehicle maintenance, training, and storage

The fleet representative stated that the trucks running biodiesel (blends and B100) have lower maintenance than diesel. One reason was because biodiesel has lower particulate matter (PM) which leads to fewer diesel particulate filter (DPF) regeneration cycles, which leads to less DPF maintenance.

The fleet representative stated that the driver training to learn how to operate the trucks equipped with the Optimus Technologies system. The systems' operation starts up/shuts down the system on diesel fuel, so trucks can be stored the in same location as conventional trucks (i.e., outside is fine). Optimus Technologies has performed any necessary warranty/maintenance work, and system service has been minimal. The fleet representative stated that they have had no issues with warranties on the Optimus system.

6.4.5 Fuel and fueling infrastructure

The fleet has experienced no issues sourcing B100 since there are three local biodiesel production facilities within 1.5 hours. As stated earlier, the City gets its lower-level biodiesel blends from the Iowa DOT.

Fuel providers will often assist customers with securing the proper infrastructure for B100 fuel tanks.

6.4.6 Costs

The cost for Ames to equip each of the first five (5) trucks with Optimus Technologies was $12,000. The systems were purchased using a combination of internal funding and grant funding.

The City of Ames gets the same cost for B100 as the diesel rack price.

The fleet's 12,000 gallon heated above ground tank and dispenser cost approximately $100,000 (2020). Ames obtained the same price per gallon for B100 as for diesel during the B100 pilot program. This pricing was in exchange for city data on the trucks to the fuel and provider and Optimus Technologies. The Optimus Technologies fuel system can now be ordered factory installed from several truck manufacturers.

Grants are available for offsetting some of the B100 infrastructure costs. The above ground B100 tank requires heating to maintain temperature and flow properties, which adds some operations costs. The cost to heat higher volumes has a lower cost per gallon.

6.5 HENNEPIN COUNTY, MN

Fleet contact: Jay Baldwin, Fleet Services Manager

6.5.1 Fleet Description

A 2007 Hennepin County initiative gave the fleet the directive to develop and implement a plan to convert the entire fleet to alternative fuels.

Hennepin County's fleet includes 710 total vehicles; 420 are light-duty (LD) up to ¾ ton and 285 are heavy-duty (HD) vehicles. Heavy-duty includes typical medium-duty (over ¾ ton) and higher weight classes which the 80 snowplow trucks are a part.

6.5.2 Alternative fuel selection and fleet conversion criteria

Biodiesel is produced locally so the costs are competitive with petroleum diesel. Biodiesel blends were a logical choice starting in 2011 for the fleet's HD vehicles with diesel engines.

Hennepin County converted all of the HD fleet to biodiesel blends at the same time. This allowed the fleet to continue using the same fuel storage and dispensing infrastructure. The County follows a 10-year purchasing cycle, so the oldest HD vehicles are 2012-13 model year.

6.5.3 Alternative fuel experience

Neat biodiesel (i.e., B100) has a lower energy content than petroleum diesel. However, the energy content of the B20 and B10 blends is low. The Fleet noted that vehicle operators do not notice difference in power or torque for driveline or PTO use in the on-road vehicles. The U.S. Environmental Protection Agency Tier 4 engines in the off-road assets also use biodiesel blends and have performed well.

The fleet uses approximately 125,000 gallons of biodiesel per year. In warmer months an average of 80,000 gallons of a typical B20 blend (20% biodiesel + 80% No.2 diesel) is used. In colder months an average of 45,000 gallons of a typical B10 winter blend (10% biodiesel + No.2 diesel + No.1 diesel + cold weather additives) is used. A very cold day in Hennepin County is approximately -20°F (or -50°F with wind chill) and the B10 winter blend has performed very well, and there have not been any fuel-related issues.

Hennepin County noted that the experience with biodiesel has been very good. This is also reflected in the 11 years of continued use.

The fleet currently removes winter maintenance equipment (e.g., snowplows) from 30-40 HD trucks to use for off-season purposes to improve vehicle utilization and reduce the fleet size. The fleet noted that it takes approximately 2-4 hours to remove/reinstall the equipment on each vehicle. The fleet is also evaluating additional options to further reduce the fleet size and improve sustainability.

6.5.4 Vehicle maintenance, training, and storage

County vehicle maintenance staff were trained on the nuances of biodiesel use and maintenance. The County has not experienced any unexpected vehicle maintenance challenges. Following the 2007 fuel switch, the fleet increased the frequency of fuel filter changes (fuel storage tanks, dispensers, and vehicles) which was anticipated for this switch. After the initial fuel tank/fuel line cleaning effect maintenance has involved just normal operations.

6.5.5 Fueling infrastructure

Hennepin County uses the same biodiesel blends in all of their HD vehicles. The result is a separate fuel storage tank and dispenser is not needed. The fleet performs normal preventative maintenance (PM) on fueling islands, dispensers, etc. in the fall.

6.5.6 Costs

Biodiesel is produced locally so fuel availability is not a concern. The County buys fuel off the State contract. The States Fuel Consortium Program, for participants located in the nine-county metropolitan area, utilizes a fixed fuel program pricing to hedge against the cost of fuel on an annual basis. Approximately 90% of the county fuel is purchased on this contract with 10% of fuel purchased at the prevailing spot prices.

The contract requires the fleet to take 100% of the committed monthly fuel amount at the fixed price contracted. This brings a challenge of accurately estimating the volume needed.

6.5.7 Future Plans

The County does not plan to increase the biodiesel blend percentage in its HD fleet from the current B20 (B10 in winter).

In 2021, Hennepin County adopted a Climate Action Plan that includes a goal of achieving net-zero carbon emissions by 2050 in the county's fleet by 2050, with interim goals of: 1) decreasing greenhouse gas emissions 30% by 2030 and 2) converting a minimum of 20% of the county's light-duty fleet vehicles to electric and 50% to hybrid by 2030.

The county fleet is on their way in achieving that goal with a current inventory of 24 hybrid and eight electric vehicles and have 33 additional hybrid vehicles and 25 EVs on order. This resulted in the total expected hybrid and electric vehicle count of 90, or 22% of the light-duty fleet. In 2023, plans are to order an additional 20 hybrid and 26 electric vehicles. Once all the vehicles arrive, the total light-duty hybrid and electric vehicle inventory will be 136, or about 32% of the total inventory.

In 2019, the County partnered with the University of Minnesota on a research study to examine the use of CNG as an alternative vehicle fuel to diesel, and then conducted a general cost comparison between CNG-fueled and electric vehicles (EVs). The report showed that CNG was not cost effective and with the maturation of heavy-duty EVs expected to continue, these are the more likely candidates to replace diesel vehicles.

6.6 WASHINGTON D.C., DEPARTMENT OF PUBLIC WORKS

Fleet contact: Jason Nordt, Fuel Management Officer

6.6.1 Fleet Description

The Washington D.C., Dept. Of Public Works (DC DPW) has several on-going sustainability vehicle programs for a variety of trucks, partially due to several alternative fuel vehicle mandates that must be followed. The fleet uses electricity (light-duty fleet), natural gas, and biodiesel for alternative fuels.

The DC DPW is responsible for the maintenance of 3,000 light-, medium-, and heavy-duty vehicles that are owned by the City. DC DPW's fleet includes 1,000 vehicles. Their snow plowing fleet consists of Ford F-550 trucks and Freightliner M2 106 MD/HD trucks (quantity 96 of M2 106). Additionally, the fleet operates over 100 refuse collection trucks.

6.6.2 Alternative fuel selection and conversion criteria

The City must comply with the Energy Policy Act (EPAct) which includes alternative fuel vehicle and fuel use. Because of this, DC DPW management uses EPAct as a guide to develop its alternative fuel program. The fleet's biodiesel fuel program began 10 years ago using B5 fuel initially. Since then, B20 fuel is also used. In 2017, the fleet began a pilot program which required several refuse trucks to have the Optimus Technologies fuel system (described in the *OEM Interviews* section) installed.

The refuse truck fleet includes four compressed natural gas (CNG) trucks. The fleet plans to replace the refuse trucks with electric trucks in the future. The fleet does have experience with electric vehicles in their light-duty fleet and have chargers installed on the property.

6.6.3 Alternative fuel experience

As previously mentioned, the fleet has not experienced any significant operational issues with CNG in winter or otherwise. However, the fleet is moving away from CNG fuel due to the expense of infrastructure and a vehicle productivity loss due to decreased fuel economy compared to diesel.

Regarding biodiesel, there were initially winter fuel gelling problems when the B20 program began, both with the vehicle and stationary tanks. These issues have been solved. The fleet uses B5 in the winter months (November - April).

Since installing the Optimus Technologies system (using B100) there have been few problems. The system is operational to an ambient temperature of -20° F. It is key to provide driver training. Using OEM vehicle training for both operation and fuel dispensers is essential to establish success. The fleet representative stated that it is quite helpful to conduct pilot vehicle programs since a small number of vehicles can first be studied and analyzed to understand the impacts of a fuel change. The Optimus system also provides redundancy because the truck will operate normally on diesel fuel if there ever was an issue with the B100 system.

6.6.4 Vehicle maintenance, training, and storage

The truck must reach operating temperature prior to use of the Optimus Technologies Vector System. The fleet representative noted that the B100 trucks have not had any issues. However, they mentioned that B100-specific fuel filters are needed.

Drivers must be trained to properly start and stop the B100 vehicles each day. Continued communication is needed to remind drivers.

6.6.5 Fuel and fueling infrastructure

The City owns operates two CNG stations. One station is only for refuse trucks, the other services the remaining CNG fleet.

Currently the DC DPW has three, leased 2,000-gallon B100 tanks located at three different locations. The tanks use a heated blanket to maintain the fuel temperature at approximately 75° F. The fleet stated they B100 is available but takes more effort and cost because it is not available from the local Port of Baltimore. Because of this, DC DPW's B100 fuel is delivered by truck from the Midwest. After a fuel order is placed it arrives in approximately three (3) days (seven [7] days has been the maximum).

6.6.6 Costs

The City owns operates two CNG stations, but the infrastructure is too costly for the low number of vehicles the City operates. B100 biodiesel fuel is approximately 20% more expensive than diesel and has followed the same price trend as diesel.

6.6.7 Future Plans

The fleet plans to add more B100 truck as well as heavy-duty electric vehicles, including street sweepers that have been ordered.

6.7 FOREST PRESERVE DISTRICT OF DUPAGE COUNTY (IL)

Fleet contact: Drew Bergenthaw, Fleet Specialist, Fleet Management Division

6.7.1 Fleet Description

The Forest Preserve District separated from the County 10+ years ago. The 177-vehicle fleet is a mix of light-, medium-, and heavy-duty vehicles, as well as additional offroad equipment. Because of the type of work, employees usually drive to a site, park their vehicles, do their work, and return to the garage. Snow plowing is done with 54 plow vehicles: Peterbilt 337/348 (PACCAR/Cummins engines) and some GM 7500. The preserve district does not include any major roads.

6.7.2 Alternative fuel selection and conversion criteria

The Forest Preserve District leadership set a goal to eliminate gasoline use in 2001. The organization's mission is environmental focused, so achieving cost parity is not necessarily the top criteria for fuel and vehicle selections.

6.7.3 Alternative fuel experience

The fleet operates a wide range of alternative fuels/powertrains: B20, E85, liquefied petroleum gas (LPG), compressed natural gas (CNG), electric, and hybrid-electric. Park Rangers run Ford F-250 bi-fuel (LPG or CNG/gasoline) trucks. The fleet representative mentioned that they have had better experience with bi-fuel LPG than bi-fuel CNG. An early bi-fuel CNG vehicle had system controller issues on fuel switchover which resulted in clogged fuel rails. The cause was design-related, not a fuel quality or maintenance reason. Later more developed systems did not have this issue.

Heavier medium-duty/heavy-duty trucks (including plowing operations) run B20 during the warmer months and B11 during the winter months. An exception is one Ford F-550 that uses a Roush dedicated LPG system that is also used as a snowplow that has performed well.

The fleet had vehicles from a variety of smaller conversion companies. They had issues with some of these small equipment companies going out of business or not being able to properly support the product. Current suppliers (including Prins) are more reliable and have had good performance.

The fleet's preferred path is bi-fuel because of operational redundancy. Biodiesel blends (e.g., B20) serve a similar redundancy role for diesel engines.

The fleet representative noted having no issues with B20 in its Cummins engines vs. diesel. They felt that using B20 results in better DPF regens and lower maintenance compared to diesel.

6.7.4 Vehicle maintenance, training, and storage

The fleet's maintenance technicians are ASE-trained and are certified to do LPG bi-fuel installations and to do CNG/LPG maintenance. All of the shops are properly equipped to service CNG/LPG vehicles.

Using bi-fuel requires driver training to ensure they use the alternative fuel and do not manually switch over to the conventional fuel (e.g., gasoline). The fleet runs monthly fuel reports and can identify when alternative fuel use is not meeting the goals. The fleet's approach to handling the situation is to remind the driver that it is the fleet policy to use the alternative fuel as much as possible.

6.7.5 Fuel and fueling infrastructure

The fleet operates two fueling stations. Location 1 has B20, E85, LPG, CNG, and electric fueling. Location 2 has LPG/propane, CNG, and electric fueling.

B20 is easy for the fuel to source. B20 cost is similar to diesel, maybe even less sometimes.

The CNG station operation is costly, so maximizing the number of CNG vehicles results in higher natural gas fuel use which results in a lower effective fuel cost (accounting for station operations costs).

6.7.6 Costs

The fleet representative mentioned that their LPG currently costs approximately $1.79/gallon ($2.42/gasoline gallon equivalent; $2.70/diesel gallon equivalent). LPG vehicles can fuel up locally if needed at Menards, but the fuel cost is 1.5 to 2.0 times higher than at the fleet depot.

6.7.7 Future Plans

The fleet is moving away from CNG. The future plans include continuing with bi-fuel LPG and biodiesel, considering increasing the biodiesel blend percentage (above B20), and adding electric vehicles.

6.8 LESSONS IDENTIFIED

This section highlights the key lessons identified from the interviews and by comparing input across interviews.

6.8.1 Alternative fuel selection and conversion criteria

Many fleets focused on a single alternative fuel, of which biodiesel was the most common. A few had used CNG in the past but have moved away from CNG because of total operating cost, including fueling stations.

One fleet (that also included light-duty in the discussion) stated “Don’t put all of your eggs in one basket...” referring to the risks of using a single alternative fuel, a single vehicle or fuel system manufacturer or a single vehicle model. Using multiple systems adds complexity, but if an issue arises it will not impact the whole fleet. This has been successful for the fleet but may not be suitable for other fleets.

For one fleet bi-fuel is their preferred path for light-duty pickup trucks because of operational redundancy. B20 in diesel vehicles achieves the same goal.

One fleet representative stated that it is quite helpful to conduct pilot vehicle programs since a small number of vehicles can first be studied and analyzed to understand the impacts of a fuel change.

6.8.2 Vehicle maintenance and training

Maintenance

- Biodiesel has lower particulate matter (PM) which leads to fewer diesel particulate filter (DPF) regeneration cycles, which leads to less DPF maintenance.

- Trucks using biodiesel blends (up to B20) follow the same preventative maintenance schedules as diesel. Several fleets stated no maintenance issues with B5-B20 usage occur if proper preventive maintenance practices are followed.

Training

- Maintenance technician and operator training is key. Manufacturer demonstrations and training are great resources, when available.

- It is key to provide driver training. Using vehicle manufacturer training for both operation and fuel dispensers is essential to establish success.

6.8.3 Low and no GHG fuel options currently widely available

Current low and no-greenhouse gas (GHG) fuel options with medium and heavy-duty truck applications that are widely available include biodiesel, NG, and LPG.

Biodiesel – Fuel delivery to customer is by truck, like other petroleum fuels. This is a liquid fuel. B100 reduces the tailpipe carbon emissions by 100% and lifecycle carbon emissions by 70-80% with current feedstocks and production processes. Biodiesel blends (with petroleum diesel) up to B20 are relatively easily accomplished at low cost. B100 is usable with specific fueling systems. Requires a fuel storage tank and dispenser. Requires either tank turnover to biodiesel (if all vehicles/equipment use biodiesel) or install a new tank. Tank hygiene and dispenser maintenance is important. B100 tracks the same index as petroleum diesel, so the fuel cost difference ($/gallon basis) is typically approximately 5% higher compared to diesel. There is currently a federal tax credit for biodiesel, that the blender/refiner may pass along all/some of the savings to the customer. Biodiesel can be less expensive than petroleum diesel in states with low carbon fuel standard (LCFS) credits.

Property – Biodiesel	**Description**
Form	Liquid
Delivery	By truck
Sustainable benefits	All blends reduce GHG emissions. B100 reduces tailpipe carbon emissions by 100% and lifecycle carbon emissions by 75-80%.
Conversion requirements	None for vehicle. Increased frequency of fuel filter swap at initial swap over (vehicle, storage, and dispensing). A new fuel storage tank and dispenser may be needed if all vehicles not swapped over.

Cost	Tracks diesel. On average 5% higher than diesel, but prices vary
Advantages	Drop-in fuel, only minor maintenance at switch over
Disadvantages	GHG reduction benefits scale with biodiesel blend percentage
Incentives	Refiner credit may be passed on. LCFS credits available in certain states.

Natural Gas (NG) – Fuel delivery to customer is by pipeline. CNG cost per diesel gallon equivalent (dge) is much lower than petroleum diesel. Fueling infrastructure (compression, storage, and dispensing) is expensive, and can be built inhouse or contracted out.

Property - NG	**Description**
Form	Gas
Delivery	Gas pipeline to fuel station. Fueling station with compressor and high-pressure storage and dispensing
Sustainable benefits	Reduces tailpipe carbon emissions by 15% and lifecycle carbon emissions by approximately 15%
Conversion requirements	Needs engine designed for NG. Fuel infrastructure required for filling station.
Cost	Operational fuel savings of approximately 50%, but significant capital cost for fuel station
Advantages	Proven engine technology. Operational fuel savings; simpler engine exhaust aftertreatment system compared to diesel
Disadvantages	Infrastructure costs are high, limited availability of public stations. Potentially somewhat higher maintenance costs than diesel. Limited GHG reduction

Property - NG	Description
Incentives	Potentially vehicle purchase incentives

<u>Liquefied Petroleum Gas (LPG) –</u> Fuel delivery to customer by truck, like other petroleum fuels. Gaseous fuel but stored as a liquid at relatively low pressure (100 psi). Requires a cost-effective fuel storage tank and dispenser. There is excess supply of LPG in the U.S. which has provided relatively low and stable fuel cost.

Property - LPG	Description
Form	Transported and stored as liquid
Delivery	Transported, stored, and dispensed as liquid 100 psi. Protective clothing for fueling required.
Sustainable benefits	Reduces tailpipe carbon emissions by 15% compared to diesel
Conversion requirements	Needs engine and fuel system designed for LPG. Fuel infrastructure required for filling station
Cost	Operational fuel savings of 30%. Fueling infrastructure relatively low cost.
Advantages	Proven engine technology. Operational fuel savings; simple engine emission equipment compared to diesel. Infrastructure costs are low.
Disadvantages	Limited GHG reduction
Incentives	Potentially vehicle purchase incentives

6.8.4 Low and no GHG fuel options with limited/increasing availability

Other fuels that are available but not widely include electric, RD, RNG, and rLPG.

Electric – Having available power, or adding capacity, at fleet depot may be a concern, especially in rural areas. Power requirements will be higher if operations require simultaneously high-power fast charging multiple vehicles (e.g., snowplows between shifts). Integrated stationary battery options are available to manage utility infrastructure upgrades. In these cases, charging station power comes from both the grid and battery, and the battery is charged when the trucks are in-service.

Property - Electric	**Description**
Form	Stored in battery
Delivery	Utility lines to facility. Charging stations to vehicles; AC Level 2 (6.6-19.2 kW) or DCFC (50-350 kW) with CCS1, CCS2, or proprietary plugs
Sustainable benefits	BEV has zero tailpipe GHG
Conversion requirements	Needs vehicle designed for BEV, PHEV, or HEV. Charging infrastructure required.
Cost	BEV fuel savings is variable depending on electric rate (can be 20% of diesel). Significant capital cost for vehicles and charging stations.
Advantages	Operational fuel savings and zero emission. High-power DCFC can provide quick charges.
Disadvantages	Infrastructure costs are high, High vehicle costs and limited availability. High power charging equipment may require expensive electrical/utility upgrades and result in high electric bills (demand charges). Lengthy charge times if using low-powered charging equipment.
Incentives	Significant vehicle incentives available; varies by state. Utilities deploying EV charging-specific tariffs.

Renewable Diesel (RD) – Fuel delivery to customer by truck, like other petroleum fuels. Liquid fuel. Drop-in diesel fuel replacement (meets ASTM D975). Using RD can reduce the lifecycle well to wheels greenhouse gas (GHG) emissions by up to 75% compared to petroleum diesel. Same storage and dispensing equipment. RD production is controlled in a tight window (isomerization). The production process engineers in cold weather properties. A -20° C cloud point is typical. Lower cloud points are possible by design rather than adding cold flow additives. RD has a near-zero ash content which contributes to lower particulate matter production and slightly improved DPF performance. RD is very stable. It can be stored for many years if stored properly. RD is even a candidate for peak operation such as winter operations. Because of current high production cost, availability will likely be regional with programs and policies that enable them (LCFS).

Property - RD	**Description**
Form	Liquid
Delivery	Truck
Sustainable benefits	Reduces tailpipe carbon emissions by 100%
Conversion requirements	None, true drop-in fuel. Meets ASTM Standard 975. Can be blended with petroleum diesel.
Cost	Currently 2x the cost of petroleum diesel.
Advantages	Proven engine technology. True drop-in fuel. Reduces carbon intensity by 65% compared to petroleum diesel
Disadvantages	High fuel cost and limited availability; currently only available in states with LCFS programs.
Incentives	LCFS credits available in certain States.

Renewable Natural Gas (RNG) – Fuel delivery to customer by pipeline, so fuel availability is certain. Same fueling infrastructure as conventional petroleum natural gas. RNG can be used in any NG engine. RNG's very low carbon intensity means that fleets technically may not have to convert as many vehicles to meet organizational GHG goals (e.g., -328 CI vs. 30% GHG reduction goal). RNG production does not have to be in the same state as where RNG is used. RNG production sites do not need to be in the LCFS states. In both cases, there must be a certified RNG pathway between production and use. An "RNG nomination" process is used to justify/ensure that RNG would be available in the station and that the LCFS credits are allocated properly. Because of current high production cost (normally 2-4 times the cost of petroleum diesel fuel) and availability will likely be regional with programs and policies that enable them (LCFS).

Property - RNG	**Description**
Form	Gas
Delivery	Gas pipeline to fuel station. Fueling station with compressor and high-pressure storage and dispensing
Sustainable benefits	Reduces tailpipe carbon emissions by 100%. Net lifecycle is >100%.
Conversion requirements	Needs engine designed for natural gas.
Cost	Operational fuel cost is more expensive than conventional natural gas and potentially diesel.
Advantages	Significant GHG benefit. Proven engine technology. Simpler engine exhaust aftertreatment system compared to diesel.
Disadvantages	High fuel costs. Infrastructure costs are high, limited availability of public stations. Potentially somewhat higher maintenance costs than diesel.
Incentives	LCFS credits available in certain states, if a certified pipeline pathway for the gas is established

<u>Renewable Liquefied Petroleum Gas (rLPG)</u> – Drop-in LPG fuel replacement for LPH engines. The rLPG carbon intensity is 30, versus 80 for conventional petroleum LPG. ROUSH stated that there is currently not a large cost differential for rLPG versus conventional LPG.

Property - rLPG	**Description**
Form	Transported and stored as liquid

Delivery	Transported, stored, and dispensed as liquid 100 psi. Protective clothing for fueling required.
Sustainable benefits	Reduces tailpipe carbon emissions by 30% compared to diesel
Conversion	Needs engine designed for LPG. Fuel infrastructure required for filling station.
Cost	Operational fuel savings of 30%. Fueling infrastructure relatively low cost.
Advantages	Operational fuel savings; simple engine emission equipment compared to diesel. Infrastructure costs are low. Incremental fuel cost (over LPG) is currently low.
Disadvantages	Fuel availability is currently low
Incentives	LCFS credits available in certain states

6.8.5 Currently available low or no-GHG vehicle fueling system options

Current widely available lower-/no-GHG vehicle fueling system options with medium-to heavy-duty truck applications include biodiesel, CNG/RNG, and LPG/rLPG.

Biodiesel – It is used in the base diesel engine, so no incremental vehicle cost. Biodiesel blends up to B20 are frequently relatively easily accomplished at low cost. Lower blends like B10 are frequently used in cold weather. Using B100 for the majority of a truck's operation is also achievable for the Optimus Technologies system described in the body of the report. The total petroleum use/GHG reduction for this system is decreased some due to the start-up and shut down on petroleum diesel. For all biodiesel blends, regular maintenance includes fuel filter swaps. Technician training, diagnostic tools, and shop infrastructure are also the same as diesel.

CNG/compressed RNG – Both are used in heavy-duty spark-ignited engines designed for NG. Cummins is the dominant engine supplier with a range of engine displacements (6.7L-15L). Cummins mentioned that the 15L contains several product improvements to increase reliability. These design improvements will trickle down to the smaller displacement engine products to improve performance and reliability. Reliable CNG fuel systems are available for these engines from a few manufacturers. The fuel system incudes composite fuel tanks, system controllers, and fuel lines to connect to the engine. Incremental vehicle cost is between $20k-$60k and varies by vehicle and engine size and fuel capacity. Similar maintenance, tools, and training as diesel, though NG does have some additional maintenance and more frequent preventative services compared to diesel. CNG-specific technician training is needed. Some NG-specific diagnostic tools are needed. The shop and garage need to be properly equipped to service and store CNG vehicles. CNG maintenance facility upgrades, and best practices are well known and documented. NG fuel is lighter than air, so rises if there is a leak. The fuel has an odorant and the facility needs sensors to monitor air quality and to communicate any fuel leaks.

LPG/rLPG – Both are used in spark-ignited engines designed for LPG. The fuel systems incudes steel fuel tanks, system controllers, and fuel lines to connect to the engine. Fuel tanks are less expensive than CNG and compressed hydrogen because of the much lower storage pressure. Incremental vehicle costs are in the $15k-$25k range and varies by vehicle and engine size and fuel capacity. Similar maintenance, tools, and training as diesel, though LPG does have some additional maintenance and more frequent preventative services compared to diesel. Liquid fuel injection provides a higher power density compared to gaseous LPG systems. This enables the engine to deliver equivalent power and torque as the base gasoline engine. The provides the same performance to the operator as a gasoline vehicle. The shop and garage need to be properly equipped to service and store LPG vehicles. LPG maintenance facility upgrades, and best practices are well known and documented. LPG fuel is heavier than air, so sinks if there is a leak. The fuel has an odorant and the facility needs sensors to monitor air quality and to communicate any fuel leaks.

The importance of customer education to ensure the base vehicle is properly specified/equipped was mentioned for all fuel and powertrain options to ensure the complete vehicle package meets the fleets' duty cycle.

Other options that are available but not widely include BEV.

BEV – Limited and ramping up full production trucks are available. Limited current availability and not many in typical DOT vehicle chassis. BEV availability will expand across manufacturers and truck models. Current battery warranties are in the 6-year/200,000-mile range. One OEM mentioned they use lithium iron phosphate battery (LFP [lithium ferro-phosphate]) chemistry type lithium-ion batteries. LFP was selected because of its better durability and high-power charging capabilities versus other lithium-ion battery chemistries. LFP's improved safety is valued by both customers and insurance companies. The BEV base vehicle weight penalty (reduces available equipment and load capacity) and long in-service hours and lack of packaging space may make BEVs a challenge for vocational truck applications. Higher energy density batteries may help improve packaging, available load capacity, and driving range. ePTO is a known need. Current ePTO are low power (~10kW), but higher power ePTO are being developed. ePTO will likely have connection options (e.g., AC plug, DC plug or AC PTO motor) to provide flexibility for equipment selection.

6.8.6 Developing no-GHG fuel options

A developing no-GHG fuel option with medium-/heavy-duty truck applications is hydrogen.

Hydrogen – Fuel delivery to customer is by truck, like other petroleum fuels. Steam methane reforming is one current process used to produce hydrogen. One company mentioned that this method is not sustainable due to its high-cost and high-carbon intensity. Better, more energy efficient processes are also available.

Property - Hydrogen	**Description**
Form	Gas
Delivery	Currently by truck. Fueling station with compressor and high-pressure storage and dispensing.
Sustainable benefits	Reduces tailpipe carbon emissions by 100%.
Conversion requirements	Needs engine designed for hydrogen.
Cost	Operational fuel cost is currently more expensive than conventional natural gas and potentially diesel.
Advantages	Significant GHG benefit. Likely simpler engine exhaust aftertreatment system compared to diesel.
Disadvantages	High fuel costs. Infrastructure costs are high, limited availability of public stations. Unknown maintenance compared to diesel.
Incentives	LCFS credits available in certain states

6.8.7 Developing no-GHG vehicle/fueling system options

Developing no-GHG vehicle/fueling system options with medium to heavy-duty truck applications include: HFCEVs and HICE.

Hydrogen Fuel Cell Electric Vehicles (HFCEVs) – One truck OEM demonstrated a small number of trucks to evaluate potential long-haul truck options. The results were encouraging, and a production version of the powertrain is being evaluated. The earliest a production version could be available in a Class 8 tractor configuration is 2025. One truck OEM stated that HFCEVs are a better option for long-distance truck routes with high average daily miles (≥300 miles). For DOT winter roads maintenance trucks this could be interpreted as long duty cycles between fueling (e.g., snow events) Another truck OEM stated that HFCEVs will likely not be offered in vocational trucks. The reason was not stated, but is likely due to powertrain cost, system weight, packaging on a vocational/DOT truck, reduce load capacity, and the amount of fuel used (strong contributor to payback).

Hydrogen Internal Combustion Engine (HICE) – Used in spark-ignited engines designed for hydrogen. Cummins and others have stated development work. Cummins introduced HICE engines in the 6.7L and 15L displacement, with production starting in the 2027 timeframe. Another truck/engine OEM mentioned investigating HICE, but no production decisions have been made.

6.8.8 Fuel, fueling infrastructure, and costs

On-premise depot fueling enables lower fuel costs and fuel availability certainty versus relying on others.

Fueling infrastructure (storage and dispensing) for liquid fuels (i.e., diesel, biodiesel, gasoline, and LPG) is cost-effective.

Outdoor aboveground storage tanks for biodiesel blends (e.g., B20) require cold flow additives to maintain flow properties, but do not require heating.

Tank heating (typically resistance heater blankets) is required for outdoor above ground B100 fuel storage to maintain flow properties.

Biodiesel fuel costs in regions where fuel is produced (e.g., Midwest) tend to be similar to diesel fuel, but not always. Transportation costs for fuel delivery to locations further from the production facilities can add a significant cost.

Several fleets mentioned the importance of tank cleaning. One fleet representative stated that twice a year all tanks are cleaned, polished and have new filters installed. Fuel samples are recorded before and after each cleaning. This fleet felt this process was a necessity for maintaining fuel infrastructure performance.

Operation of a CNG station is costly, so maximizing the number of CNG vehicles results in higher natural gas fuel use which results in a lower effective fuel cost (accounting for station operations costs).

6.9 RECOMMENDATIONS

24. Stay aware of the quickly evolving industry, both vehicles and fuel. Learn from manufacturers, fuel providers, and multiple peer organizations.

25. Conduct a pilot vehicle program to collect and analyze data to understand the impacts of a fuel change prior to full-scale adoption.

26. Understand and follow the preventative maintenance schedule for each fuel and stay current on practice updates.

27. Use on-premises depot fueling infrastructure (storage and dispensing) for liquid fuels as it is cost-effective and provides fuel certainty.

CHAPTER 7: OEM SUMMARY OF CURRENT AND FUTURE AVAILABILITY

7.1 PURPOSE

This report summarizes the process to conduct, and the results of, an industry outreach study to learn about current and projected low- and zero-carbon powertrain and fuel options available for heavy-duty vehicles that could support State Department of Transportation (DOT) operations.

The project team compiled a list of leading related companies including medium-/heavy-duty truck and engine manufacturers, medium-/heavy-duty truck engine manufacturers, fueling system manufacturers, electric vehicle charging equipment/service providers, and alternative fuel producers/providers. The term original equipment manufacturer (OEM) is used in this report to describe the manufacturer of vehicles, engines, and fueling systems. Additional connections were made during the process from interviews and other pathways which added organizations to the contact list. The list below includes the organizations interviewed:

- Medium-/heavy-duty truck and engine manufacturers
  - Navistar
  - PACCAR (Kenworth and Peterbilt brands)
- Medium-/heavy-duty truck engine and powertrain suppliers
  - Cummins
- Fueling system manufacturers
  - Optimus Technologies
  - ROUSH CleanTech
  - Cummins Clean Fuel Technologies
- Alternative fuel producers/providers/industry organizations
  - Neste
  - Clean Energy Fuels

Many organizations were contacted but did not respond to multiple requests. This included electric vehicle charging equipment providers and charging network service providers.

The primary information collection method was phone or web conference interviews using the Clear Roads project Technical Advisory Committee (TAC) approved interview guide. The following interview questions were used to guide the conversation:

1. What lower-carbon powertrain/vehicle options does your company offer? (e.g. electric, propane/liquefied petroleum gas (LPG), natural gas (NG), hydrogen, biodiesel). In what vehicle classes/configurations? What is the carbon comparison of your solution(s) to diesel?

2. Can you share the types, models, availability, list price, estimated incremental cost, and total cost of ownership for these lower-carbon vehicles? Are these vehicles widely available, in limited geographic areas, in limited numbers?

3. Are there any low-carbon vehicle options that you do NOT recommend for winter roads maintenance?

4. How do the low-carbon vehicle/powertrain options compare to diesel with respect to power, torque, maintenance, reliability, and durability? Do you have concerns with snow removal's corrosive and cold working environment?

5. What are the challenges (operational, maintenance, and business) to implement your low-carbon vehicle solution(s)? Thinking about cold climate conditions and high equipment usage during winter maintenance operations, are there additional challenges to operate your low-carbon vehicle solution(s)?

6. Are there specific fuel storage/fueling challenges with your low-carbon vehicle solution(s), either operational or business-related? Will fleets need an outside vendor for ongoing onsite fueling operations? Is the fuel available nationally? What is a typical fueling time?

7. What facility upgrades are needed for vehicle maintenance, fueling, and/or storage?

8. Are there maintenance challenges with your low carbon vehicle solution? Can fleets do their own maintenance on low carbon vehicles (preventative maintenance and repairs)? Are the warranties the same as for diesel?

9. What will happen to batteries at the end of life (battery and vehicle)? Will this be an end-user or manufacturer responsibility?

10. Are there any concerns with the power take-off (PTO) demands for vehicle-attached equipment for the low-carbon options?

11. What additional low-carbon vehicle/fuel type offerings that would support winter roads maintenance do you expect to commercialize over the next five years?

A summary was developed for each interview. The initial draft of each was shared with the interviewee(s) to ensure accuracy and that no sensitive information was included. The interview summary for each organization is included as a separate section. Some of the interviewees could not delve into the required technical details and those summaries are a higher-level overview of the product. A summary of the key lessons identified is located at the end of this report section.

7.2 NAVISTAR

Company type: Medium and Heavy-Duty Trucks & Buses

Contact: Scott Metroff, Vocational Sales Director

7.2.1 Zero- or low-greenhouse gas (GHG) options

Navistar provides trucks in the Class 4-8 range with their International Truck brand in the U.S. Their current diesel vocational trucks are aligned well with typical State DOT heavy-duty truck specifications. The diesel engines offered by class are as follows:

- Class 4-5 – International 6.6L and Cummins 6.7L
- Class 6-7 – Cummins B6.7 and 9.0L
- Class 8 – International A26, Traton (Navistar's parent company) S13 (in 2023) and Cummins ISX

Navistar's current low greenhouse gas (GHG) powertrain options include the use of biodiesel blends up to B20 (i.e., 20% biodiesel and 80% petroleum diesel) in its diesel engine products as well as battery electric vehicle (BEV) International eMV Class 6/7 trucks. Navistar does not currently offer a Natural Gas (NG) option. The company mentioned that it is investigating hydrogen internal combustion engines (HICE), but no production decisions have been made. HICE are similar to NG-fueled engines but are fueled by gaseous hydrogen (typically stored compressed at high pressure). Since hydrogen fuel has no carbon, the tailpipe emissions are zero-GHG. Other tailpipe emissions such as Nitrogen Oxides (NOx) and particulate matter will require exhaust aftertreatment solutions.

Navistar sees its current battery electric (BEV) trucks as being the best fit for distribution routes. The eMV BEV trucks are assembled on the main production line, so are full production models. The eMV vocational trucks do not currently offer an electric PTO (ePTO). The company expects an ePTO to be available by Q2 2023. The BEV trucks are available nationwide, but Navistar will ensure that the truck will meet the fleet's application and that local service (dealer, service, training, install charging, etc.) is available. The process will be slow but is in line with other medium and heavy-duty truck OEMs.

Navistar anticipates that the first International BEV day cab tractors will become available in 2024. The company mentioned that the BEV base vehicle weight penalty (reduces available equipment and load capacity) and long in-service hours and lack of packaging space make BEVs a challenge for vocational truck applications. Higher energy density batteries may help improve packaging, available load capacity, and driving range.

The company mentioned that 2030 seems to be the target date when approximately 50% of its annual truck production will be BEV. It is likely, however, that DOT winter roads relevant trucks will only become available sometime after 2030.

Hydrogen fuel cell electric vehicle (HFCEV) powertrains include both a hydrogen fuel cell and smaller capacity battery pack than a BEV truck. HFCEV long-haul tractors are in development and may be available after 2025. HFCEV powertrains will likely not be offered in vocational trucks.

7.2.2 Service and support

Powertrain service for the current (first generation) of Navistar BEV trucks will be done at Navistar dealers.

7.2.3 Warranty

The battery pack has a five-year, 100,000-mile warranty. Navistar may update the terms if ePTO is used.

7.2.4 System cost

The International eMV Class 6-7 vocational BEV truck base list price is approximately $260,000 without the body installed. Incentives are typically available to help reduce the initial cost. A comparable base diesel truck list price is in the range of $120,000 to $140,000.

7.2.5 Fuel cost

Electricity costs will depend on utility rates at the customers' location.

7.2.6 Winter roads cold and corrosive operations

The BEV trucks are undergoing final winter testing this year to determine their cold weather performance including driving range. Lab-based corrosion testing results were good. Navistar is looking forward to real-world and long-term usage data to compare and learn from.

7.2.7 Charging infrastructure

Navistar's consulting division, NEXT eMobility Solutions, works with customers to understand the customer's application, perform route analyses, and perform a charging system analysis to understand the operation and charging requirements. The output is a determination if Navistar's current BEVs makes sense in the fleet's application(s). If BEV makes sense to Navistar and the fleet, Navistar partners with InCharge for the option of the company providing customers with the needed charging solution.

7.2.8 Other topics

Navistar is evaluating options for how to handle with batteries post-end of use (e.g., second use, recycling).

7.3 PACCAR

Company type: Medium- and heavy-duty truck manufacturer

Contact: Alec Cervenka, Zero Emission Sales Manager

PACCAR's North American truck brands include Kenworth Truck Company (Kenworth) and Peterbilt Motors Company (Peterbilt). This interview was with Kenworth staff, but PACCAR's powertrain options are used across both brands.

7.3.1 Current powertrain options

Kenworth's current low or no-GHG powertrain options include compressed natural gas (CNG) liquefied natural gas (LNG), and battery electric vehicles (BEVs). The natural gas (NG) engines and BEV powertrains are available in both medium-duty (MD) and heavy-duty (HD) truck models. The company mentioned that CNG could be a bridge fuel, especially in non-California Air Resources Board (CARB) states.

Production of Kenworth's BEV trucks started in June 2022. PACCAR's BEVs use lithium iron phosphate battery (LFP [lithium ferro-phosphate]) chemistry type lithium-ion batteries. LFP was selected because of its better durability and high-power charging capabilities versus other lithium-ion battery chemistries. LFP's improved safety is valued by both customers and insurance companies. PACCAR currently has a 6-year, 200,000-mile warranty on the battery packs.

The BEV trucks currently have the capability to provide 10 kW of ePTO power or a high-voltage plug/power output.

As of January 2023, the following vehicle types/applications are available. Model availability, load capability, and driving range are expected to expand.

Brand	**Model**	**Powertrain**	**Application/Type**	**Max range**
Kenworth	T680E	Battery electric	HD, Class 8, day cab, drayage, straight truck, regional or short-haul	280
Kenworth	K270E	Battery electric	MD, Class 6, LCOE, straight truck, pickup and delivery	200
Kenworth	K370E	Battery electric	MD, Class 7, LCOE, straight truck, pickup and delivery	200
Kenworth	Various	Cummins natural gas engine	HD, Class 8, day cab, straight truck, short-, regional-, and long-haul, drayage, long-haul	Competitive with diesel

Brand	Model	Powertrain	Application/Type	Max range
Kenworth	Various	Cummins natural gas engine	MD, straight truck, pickup and delivery	Competitive with diesel
Peterbilt	579EV	Battery electric	HD, Class 8, day cab, drayage, straight truck, regional-/short-haul	280
Peterbilt	520EV	Battery electric	HD, LCOE, refuse collection	n/a
Peterbilt	220EV	Battery electric	MD, Class 6 & 7, LCOE, straight truck, pickup and delivery	200
Peterbilt	Various	Cummins natural gas engine	HD, Class 8, day cab, straight truck, short-, regional-, and long-haul, drayage, long-haul	Competitive with diesel
Peterbilt	Various	Cummins natural gas engine	MD, straight truck, pickup and delivery	Competitive with diesel

7.3.2 Potential future powertrain options

PACCAR is involved in both BEV and HFCEV powertrains, include both a hydrogen fuel cell and smaller capacity battery pack than a BEV, as the trucking industry is developing solutions for both short- and long-haul (or operating times). Initial BEV efforts were discussed above, and applications will likely expand. Kenworth vocational BEV trucks are anticipated to be available prior to 2030.

In general, hydrogen fuel cell electric vehicles (HFCEVs) may be a better option for trucks that travel over 300 miles/day. Kenworth partnered with Toyota to produce a small fleet of Kenworth T680 HFCEV demonstrator trucks to evaluate potential long-haul truck options. The trucks used "a pair of 114-kilowatt (153-horsepower) Toyota Mirai fuel-cell stacks and a 12-kwh Toshiba lithium-ion battery pack to store energy for use when maximum power is required".[6] The results were encouraging, and a production version of this powertrain is being evaluated. The earliest a production version could be available in a Class 8 tractor configuration is 2025.

PACCAR is developing higher power (estimated 70-80 kW) ePTO options for Class 7-8 trucks that could serve state DOT winter roads fleets. These ePTO systems could have various power connection options

6 "Voleckner, J., "Toyota and Kenworth to Build 10 Fuel-Cell Semis for LA Power Duty", https://www.greencarreports.com/news/1120765_toyota-and-kenworth-to-build-10-fuel-cell-semis-for-la-port-duty, Green Car Reports, 2019.

(AC plug, DC plug or AC PTO motor) to power vehicle-mounted equipment that could be useful for state DOT winter roads maintenance vehicles such as snowplows, salt spreaders and brine sprayers. This would be applicable to both BEV and HFCEV powertrains.

HICE is also being evaluated by PACCAR's NG engine provider Cummins in U.S.

7.3.3 Winter roads (cold/corrosive) operations

Like diesel powertrains, all PACCAR powertrains are developed for the truck's design envelope and operating conditions.

HFCEV exhaust is water vapor, so freezing concerns will be taken into consideration. This could result in techniques such as pre-warming the system before startup and ensuring that the exhaust is warm enough. PACCAR stated that there is no guarantee that HFCEVs will be operational at the beginning of a shift if they are parked outside in freezing weather. Therefore, inside heated vehicle storage may be required. This is new territory, so development is needed to develop solutions.

7.3.4 Batteries

PACCAR will replace a battery module(s) or entire pack if they need to be replaced during BEV trucks' battery warranty period. PACCAR would refurbish, resell, or recycle the replaced module(s) or pack. At the true end-of-life of the module(s) or pack the modules will be resold or recycled using already developed processes and suppliers. PACCAR described that truck OEMs need to establish the full battery lifecycle to comply with the CARB's Zero-Emission Certification Powertrain Certification (ZEPCert) process.

7.3.5 Charging infrastructure

The PACCAR Parts division provides a service for customers to identify or sell charging station options to ease the transition. The division can also assist with charging infrastructure installation and operations with partners.

7.4 CUMMINS

Company type: Medium-/heavy-duty truck engine and powertrain supplier

Contact: Puneet S Jhawar – General Manager, Global Spark-Ignited Business

7.4.1 Zero- or low-greenhouse gas options

Cummins develops and sells spark-ignited medium to heavy-duty engine products and powertrain solutions. Their spark-ignited engine products currently include compressed natural gas (CNG), renewable natural gas (RNG), LPG (propane), and hydrogen internal combustion (HICE).

Cummins' current generation of natural gas (NG) engines includes the 6.7L, 9L and 12L displacements. Using petroleum-derived NG reduces greenhouse gas emissions by approximately 16% compared to petroleum diesel.

The 15L NG engine is anticipated to be ready for production in late 2023. It will offer the same power levels (400-500 hp) and experience as diesel. The 15L is being packaged to install in the same truck envelope that the current 12L uses. The 15L contains several product improvements to increase reliability. These design improvements will trickle down to the smaller displacement engine products to improve performance and reliability. Cummins anticipates more national adoption of NG engines with the higher power of the 15L and the ability to travel between 1,000-1,200 miles per fuel fill. The use of RNG, rather than conventional petroleum NG, is also rapidly expanding as a low GHG fuel option. RNG is discussed in detail in a later section.

LPG fueled engines are being developed, starting with the 6.7L for Class 4-6 trucks with production as early as 2025.

Cummins introduced HICE engines in the 6.7L and 15L displacements, with anticipated production starting in the 2027 timeframe.7

E85 (85% ethanol and 15% petroleum gasoline) is being considered but is not on the product roadmap.

7.4.2 Service and support

Diagnostic tools are common across the Cummins engine platforms and fuels. Cummins dealers provide full support for all fuel options. Workshop practices for CNG and LPG are well-established and include the requirement to install leak detection sensors in the facility and other upgrades.

Fleets need to understand that there are maintenance differences between diesel and NG engines. Diesel is more forgiving than spark-ignited fuels like NG and LPG.

Fleet shops and garages need to be properly equipped to service and store CNG vehicles. CNG maintenance facility upgrades, and best practices are well known and documented. CNG fuel is lighter than air, so rises if there is a leak. The fuel has an odorant (ethyl mercaptan) and the facility needs sensors to monitor air quality and to communicate any fuel leaks.

7.4.3 Warranty

Cummins has standard warranties for their engine products.

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7 Cummins Inc. Debuts 15-Liter Hydrogen Engine ay ACT Expo, https://www.cummins.com/news/releases/2022/05/09/cummins-inc-debuts-15-liter-hydrogen-engine-act-expo, May 9, 2022.

7.4.4 System cost

Costs were not discussed in this interview, but some information is provided in the Cummins Clean Fuel Technologies section.

7.4.5 Fuel cost

Although not discussed in the interview, typical CNG cost per diesel gallon (energy) equivalent (dge) are much lower. Low carbon fuel standard (LCFS) credits are normally required for RNG to be cost-competitive.

7.4.6 Winter roads cold and corrosive operations

The main concern noted for cold operations is to be vigilant regarding the different and increased maintenance procedures required for CNG and RNG engine systems compared to diesel engines.

7.4.7 Fueling infrastructure

Although not discussed in the interview, fueling infrastructure costs are significant.

7.5 OPTIMUS TECHNOLOGIES

Company type: Fueling system manufacturer

Product type: Dual-chamber fuel tank system that enables B100 biodiesel operation

Contact: Colin Huwyler, Chief Executive Officer

7.5.1 Zero- or low-greenhouse gas options

The Optimus Technologies (Optimus) Vector system is a fuel system technology that integrates into existing vehicles and engines without significant modifications and enables diesel engines to operate on neat or 100% biodiesel (B100). B100 reduces the Scope 1 (tailpipe) carbon emissions by 100% and, according to the company, reduces lifecycle carbon emissions by approximately 70-80% with current feedstocks and production processes.

The Vector system replaces the standard fuel tank with a dual-chamber fuel tank - one for B100 and a smaller volume tank for petroleum diesel. The system also includes a dedicated fuel filter, pump, and sensors. No other engine, fuel system, controller, or other changes are made to the base engine. The system is designed to primarily operate on B100. The exceptions are:

- Start-up – The engines always start on petroleum diesel and are operated for a short warm-up period. During this time the engine coolant loop heat is used to raise the B100 fuel temperature to an operating temperature of approximately 100°F to avoid biodiesel fuel gelling and ensure fuel flow.

- Shut down – At shut-down, the engines are always switched back to petroleum diesel to flush the B100 fuel from the fuel lines to avoid fuel gelling issues at the next start up. This is done automatically at key-off with a system controller function that switches back to 100% diesel fuel and idles the engine for a prescribed amount of time.

The system's integrated controller manages the fuel flow from the B100 and petroleum diesel sides of the tank to maintain proper operation and to maximize B100 use. If a fault code is experienced during operation, the system reverts to petroleum diesel use. Because of this, it is important that fleets have the right amount of diesel fuel as backup. The truck could be swapped back and forth between B100 and petroleum diesel if needed. These redundancy features are important because they enable the truck to complete its mission.

B100 has slightly less energy density than petroleum diesel. The result is a 3 to 5% peak power and torque reduction that is only noticeable during some high-power operations when the engine is specified at the limit of the duty cycle power demands. Optimus stated that the real-world performance in terms of power and fuel economy are equivalent to petroleum diesel. Biodiesel produces approximately 50%-70% lower particulate matter emissions than petroleum diesel. The result is that the diesel particulate filter (DPF) may experience fewer regeneration cycles especially in applications with a lot of idling.

Optimus works with several truck OEMs and is open to working with others. The Vector system can be integrated by new vehicle factory-fit installation, ship through services such as Fontaine Modification, or by a retrofit of existing in-use vehicles.

Optimus noted that several public fleets are using the Vector system for year-round use including snowplowing operations. This includes the City of Ames (IA) and the City of Madison (WI).

7.5.2 Service and support

The only regular Vector system preventative maintenance is a dedicated B100 fuel filter. Optimus sells and services the system nationally. The company trains the fleet's service technicians to maintain and repair the system. Optimus will also work with the fleet customers' dealership, and if interested, train dealer service. Dealers have been interested in being trained because they are learning a new skill that can potentially lead to more work in the future.

7.5.3 Warranty

Optimus stated that the Vector system does not impact the original manufacturers' engine or truck warranty. Optimus stated that the truck and engine manufacturers do not have to be notified when the system is installed. This is because the system simply replaces the fuel tank and does not make any fundamental engine changes to the Electronic Control Unit (ECU) or fuel injectors. Optimus provides a two-year supplemental warranty to cover engine components if a fuel system part failure was not covered by the original manufacturers' warranty. However, this supplemental Optimus warranty has never been needed.

7.5.4 System cost

The system costs approximately $20,000 and in some cases can be reimbursed by tax and LCFS credit grants. Optimus charges an optional $500 per truck annual fee (after year three) if customers want access to system and emissions analytics. The data also provides predictive maintenance analysis information and the ability to track carbon credit generation.

Education is important to make sure fleet customers understand the proper vehicle specs, fuel incentives, and tax credits at the beginning of the process of transitioning to a new fuel so fleets can factor them into their financial calculations and decision process.

7.5.5 Fuel cost

B100 tracks the same index as petroleum diesel, so the fuel cost difference ($/gallon) is typically 5% higher compared to diesel. There is currently a federal tax credit for biodiesel, but the blender or refiner captures the credit and can decide if they pass any of the savings along to the customer. LCFS credits in certain states (CA, OR, and WA) can result in biodiesel prices that are $0.25 to $0.50 less than petroleum diesel.

7.5.6 Winter roads cold and corrosive operations

There are no concerns with winter conditions. Like standard diesel trucks the Vector fuel system is made for the truck's design specification envelope and operating conditions, including the use of aluminum fuel tanks.

7.5.7 Fueling infrastructure

Optimus does not provide the fueling infrastructure but provides a service to assist customers to properly design a fuel storage and dispensing solution. Above ground tanks must be heated with a resistance heater blanket and insulated to avoid fuel gelling. The B100's gel point is approximately 35° to 40°F. As with all fuels, tank maintenance and hygiene are key to maintaining fuel quality and performance.

7.5.8 Other challenges

Optimus has seen some State DOT fleets specify vehicle engines at the upper end of the required duty cycle power. This requires maximum engine power and results in a highly stressed engine. This can be critical for duty cycles with sustained high-power demands like snowplowing. The small peak torque or horsepower reduction from B100 could create an issue when engines are operating at the maximum limit. Optimus stated that customer education is important to ensure the base vehicle is properly equipped.

7.6 ROUSH CLEANTECH

Company type: Fueling system manufacturer

Product type: Dedicated propane fuel tank and engine fueling system

Contact: Chelsea E. Uphaus, Director of Marketing

7.6.1 Zero- or low-greenhouse gas options

ROUSH CleanTech (ROUSH) provides liquefied petroleum gas (LPG) fuel systems that are installed on OEM vehicles (currently Ford). Vehicles can be ordered directly from Ford with the ROUSH LPG system installed. Customers order their vehicles directly from the dealer and the assembled vehicles are shipped to ROUSH to have the LPG system installed. The vehicle is then shipped to the customer's dealer, so the process is seamless to the customer.

ROUSH has more than 40,000 vehicles in operation. Most use a Ford 6.8L V10 or a Ford 7.3L V8 engine. Only Ford engines are currently used as the base engine because of the level of software and controls access ROUSH has earned from Ford. ROUSH is interested in expanding to work with other manufacturers. The vehicles using the engines are mainly Class 5-7 and are in the following chassis F-450, F-550, F-650, F-750, step vans, and school buses. Approximately 50% of Blue Bird school bus production uses ROUSH's fuel system.

The systems and engines can also use renewable LPG (rLPG). rLPG is identical in chemical structure to petroleum propane and is normally produced in refineries making renewable diesel (RD). Approximately 25 million gallons of rLPG are currently produced in the U.S. annually. The carbon intensity of conventional petroleum LPG is 80, while the carbon intensity of rLPG is 30. ROUSH stated that there is currently not a large cost differential for rLPG versus conventional LPG.

ROUSH's LPG fuel systems inject liquid propane into the engine combustion chamber. This is an important difference compared to gaseous LPG systems. The result of the liquid injection is a higher power density compared to gaseous LPG systems. This enables the ROUSH LPG system to deliver equivalent power and torque as the base gasoline engine. The result is an engine that has the same performance to the operator as a gasoline vehicle. All other engine performance attributes are like gasoline or diesel engines. The pressure in the storage tank and fuel system components to the fuel port is approximately 100 psi.

Like CNG fueled vehicles, zinc-plated spark plugs are recommended, and fuel filters should be serviced every 50,000 miles which is comparable to gasoline engines. The same diagnostic tools are used for Ford vehicles for propane or gasoline for most issues. ROUSH specific service tools are available for propane specific faults.

Because the fuel is heavier than air, special precautions are required in service facilities, but these are minimal compared to some other alternative fuels.

7.6.2 Maintenance

ROUSH provides fleets with training. The first step is a set of web-based modules. In-person hands-on training with ROUSH trainers follows. ROUSH also has a network of ROUSH-certified garages and dealers if fleets prefer to outsource work.

For most issues, ROUSH vehicles use the same diagnostic tools as conventional Ford vehicles. There is a ROUSH-specific tool for system-specific faults. Vehicle liquid fuel pumps are the most common bigger service. The replacement process is not a major job, and it uses a well-defined process.

The fleets' shop and garage need to be properly equipped to service and store LPG vehicles. LPG maintenance facility upgrades, and best practices are well known and documented. LPG fuel is heavier than air and sinks if there is a leak. The fuel has an odorant (ethyl mercaptan) and the facility needs sensors to monitor air quality and to communicate any fuel leaks.

7.6.3 Product cost

The cost of the Ford gaseous-prepped engine order option is approximately $300, while the installed system price is $18,000 to $23,000, depending on the chassis.

The ROUSH system's NOx emissions are below the CARB optional/low NOx limits. This is important because it enables the engines to be eligible for incentive funding in California.

7.6.4 Fuel cost

LPG is available across the country. It is transported by pipeline to LPG depots and then by truck for local distribution and delivery. There is excess supply of LPG in the U.S. and two-thirds of U.S. propane production is exported. This situation has been relatively consistent for many years which helps provide a low and stable fuel cost. This provides a fuel cost savings opportunity for fleets. ROUSH stated that the LPG wholesale bulk fuel costs are approximately $1/gallon with typical government contract prices between $1.30 and $1.40/gallon. Factoring in the 35% increased volume needed to achieve the same energy content results in a final government contract price of about $1.60 per gallon. The fuel economy on a diesel gallon equivalent volume of fuel will be somewhat lower given the efficiency difference between a diesel (compression-ignition) engine and a spark-ignited LPG engine.

7.6.5 Fueling infrastructure

ROUSH supports fleets to determine an optimal fueling infrastructure by coordinating with their fuel provider partners. Fuel filter replacements are also needed for the fueling infrastructure dispenser.

7.6.6 Winter roads cold and corrosive operations

The ROUSH system is designed for use between -40° F and +120° F. ROUSH stated that gaseous LPG systems have vapor freezing limits/issues in very cold weather. ROUSH's liquid LPG system does not have this issue which enhances cold weather performance.

ROUSH LPG-equipped trucks have been used across Canada and Alaska. Canadian fleets running ROUSH trucks are operating with no reported issues at -40° F. Operation in an application in northern Alaska was recorded down to -65° F with the aid of tank heaters. Hot climates usually present more challenges for LPG vehicles. Historically fuel vaporization in the fuel lines caused engine performance issues. ROUSH solved the issue by using fuel chillers in the system lines.

7.7 CUMMINS CLEAN FUEL TECHNOLOGIES

Company type: Fueling system manufacturer

Product type: Compressed natural gas (CNG) fuel systems, MD/HD vehicles

Contact: Mike Zimmerman, General Manager

7.7.1 Zero- or low-greenhouse gas options

Cummins Clean Fuel Technologies is a joint venture between Cummins and Rush Enterprises. Cummins Clean Fuel Technologies offers a variety of CNG fuel system configurations that integrate with all truck OEMs and engines and have a range of body configurations (size, number, and placement of fuel tanks and control hardware) to meet customer needs. Cummins Clean Fuel Technologies fuel systems are used on a variety of truck applications such as refuse, on-road, and vocational chassis.

The vehicle fuel system stores and delivers CNG or RNG to the Cummins engine. Currently their fuel systems are used on the Cummins 6.7L, 9L,12L, and 15L engines.

7.7.2 Service and support

The company provides over 300 service and support locations around the U.S., while also providing training and web-based support to fleets.

Fleet shops and garages need to be properly equipped to service and store CNG vehicles. CNG maintenance facility upgrades, and best practices are well known and documented. CNG fuel is lighter than air, so rises if there is a leak. The fuel has an odorant (ethyl mercaptan) and the facility needs sensors to monitor air quality and to communicate any fuel leaks.

7.7.3 Warranty

Not discussed in the interview.

7.7.4 System cost

Costs were not discussed in the interview, although the company does provide assistance for obtaining grant funding at the federal, state and local level.

7.7.5 Fuel cost

Fuel costs were not discussed in the interview, but typically CNG cost per dge is much lower than petroleum diesel. Low carbon fuel standard (LCFS) credits are normally required for RNG to be cost-competitive.

7.7.6 Winter roads cold and corrosive operations

Most of the company's customers are vocational truck fleets, so fuel system components are designed for cold, corrosive, and physical conditions.

All fuel tanks are composite, so are naturally corrosion resistant. The fuel tanks are also tested and certified for chemical resistance to substances like battery acid. Stainless steel plumbing is used throughout the system and provides corrosion resistance. Most of the system structures are aluminum for weight reasons, but this also provides corrosion resistance. All steel components are in high strength-required areas and are painted for corrosion resistance.

CNG fuel components are typically subjected to wide temperature swings just from normal fuel flow. O-rings are designed for -60° F operation. Cold weather operations require vigilance regarding the increased maintenance procedures that are required for CNG and RNG engine systems.

CNG trucks have the same vehicle storage requirements as diesel trucks (a block heater is used).

7.7.7 Fueling infrastructure

Although not discussed in the interview, fueling infrastructure costs are typically significant.

7.7.8 Other topics

A front grille cover (winter front) is recommended for winter operations to not overcool the engine bay.

7.8 NESTE

Company type: Renewable diesel (RD) fuel provider

Contacts: Matt Leuck, Technical Manager and Wendy Wang, Program Manager

7.8.1 Company background and product description

Neste is the world's largest producer of renewable diesel fuel and has existing refineries in Finland, Singapore, and the Netherlands. Neste has a partnership with Marathon Oil in the U.S. to upgrade its refinery in Martinez, CA to soon produce renewable diesel in the U.S.

7.8.2 Product and operation

Neste MY Renewable Diesel is a hydrotreated vegetable oil (HVO) made from 100% sustainably sourced renewable resources. Neste's primary feedstock consists of food industry waste such as used cooking oil and animal fat. Neste MY is chemically identical to fossil diesel, making it an excellent drop-in replacement fuel for organizations committed to reducing their fleet carbon emissions with no engine modifications or capital investment required. It also meets the Low Carbon Fuel Standard established by the California Air Resources Board (CARB) and is fully compatible with all existing diesel engines.[8]

The fuel meets the ASTM D975 and EN 15940 fuel standards specification. Engines using the RD fuel have the same power and torque as petroleum diesel. Using Neste's RD can reduce the lifecycle well to wheels GHG emissions by up to 75% compared to petroleum diesel. The GHG emission reductions are compared to petroleum diesel and based on current feedstock pathways. The calculation method complies with the LCFS CA-GREET 3.0 in the U.S. and European Union's (EU) Renewable Energy Directive II (2018/2001/EU) in the EU.

Fuel delivery to customer is by truck, like other petroleum fuels. It is possible to transport RD by pipeline, but it is not currently done.

Since RD is a drop-in fuel and the engine is not modified, the fuel can be swapped back and forth between RD and petroleum diesel if needed.

7.8.3 Fuel cost

RD is currently two to four times more expensive than petroleum diesel. As a result, policy incentives are needed to make RD attractive. Low carbon fuel standard (LCFS) credits can make renewable diesel fuel economically viable. Neste's RD is only available in California and other opt-in states such as Oregon, Washington, and British Columbia (in Canada). Neste mentioned that a few other states in the U.S. northeast are considering implementing an LCFS program.

7.8.4 Maintenance and warranty

RD is a drop-in fuel so there is no difference in engine, parts, service, or warranty compared to a conventional diesel engine.

7.8.5 Fueling Infrastructure

Since renewable diesel is a drop-in fuel, no special fueling infrastructure is required. RD is very stable. It can be stored for many years if stored properly. This makes RD a candidate for peak or seasonal operations such as winter roads maintenance or agriculture.

8 Neste MY Renewable Diesel Lowers Your CO2 Emissions, https://www.neste.us/neste-my-renewable-diesel, accessed January 26, 2023.

7.8.6 Winter roads cold and corrosive operations

Petroleum diesel is a mixture of petroleum molecules. Cold weather diesel (No. 1) is a blend of lighter molecules. RD production is controlled in a tight window (isomerization). This production process engineers in cold weather properties. A -20° C (-4° F) cloud point is typical and -30° C (-22° F) is possible.

The performance of the fuel is identical to petroleum diesel and provides the same power and torque. Some fleets report slightly improved DPF performance due to lower particulate matter production and the near-zero ash content of renewable diesel. Winter performance is also improved since the fuel can be used down to -34° C (-29° F). If desired for additional cold weather benefit, it can be blended in any mix with Kerosene.

7.9 CLEAN ENERGY FUELS

Company type: Renewable natural gas (RNG) fuel provider

Contact: Chad Lindholm, Senior Vice President

7.9.1 Company background and product description

Clean Energy Fuels is the largest provider of RNG for the transportation industry in North America. The company has a network of 550+ fueling stations across the U.S. that supports fueling for 25,000 heavy-duty trucks, buses, and other large vehicles running on RNG.

RNG is made from organic waste (cow manure, landfill). RNG reduces carbon emissions by an average of 300% versus diesel, and at a lower price. RNG's very low carbon intensity (-328) means that fleets may not have to convert as many vehicles to meet organizational GHG reduction goals (-328 CI vs. 30% GHG reduction goal). Therefore, one vehicle operating on RNG essentially reduces net GHG emissions of roughly three identical vehicles, instead of a hypothetical fleet GHG reduction goal of 30%.

7.9.2 Product operation

RNG can be used in any NG engine. RNG production does not have to be in the same state as where RNG is used. RNG production sites do not need to be in the LCFS states. In all cases, there must be a certified RNG pathway between production and use. An RNG nomination process is used to ensure that RNG will be available in the station and that the LCFS credits are allocated properly.

7.9.3 Vehicle cost

Fuel system costs, including vehicle fuel tanks, are approximately $25,000 for a medium-duty vehicle and $60,000 (with 175 dge fuel storage) for a heavy-duty vehicle. Clean Energy Fuels recommends fleets to not oversize the fuel storage volume because of the high cost of the composite tanks. Instead, using less fuel storage could meet the fleet's needs with daily fueling, instead of every two days.

7.9.4 Fuel cost

LCFS developed at the downstream dispenser locations are usually required to make RNG production economically viable.

7.9.5 Fueling Infrastructure

Clean Energy Fuels' core business is to deliver RNG. This can be achieved in one of several ways. They can buy the infrastructure outright if grants are available. As an alternative to buying, Clean Energy can fund capital for a lease or loan program. The company can also install a CNG station at a fleet location. Stations can cost between $500,000 (small, low throughout) up to $10 million (very large, high throughout). As a general guideline, the economics tend to breakeven when ≥500 dge/day are used.

7.9.6 Winter roads cold and corrosive operations

Compressed natural gas (CNG) stations do not have operational issues in cold weather. Clean Energy Fuels operates stations in more than forty states and five Canadian provinces with temperature ranging from -40° F to 120° F. The Denver airport has been operating CNG shuttle buses for 20 years.

7.10 LESSONS IDENTIFIED

This section highlights the key lessons identified through the interviews and research conducted by the project team.

Like diesel powertrains, all powertrains are designed for the truck's design envelope and operating conditions. Manufacturers universally stated that the fuel storage systems, fuel lines, system structure, and engine operation for all liquid (biodiesel and RD) and gaseous (CNG, RNG, LPG, rLPG, and hydrogen) fuels are designed for and are proven in very cold weather conditions.

BEVs will also operate in very cold temperatures, though usable battery capacity decreases with temperature. Solutions to mitigate this are in development. HFCEVs' exhaust is water vapor, so freezing concerns will be designed around this. Currently HFCEVs cannot be parked outside in freezing weather and operate reliably at the beginning of a shift. Inside heated vehicle storage may be required. This is new territory, so further testing is needed to develop solutions.

CNG stations do not have operational issues in cold weather and operate in a wide range of temperature conditions.

7.11 RECOMMENDATIONS

28. Look for opportunities and solutions to potential issues with vehicle or fuel options with most significant GHG reduction benefits that meet the fleet's mission

29. Focus on proven vehicle and fueling system vendors

30. Stay aware of potential funding incentives (federal, state, utility) and if fleet is in a state with a low carbon fuel standard program (reduce fuel costs)

CHAPTER 8: IMPLEMENTATION AND CONVERSION

Our overall findings with regards to electrification and alternative fuel technologies for winter roads maintenance operations are:

- There are limited examples of alternative fuel vehicles (AFV) use in winter roads maintenance operations.
- It is early days for winter roads maintenance vehicle electrification discussions.
- Most organizations have reasonable concerns with adoption of AFVs.
- DOT fleets vary in their adherence to industry best practices.
- DOT representatives need access to information on legislative requirements and emerging AFV technologies.

The 30 recommendations provided can be approached by level of priority and level of effort which are classified as shown:

Priority	Timeframe	Effort	Resources
1	Within 6 months	1	Minimal staff and/or budget
2	6 to 12 months	2	Under 80 hours or $50,000
3	Beyond 12 months	3	More than 80 hours or $50,000

Recommendations	P	L
1. Create a robust policy framework including a Fleet Policy Manual, a Driver's Handbook and Service Level Agreements with supported departments.	1	2
2. Develop a policy on fleet utilization detailing usage thresholds and the need and process for an annual review.	1	1
3. Ensure that the replacement of older vehicles is done on a one-for-one basis to prevent the creation of a shadow fleet.	1	1

Recommendations	**P**	**L**
4. Encourage all winter roads maintenance fleet operators to be proactive about identifying assets that can be eliminated or that require replacement.	1	1
5. Use cooperatives for the purchase of winter roads maintenance equipment where available for favorable pricing and a reduction in administration.	2	1
6. Calculate and respect optimum lifecycles based on the Total Cost of Ownership of the asset.	2	2
7. Create a multi-year replacement plan and ensure funds are available to replace vehicles at the optimum point.	2	2
8. Consider sustainability as a criterion in fleet replacement.	1	1
9. Establish mechanic positions according to a Vehicle Equivalency Unit (VEU) analysis.	2	1
10. Create a formal preventative maintenance (PM) program and ensure 95% compliance is observed.	2	1
11. Develop a formal training plan for mechanics to retain and improve their skills on ICE and AFVs.	2	2
12. Create fleet funds that have a separation between operating and capital replacement funds.	2	1
13. Assess the condition of assets due for replacement where funding is insufficient to replace all vehicles that are due.	2	1
14. Plan for the increased costs of AFVs and supporting infrastructure in the future.	2	1
15. Acquire and use a Fleet Management Information System (FMIS) to monitor fleet acquisition, utilization, maintenance, fuel and replacement.	1	3
16. Acquire and use a Fuel Management System that is integrated into the FMIS.	2	3

Recommendations	P	L
17. Install telematics to monitor vehicle performance, utilization, and driver behavior.	2	3
18. Create a performance measurement framework that details what information needs to be reported to what level at what frequency.	1	1
19. Keep informed on advancements in AFVs by staying connected with other DOT fleets and OEMs.	1	1
20. Draft a Sustainable strategy for the organization with realistic targets for AFV introduction and GHG emissions reduction.	2	2
21. Evaluate the affordability of AFVs based on total cost of ownership (TCO) and not the acquisition costs of vehicles.	2	2
22. Educate stakeholders on the use and benefits of AFVs to eliminate barriers to introduction.	2	2
23. Ensure fuel and infrastructure availability in advance of any alternative fuel transition.	3	3
24. Stay aware of the quickly evolving industry, both vehicles and fuel. Learn from manufacturers, fuel providers, and multiple peer organizations.	1	1
25. Conduct a pilot vehicle program to collect and analyze data to understand the impacts of a fuel change prior to full-scale adoption.	2	3
26. Understand and follow the preventative maintenance schedule for each fuel and stay current on practice updates.	2	1
27. Use on-premises depot fueling infrastructure (storage and dispensing) for liquid fuels as it is cost-effective and provides fuel certainty.	2	1
28. Look for opportunities and solutions to potential issues with vehicle or fuel options with most significant greenhouse gas (GHG) reduction benefits that meet the fleet's mission	1	2

Recommendations	P	L
29. Focus on proven vehicle and fueling system vendors	1	1
30. Stay aware of potential funding incentives (federal, state, utility) and if fleet is in a state with a low carbon fuel standard program (reduce fuel costs)	1	2

CLEAR ROADS

research for winter highway maintenance

Lead state:

Minnesota Department of Transportation

Research Services

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