Evaluating Alternative Fuels for Snowplow/Maintenance Vehicles and Identifying Barriers to Adoption

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16. Abstract

Biodiesel is a sustainable fuel for use in any diesel engine and can be adopted in varying blends from 5% biodiesel (B5) to 100% biodiesel (B100). Blends up to B20 can be used in most diesel engines with minor or no modifications. For biodiesel blends greater than 20%, advanced technologies can be integrated into existing vehicles to ensure compatibility and successful performance. B5 and B20 are the most commonly used biodiesel blends, while B100 is less commonly used due to pricing, a lack of regulatory incentives, and performance concerns.

A number of agencies have expressed interest in evaluating the use of B100 in their maintenance vehicle fleets, but concerns with engine maintenance and performance have hampered adoption. As part of a pilot program, the Iowa Department of Transportation invested in B100 conversion kits for several new and existing snowplows in July 2020.

The objective of this research was to conduct an independent evaluation of the impact of adopting B100 biodiesel on the performance of the Iowa DOT snowplow fleet, including impacts on fuel economy, maintenance, carbon reduction, and driver/maintenance personnel concerns. The resulting information can be used to address concerns and assist agencies in decision-making regarding the adoption of biodiesel in their fleets.

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EVALUATING ALTERNATIVE FUELS FOR SNOWPLOW/MAINTENANCE VEHICLES AND IDENTIFYING BARRIERS TO ADOPTION

Final Report
February 2026

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EXECUTIVE SUMMARY

Biodiesel is a sustainable fuel for use in any diesel engine and can be adopted in varying blends from 5% biodiesel (B5) to 100% biodiesel (B100). Blends up to B20 can be used in most diesel engines with minor or no modifications. For biodiesel blends greater than 20%, advanced technologies can be integrated into existing vehicles to ensure compatibility and successful performance. B5 and B20 are the most commonly used biodiesel blends, while B100 is less commonly used due to pricing, a lack of regulatory incentives, and performance concerns.

A number of agencies have expressed interest in evaluating the use of B100 in their maintenance vehicle fleets, but concerns with engine maintenance and performance have hampered adoption. As part of a pilot program, the Iowa Department of Transportation invested in B100 conversion kits for several new and existing snowplows in July 2020.

The objective of this research was to conduct an independent evaluation of the impact of adopting B100 biodiesel on the performance of the Iowa DOT snowplow fleet, including impacts on fuel economy, maintenance, carbon reduction, and driver/maintenance personnel concerns. The resulting information can be used to address concerns and assist agencies in decision-making regarding the adoption of biodiesel in their fleets.

1. INTRODUCTION

1.1. Background

Alternative fuels, including biodiesel, have a number of benefits, including that they are domestically sourced and have the potential to reduce dependence on foreign oil. Alternative fuels also may also reduce transportation energy costs.

However, biofuels have several drawbacks relative to petroleum-based fuels, including lower energy content and cold-flow issues. Additionally, while agencies can play a significant role in encouraging utilization of these fuels, adoption is hampered by a lack of information and resistance to change.

Biodiesel is a sustainable fuel for use in any diesel engine and can be adopted in varying blends from 5% biodiesel (B5) to 100% biodiesel (B100). Blends up to B20 can be used in most engines that use diesel fuel with minor or no modifications (NREL 2009). For blends greater than 20% biodiesel, advanced fuel technologies can be integrated into existing snowplow or maintenance vehicles to ensure compatibility and successful performance. These upgrades can address common concerns with biodiesel, such as gelling, which is particularly problematic in subzero conditions (Optimus Technologies 2022a). One such upgrade includes a split tank with petroleum diesel on one side and biodiesel on the other. The regular diesel is used when the engine starts up to address cold-flow issues. Once the system warms the biodiesel, the engine switches back to the higher-blend biodiesel. Once the vehicle is shut off, the engine idles long enough to replace the higher-blend biodiesel in the fuel lines with regular diesel (Klein 2022). Although biodiesel can be stored and used with the same fueling infrastructure as regular diesel, many fleets install a dedicated biodiesel fueling tank (Klein 2022).

B5 and B20 are the most commonly used biodiesel blends. While B100 can be used in most engines built since 1994, it is less commonly used than lower blends due to pricing and a lack of regulatory incentives. Moreover, B100 has a solvent effect, which can clean a vehicle’s fuel system and release deposits accumulated from petroleum diesel that may initially clog filters. To avoid engine operational issues, B100 must meet the requirements of ASTM D6751 (USDOE n.d.-a).

A number of agencies are interested in evaluating the use of B100 in fleet vehicles such as snowplows and other maintenance vehicles. However, concerns with maintenance and engine performance have hampered adoption. This report summarizes the advantages and disadvantages of biodiesel for use in transportation maintenance vehicles. Known adopters of B20 and B100 were identified, the performance of their vehicles was evaluated, and their experiences were summarized when available. The resulting information can be used to address concerns and assist agencies in decision-making and marketing when considering the adoption of biodiesel in their fleets.

1.2. Project Objectives

The Iowa Department of Transportation (Iowa DOT) invested in B100 conversion kits for several snowplows. The objective of this project was to conduct an independent evaluation of the impact of B100 biodiesel on the Iowa DOT snowplow fleet, including its impacts on fuel economy, vehicle maintenance, carbon reduction, and driver/maintenance personnel concerns.

1.3. Summary of Report

The report is organized as follows:

- **Chapter 2** summarizes the available literature about the advantages and disadvantages of biodiesel, the fuel economy and emissions impacts of biodiesel, and fleet experiences with biodiesel.
- **Chapter 3** describes the Iowa DOT's biodiesel snowplow fleet and information on engine output available from the vendor.
- **Chapter 4** describes the process of collecting information on fuel economy in the field through reports from snowplow drivers and an evaluation of data collected from snowplow engines.
- **Chapter 5** summarizes a discussion with Iowa DOT staff about their experience with the biodiesel snowplows.
- **Chapter 6** describes the development of various tools for assessing the emissions and fuel economy of biodiesel vehicles.

2. BACKGROUND

This chapter summarizes the known benefits and drawbacks of biodiesel based on a review of the literature.

2.1. Advantages and Disadvantages Attributed to Biodiesel

Biodiesel has several advantages over conventional diesel. The main advantage is that it is a renewable energy source. It is also nontoxic and has almost no sulfur or aromatics content, which lessens the risk of respiratory illnesses in people exposed to it. It is also safer to use, store, and transport. Biodiesel has a lower flashpoint than conventional diesel and is less likely to accidently ignite, which makes transportation and storage safer and easier (Miller 2016). It also poses less harm to the environment than conventional diesel if spills occur (Ghadikolaei et al. 2021).

Biodiesel has a greater lubricating effect than conventional diesel. As a result, it can initially act like a solvent that loosens existing deposits in the engine, which can lead to clogging. However, because of the lubricity, additional engine deposits do not occur with longer-term use (Soomro n.d.). The lubricity also raises the cetane number for the fuel, resulting in a cleaner burn that produces less soot (USEPA 2022). The higher cetane number also provides a shorter ignition time, which results in more complete combustion and more efficient engine operation.

Lower biodiesel blends (B20 or lower) have been shown to yield a similar engine power to conventional diesel (Ghadikolaei et al. 2021). Argonne National Laboratory evaluated 25 ways of producing biofuel optimized for a specific diesel engine type and found overall that biofuels were cost-competitive with current fuel prices (Burmahl 2022).

Several concerns have been noted with the use of biodiesel. This report focuses on those concerns that are relevant to fleet managers considering adoption of biodiesel. Other concerns, such as deforestation, the use of food for fuel, and so on, are beyond the scope of this report.

Biodiesel is typically developed from a variety of different crops (e.g., soy, rapeseed) or used cooking oil. As a result, when oil is extracted and converted to fuel, the quality of the biodiesel can vary in terms of clouding point and burn characteristics (Sachin 2023).

Biodiesel also tends to gel in cold weather depending on the bio-product used to make it. Gelling occurs when the temperature drops, with the paraffin component starting to crystallize around 32°F. At 10°F, the fuel becomes a gel, which may clog the tank, narrow fuel lines, and fuel filters (Farm Energy 2019).

Contaminants such as glycerides, monoesters and diesters, and sterol glucosides can be present in biodiesel after an incomplete purifying process. As noted above, biodiesel can also act as a solvent, which can lead to early filter plugging (CAT 2023). For instance, Proc et al. (2006) evaluated B20 in transit buses and found some initial fuel filter plugging, which they attributed to out-of-specification biodiesel. Higher blends may also damage the rubber and plastic parts of the fuel system (Ghadikolaei et al. 2021).

Biodiesel also has a shorter storage life than conventional diesel due to biodiesel's lower oxidation stability (CAT 2023). Additionally, higher biodiesel blends are more likely to dissolve and absorb water than conventional diesel fuel. This can lead to possible contamination of fuel storage tanks due to microbial growth and sludge formation (Ghadikolaei et al. 2021).

2.2. Biodiesel Performance

2.2.1. Fuel Economy

The fuel economy of biodiesel has generally been thought to be lower than that of regular diesel. Actual differences depend on the biodiesel blend, the fuel quality of the fuel, and engine load. Proc et al. (2006) evaluated the fuel economy of five transit buses that ran on B20 and four that ran on regular diesel. The buses were operated on the same route, and each bus accumulated about 100,000 miles during the study. The authors found no difference in on-road average fuel economy between the two groups, which was about 4.41 mpg. Laboratory tests showed a 2% reduction in fuel economy for biodiesel. However, the authors concluded that there were no statistically significant differences between the two fuels.

Ghadikolaei et al. (2021) noted that the use of biodiesel can lead to a reduction in engine power as well as reductions in fuel economy (2% for B20 and 10% for B100). Emaish et al. (2021) used a dynamometer to evaluate the impacts of biodiesel derived from deep-fryer oil on the emissions and fuel economy of tractor diesel engines. They evaluated regular diesel (B0), B5, B20, and B100. They reported that fuel economy was 4.6%, 6.1%, and 9.9% lower for B5, B20, and B100, respectively, compared to B0. Anderson (2012) reviewed the impact of biodiesel blends on emissions and summarized studies that had used a chassis dynamometer to test emissions for heavy-duty vehicles. The author found that the fuel economy for B20 was 2.6% lower than for conventional diesel. Anderson (2012) also summarized studies that had conducted on-road evaluations of biodiesel and reported that the on-road fuel economy for B20 was 6.3% higher than for regular diesel.

The United States Environmental Protection Agency (USEPA) provides a spreadsheet tool to estimate the fuel economy and emissions differences between biodiesel and conventional diesel (USEPA 2022). According to this tool, the fuel economy of soybean-based B100 is 4.6% to 10.6% lower than that of clean base diesel. As a result, the reductions in fuel economy in the various studies cited above have an overall range of 0% to 6.1% for B20 and an average of 10% for B100.

2.2.2. Emissions

The emissions produced by biodiesel also vary by engine load, type of biodiesel, and quality of biodiesel. In general, biodiesel has lower emissions for most pollutants, with higher levels of nitrogen oxides (NO_x) noted in some instances.

Using a laboratory chassis emission test, Proc et al. (2006) found that the soot levels measured in engine lubricants as a result of fuel combustion were significantly lower for B20 vehicles. They also found a 4.9% decrease in NOx, a 28.7% decrease in hydrocarbons (HC), a 23.9% decrease in carbon monoxide (CO), and an 18.2% decrease in particulate matter (PM). Chen et al. (2018) reported a 66% to 76% reduction in greenhouse gas (GHG) emissions with soy biodiesel. Pandhare and Padalkar (2013) evaluated emissions in a single-cylinder diesel engine using biodiesel blends derived from jatropha oil. Emissions and fuel economy were evaluated using a dynamometer and were tested across various levels of engine load. At a medium engine load, NOx emissions were 3.0% higher for B20 and 8.3% higher for B100. CO emissions were about 11.8% lower for B20 and 12.9% lower for B100. HC emissions were 15.3% and 32.9% lower for B20 and B100, respectively.

Emaish et al. (2021) used a dynamometer to evaluate the impacts of biodiesel derived from deep-fryer oil on the emissions and fuel economy of tractor diesel engines. Compared to the B0 fuel used in the study, CO_2 emissions were around 1% lower for B5 and B20 and were 7.2% lower for B100. CO emissions were 4.2%, 13.2%, and 48% lower for B5, B20, and B100, respectively, compared to regular diesel. NOx emissions were slightly higher for the biodiesel blends (0.8% for B5, 1.4% for B20, and 5.2% for B100) than for regular diesel. Finally, SO_2 emissions were significantly lower for the biodiesel blends (13.6% for B5, 32.2% for B20, and 100% for B100) than for regular diesel.

Anderson (2012) reviewed the impact of biodiesel blends on emissions from studies that had utilized a chassis dynamometer to test emissions on heavy-duty vehicles. The author found that, compared to conventional diesel, HC emissions were 5.7% lower for B20 and 23% lower for B100. NOx emissions were 3.5% higher for B20 and 9.0% higher for B100. CO emissions were 4.1% and 24% lower for B20 and B100, respectively. CO_2 emissions were 0.4% lower for B20, and PM emissions were 13.3% lower.

Anderson (2012) also summarized studies that had evaluated on-road emissions for biodiesel in heavy-duty trucks. The author compared B20 to regular diesel and reported that HC emissions were 21.7% lower for B20, NO_X emissions were 3.3% lower, CO emissions were 6.6% lower, and PM emissions were 15.2% lower. An increase in CO_2 emissions of 3.0% was noted with the use of B20 versus regular diesel.

Argonne National Laboratory (Burmahl 2022) evaluated 25 ways of producing biofuel optimized for a specific diesel engine type. They estimated that the GHG emissions for US biodiesel were about 30% lower than for normal diesel.

The USEPA (2022) provides a spreadsheet tool to estimate the fuel economy and emissions differences between biodiesel and conventional diesel. According to this tool, soybean-based B100 yields the following reductions versus clean base diesel for several emissions:

- PM: 31% lower
- CO: 36% lower
- NOx: 8% higher
- HC: 50% lower

As discussed, biodiesel results in significantly lower PM, CO, and HC emissions. Biodiesel improves fuel lubricity and raises the cetane number for the fuel, resulting in cleaner burning (USEPA 2022). However, NOx is generally increased slightly. On average for B20, NOx emissions are 1% to 5% higher, PM emissions are 15% to 18% lower, CO emissions are 4% to 24% lower, HC emissions are 6% to 15% lower, and CO_2 emissions are 1% to 3% lower. On average for B100, NOx emissions are 5% to 9% higher, CO emissions are 7% to 48% lower, HC emissions are 23% to 33% lower, and CO_2 emissions are 7% lower.

2.3. Fleet Experience With Biodiesel

Since the use of higher blends of biodiesel requires some fueling infrastructure, fleets are ideally suited to conversion to higher blends. A number of agencies in the United States are moving in this direction, but concerns have lingered, as noted in Section 2.1. B20 has been the most common blend used, with a number of agencies converting their fleets to B20. All major diesel engine manufacturers approve biodiesel blends of up to 20%. B100, however, requires some engine modifications. Known fleet applications for various blends are summarized below, along with these fleets' experiences in using higher biodiesel blends (when known).

Fort Wayne, Indiana, has used B20 in its public fleet vehicles since 2004 (Biodiesel n.d.). No information was available about their experience.

Fort Collins, Colorado, started using B20 in 2005 with the goal of reducing GHG emissions by 20% by 2020 (Biodiesel n.d.). The city met this initial goal and plans to reach its goal of 80% reduction by 2030. It uses biodiesel blends year round in 389 vehicles, which includes construction equipment, dump trucks, snowplows, and some transit vehicles. A total of 200,000 gallons of B20 is used annually. The city transitioned to B20 in regular vehicles without using engine add-ons and has noted no loss of power and no difference in fuel economy.

St. Louis, Missouri, has been using B20 since 1990 in vehicles at the St. Louis International Airport. The city notes that biodiesel has a higher lubricity, which has cut down on the number of times that injectors and fuel injection pumps must be cleaned and replaced (Biodiesel n.d.).

New York City uses B20 in its entire fleet of 1,750 vehicles, including construction vehicles, snowplows, and trash collectors (ASA 2019).

Moline, Illinois, implemented B20 in its diesel-powered fleet in 2005 (Illinois Soybean Association 2020). The city's fleet includes fire equipment, sanitation trucks, end loaders, snow removal equipment, and other trucks up to Class 8. During the initial switch to B20, drivers were not notified about the change to biodiesel because the agency felt that "ghost symptoms" could be reported by drivers who may have concerns about the new fuel type. The city uses approximately 70,000 gallons of B20 annually in 55 vehicles. The city notes that it has not experienced fuel-related maintenance incidents since implementing B20.

The Metropolitan Sewerage District in Asheville, North Carolina, switched its fleet of 81 diesel vehicles to B20 and currently uses more than 70,000 gallons of biodiesel annually (USDOE 2015). During winter months, the district transitions back to B10. When older vehicles initially transitioned to B20, the district noted that fuel filters needed to be changed. This occurred within the first six months after the switch to B20, since biodiesel cleans out a vehicle's fuel system. This issue was only noted for older vehicles, as newer vehicles did not require filter changes. The district also noted that maintenance staff and drivers have not noticed a change in performance.

The City of Toronto, Canada, has several light- and medium-duty vehicles that use B20. The city additionally has various heavy-duty vehicles that use biodiesel, including buses and dump trucks.

The City of Ames, Iowa, adapted 5 city snowplows in 2020 to operate using B100, with the program later expanding to 12 trucks. The city used an add-on technology to adapt the engines to the new fuel, since it felt that the use of B100 was not practical during winter weather without the upgrade. The snowplows have burned over 1,000 gallons of B100, and no issues in truck operations have been noted (Giardino 2021). After a successful pilot through 2020, the city is adding 7 new all-purpose dump trucks to the fleet that will use B100 (Government Fleet Staff 2020).

City of Ames, Iowa

Figure 2-1. Snowplow running biodiesel

A collaboration between Archer Daniels Midland (ADM), Optimus Technologies, the Illinois Soybean Association, the American Lung Association, and the Missouri Soybean Merchandising

Council funded the conversion of five long-haul commercial trucks to use B100 (Class 8 Mack tractor-trailers). The trucks used 73,186 gallons of biodiesel over 623,922 miles in temperatures as low as -23°F. No operational issues were noted (Reid 2022).

ADM Trucking conducted a field trial that compared the five trucks using B100 to a control group of five similar trucks that utilized B11. Both sets of trucks were operated on similar routes with similar duty cycles and conditions. Collectively, the trucks drove over 1.3 million miles. A 1.3% increase in fuel economy was noted with B100 over the traditional B11 blend (6.32 mpg versus 6.24 mpg). The study also noted a 32% reduction in the ash accumulated in diesel particulate filters (DPFs), a 22% reduction in time spent actively regenerating the DPFs, and a 50% reduction in active DPF regenerations. No negative impacts on engine oil were found, and viscosity differences across crankcase oil samples were not statistically different. There were also no differences in maintenance costs and no additional downtime with the B100 trucks (Optimus Technologies 2022b).

Optimus Technologies (2022b) interviewed six drivers to gather feedback about their experience in using the biodiesel trucks. Drivers reported having positive experiences with the trucks. None reported any diminished power or performance or any negative impacts on day-to-day operations (Optimus Technologies 2022b).

The City of Madison, Wisconsin, converted 17 fleet vehicles (3 dump trucks, 12 garbage trucks, 1 644K loader, and 1 wood grinder) to operate on B100 (Optimus Technologies 2022c). The city's goal is to achieve 100% renewable energy and zero net carbon emissions for city operations by 2030. No information was available about the city's experience.

The District of Columbia Department of Public Works (DCDPW) started out using B20 in its fleets and then converted to B100 in its sanitation vehicles. The department estimated that emissions were reduced by 75% (Biodiesel n.d.). DCDPW deployed 6 B100 garbage trucks in 2019. In 2021, it added 37 six-wheel B100 dump trucks and plans to ultimately have 97 total fleet vehicles operating on B100 (Dorfman 2021). DCDPW also plans to use B100 in all new refuse trucks. The use of B100 is attractive for these vehicles because refuse trucks contribute the highest amount of emissions per vehicle among all fleet vehicles. The department installed a dedicated B100 fueling tank, which helped streamline fueling operations for the B100 fleet. Radio frequency identification (RFID) technology was installed in the fuel nozzles of the tank's dispensers and on the fuel cap of each B100 vehicle to allow the department to track and prevent vehicles not designated for B100 from using the B100 tank. DCDPW indicated that it has had no problems with the use of B20 in its fleet and further has noted no problems with the use of B100 (Bennett 2020).

A Canadian study assessed the experience of the JK Trucking fleet in using B10. The study included 52 heavy vehicles, which included 46 International 9900Is with Cummins engines and 4 International 9900Is with CAT engines, with all vehicles approved for B20 under original equipment manufacturer (OEM) warranty statements. A cold start was required each morning. During the four months of the study, the fleet traveled 1.06 million miles in western Canada and the western United States using 101,326 gallons of B10. Due to sourcing issues, a variety of feedstock sources were utilized. Vehicle performance was tracked using an electronic control module. The fleet was also mapped with Global Positioning System (GPS) units, and temperatures were recorded from a nearby weather station, with the lowest temperature recorded at -43°F. The fleet reported no unit shutdowns; no engine performance, mechanical, or maintenance issues due to biodiesel; and no change in operations (MacLean et al. 2019).

Another Canadian study evaluated the use of B5 and B20 in a fleet of 157 buses in Montreal, Canada. Over the course of the 12-month study, the fleet used 145,295 gallons of biodiesel. B20 was utilized in a number of vehicles that were not warranted for this level of blend. Temperatures of -4°F to -22°F were frequently recorded. Driver calls used to report technical problems indicated no recorded on-road incidents due to biodiesel (MacLean et al. 2019).

Humburg et al. (2006) conducted a survey of US state departments of transportation about their experience related to biodiesel blends. At the time of the survey, 19 states had some level of experience with biodiesel blends. The most commonly used blend was B20 (14 states). Seventeen of the nineteen states that had utilized biodiesel responded to questions about maintenance. A total of 88.2% of these states (n = 15) indicated that they had found no difference in vehicle power with the use of biodiesel. One state noted a difference but did not indicate whether the difference was positive or negative. Another state noted that vehicles produced less power when operating with biodiesel. More than one-third of the responding states (35.3%, n = 6) indicated that they had experienced no change in fuel efficiency. Two states noted small declines in fuel efficiency, and two states noted a decrease in fuel efficiency of 1 to 3 mpg. Almost half of the responding states (47.1%, n = 8) indicated that they had experienced no noticeable change in fuel pump or injector durability with the use of biodiesel. No states indicated fuel pump issues. One state noted that injectors ran cleaner with biodiesel, while nine states indicated that they did not monitor this factor. No states noted fuel system leaks or fuel line leaks. Engine oil analyses that had been performed by states indicated that biodiesel performed similar to petroleum, and no states reported changes in viscosity, oil acidity, engine wear, or other oil-related characteristics with the use of biodiesel. None of the states had changed oil maintenance schedules due to biodiesel, and none reported any other maintenance issues with the use of biodiesel. The survey results indicated that there were few cold weather operability issues among state transportation agencies that had adopted the fuel. Only two states reported filter plugging, which had occurred during a cold weather period.

3. DESCRIPTION OF IOWA DOT BIODIESEL SNOWPLOW FLEET

The Iowa DOT has used B20 in its snowplow/maintenance fleet for more than 20 years and was the first in the nation to deploy B100 snowplows. The agency opted for B100 because electric alternatives are not feasible for snowplows due to the battery size that would be required and the cold weather performance of electric vehicle batteries (Optimus Technologies 2022a). During the 2021/2022 winter season, the snowplows used over 9,000 gallons of biodiesel over 55,000 miles of roadway (Zimmerman 2022). In order to implement B100, the Iowa DOT used an engine add-on technology from Optimus Technologies that facilitates the use of B100 in the snowplows.

At the start of the study, the Iowa DOT had 10 snowplows that were upgraded with the add-on technology to run on both normal diesel and biodiesel blends up to 100%. Each truck has two tanks: one for regular diesel and one for 100% biodiesel. The vehicles use normal diesel during the warm-up period, then switch to B100. During engine shutdown, the fuel system switches back to regular diesel, and the engine runs until all of the B100 is purged. Each tank is 60 gallons.

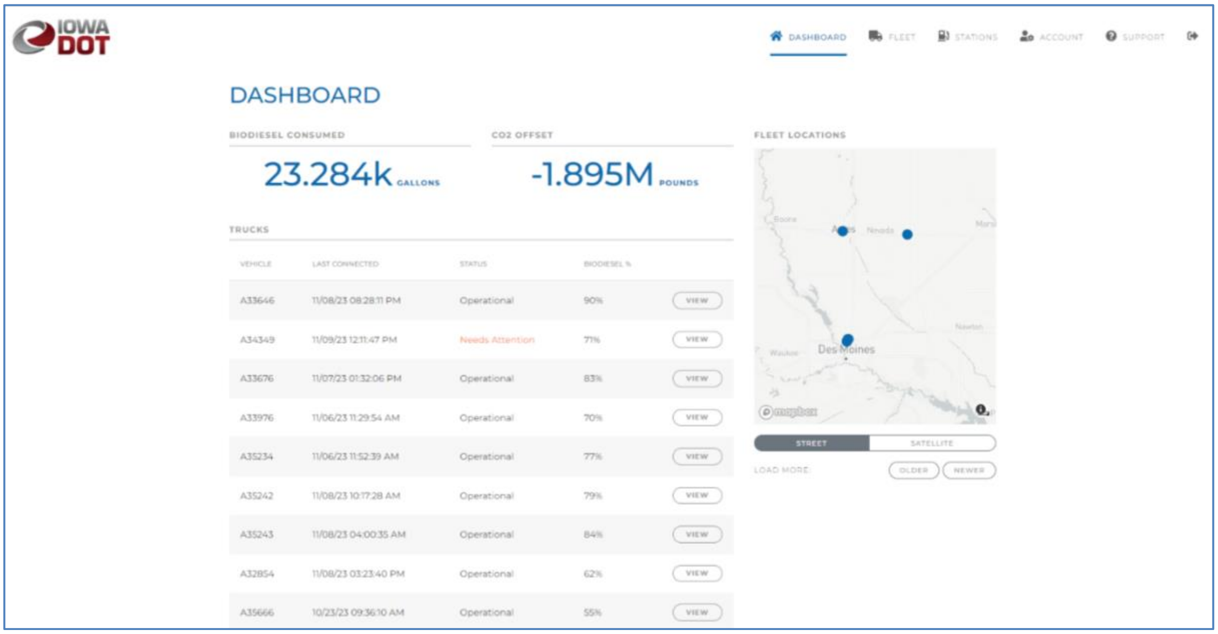
RFID devices were installed at each of the fueling stations for the B100 and in each vehicle. As a result, the number of gallons of B100 used by the vehicles could be logged and reported to Optimus Technologies. The Iowa DOT did note that the RFID devices experienced some communications issues (December 2022). After some parts were changed, the Iowa DOT felt that the information from the devices was more accurate.

Each truck had an assigned route and was operated over that route most of the time. However, during winter weather events, trucks could be relocated to other areas of the state.

The majority of the trucks were assigned to the Iowa DOT District 1 maintenance yard, with the truck assignments as follows:

- A33646 – District 1 Des Moines
- A34349 – District 1 Des Moines
- A33676 – District 1 Des Moines
- A33976 – District 1 Des Moines
- A35234 – Ames
- A35242 – District 1 Des Moines
- A35243 – District 1 Des Moines
- A32854 – Ames
- A35666 – Ames
- A35705 – District 1 Des Moines

Optimus Technologies maintained a dashboard that displayed both fleet (Figure 3-1) and individual (Figure 3-2) truck statistics. The company also downloaded truck information collected through an onboard diagnostic (OBD) system.



DASHBOARD

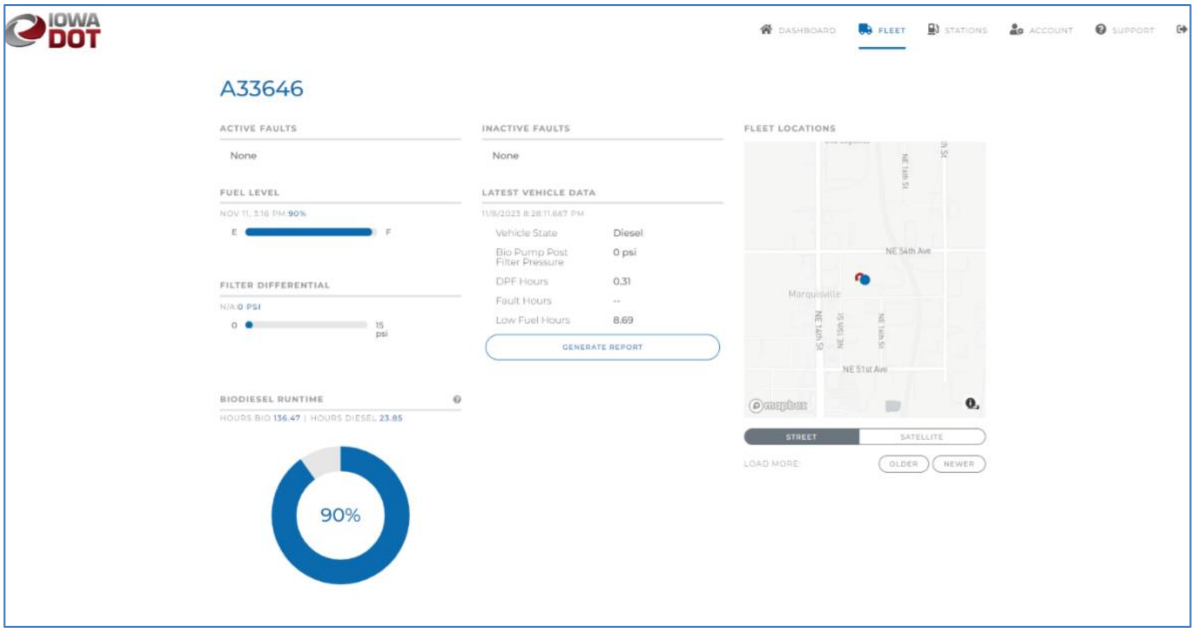
BIODIESEL CONSUMED: 23.284k GALLONS

CO2 OFFSET: -1.895M POUNDS

TRUCKS

VEHICLE	LAST CONNECTED	STATUS	BIODIESEL %
A33646	11/08/23 08:28:11 PM	Operational	90%
A34349	11/09/23 12:11:47 PM	Needs Attention	71%
A33676	11/07/23 01:32:06 PM	Operational	83%
A33976	11/06/23 11:29:54 AM	Operational	70%
A35234	11/06/23 11:52:39 AM	Operational	77%
A35242	11/08/23 10:17:28 AM	Operational	79%
A35243	11/08/23 04:00:35 AM	Operational	84%
A32854	11/08/23 03:23:40 PM	Operational	62%
A35666	10/23/23 09:36:10 AM	Operational	55%

Figure 3-1. Dashboard showing fleet statistics



A33646

ACTIVE FAULTS: None

INACTIVE FAULTS: None

FUEL LEVEL: NOV 11, 3:16 PM: 90%

LATEST VEHICLE DATA: 11/8/2023 8:28:11.667 PM

Vehicle State	Diesel
Bio Pump Post Filter Pressure	0 psi
DPF Hours	0.31
Fault Hours	--
Low Fuel Hours	8.69

FILTER DIFFERENTIAL: N/A: 0 PSI

BIODIESEL RUNTIME: HOURS BIO 136.47 | HOURS DIESEL 23.85

Figure 3-2. Dashboard showing statistics for an individual truck

Truck engine data could be downloaded for each truck using the dashboard. Data fields for the truck engine data were reported at approximately two-second intervals for each truck. Variables included the following:

- Timestamp (UTC): Shown as, for example, "2022-08-16T11:43:38.800Z," reported in military time.
- Report Format (Number)

- Latitude (deg): GPS latitude.
- Longitude (deg): GPS longitude.
- Heading (deg)
- GPS Speed (km/h): Speed reported by GPS
- Altitude (meters)
- HDOP
- PDOP
- VDOP
- NumSatellites
- GPS Valid
- Vehicle_State
- Flt_Biofuel_Tank_Level: Measured in state. 0 = no fault, 1 = tank is at less than 20% volume, 2 = tank is below 10% volume.
- Flt_Delta_Pressure
- Flt_Post_Filter_Pressure
- Flt_PreBelowPost
- Flt_FuelLevelRate**:** Measured as 0 or 1. 0 = no fault, 1 = fault.
- Flt_Controller
- Flt_Display_Comm
- Flt_Act_DTC
- Flt_Bio_Temp_Low
- Biomode_And_KeyOff
- DPF_Regen
- Purge_Countdown(s)
- ESTOP_Counter
- Standard_Purge_Cntr
- PumpPrimingEnbld
- SystemDisbld
- Standard_Purge_AboveLmt
- Vector_Purge_AboveLmt
- Bio_Pump_Pre_Fltr_Pressure (psi)
- Bio_Pump_Post_Fltr_Pressure (psi)
- Bio_Tank_Level (%)
- Bio_Filter_Change_Needed
- Coolant_Temp_In (°F)
- Coolant_Temp_Out (°F)
- Fuel_Temp_In (°F)
- Fuel_Temp_Out (°F)
- Ambient_Temp (°F)
- Hours_Diesel (Hours)**:** Measured from key on to key off.
- Hours_Bio (Hours)
- Hours_DPF (Hours)**:** Hours of active diesel particulate filter regeneration.
- Hours_Fault (Hours)
- Hours_LowFuel (Hours)

- HghRslutionTotalVehicleDist_Mile (miles)**:** OEM calculation of vehicle mileage. Taken from the OEM CPU.
- ESTOP_Status
- PumpPrimingBtn
- EnableDisableBtn
- Supply_Current (A)
- Return_Current (A)
- Loop_Current (A)
- Flt_Supply
- Flt_Return
- Flt_Loop
- Flt_Flush
- Flt_Coolant
- Supply_Status
- Return_Status
- Loop_Status
- Flush_Status
- Coolant_Status
- Accessory_Status
- Flt_Accessory
- Bio_Current (A)
- Bio_Relay_Status
- Bio_Status
- Flt_Bio_Relay
- Flt_Bio
- Heater_Current (A)
- Heater_Relay_Status
- Heater_Status
- Flt_Heater_Relay
- Flt_Heater
- Coolant_Temp_Warmup (°F)
- Fuel_Temp_Dropout (°F)
- Fuel_Temp_Dropout_Attempts
- Fuel_Temp_Dropout_Duration (seconds)
- Fuel_Temp_Bio (°F)
- Fuel_Temp_Diff_Bio_Switch (°F)
- Low_Pressure_Min (psi)
- Pressure_Diff (psi)
- Pressure_Diff_Time (seconds)
- Idle_Time_To_Purge(s)
- PM_Filter_Change_Alert(psi)
- KeySwType(enum)
- Purge_Duration(s)
- Supplemental_Valve_Config

- Critcal_Low_Fuel_Tank(%)
- High_Current_Config
- Fuel_Valve_Config
- Tank_Level_Min_Cal (ADC)
- Tank_Level_Full_Cal (ADC)
- Bio_Delay (seconds)
- Post_DPF_Lamp_Diesel_Md_Cntdwn (seconds)
- Ignore_DPF_Regen_Bio_On
- Flush_Valve_On_Duration (seconds)
- Bio_After_Regen_Off_Delay (seconds)
- Minimum_DPF_Speed(mph): Minimum speed for vehicle to enter on-road active regeneration of diesel particulate filter. Parameter set by OEM.
- Inhibit_Bio
- Minimum_DPF_Speed_Duration (seconds)
- J1939_AmbTemp_Mode
- Pre_Fltr_Pressure_ADC
- Pre_Fltr_Pressure_Vld
- Post_Fltr_Pressure_ADC
- Post_Fltr_Pressure_Vld
- EngInstantaneousFuelEconomy_MPG (mpg): OEM calculation. Measured for both fuels. Assumed to be accurate.
- EngAverageFuelEconomy_MPG(mpg): OEM calculation. Measured for both fuels. Assumed to be accurate.
- RpgNumber
- EngineOn
- KeySwitchOn
- TeleUpdateAvail
- VehicleSubState
- ECUType
- CAN2BaudRate
- Coolant_Temp_In_Flt
- Coolant_Temp_Out_Flt
- Fuel_Temp_In_Flt
- Fuel_Temp_Out_Flt
- Bio_Tank_Level_Flt
- Bio_Pump_Pre_Fltr_Pressure_Flt
- Bio_Pump_Post_Fltr_Pressure_Flt
- Heater_Temp_Option
- FuelLevel2 (%): OEM fuel tank sensor. Trucks don’t have a second OEM diesel tank, which may be why this value doesn't change.
- FuelLevel1 (%): OEM fuel tank sensor for diesel.
- EngTotalHoursOfOperation (hour): OEM counter for total engine hours.
- DslPrtcltFltrActvRgnrtnFrcdStts
- DslPrtcltFltrActvRgnrtnInhb_0000

- DslPrtcltFltrActvRgnrtnInhbtdDTL
- DslPrtcltFltrActvRgnrtnInhbtdDTI
- DslPrtcltFltrActvRgnrtnInhbtdStt
- DieselParticulateFilterStatus
- DslPrtcltFltrActvRgnrtionStatus
- DslPrtcltFltrPssvRgnrtionStatus
- DieselParticulateFilterLampCmd
- Aftrtrtmnt1SCRCtlystCnvrsnEffcnc (%)
- Aftrtrtmnt1SCRCmddCtlystRgntCnsm (Liters/hour)
- EngTotalIdleHours (hour)**:** OEM counter for total idle hours.
- EngTotalIdleFuelUsed (L)**:** OEM coutner for total liters of fuel used for the lifetime of vehicle.
- EngExhaustGasTemp (°C)
- EngIntakeManifold1Temp (°C)
- EngDslPrtclateFilterIntakePress (kPa)
- VehicleIdentificationNumber
- HghReslutionTotalVehicleDistance (kilometer)**:** OEM odometer reading in kilometers.
- EngTotalAverageFuelEconomy (km/L)**:** OEM calculation in liters, for both fuels, assumed to be accurate.
- EngTotalAverageFuelRate (L/h)**:** OEM fuel consumption calculation, for both fuels. Assumed to be accurate. Fuel rate is time-based; fuel economy is distance-based. Liters per hour versus liters per kilometer. Time spent at idle or standing still will still consume fuel but not cover distance.
- EngAverageFuelEconomy (km/L)**:** OEM calculation in kilometers/liter, for both fuels. Assumed to be accurate.
- EngInstantaneousFuelEconomy (km/L)**:** OEM calculation of fuel economy in kilometers/liter, for both fuels. Assumed to be accurate.
- EngFuelRate (L/h)
- EngFuelTemp1 (°C)
- EngCoolantTemp (°C)
- EngInjectorMeteringRail2Press (MPa)
- EngInjectorTimingRail1Press (MPa)
- EngInjectorMeteringRail1Press (MPa)
- EngCoolantLevel (%)
- EngCrankcasePress (kPa)
- EngOilPress (kPa)
- EngOilLevel (%)
- EngFuelDeliveryPress (kPa)
- DPFThermalManagementActive
- EngDemandPercentTorque (%)
- EngSpeed (rpm)**:** Revolutions per minute (RPM). Constantly adjusting based on how hard/fast the engine is working.
- ActualEngPercentTorque (%)
- DriversDemandEngPercentTorque (%)

- DslPrtcltFltrRgnrtonForceSwitch
- DslPrtcltFltrRgnrtnInhbitSwitch
- WheelBasedVehicleSpeed (km/h)
- Aftrtratment1RegenerationStatus
- Aftertreatment1FuelRate (L/h)
- Aftertreatment1FuelPress1 (kPa)
- Aftrtrtmnt1IntkNOxReadingStable
- Aftertreatment1IntakeNOx (ppm)
- Aftertreatment1ExhaustGasTemp1 (°C)
- Aftrtrtmnt1DslPrtcltFltrInt_0000 (°C)
- Aftrtrtmnt1DslPrtcltFltrInt_0001 (°C)
- Aftrtrtmnt1DslPrtcltFltrDffPrss (kPa)
- Aftertreatment1ExhaustGasTemp2 (°C)
- Aftrtrtmnt1OtltNOxReadingStable
- Aftertreatment1OutletNOx (ppm)
- Aftrtrtmnt1DslPrtcltFltrOtltGsTm (°C)
- Aftertreatment1ExhaustGasTemp3 (°C)
- DslPrtclteFilter1AshLoadPercent (%)
- DslPrtcltFilter1SootLoadPercent (%)
- Aftertreatment1TripFuelUsed (L)
- Aftrtrtmnt2IntkNOxReadingStable
- Aftertreatment2IntakeNOx (ppm)
- Aftertreatment2OutletNOx (ppm)
- DslPrtclteFilter2AshLoadPercent (%)
- DslPrtcltFilter2SootLoadPercent (%)
- Aftertreatment2TripFuelUsed (L)
- EngAirIntakeTemp (°C)
- AmbientAirTemp (°C)
- ChargingSystemPotential (V)
- AltCurrent (A)
- KeyswitchBatteryPotential (V)
- BatteryPotential_PowerInput1 (V)
- EF_Dynamic_Viscosity (Cp)
- EF_Density (g/cc)
- EF_Temp (°C)
- Req_Fuel_Mass_Rate (g/m)
- HCD_Injecting_Sts
- EngFuelDeliveryAbsPress (kPa)
- EngFltrdFuelDeliveryPress (kPa)
- EngFltrdFuelDeliveryAbsPress (kPa)
- SpeedFeedback (RPM)
- Current (A)
- Voltage (V)
- Temp (°C)

- Software (Revision)
- LostIgnFault (on/off)
- LowVoltageFault
- OverCurrentFault
- OverVoltageFault
- MotorMode
- CurrentLimitingFault
- InputParameterRangeFault
- FailedStart
- SpeedCommand (RPM)
- RunCommand

The following daily weather information was archived for the period between December 2022 to October 2024:

- Temperature (°F)
  - Max
  - Avg
  - Min
- Dew Point (°F)
  - Max
  - Avg
  - Min
- Humidity (%)
  - Max
  - Avg
  - Min
- Wind Speed (mph)
  - Max
  - Avg
  - Min
- Pressure (in.)
  - Max
  - Avg
  - Min
- Precipitation total (in.)

4. EVALUATION OF BIODIESEL FUEL ECONOMY

Two different evaluations were carried out to assess the fuel economy of vehicles running on B100 compared to regular diesel. The first used logs kept by snowplow drivers. The second assessed the truck engine data downloaded from the Optimus Technologies dashboard to determine fuel economy.

4.1. Field-Collected Fuel Economy

Snowplow drivers in District 1 for both biodiesel and regular diesel vehicles were provided with a data collection sheet to track certain information when each truck was fueled. Drivers were asked to enter the date, odometer reading, number of gallons filled, and type of fuel for each fueling. However, getting drivers to record this information proved challenging, even with reminders, and ultimately data were only obtained for two biodiesel trucks and two regular trucks.

Logs were available for about two months for each truck, from February to March 2023. In some cases, there were gaps in the data, and some data had to be excluded. The fuel economy calculations for the biodiesel trucks included the use of both biodiesel and regular diesel. As noted above, the biodiesel is “cleared” from the fuel lines before engine shutdown using regular diesel. It is not known how much fuel is used for this process and how much of the regular diesel is used for actual truck operation.

Figure 4-1 shows the results for the four trucks. As shown in the figure, the average fuel economy was 3.71 mph for the first biodiesel truck and 4.61 mpg for the second. In comparison, the average fuel economy was 5.40 mpg for the first regular diesel truck and 4.86 mph for the second. The average fuel economy for the biodiesel trucks was 4.23 mph, while the average fuel economy for the regular diesel trucks was 5.14 mpg. This is an estimated 17.9% reduction in fuel economy for the biodiesel trucks. However, as noted above, the biodiesel trucks use some fuel to purge the fuel lines, which might slightly impact their fuel economy.

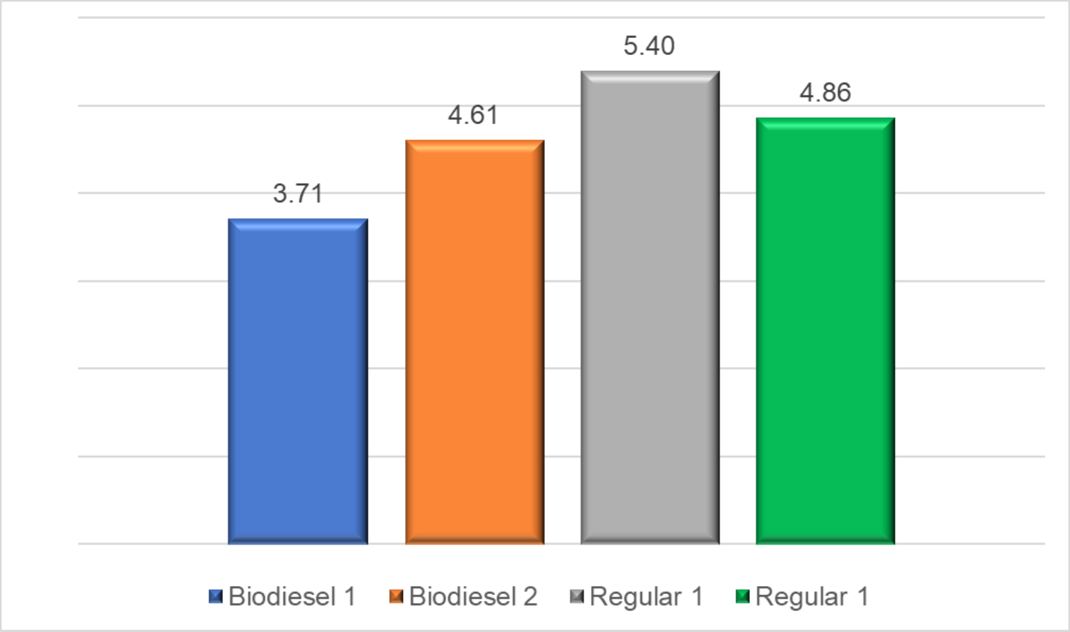


Figure 4-1. Comparison of fuel economy using fueling data collected from drivers

The limitations with this evaluation were the limited amount of data collected and that data were only obtained for four vehicles. As a result, this information provides some information about the likely fuel economy of biodiesel snowplows but is based on a limited sample size.

4.2. Fuel Economy Estimates Based on Engine Data

The initial plan for estimating fuel economy based on engine data was to collect engine data through OBD for both regular diesel and biodiesel-enabled snowplows. OBD data are already available for the biodiesel snowplows through a dashboard provided by Optimus Technologies. Ideally, data would also be collected for regular diesel vehicles using OBD. However, instrumenting the regular diesel trucks entailed finding OBD technology similar to that used in the biodiesel trucks to ensure similar outputs. Additionally, a GPS and cellular link are needed for the OBD technology. Since the equipment is costly, the team worked with the technical advisory committee (TAC) to apply twice for the Iowa Energy Center (IEC) to fund an expanded study that would have allowed instrumentation of a large number of snowplows (or other fleet vehicles) to ensure representative results. However, the IEC did not think that the idea was sufficiently broad to benefit its ratepayers, who are the primary funders of the IEC. Next, the team explored different off-the-shelf OBD options that could be installed by either the team or District 1 staff. However, as noted, instrumentation of multiple vehicles (which is needed to ensure that results are statistically significant) is costly. Additionally, the Optimus Technologies equipment is proprietary, so it would be difficult to ensure that other OBD options provided the same metrics.

The team then explored the option of partnering with Optimus Technologies to have the company install its OBD technology in the regular diesel snowplows. This would have ensured that the data were collected consistently. Several virtual meetings were conducted with Optimus

Technologies. However, after initial positive discussions and a protracted wait for a final answer, Optimus Technologies declined to participate. This was likely based on the company's desire to have a robust side-by-side comparison of regular diesel versus biodiesel snowplows, which would have required an extensive number of test runs with multiple snowplows, a goal significantly beyond project resources.

The team then worked with the TAC to determine the next course of action. It was decided to attempt an analysis using the engine data downloaded via the Optimus Technologies dashboard (see Chapter 3). This effort is described in Section 4.3.

4.3. Evaluation of Engine Data from the Optimus Technologies Dashboard

The team initially began an analysis using the on-board engine data, which was downloaded via the Optimus Technologies dashboard. This entailed selecting several months during cold weather (December to February) and warm weather (June to August). Data were downloaded, and some initial analyses were conducted. However, the team then discovered that there were issues with the snowplows' operation during winter weather events, and in some cases the snowplows were run using regular diesel. These concerns and the data collection timelines were recorded by the team and are summarized in Chapter 5.

4.3.1. Data Overview

The dataset consists of various parameters captured by OBD sensors, including timestamp, geolocation (latitude and longitude), engine oil pressure, wheel-based vehicle speed, ambient temperature, instantaneous fuel economy (in mpg or km/L), and engine fuel rate (in liters per hour). For this analysis, only a subset of variables was selected, either based on their documented influence on fuel efficiency in the literature or based on observed correlations with fuel economy metrics.

Data were available from 10 snowplow trucks. However, 3 of these reported fuel economy only in km/L, while the remaining 7 provided data in both mpg and km/L directly from the OBD system. When comparing these two metrics, the conversion between mpg and km/L resulted in inconsistent values across the dataset. This suggested possible differences in sensor calibration, data processing lag, or calculation methods. To ensure consistency, only the 7 trucks with stable and dual-unit fuel economy data were retained for analysis.

4.3.2. Data Collection Period

To assess the influence of seasonal temperature variations on fuel economy, data were collected across both winter and non-winter months. The selected periods included the following:

- January and February (2022, 2023)
- August and September (2022, 2023)

These dates were selected because there were issues with various trucks during winter months, as explained in Chapter 5, so these time periods were the most likely to have included B100 use. It should be noted that for the winter of 2023, some snowplows may have operated on regular diesel instead of biodiesel. Therefore, dates for winter weather events in 2023 were gathered from meteorological data, and data associated with severe winter storm periods were excluded from the analysis to reduce fuel type-related variability.

4.3.3. Data Cleaning and Filtering

The data for each truck were processed individually before being merged for final analysis. Key preprocessing steps included the following:

- **Duplicate Removal**: Records with identical timestamps were removed to ensure data integrity.
- **Trip Segmentation**: If two consecutive timestamps had a time difference greater than five minutes, that break was used to segment trips. A unique Trip_ID was then assigned to each continuous segment to support structured analysis.
- **Garage Filtering**: Snowplows may remain idle inside Iowa DOT garage facilities for extended periods, especially during engine startup phases. These idle intervals can introduce misleading fuel consumption values. To address this, two geographic polygons were defined to represent garage locations. Using latitude and longitude data, a new column was created to flag when vehicles were within garage boundaries. Records associated with these locations were removed from further analysis.
- **Outlier Filtering**: In the raw OBD data, instantaneous fuel economy and fuel rate values showed occasional extreme spikes. The 97.5th percentile was calculated for each variable, and values exceeding this threshold were masked (set to missing). These missing values were then filled using the average of the preceding and following valid values. Rows that still contained missing values after this interpolation (e.g., due to consecutive outliers) were dropped.
- **Smoothing**: To reduce noise in the time series, moving average smoothing with window sizes of 5 and 10 was applied to the filtered fuel economy and fuel rate data. In addition, a simple Kalman filter was implemented to provide an alternative smoothed estimate that could retain dynamic patterns while minimizing sensor noise.

After cleaning each truck’s data, the datasets were combined, and additional filtering was performed:

- **Winter Storm Flagging**: Records corresponding to known winter storm periods were flagged for potential exclusion, given their deviation in fuel type or operational behavior.
- **GPS Validation**: Records where the GPS_valid field was equal to 0 were removed to ensure accurate geolocation tracking.
- **Timestamp Gaps Within Trips**: Normally, data points within a trip are recorded at two-second intervals. For each Trip_ID, if more than 20% of the time gaps between consecutive records exceeded 10 seconds, the entire trip was excluded to maintain data consistency.

- **Idling Detection**: Idling periods were flagged separately. For modeling purposes, only data where the snowplows were not idling were included in the final analysis.

4.3.4. Modeling

To examine the factors influencing fuel economy (measured in mpg), a generalized additive model (GAM) was developed using a Gaussian family with an identity link function. This flexible modeling approach allows for the inclusion of both linear and nonlinear relationships between the response variable and predictor variables. The predictor variables used in the models included biofuel tank level (Bio_Tank_Level, %), regular diesel tank level (FuelLevel1, %), wheel-based vehicle speed (WheelBasedVehicleSpeed, mph), ambient air temperature (AmbientAirTemp, °C), driver-requested torque (DriversDemandEngPercentTorque), engine fuel delivery pressure (EngFuelDeliveryPress, kPa) and engine oil pressure (EngOilPress, kPa). The response variable is fuel economy (mpg), derived using Kalman filter smoothing. Around 100,000 random samples were used in the model.

The model was specified as follows:

fuel_economy_mpg~te(speed_mph, temp_c) + s(driver_demand_torque) + bio_tank_level + s(eng_fuel_Delivery_pressure) + s(eng_oil_pressure) + fuel_level1

where,

- **te(speed_mph, temp_c)**: A tensor product smooth term capturing the joint nonlinear effect of vehicle speed and ambient temperature.
- **s(driver_demand_torque)**: A smooth term to model the effect of driver-requested torque.
- **bio_tank_level(%)** and **fuel_level1(%)**:Parametric linear terms.
- **s(eng_fuel_Delivery_pressure)** and **s(eng_oil_pressure)**: Smooth terms capturing nonlinear effects of engine performance parameters.

The results of the model are shown in Tables 4-1 through 4-3.

Table 4-1. Model results for fuel economy (mpg): Parametric coefficients

Predictor	Estimate	Std. Error	t-value	p-value	Significance
Intercept	5.059	0.0305	165.860	< 2e-16	***
Bio_Tank_Level (%)	-0.001	0.0003	-5.750	9.22E-09	***
FuelLevel1 (%)	-0.005	0.0003	-14.470	< 2e-16	***

Table 4-2. Model results for fuel economy (mpg): Smooth terms (nonlinear effects)

Smooth Term	edf	Ref.df	F-value	p-value
te(WheelBasedVehicleSpeed (mph), Ambient Air Temperature (°C))	22.750	23.66	1054.8	< 2e-16
s(DriversDemandEngPercentTorque)	8.760	8.98	651.2	< 2e-16
s(Engine Fuel Delivery Pressure (kPa))	8.810	8.98	496.9	< 2e-16
s(Engine Oil Pressure (kPa))	7.810	8.51	196.3	< 2e-16

Table 4-3. Model results for fuel economy (mpg): Model fit statistics

Statistic	Value
Adjusted R^2	0.289
Deviance Explained (%)	28.90%
Number of Observations	100,000

The model was fit to a dataset containing 100,000 random observations. All predictor variables were found to be statistically significant ($p < 2e-16$). The following observations were notable:

- The tensor product smooth term of speed and temperature had an effective degrees of freedom value of 22.747 and a high F-statistic (1,054.8), indicating a strong nonlinear interaction effect.
- The smooth terms for torque, delivery pressure, and oil pressure also showed strong significance.
- The parametric terms for biofuel tank level and diesel fuel tank level were negatively associated with fuel economy and highly significant.

4.3.5. Interpretation and Fuel Economy under Different Conditions

The GAM results suggest that fuel economy is significantly influenced by the joint interaction between speed and ambient temperature.

Understanding the combinations of ambient temperature and vehicle speed that yield the highest fuel economy is particularly valuable for optimizing snowplow operations. To explore this, the interaction between temperature and speed was examined using model-based plots derived from the fitted GAM.

Figure 4-2 presents a smoothed contour plot illustrating the combined effect of ambient temperature (°C) and vehicle speed (mph) on predicted fuel economy (mpg). The plot shows that fuel efficiency tends to improve with increasing speed up to around 40 to 50 mph, particularly when ambient temperatures are moderate (10°C to 40°C). In contrast, lower fuel economy is observed at very low speeds. For example, a vehicle running below 10 mph has lower mpg values.

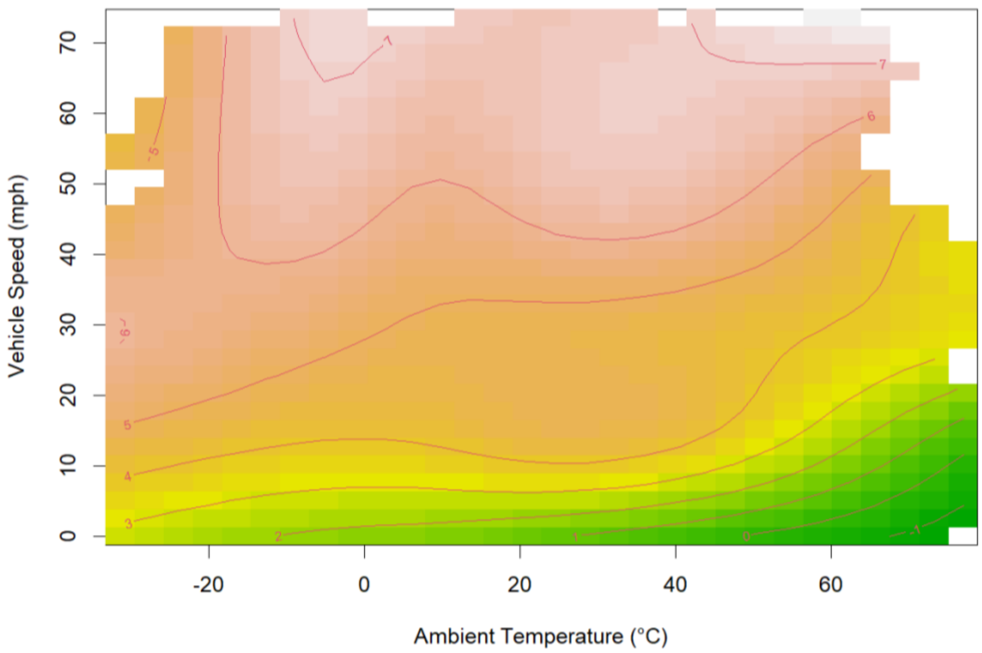


Figure 4-2. Contour plot (predicted mpg versus temperature and speed)

Figure 4-3 represents a 3D surface plot that visualizes the same relationship from a different perspective. The surface clearly shows a ridge where fuel economy peaks, emphasizing that optimal performance occurs at mid-range speeds and moderate temperatures. A decline in mpg is observed in regions representing high temperatures and low speeds, reinforcing the interaction captured in the statistical model.

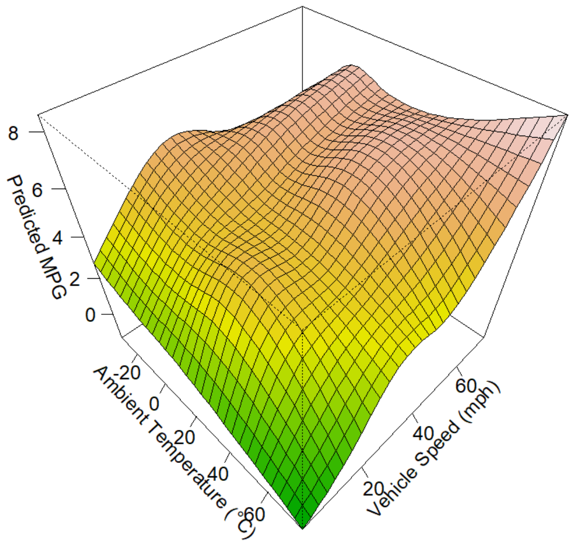


Figure 4-3. 3D surface plot (predicted mpg versus temperature and speed)

The plot shows that fuel economy increases with speed up to a certain point (approximately 40 to 50 mph), after which it begins to level off or decline slightly. Extremely low temperatures (lower than 0°C) are associated with reduced fuel economy, especially at lower speeds. Moderate temperatures (10°C to 40°C) combined with moderate speeds (30 to 50 mph) are associated with peak fuel efficiency, shown at the top of the surface. At very high ambient temperatures (above 50°C) or very low speeds (under 10 mph), the predicted mpg tends to decrease, forming a noticeable dip on the surface.

To identify the most fuel-efficient operating conditions, Table 4-4 summarizes the maximum predicted fuel economy (mpg) within each ambient temperature bin and the corresponding speed range at which it occurs. Ambient air temperatures are grouped in 10°F intervals (with equivalent Celsius ranges), and vehicle speeds are categorized in 5 mph increments. Although the highest predicted mpg of 6.8 is observed in the 120°F to 130°F (48.9°C to 54.4°C) range at speeds of 45 to 70 mph, this value occurs at the extreme boundary of the temperature axis (as shown in Figures 4-2 and 4-3) and therefore can be disregarded for practical use. The table helps reveal more consistent optimal conditions, such as moderate speeds (40 to 70 mph) combined with temperatures between 50°F and 100°F (10°C and 40°C), where fuel economy remains relatively high.

Table 4-4. Maximum predicted fuel economy (mpg) across ambient temperature bins and corresponding speed ranges

Ambient Air Temp. (°F)	Ambient Air Temp. (°C)	Speed Range (mph)	Avg Fuel Economy (mpg)
(-10,0)	(-23.3, -17.8)	30 to 70	6.07
(0,10)	(-17.8, -12.2)	45 to 70	5.97
(10,20)	(-12.2, -6.7)	45 to 65	6.11
(20,30)	(-6.7, -1.1)	45 to 70	6.12
(30,40)	(-1.1, 4.4)	60 to 75	6.37
(40,50)	(4.4, 10)	55 to 70	5.92
(50,60)	(10, 15.6)	55 to 75	6.29
(60,70)	(15.6, 21.1)	50 to 75	6.11
(70,80)	(21.1, 26.7)	45 to 75	6.23
(80,90)	(26.7, 32.2)	40 to 75	6.29
(90,100)	(32.2, 37.8)	40 to 75	6.39
(100,110)	(37.8, 43.3)	40 to 70	6.36
(110,120)	(43.3, 48.9)	55 to 70	6.56
(120,130]	(48.9, 54.4)	45 to 70	6.8

Table 4-5 summarizes the highest and lowest predicted fuel economy values for each 10°F ambient air temperature bin, along with the 5 mph speed intervals at which those values occur. Temperature ranges are shown in both Fahrenheit and Celsius. Across all temperature bins, the lowest fuel economy consistently occurs in the 0 to 5 mph range, reflecting the inefficiency of low-speed snowplow operations, likely due to prolonged idling (slower movement) and heavy load demands. Conversely, the highest mpg values are generally observed at higher speeds, particularly between 55 and 75 mph, depending on the temperature bin.

Predicted mpg values for all levels of temperature and speed are presented in Appendix A.

Table 4-5. Maximum and minimum predicted fuel economy (mpg) for 5 mph speed bins

Ambient Air Temp. (°F)	Ambient Air Temp. (°C)	Speed Range for Max mpg (mph)	Max Fuel Economy (mpg)	Speed Range for min mpg (mph)	Min Fuel Economy (mpg)
(-10,0)	(-23.3, -17.8)	(65,70)	6.57	(0,5)	3.6
(0,10)	(-17.8, -12.2)	(60,65)	6.19	(0,5)	3.32
(10,20)	(-12.2, -6.7)	(60,65)	6.19	(0,5)	3.08
(20,30)	(-6.7, -1.1)	(60,65)	6.28	(0,5)	3.02
(30,40)	(-1.1, 4.4)	(65,70)	6.9	(0,5)	2.97
(40,50)	(4.4, 10)	(65,70)	6	(0,5)	2.91
(50,60)	(10, 15.6)	(70,75]	6.66	(0,5)	2.88
(60,70)	(15.6, 21.1)	(70,75]	6.3	(0,5)	2.79
(70,80)	(21.1, 26.7)	(70,75]	6.34	(0,5)	2.77
(80,90)	(26.7, 32.2)	(55,60)	6.5	(0,5)	2.71
(90,100)	(32.2, 37.8)	(55,60)	6.64	(0,5)	2.45
(100,110)	(37.8, 43.3)	(70,75]	8.64	(0,5)	2.48
(110,120)	(43.3, 48.9)	(65,70)	7.2	(0,5)	2.17
(120,130]	(48.9, 54.4)	(65,70)	7.41	(0,5)	1.95

4.3.6. Summary

This study demonstrates that the fuel economy for biodiesel-powered snowplows is significantly influenced by vehicle speed, ambient temperature, and engine parameters. Using a GAM fitted to cleaned OBD data, it was found that fuel efficiency generally improves at moderate speeds (40 to 60 mph) and moderate ambient temperatures (10°C to 40°C/50°F to 100°F). The model effectively captures nonlinear interactions, particularly between speed and temperature, providing insights into optimal operating conditions for biodiesel-powered snowplows. While extreme temperature-speed combinations showed high fuel economy, these occurred at the boundary of the dataset and should be interpreted cautiously.

5. DESCRIPTION OF THE IOWA DOT’S B100 SNOWPLOW PILOT PROGRAM

One of the initial project objectives was to survey snowplow operators to assess their experiences and identify attitudes and barriers that would hinder further adoption of B100 snowplows or maintenance vehicles. The survey was slated for late 2024/early 2025. However, as the survey was being prepared, the Iowa DOT advised the research team that there had been issues with the snowplows that were significantly impacting their further use. As a result, a survey to identify barriers was not going to be of further value to the Iowa DOT. After discussion with the TAC, it was agreed that the team would meet with the Iowa DOT and summarize the agency’s experience with the B100 technology. Several discussions and email exchanges were held, which are summarized in this chapter.

**Note that some of the information in this chapter overlaps with the discussion in the introduction chapter but was preserved so that this record encompasses the entire discussion.*

5.1. Description of Vehicles

The Iowa DOT B100 snowplow pilot program began in July 2020 with a retrofit of five trucks with the Optimus Technologies system and the purchase of three new snowplows under the Diesel Emission Reduction Act (DERA) of 2020 that were fitted with the same technology. The new trucks were purchased from the same vendor that installed the B100 compatibility systems. The City of Ames, Iowa, also purchased two snowplows. The trucks included the following:

Des Moines North:

- A32854 - Tandem (fiscal year [FY] 2023 replacement program)
- A33646 - Single axle (FY 2025 replacement program)
- A33676 - Tandem (FY 2026 replacement program)
- A33976 - Tandem (FY 2026 replacement program)
- A34349 - Single axle
- A35242 - Single axle (DERA FY 2020)
- A35243 - Single axle (DERA FY 2020)
- A35705 - Tandem

Ames (All New Builds):

- A35234 - Single axle (DERA FY 2020)
- A35666 - Single axle

5.2. Original Expectations

The Iowa DOT expected the B100 snowplows to operate similarly to those using regular diesel. (Note that the regular diesel used by the Iowa DOT is a biodiesel blend.) The agency also expected similar maintenance requirements. One of the main incentives for piloting the B100 technology was to reduce emissions and to support local agriculture.

5.3. Issues with the Trucks

The Iowa DOT indicated that the five trucks retrofitted in July 2020 initially worked fine. The first issues that operators reported were related to low engine power (torque, horsepower, boost), which were reported for all trucks. The Iowa DOT conducted a chassis dynamometer test comparing B100 and regular diesel, which showed an 11% reduction in all power-related metrics (horsepower, torque, boost) for B100 compared to regular diesel.

Additional concerns with the new trucks were then reported, which included loss of power and instances of the trucks shutting off while driving on the road. These issues were first noted early in 2023. In an attempt to address the problems, the B100 fuel was tested, and the Iowa DOT was notified that more cetane was present than expected. No other information about the fuel was provided.

In a further effort to address the problems, pumps were changed, fuel systems were replumbed, different filters were tried, and pumps were switched to raise fuel pressure. In April 2024, an entirely new fuel system was put into one truck. However, the issues were not resolved. Error codes were provided in some cases, and Optimus Technologies tried to interpret and address them. An attempt was made to let Optimus Technologies know when any of the systems was having issues or giving a specific error code, but the issues were so intermittent that the Iowa DOT could not replicate the issue.

As of March or April of 2024, the trucks were noted as performing better in the summer in terms of power. However, some cut-out and shutoff issues were still noted. In September 2024, Optimus Technologies was alerted to the issues again, and the biodiesel technology was removed from the trucks and replaced with a regular diesel system. The work was performed by a third party that was subletted by Optimus Technologies with the objective of replacing the entire B100 system at a later date. Around September 3, 2024, the Iowa DOT discussed the issues with Optimus Technologies and was notified by the company that its workload was too high to complete the installations. As a result, the Iowa DOT is currently running all of the trucks as regular diesel vehicles.

The most recent issues are noted below:

- A35243 showed engine codes (559) and fuel codes, did not stay running at times, and would die in the road randomly.
- A35242 would die randomly when traveling on the road, had difficulty starting at times, showed constant engine codes (559), and was underpowered.
- A35705 would randomly surge and die at times, operators complained of low power in B100 mode, and the system would stop working randomly.

- A34349 showed injector codes indicating low flow and codes indicating that the DPF is missing and had trouble going in and out of B100 mode.
- A33976 had difficulty switching into B100 mode beginning in June 2024, and the Iowa DOT notified Optimus Technologies three or four times of this problem. The company sent technicians to resolve the issues, but nothing was achieved as of November 13, 2024. A technician finally determined that the vehicle needed a wiring harness.
- A35242, A35243, and A35705 had problems for 1½ years. The Iowa DOT worked with Optimus Technologies for four months on a temporary fix so that the vehicles would be able to plow snow during the winter seasons, but the problems persisted. Ultimately, Optimus Technologies put factory fuel tanks back into the vehicles to temporarily bypass all use of B100 for the winter season.

As of approximately October 1, 2024, the B100 system was completely disabled in the three new trucks (A35242, A35243, and A35705). The 60/40 split biofuel/regular diesel tanks were removed so that the vehicles were able to run strictly on regular diesel during the 2024/2025 winter season.

5.4. Fuel Tank

At the same time that the original five trucks were retrofitted, a B100 storage and dispenser fuel tank was installed at the Des Moines North garage. The tank was built by Separation by Design, and REG provides fuel and owns one side of the tank. The tank is heated and insulated to keep the B100 above the cloud point temperature (over 32°F). However, it was reported that the fuel tank repeatedly lost power to heat or dispense fuel. It was also noted that the fuel dispensed slowly. Optimus Technologies and REG are able to view tank information remotely. The Iowa DOT does not receive any tank information, although it was supposed to be provided with alerts that would inform the agency of issues with heating. A service contract for monthly tank inspections was used to make sure everything was functioning. However, the contractor stopped performing these inspections and as of October 2024 had not been to the site in almost a year.

Optimus Technologies uses sensors on the tank and on the trucks to record and dispense fuel. These include an RFID reader on the tank and a ring tag for each truck that matches the trucks to the appropriate tank and prevents trucks without B100 retrofits from receiving B100. However, it was reported that the ring tags would occasionally lose connection with the tanks and would need to be reset to get them working. The fix was to provide the tank attendant with a handheld ring tag, but this allowed the possibility that B100 would be placed in the wrong tanks.

The Iowa DOT estimates that the cost of additional electricity to heat the tanks from February 5, 2020, to October 31, 2024, was $13,548.54, or approximately $237.69 per month, although costs are higher in the winter ($501.18 in January 2021 compared to $41.16 in July 2021).

5.5. B100 Use

After the retrofit, the trucks were initially run using B100 year-round. After the engine power issues described above were first noted around December of 2022 and could not be resolved, the trucks were switched to regular diesel during winter storms because additional power is required during winter weather operations to run the three plows (front, underbody, and wing).

The trucks have a mechanically driven hydraulic pump that runs everything on the truck that requires horsepower. The trucks have a relatively small engine, and as a result there is little margin to lose power and complete winter weather operations because power loss has a 10X factor in terms of its impacts on truck operations. With the issues noted above regarding loss of power due to the use of B100, the underbody plow could not be used during some winter storms due to horsepower issues. The impact depended on the storm and the amount of power required. The issue was not as critical in the summer months, when there were fewer power demands on the trucks.

For regular operations, the Iowa DOT typically uses a B20 blend in the summer months (May to September) and a B2 blend during the winter months (November to March).

In late 2022 to 2023, regular diesel would have been used in the trucks at times when the Iowa DOT determined that a snow event would require more horsepower than B100 could provide. As a result, when B100 was not used, the above types of fuel would have been used in the trucks.

The number of times trucks were fueled using the B100 tank was determined through data obtained from the Optimus Technologies dashboard and is shown in Figure 5-1. Similar to what was reported by the Iowa DOT, use of the B100 fueling system declined after approximately October 2024.

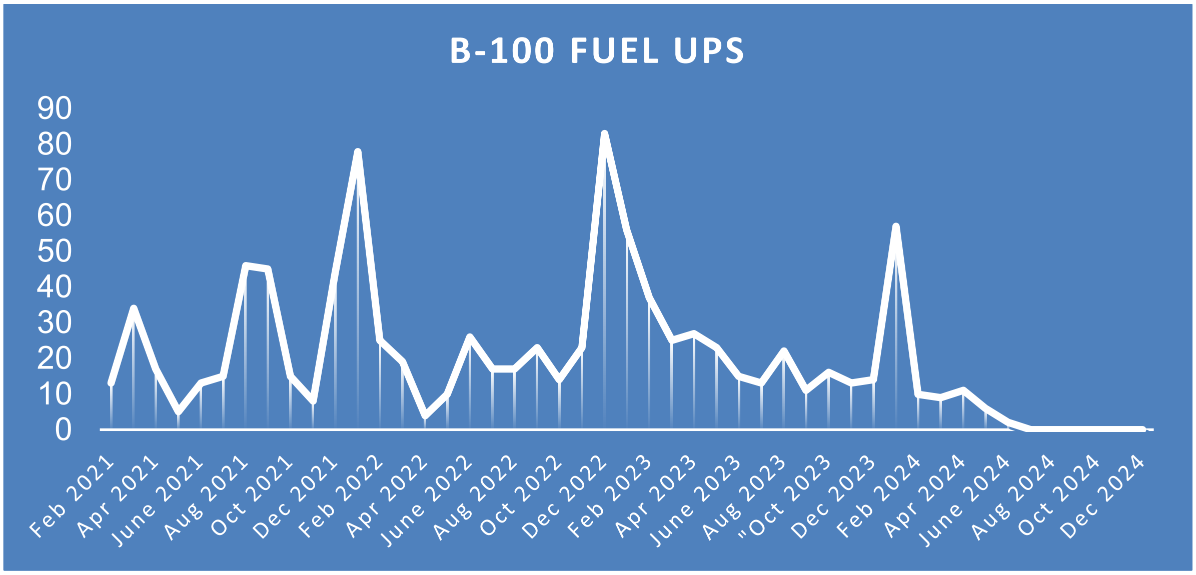


Figure 5-1. Timeline for B100 fueling

5.6. Next Steps

The Iowa DOT wanted to ensure that it had met its commitment for the B100 snowplow trials and now would prefer to send the five new trucks back to stock. The agency feels that the use of B100 could have merit for some applications, but in its experience the fuel is not suitable for the power demand needed to plow snow given the current technology.

5.7. Additional Truck Information

Additional information about each truck was also provided, as shown in Table 5-1.

Table 5-1. Truck information

Truck	Make/Model	Engine	Frontal area
A32854	International, 7500	Maxxforce 10	13.5 feet x 8.5 feet
A33646	International, 7300	Maxxforce DT	10 x 8 feet
A33676	International, 7500	Maxxforce 10	13.5 feet x 8.5 feet
A33976	International, 7400	Maxxforce 1	13 x 8 feet
A34349	International, 7400	Maxxforce 1	13 x 8 feet
A35242	International, HV507	Cummins L9	9.6 X 8 feet
A35243	International, HV507	Cummins L9	9.6 X 8 feet
A35705	International, HV507	Cummins L9	9.6 X 8 feet
A35234	International, HV507	Cummins L9	9.6 X 8 feet
A35666	International, HV507	Cummins L9	9.6 X 8 feet

6. DEVELOPMENT OF TOOLS TO ESTIMATE EMISSIONS AND FUEL ECONOMY

This chapter describes the development of four tools that can be used by the Iowa DOT to estimate the fuel economy and emissions of various biodiesel blends, with an emphasis on B20 and B100. The information sources on which the tools are based are described below, along with a short summary of how each tool was developed.

**Note that due to recent Federal Executive Orders, some information that was originally gathered by the team has been removed from the USEPA website and may not be locatable.*

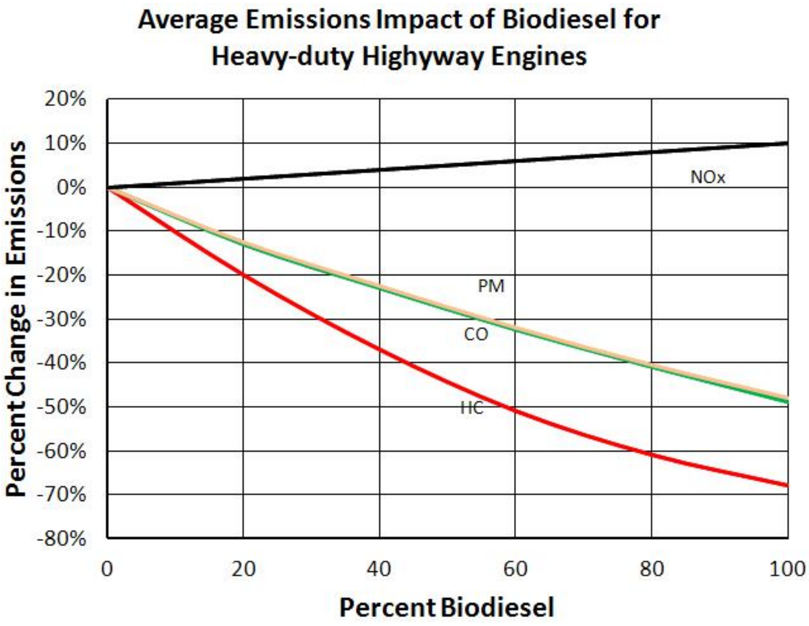
6.1. Emissions Calculator

The first tool is an emissions calculator that can be used to estimate the change in PM, CO, NOx, and HC resulting from the use of biodiesel.

Information to develop estimates was gathered through a comprehensive review of literature that identified the emissions impacts of biodiesel versus regular diesel. The team reviewed each information source to determine whether it was applicable to Iowa conditions using the following filters to prioritize information:

- US studies
- Biodiesel source (studies were used only if soybean or corn was the principal source)
- Evaluation method (information was disaggregated by dynamometer evaluations versus on-road evaluations)
- Life cycle (information was disaggregated by life-cycle studies versus fuel-only studies)

The emissions information from the literature sources was compared to emissions estimates for various biodiesel blends calculated by a spreadsheet tool developed by the USEPA, *Biodiesel Emission Reduction Calculation Spreadsheet (BERCS)*. The tool can be found at https://www.epa.gov/verified-diesel-tech/various-technology-biodiesel-1-100. The tool was developed to assist agencies in complying with USEPA emissions standards for diesel engines in order for those engines to receive USEPA certification as a Clean Diesel Technology. Although the source of the data used by this tool is not stated, the results are similar to those calculated by Argonne National Laboratory (USDOE n.d.-b), as shown in Figure 6-1.



USDOE n.d.-b

Figure 6-1. Emissions impacts of biodiesel

In addition to the information summarized in Chapter 2, the sources listed in Tables 6-1 through 6-5 were determined to be the most applicable to Iowa conditions. Each table shows the most relevant emissions-related information from these studies. Estimates were available for B20 and B100 in most cases, since these are the common values reported in emissions studies. The last row of each table shows the value calculated using the USEPA's BERCS (USEPA 2022).

Emissions estimates for PM-10 are shown in Table 6-1. Reductions for B20 compared to regular diesel range from 6.5% to 18.6% (average 13.1%) depending on the source. A reduction of 9% is estimated by BERCS, which is within the range of estimates from other sources. Reductions of 32% to 48% (average 37.5%) are noted for B100 compared to regular diesel. BERCS estimates a reduction of 37%, which is around the average value from other sources.

Table 6-1. Emissions estimates for PM-10

Study Type	Change from Petroleum Diesel to B20	Change from Petroleum Diesel to B100	Sources
Life Cycle	-6.5%	-32.4%	Sheehan et al. 1998
Dynamometer	-13.3%	NA	Anderson 2012
On-Road	-15.2%	NA	Anderson 2012
Dynamometer	-18.6%	NA	Proc et al. 2006.
Life Cycle	NA	-32.0%	Sheehan et al. 1998
Not stated	-12.0%	-48.0%	https://afdc.energy.gov/vehicles/diesels-emissions
Not stated	-9.0%	-37.0%	USEPA 2022

Emissions estimates for CO are shown in Table 6-2. Estimates for B20 range from a reduction of 4.1% to a reduction of 23.6% (average 10.6%). BERCS estimates a reduction of 10%, which is near the average of estimates from other sources. Reductions of 32% to 48% (average 35.4%) are noted for B100 compared to regular diesel. BERCS estimates a reduction of 42.0%, which is within the range of values from other sources.

Table 6-2. Emissions estimates for carbon monoxide

Study Type	Change from Petroleum Diesel to B20	Change from Petroleum Diesel to B100	Sources
Life Cycle	-6.9%	-34.5%	Sheehan et al. 1998
Dynamometer	-4.1%	-24.0%	Anderson 2012
On-Road	-6.6%	NA	Anderson 2012
Dynamometer	-23.6%	NA	Proc et al. 2006
Life Cycle	NA	-35.0%	Sheehan et al. 1998
Not stated	-12.0%	-48.0%	https://afdc.energy.gov/vehicles/diesels-emissions
Not stated	-10.0%	-42.0%	USEPA 2022

Emissions estimates for NOx are shown in Table 6-3. Estimates for B20 range from a reduction of 4.9% to an increase of 2.7% (average 0.5%). BERCS estimates an increase of 1.0%, which is near the average of estimates from other sources. Increases from 9.0% to 13.4% (average 11.5%) are noted for B100 compared to regular diesel, depending on the source. An increase of 4.0% is estimated by BERCS, which is within the range of values from other sources.

Table 6-3. Emissions estimates for nitrogen oxides

Study Type	Change from Petroleum Diesel to B20	Change from Petroleum Diesel to B100	Sources
Life Cycle	2.7%	13.4%	Sheehan et al. 1998
Dynamometer	3.5%	9.0%	Anderson 2012
On-Road	-3.3%	NA	Anderson 2012
Dynamometer	-4.9%	NA	Proc et al. 2006
Life Cycle	2.7%	13.4%	Sheehan et al. 1998
Not stated	2.0%	10.0%	https://afdc.energy.gov/vehicles/diesels-emissions
Not stated	1.0%	4.0%	USEPA 2022

Table 6-4 shows emissions estimates for HC. Estimates for B20 range from a reduction of 28.0% to an increase of 7.2% (average -13.6%). BERCS estimates a reduction of 21.0%, which is near the average of estimates from other sources. Estimates for B100 range from a decrease of 68% to an increase of 36% (average 5%). BERCS estimates a reduction of 69.0%, which is lower than other estimates. It should be noted that several of the sources found an increase in HC, which is not expected.

Table 6-4. Emissions estimates for hydrocarbons

Study Type	Change from Petroleum Diesel to B20	Change from Petroleum Diesel to B100	Sources
Life Cycle	7.2%	36.0%	Sheehan et al. 1998
Dynamometer	-5.7%	-23.0%	Anderson 2012
On-Road	-21.7%	NA	Anderson 2012
Dynamometer	-28.0%	NA	Proc et al. 2006
Life Cycle	-	35.0%	Sheehan et al. 1998
Not stated	-20.0%	-68.0%	https://afdc.energy.gov/vehicles/diesels-emissions
Not stated	-21.0%	-69.0%	USEPA 2022

Table 6-5 shows emissions estimates for CO_2. Estimates for B20 range from a reduction of 15.7% to an increase of 3.0% (average -4.4%). No estimates were available for B100, and BERCS does not provide estimates for CO_2.

Table 6-5. Emissions estimates for carbon dioxide

Study Type	Change from Petroleum Diesel to B20	Change from Petroleum Diesel to B100	Sources
Dynamometer	-0.4%	NA	Anderson 2012
On-Road	3.0%	NA	Anderson 2012
Dynamometer	NA	NA	Proc et al. 2006
Life Cycle	-15.7%	NA	Sheehan et al. 1998
Not stated	NA	NA	USEPA 2022

As noted in the tables, all of the sources were consistent with the estimates calculated by the USEPA spreadsheet tool. As a result, values from BERCS were used for consistency. The value in using BERCS is that it is a recognized tool, and values can be estimated for various biodiesel blends. BERCS estimates emissions reductions using a formula and coefficients that are based on yearly data. The data from the most recent year available (2020) and the coefficients for that year were used in the calculations here.

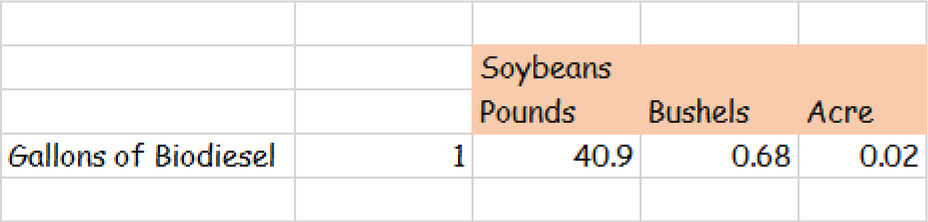
6.2. Soybean Calculator

The next tool was developed to estimate the amount of soybeans (in pounds, bushels, and acres) needed to create a given quantity of biodiesel. This tool can be used to estimate the amount of agricultural resources needed to meet biodiesel production needs.

No single source of information was found that provided the amount of soybeans needed for each gallon of biodiesel. As a result, the following information was gathered from two sources (Sadaka 2017, Penn State Extension 2023):

- 1 acre of soybeans produces about 39 bushels.
- 1 bushel of soybeans weighs 60 pounds.
- 1 acre of soybeans produces about 2,340 pounds of soybeans.
- 1 bushel of soybeans produces 11 pounds of oil.
- 1 acre of soybean land produces 429 pounds of oil.
- 1 pound of soybean oil produces about 0.973 pounds of biodiesel.
- 1 gallon of biodiesel weighs 7.3 pounds.
- 1 acre of soybeans produces about 57 gallons of biodiesel.
- Therefore, 1 bushel of soybeans produces about 1.5 gallons of biodiesel.

Using the above information as inputs, a spreadsheet form was created that allows users to enter various gallons of biodiesel to estimate the amount of soybeans used (in pounds, bushels, and acres) in the production of that amount of fuel, as shown in Figure 6-2.



		Soybeans		
		Pounds	Bushels	Acre
Gallons of Biodiesel	1	40.9	0.68	0.02

Figure 6-2. Spreadsheet for estimating the amount of soybeans needed to produce a given amount of biodiesel

6.3. Carbon Reduction Calculator

Another tool was developed to estimate the amount of carbon reduction that would result from the use of various amounts and blends of biodiesel. Carbon reduction is the amount of carbon dioxide (CO_2) emissions that are reduced due to the use of a particular type of fuel. No studies were found that specifically estimate the amount of CO_2 produced by biodiesel compared to regular diesel. As a result, the tool's estimates are calculated based on several assumptions. The USEPA (2025) estimates that a gallon of regular diesel produces 10,180 grams (22.44 pounds) of CO_2. The United States Department of Energy (USDOE) estimates that B100 reduces CO_2 emissions by around 75% and that B20 reduces CO_2 emissions by 15% (USDOE 2011). Since biodiesel has a lower energy content than regular diesel, around 1.05 gallons of B100 are required to produce the same amount of energy as 1 gallon of regular diesel (USDOE n.d.-a), and 1 gallon of B20 has around 1% to 2% lower fuel content than regular diesel (USDOE n.d.-c).

Using the above information, the equivalent amount of CO_2 produced by B100 can be estimated using the following:

- Around 1.05 gallons of B100 are required to produce the same amount of energy as 1 gallon of regular diesel.
- B100 produces approximately 75% fewer pounds of CO_2 than regular diesel.

- One gallon of regular diesel creates 22.44 pounds of CO_2.
- So, the equivalent number of gallons of B100 create (1.05 x 22.44 x 0.25 =) 5.89 pounds of CO_2, or 17.67 fewer pounds of CO_2 than regular diesel.

Using the above information, the equivalent amount of CO_2 produced by B20 can be estimated using the following:

- Around 1.01 gallons of B20 are required to produce the same amount of energy as 1 gallon of regular diesel.
- B20 produces approximately 15% fewer pounds of CO_2 than regular diesel.
- One gallon of regular diesel creates 22.44 pounds of CO_2.
- So, the equivalent number of gallons of B20 create (1.01 x 22.44 x 0.85 =) 19.26 pounds of CO_2, or 3.40 fewer pounds of CO_2 than regular diesel.

6.4. Fuel Economy Calculator

Another tool was developed that compares the fuel economy of various biodiesel blends to that of regular diesel.

An attempt was made to develop fuel economy factors specific to Iowa conditions using data by comparing field estimates or by using the engine data obtained from the Optimus Technologies dashboard, as described in Chapter 4. However, as described in that chapter, numerous problems arose that made it challenging to do so. As a result, national fuel economy standards were used and then adjusted based on Iowa-specific data, as described below.

The original intent was to adjust the B100 fuel economy calculated in Section 4.3.5 based on expected speeds and temperature. Normally, fuel economy is lower at lower temperatures (USDOE n.d.-d). It was expected that the evaluation of the engine data from the Optimus Technologies dashboard would show a similar trend, but the trend based on temperature was inconsistent with expectations. However, fuel economy also varies by speed. Since the speed values were reasonably consistent in the analysis of the engine data, reduction factors were developed based on average fuel economy by speed for mid-range temperatures (40°F to 70°F), as shown in Figure 6-3.

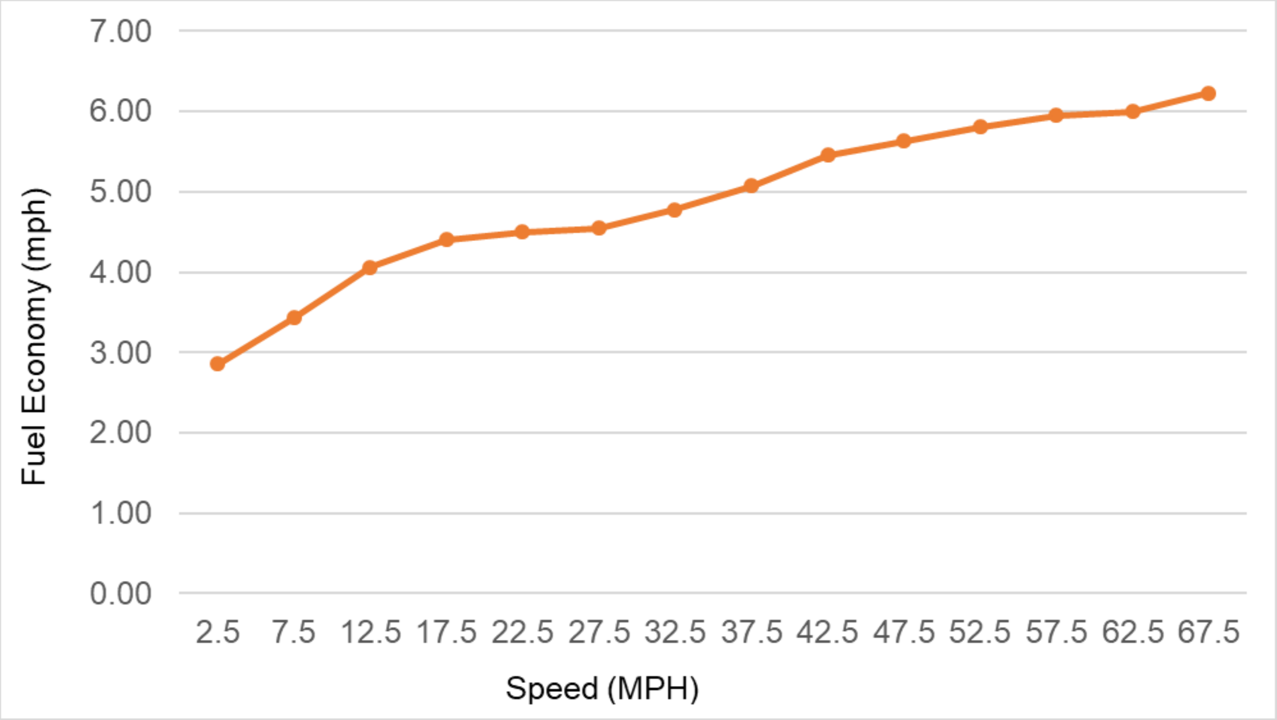


Figure 6-3. B100 fuel economy (mpg) versus speed (mph)

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APPENDIX A. PREDICTED FUEL ECONOMY (MPG) BY AMBIENT TEMPERATURE AND VEHICLE SPEED BINS

Temperature Bin (10°F Interval)	Temperature Bin (°C)	Speed Bin (5 mph Interval)	Predicted mpg
(0,10)	(-17.8, -12.2)	(0,5)	3.32
(0,10)	(-17.8, -12.2)	(5,10)	3.63
(0,10)	(-17.8, -12.2)	(10,15)	4.22
(0,10)	(-17.8, -12.2)	(15,20)	4.56
(0,10)	(-17.8, -12.2)	(20,25)	4.82
(0,10)	(-17.8, -12.2)	(25,30)	5.09
(0,10)	(-17.8, -12.2)	(30,35)	5.32
(0,10)	(-17.8, -12.2)	(35,40)	5.6
(0,10)	(-17.8, -12.2)	(40,45)	5.8
(0,10)	(-17.8, -12.2)	(45,50)	5.92
(0,10)	(-17.8, -12.2)	(50,55)	6.03
(0,10)	(-17.8, -12.2)	(55,60)	5.83
(0,10)	(-17.8, -12.2)	(60,65)	6.19
(0,10)	(-17.8, -12.2)	(65,70)	6.04
(-10,0)	(-23.3, -17.8)	(0,5)	3.6
(-10,0)	(-23.3, -17.8)	(5,10)	3.87
(-10,0)	(-23.3, -17.8)	(10,15)	4.35
(-10,0)	(-23.3, -17.8)	(15,20)	4.75
(-10,0)	(-23.3, -17.8)	(20,25)	5.08
(-10,0)	(-23.3, -17.8)	(25,30)	5.56
(-10,0)	(-23.3, -17.8)	(30,35)	6.04
(-10,0)	(-23.3, -17.8)	(35,40)	5.75
(-10,0)	(-23.3, -17.8)	(40,45)	5.83
(-10,0)	(-23.3, -17.8)	(45,50)	5.74
(-10,0)	(-23.3, -17.8)	(50,55)	6.42
(-10,0)	(-23.3, -17.8)	(55,60)	5.99
(-10,0)	(-23.3, -17.8)	(60,65)	6.23
(-10,0)	(-23.3, -17.8)	(65,70)	6.57
(10,20)	(-12.2, -6.7)	(0,5)	3.08
(10,20)	(-12.2, -6.7)	(5,10)	3.46
(10,20)	(-12.2, -6.7)	(10,15)	3.97
(10,20)	(-12.2, -6.7)	(15,20)	4.4
(10,20)	(-12.2, -6.7)	(20,25)	4.77
(10,20)	(-12.2, -6.7)	(25,30)	5.1
(10,20)	(-12.2, -6.7)	(30,35)	5.26
(10,20)	(-12.2, -6.7)	(35,40)	5.44
(10,20)	(-12.2, -6.7)	(40,45)	5.78
(10,20)	(-12.2, -6.7)	(45,50)	5.96
(10,20)	(-12.2, -6.7)	(50,55)	6.12
(10,20)	(-12.2, -6.7)	(55,60)	6.17
(10,20)	(-12.2, -6.7)	(60,65)	6.19
(10,20)	(-12.2, -6.7)	(65,70)	5.61
(10,20)	(-12.2, -6.7)	(70,75]	5.61

Temperature Bin (10°F Interval)	Temperature Bin (°C)	Speed Bin (5 mph Interval)	Predicted mpg
(20,30)	(-6.7, -1.1)	(0,5)	3.02
(20,30)	(-6.7, -1.1)	(5,10)	3.46
(20,30)	(-6.7, -1.1)	(10,15)	3.92
(20,30)	(-6.7, -1.1)	(15,20)	4.34
(20,30)	(-6.7, -1.1)	(20,25)	4.59
(20,30)	(-6.7, -1.1)	(25,30)	4.98
(20,30)	(-6.7, -1.1)	(30,35)	5.19
(20,30)	(-6.7, -1.1)	(35,40)	5.47
(20,30)	(-6.7, -1.1)	(40,45)	5.67
(20,30)	(-6.7, -1.1)	(45,50)	6.05
(20,30)	(-6.7, -1.1)	(50,55)	6.12
(20,30)	(-6.7, -1.1)	(55,60)	6.14
(20,30)	(-6.7, -1.1)	(60,65)	6.28
(20,30)	(-6.7, -1.1)	(65,70)	6.01
(30,40)	(-1.1, 4.4)	(0,5)	2.97
(30,40)	(-1.1, 4.4)	(5,10)	3.33
(30,40)	(-1.1, 4.4)	(10,15)	3.85
(30,40)	(-1.1, 4.4)	(15,20)	4.21
(30,40)	(-1.1, 4.4)	(20,25)	4.51
(30,40)	(-1.1, 4.4)	(25,30)	4.76
(30,40)	(-1.1, 4.4)	(30,35)	5.11
(30,40)	(-1.1, 4.4)	(35,40)	5.29
(30,40)	(-1.1, 4.4)	(40,45)	5.65
(30,40)	(-1.1, 4.4)	(45,50)	5.7
(30,40)	(-1.1, 4.4)	(50,55)	5.73
(30,40)	(-1.1, 4.4)	(55,60)	5.8
(30,40)	(-1.1, 4.4)	(60,65)	6.07
(30,40)	(-1.1, 4.4)	(65,70)	6.9
(30,40)	(-1.1, 4.4)	(70,75]	6.13
(40,50)	(4.4, 10)	(0,5)	2.91
(40,50)	(4.4, 10)	(5,10)	3.33
(40,50)	(4.4, 10)	(10,15)	3.82
(40,50)	(4.4, 10)	(15,20)	4.19
(40,50)	(4.4, 10)	(20,25)	4.43
(40,50)	(4.4, 10)	(25,30)	4.6
(40,50)	(4.4, 10)	(30,35)	4.82
(40,50)	(4.4, 10)	(35,40)	5.07
(40,50)	(4.4, 10)	(40,45)	5.35
(40,50)	(4.4, 10)	(45,50)	5.58
(40,50)	(4.4, 10)	(50,55)	5.7
(40,50)	(4.4, 10)	(55,60)	5.94
(40,50)	(4.4, 10)	(60,65)	5.81
(40,50)	(4.4, 10)	(65,70)	6
(50,60)	(10, 15.6)	(0,5)	2.88
(50,60)	(10, 15.6)	(5,10)	3.35
(50,60)	(10, 15.6)	(10,15)	4.03
(50,60)	(10, 15.6)	(15,20)	4.39

Temperature Bin (10°F Interval)	Temperature Bin (°C)	Speed Bin (5 mph Interval)	Predicted mpg
(50,60)	(10, 15.6)	(20,25)	4.49
(50,60)	(10, 15.6)	(25,30)	4.53
(50,60)	(10, 15.6)	(30,35)	4.73
(50,60)	(10, 15.6)	(35,40)	4.91
(50,60)	(10, 15.6)	(40,45)	5.25
(50,60)	(10, 15.6)	(45,50)	5.5
(50,60)	(10, 15.6)	(50,55)	5.74
(50,60)	(10, 15.6)	(55,60)	5.86
(50,60)	(10, 15.6)	(60,65)	6.13
(50,60)	(10, 15.6)	(65,70)	6.53
(50,60)	(10, 15.6)	(70,75]	6.66
(60,70)	(15.6, 21.1)	(0,5)	2.79
(60,70)	(15.6, 21.1)	(5,10)	3.61
(60,70)	(15.6, 21.1)	(10,15)	4.33
(60,70)	(15.6, 21.1)	(15,20)	4.63
(60,70)	(15.6, 21.1)	(20,25)	4.58
(60,70)	(15.6, 21.1)	(25,30)	4.51
(60,70)	(15.6, 21.1)	(30,35)	4.79
(60,70)	(15.6, 21.1)	(35,40)	5.24
(60,70)	(15.6, 21.1)	(40,45)	5.77
(60,70)	(15.6, 21.1)	(45,50)	5.8
(60,70)	(15.6, 21.1)	(50,55)	5.98
(60,70)	(15.6, 21.1)	(55,60)	6.04
(60,70)	(15.6, 21.1)	(60,65)	6.06
(60,70)	(15.6, 21.1)	(65,70)	6.16
(60,70)	(15.6, 21.1)	(70,75]	6.3
(70,80)	(21.1, 26.7)	(0,5)	2.77
(70,80)	(21.1, 26.7)	(5,10)	3.87
(70,80)	(21.1, 26.7)	(10,15)	4.78
(70,80)	(21.1, 26.7)	(15,20)	5.02
(70,80)	(21.1, 26.7)	(20,25)	4.92
(70,80)	(21.1, 26.7)	(25,30)	4.8
(70,80)	(21.1, 26.7)	(30,35)	5.02
(70,80)	(21.1, 26.7)	(35,40)	5.51
(70,80)	(21.1, 26.7)	(40,45)	5.85
(70,80)	(21.1, 26.7)	(45,50)	6.23
(70,80)	(21.1, 26.7)	(50,55)	6.27
(70,80)	(21.1, 26.7)	(55,60)	6.11
(70,80)	(21.1, 26.7)	(60,65)	6.2
(70,80)	(21.1, 26.7)	(65,70)	6.25
(70,80)	(21.1, 26.7)	(70,75]	6.34
(80,90)	(26.7, 32.2)	(0,5)	2.71
(80,90)	(26.7, 32.2)	(5,10)	3.78
(80,90)	(26.7, 32.2)	(10,15)	4.79
(80,90)	(26.7, 32.2)	(15,20)	5.05
(80,90)	(26.7, 32.2)	(20,25)	4.97
(80,90)	(26.7, 32.2)	(25,30)	4.84

Temperature Bin (10°F Interval)	Temperature Bin (°C)	Speed Bin (5 mph Interval)	Predicted mpg
(80,90)	(26.7, 32.2)	(30,35)	4.98
(80,90)	(26.7, 32.2)	(35,40)	5.6
(80,90)	(26.7, 32.2)	(40,45)	6.07
(80,90)	(26.7, 32.2)	(45,50)	6.32
(80,90)	(26.7, 32.2)	(50,55)	6.49
(80,90)	(26.7, 32.2)	(55,60)	6.5
(80,90)	(26.7, 32.2)	(60,65)	6.36
(80,90)	(26.7, 32.2)	(65,70)	6.26
(80,90)	(26.7, 32.2)	(70,75]	6.02
(90,100)	(32.2, 37.8)	(0,5)	2.45
(90,100)	(32.2, 37.8)	(5,10)	3.64
(90,100)	(32.2, 37.8)	(10,15)	4.66
(90,100)	(32.2, 37.8)	(15,20)	5.06
(90,100)	(32.2, 37.8)	(20,25)	4.83
(90,100)	(32.2, 37.8)	(25,30)	4.74
(90,100)	(32.2, 37.8)	(30,35)	4.81
(90,100)	(32.2, 37.8)	(35,40)	5.42
(90,100)	(32.2, 37.8)	(40,45)	6.02
(90,100)	(32.2, 37.8)	(45,50)	6.45
(90,100)	(32.2, 37.8)	(50,55)	6.6
(90,100)	(32.2, 37.8)	(55,60)	6.64
(90,100)	(32.2, 37.8)	(60,65)	6.36
(90,100)	(32.2, 37.8)	(65,70)	6.38
(90,100)	(32.2, 37.8)	(70,75]	6.24
(100,110)	(37.8, 43.3)	(0,5)	2.48
(100,110)	(37.8, 43.3)	(5,10)	3.43
(100,110)	(37.8, 43.3)	(10,15)	4.49
(100,110)	(37.8, 43.3)	(15,20)	4.61
(100,110)	(37.8, 43.3)	(20,25)	4.38
(100,110)	(37.8, 43.3)	(25,30)	4.42
(100,110)	(37.8, 43.3)	(30,35)	4.73
(100,110)	(37.8, 43.3)	(35,40)	5.37
(100,110)	(37.8, 43.3)	(40,45)	6.03
(100,110)	(37.8, 43.3)	(45,50)	6.33
(100,110)	(37.8, 43.3)	(50,55)	6.59
(100,110)	(37.8, 43.3)	(55,60)	6.47
(100,110)	(37.8, 43.3)	(60,65)	6.38
(100,110)	(37.8, 43.3)	(65,70)	6.35
(100,110)	(37.8, 43.3)	(70,75]	8.64
(110,120)	(43.3, 48.9)	(0,5)	2.17
(110,120)	(43.3, 48.9)	(5,10)	2.95
(110,120)	(43.3, 48.9)	(10,15)	4.05
(110,120)	(43.3, 48.9)	(15,20)	4.16
(110,120)	(43.3, 48.9)	(20,25)	4.26
(110,120)	(43.3, 48.9)	(25,30)	4.45
(110,120)	(43.3, 48.9)	(30,35)	4.53
(110,120)	(43.3, 48.9)	(35,40)	5.01

Temperature Bin (10°F Interval)	Temperature Bin (°C)	Speed Bin (5 mph Interval)	Predicted mpg
(110,120)	(43.3, 48.9)	(40,45)	5.6
(110,120)	(43.3, 48.9)	(45,50)	5.58
(110,120)	(43.3, 48.9)	(50,55)	6.05
(110,120)	(43.3, 48.9)	(55,60)	6.46
(110,120)	(43.3, 48.9)	(60,65)	6.55
(110,120)	(43.3, 48.9)	(65,70)	7.2
(120,130]	(48.9, 54.4)	(0,5)	1.95
(120,130]	(48.9, 54.4)	(5,10)	2.55
(120,130]	(48.9, 54.4)	(10,15)	3.42
(120,130]	(48.9, 54.4)	(15,20)	3.91
(120,130]	(48.9, 54.4)	(20,25)	4.23
(120,130]	(48.9, 54.4)	(25,30)	4.32
(120,130]	(48.9, 54.4)	(30,35)	4.73
(120,130]	(48.9, 54.4)	(35,40)	5.41
(120,130]	(48.9, 54.4)	(40,45)	5.4
(120,130]	(48.9, 54.4)	(45,50)	6.26
(120,130]	(48.9, 54.4)	(50,55)	6.64
(120,130]	(48.9, 54.4)	(55,60)	6.74
(120,130]	(48.9, 54.4)	(60,65)	6.95
(120,130]	(48.9, 54.4)	(65,70)	7.41