NREL Fleet Analysis Support Through Technology Integration Collaboration

Lauren Lynch and Grant Payne

National Renewable Energy Laboratory

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Technical Report
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List of Acronyms

AC	alternating-current
AWD	all-wheel drive
CAN	Controller Area Network
CO_2	carbon dioxide
CSV	comma-separated values
DC	direct-current
DOE	U.S. Department of Energy
EV	electric vehicle
GTA	Green Truck Association
HEM	HEM Data Corporation
HEV	hybrid electric vehicle
MPG	miles per gallon
MPH	miles per hour
NFS	network file system
NO_x	nitrogen oxide
NREL	National Renewable Energy Laboratory
NTEA	The Association for the Work Truck Industry
VIN	vehicle identification number
VPN	virtual private network

Executive Summary

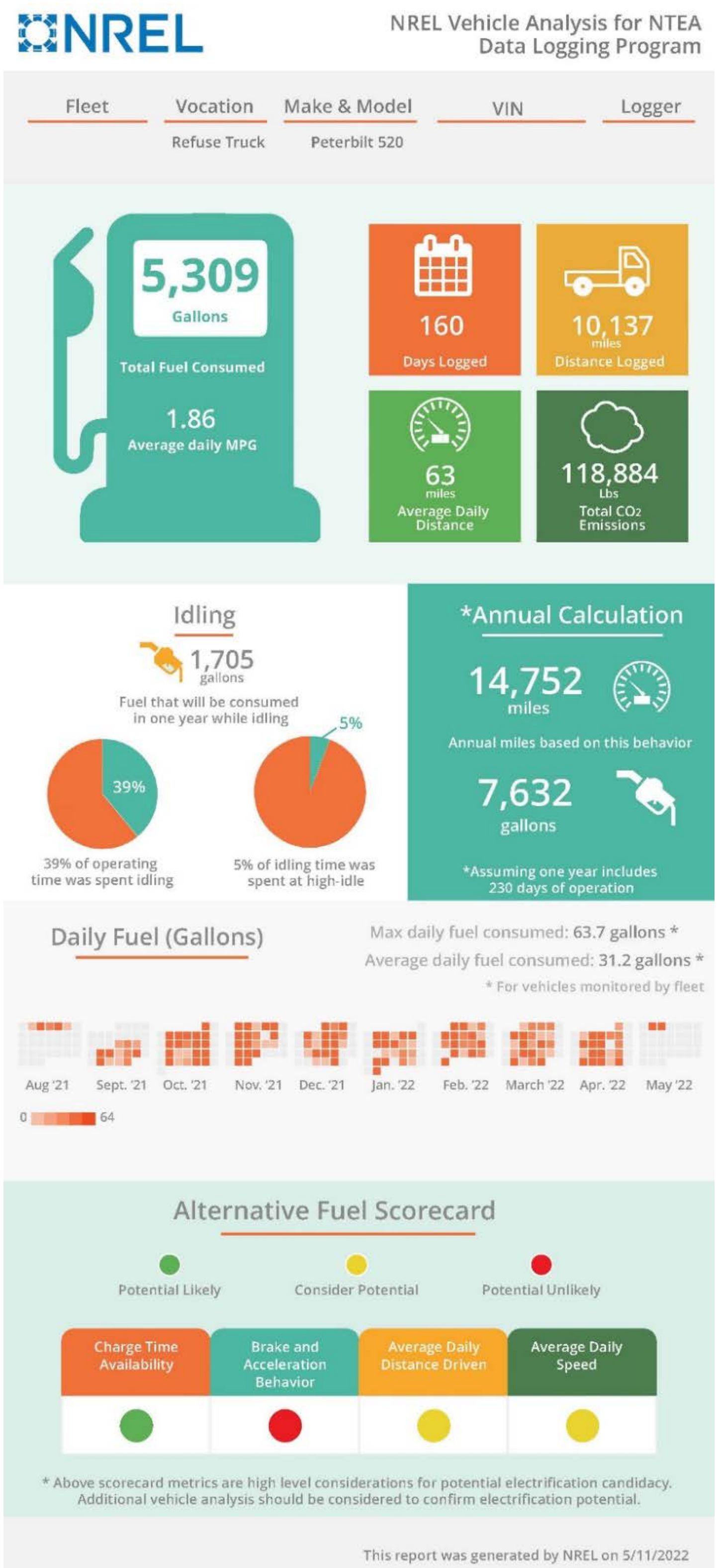
This study leveraged the collaboration between the U.S. Department of Energy (DOE) Vehicle Technologies Office Technology Integration Program and NTEA – The Association for the Work Truck Industry to launch a vehicle and fleet analysis project that assisted fleets in identifying opportunities to save energy, improve efficiency, reduce costs, and meet environmental goals via short-term data logging and analysis. The National Renewable Energy Laboratory (NREL) sought to establish a process that included initial data acquisition, provided data storage, and developed analytic methods to inform fleets of areas of opportunity based on approximately 30 days of in-use vehicle performance data. However, in the long term, the project concept will require additional development to meet the objective of establishing a data sharing platform with a larger aggregated dataset to enable more complex analysis.

NREL established a procedure for initial data acquisition that included NTEA's purchase and upfitting of HEM Data Corporation's (HEM's) J1939 data loggers to acquire Controller Area Network (CAN) J1939 and J1978 data. NREL worked with HEM to identify key J1939 signals essential for analyzing the vehicles' in-use performance. Once NTEA had upfitted a vehicle within a Green Truck Association (GTA) fleet, HEM stored the data logged on their internal site and granted NREL access to the raw data files. NREL then established a process that transferred the data and structured them according to an NREL internal format that is being systematized across multiple data storage platforms developed by the laboratory. After the data were structured, they were analyzed and processed using a Python software script developed by NREL that calculated high-level statistics from the sampled data to determine key characteristics of the vehicles' in-use performance. The analysis was summarized into a one-page document that highlighted key performance indicators and recommendations for the fleet to potentially save energy, improve efficiency, reduce costs, and meet environmental goals. The summary analysis report was then presented to the fleet by NTEA in exchange for their participation in the data logging project.

The collected vehicle data were aggregated into high-level statistics that summarized the vehicles' in-use performance and identified potential areas of opportunity that may result in cost savings for fleets. The vehicle make and model, vocation, days logged, total distance, average daily distance, total fuel consumption, average daily fuel consumption, total carbon dioxide (CO_2) emissions, idling percent, fuel used due to idling, and high idling percent were represented in the summarized results. In addition, the annual distance in miles and annual fuel consumption were projected based on the vehicle's behavior. NREL also employed a calendar illustration to visually portray daily fuel usage and identified the maximum daily fuel consumed and average daily fuel consumed. Each analysis also included an "Alternative Fuel Scorecard" that provided a high-level assessment of the potential to utilize an electric vehicle for the application. The potential was based on the charge time availability, brake and acceleration behavior, average daily distance driven, and average daily speed. These were broad considerations that indicated where electric vehicles could be used, but additional vehicle analysis was recommended to confirm the electrification potential and technology trade-offs.

All data gathered during this vehicle and fleet analysis project were anonymized, and only vehicle characteristics were identified in addition to the selected J1939 data signals. The GTA fleets that contributed data were publicly owned and did not require a nondisclosure agreement

to share logged data with NTEA and NREL. Therefore, NREL is also able to store these data sets and utilize them in other analysis projects, providing great value to multiple analysis needs across the laboratory. An example summary analysis report is shown below:



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1 Introduction and Background

The National Renewable Energy Laboratory's (NREL's) broad collaboration with new and existing partners increases energy security by encouraging the use of alternative and renewable fuels, idle-reduction measures, fuel economy improvements, and emerging transportation technologies. NREL leverages in-house expertise to provide both proactive and reactive problem-solving to assist partners and stakeholders in overcoming specific operational and technology barriers, addressing safety issues, or resolving technical issues. NREL provides technical assistance to Clean Cities coalitions, fleet managers, and other industry stakeholders by answering questions and providing fuel-neutral resources. This allows stakeholders to explore and understand alternative fuel and advanced vehicle technologies, prevent problems before they arise, and quickly address any problems that come up. Most importantly, the assistance provides feedback on the planning, implementation, and operational challenges facing end users of new transportation technology.

NREL leveraged the collaboration between the Department of Energy's (DOE) Vehicle Technologies Office's Technology Integration Program and NTEA – The Association for the Work Truck Industry to launch a vehicle and fleet analysis project offered to members of the Green Truck Association (GTA) that assisted fleets in identifying opportunities to save energy, improve efficiency, reduce costs, and meet environmental goals. The project sought to establish a process that included initial data acquisition, provided data storage, and developed analytic methods to inform fleets of areas of opportunity via short-term analysis and assist with quick decision-making needs. A long-standing goal is to create an anonymized data set large enough to provide greater observations of vehicle performance per vocation. These data would then be available via a public dashboard where users would be able to select specific data sets of interest. However, in the long term, the project concept will require additional development to meet the objective of establishing a data sharing platform with a larger aggregated dataset to enable more complex analysis. In addition, such data gathering, storing, and analysis could contribute to other efforts.

1.1 Collaborator Organizations

Experts from the U.S. Department of Energy and national laboratories provide expertise and support across multiple DOE enterprises.

1.1.1 Technology Integration Program

The Technology Integration Program provides funding for alternative fuel and advanced technology vehicle and infrastructure projects, subject matter expertise, collaboration among DOE initiatives, and access to on-the-ground insight from the national Clean Cities Coalition Network. Clean Cities is comprised of more than 75 coalitions working locally with 20,000 stakeholders to integrate alternative fuels and advanced vehicle technologies in their communities.

1.1.2 NREL

NREL provides technical expertise and project management to Clean Cities coalitions across the country by continuously evaluating and strategically responding to coalition and stakeholder needs. NREL deployment experts develop tools and resources that coalitions can leverage to advance affordable, domestic transportation fuels; energy-efficient mobility systems; and other fuel-saving technologies and practices. These resources include online training courses, workshops, outreach materials, technical publications, and analysis tools. NREL also provides technical assistance for individualized problem-solving support.

1.1.3 NTEA and GTA

NTEA was established in 1964 and represents more than 2,000 companies that manufacture, distribute, install, sell, and repair commercial trucks, truck bodies, truck equipment, trailers, and accessories. NTEA provides in-depth technical information, education, and member programs and services to expand the knowledge, growth, and profitability of the work truck industry. GTA is a division of NTEA that was established in 2010. GTA is a voice for companies that focus on sustainability in the creation of their vocation trucks and products. Their mission is to improve the efficiency and productivity of work trucks by developing and deploying strategies to reduce the use of petroleum fuels and the associated environmental impacts.

2 Approach

NREL worked closely with NTEA to establish a process for collecting medium- and heavy-duty vehicle data that would replace NTEA's existing data collection service with a third-party telematics provider. NTEA was responsible for acquiring data loggers that met their budget requirements. NREL also provided guidance on potential data logger options based on previous project experience and data needs. NTEA worked with GTA members interested in the vehicle and fleet data logging project and arranged to upfit the fleets' vehicle(s) with the data loggers. NTEA received technical assistance during the upfit and configuration process from the data logger manufacturer, HEM Data Corporation (HEM). NREL also worked with HEM's technical assistance team to define the database configuration files to identify all necessary parameters and define units of measure properly.

Once a vehicle was upfitted with the data logger and it was successfully recording in-use performance data, the data were stored on HEM's internal website, where NREL was granted user access. NREL then transferred the data into an internal data platform, where the data were formatted in a method that is being systematized across multiple data storage platforms developed by the laboratory. Python software processing scripts developed by NREL extracted the data and conducted the statistical analysis as programmed to evaluate the vehicles' in-use performance. Once the results of the analysis were complete, NREL's web development team formatted the results into a single-page template developed by NREL based on NTEA's feedback. NTEA then shared this single-page report with the fleet.

2.1 Data Acquisition

NREL worked with NTEA to compile information on the vehicles and fleets participating in the data collection and analysis. A "Vehicle Specification Survey" was developed to define vehicle information, duty cycle characteristics, fuel type, powertrain information, chassis details, engine details, and payload information. NREL focused on gathering information that would contribute to the vehicle performance characteristics to better understand the operating conditions and resulting data.

The stand-alone data logger provider by HEM acquired 1-Hz Controller Area Network (CAN) bus data from the medium- or heavy-duty vehicle according to SAE International J1939 and J1978 protocols and had a GPS receiver and antenna. The logged data were translated into a comma-separated values (CSV) file that was stored on HEM's internal website.

2.2 Data Storage

The CSV data files for each vehicle were downloaded from a login-protected website provided by HEM. From there, they were stored on a protected virtual private network (VPN) within NREL's network drives and catalogued. Each vehicle was assigned a unique identifier and stored in a database, where vehicle characteristics, fleet information, and telematics data were all extracted and stored in tables accordingly. This data storage process utilized many of the same processing pipeline and archiving practices of NREL's Fleet DNA data retrieval system in hopes of harmonizing data formatting for future aggregation and analysis.

This process began with extracting CSV files with standardized headers from the raw data downloaded from HEM's web portal. The CSV files were then processed by Python software scripts originally developed for Fleet DNA, mapping the columns in the raw data to standardized names based on the SAE J1939 and J1978 protocols. The data were then concatenated and segmented into operational driving days based on the date-time column. These organized data files were stored in a secure network file system (NFS) drive and finally loaded into the database.

2.3 Data Analysis

Processed data from the database were extracted by the Python software processing scripts, which utilized the standardized data columns to produce a suite of analysis statistics on drive cycle characteristics. Key characteristics included aerodynamic velocity, distance traveled, amount of time the vehicle spent moving, amount of time the vehicle spent at idle, fuel consumed, power consumed, carbon dioxide (CO_2) emissions, nitrogen oxide (NO_x) emissions, engine brake horsepower, engine torque distributions, and engine speed distributions. Other key characteristics were derived using these data points.

The abundant set of vehicle operation statistics was used to create an analysis report that summarized the vehicles' in-use performance and identified areas of opportunity for the fleet to achieve costs savings or improve environmental impacts. The summary analysis report was meant to serve as a physical dashboard illustrating top-line figures on vehicle operation such as days of data logged, total distance driven, average daily distance, total fuel consumption, average daily fuel consumption, total CO_2 emissions, idling percent, fuel used due to idling, and high idling percent. In addition, annual values for distance in miles and fuel consumption were projected based on these data. A visual representation of fuel usage per day was included to easily disseminate the vehicles' fuel use across the period of data logged.

Each analysis also incorporated an "Alternative Fuel Scorecard" to provide a high-level assessment of the potential to utilize a vehicle with an electric powertrain for the application that may result in cost savings from reduced fuel and maintenance expenses, as well as lower emissions from the fleet's operations. The broad assessment to electrify the application was based on the charge time availability, brake and acceleration behavior, average daily distance driven, and average daily speed. These metrics were an initial transitory evaluation, and additional vehicle analysis was recommended to confirm the electrification potential and other alternative fuel technology trade-offs.

2.3.1 Vehicle Information

NREL developed a "Vehicle Specification Survey" to record information from each fleet based on the vehicle upfitted with a data logger to enrich analysis. This survey defined vehicle and fleet specifications as defined in Table 1.

Table 1. Vehicle Specification Survey

Information	Comment
Fleet	
Targeted start date	Beginning of logger installation (estimate OK)
Targeted end date	End of logger installation (estimate OK)
Unique vehicle ID	Some sort of unique identifier for each vehicle that will remain consistent over time—doesn't necessarily need to be a vehicle identification number (VIN)
Weight class	1–8 as per Federal Highway Administration, for example. If the vehicle is "off road" it could be classified as, say, −1
Vocation or segment	Something to reflect the type of work for which the vehicle is used (e.g., beverage delivery, transit bus, school bus, regional haul, drayage)
Fleet type	Individual-private/government/utility/manufacturer/lease/for-hire
Duty cycle	Returns to hub daily or longer-haul with few returns
Body type	Dump, flatbed, aerial, service, etc.
Vehicle operation description	Briefly describe the vehicle duty cycle
Engine idle manipulation	High-speed switch, SEIC control module, etc.
Installation method	J1939 or OBD2
VIN (optional but preferred)	Official VIN
Fuel (current)	Diesel, renewable diesel, electric, diesel/electric hybrid electric vehicle (HEV), propane, etc.
Fuel (desired)	Diesel, renewable diesel, electric, diesel/electric HEV, propane, etc.
Drivetrain type	Conventional (typical gasoline/diesel combustion), electric, parallel hybrid, hybrid, hydraulic hybrid, series hybrid, etc.
Drive	4x2, 4x4, all-wheel drive (AWD), etc.
Chassis manufacturer	e.g., Kenworth
Chassis model	e.g., T-370
Chassis year	e.g., 2009
Engine manufacturer	e.g., Cummins
Engine model	e.g., ISC-285 6-cylinder
Engine year	e.g., 2010
Maximum horsepower	
Maximum torque	ft-lb or N·m
Fuel capacity	gal
Battery chemistry (HEV/electric vehicle [EV])	e.g., lithium-ion, LiPo, $LiFePO_4$, NMC
Battery capacity (HEV/EV)	kWh
Charging location	Depot/hub or public/home

Information	Comment
Electricity rates at charging location	$/kWh
Motor size (HEV/EV)	kW
Transmission manufacturer	e.g., Eaton
Transmission model	e.g., Fuller Ultrashift
Transmission type	e.g., manual
Curb weight (laden)	lb
Curb weight (unladen)	lb
Gross vehicle weight rating	lb
Front axle ratio	e.g., 3.58:1
Rear axle ratio	
Payload type	Diminishing/static/increasing
Payload	Weight
Estimated percent of time with payload	
Towing	Y/N
Laden trailer weight	
Estimated percent of time towing	
Trailer type	
Accessory loads?	Lighting, power takeoff equipment, clutch pump equipment, etc.

2.3.2 Daily Energy

Daily energy, computed in kilowatt-hours, is the total mechanical energy required to complete the vehicle's daily work derived from the engine power signal after mechanical losses, such as friction, for the vehicle's operational day. The sample chart shown in Figure 1 depicts the effective work done by the vehicle, including idling, per day in operation.

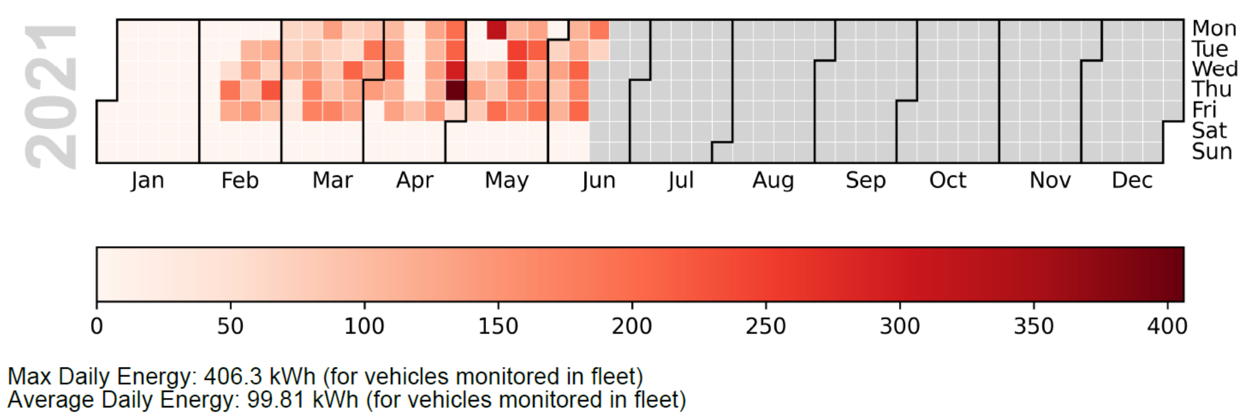

Figure 1. Daily energy

2.3.3 Daily Fuel

Daily fuel, computed in gallons, is the measured fuel consumed for the vehicle's operational day. Like daily energy, this measure shows the fuel used in both operations and idling for each operational day and can be used to estimate a typical day's worth of fuel requirements. Figure 2 is an example chart of daily fuel.

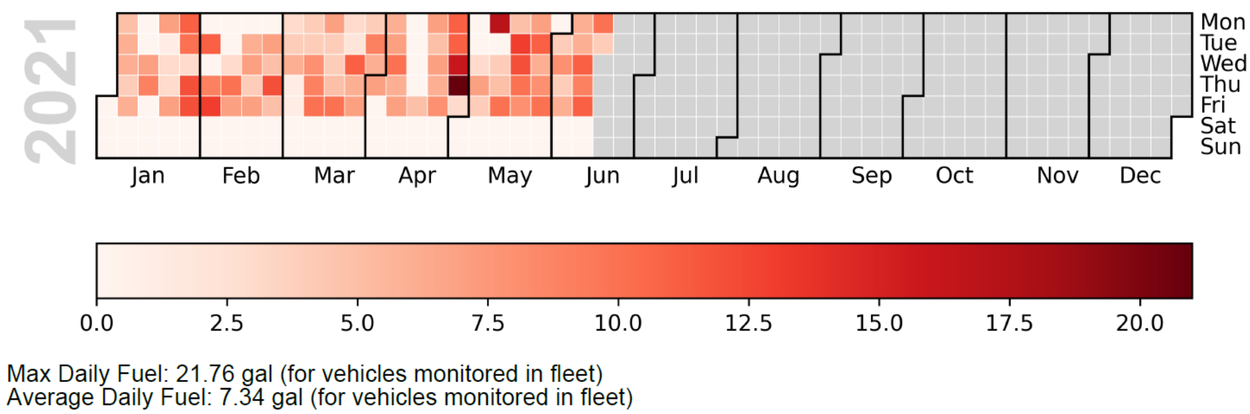

Figure 2. Daily fuel

2.3.4 Average Speed and Distance Distributions

The distribution of the daily average speed in miles per hour (MPH) for all vehicles and a distribution of the daily average travel in miles was calculated to understand the average speed and distance traveled of the vehicle and to evaluate the powertrain requirements, as illustrated in Figure 3. The electrification potential was also assessed, where lower speeds are generally more efficient for EVs as the energy use per mile is reduced compared to the energy use per mile at higher speeds.

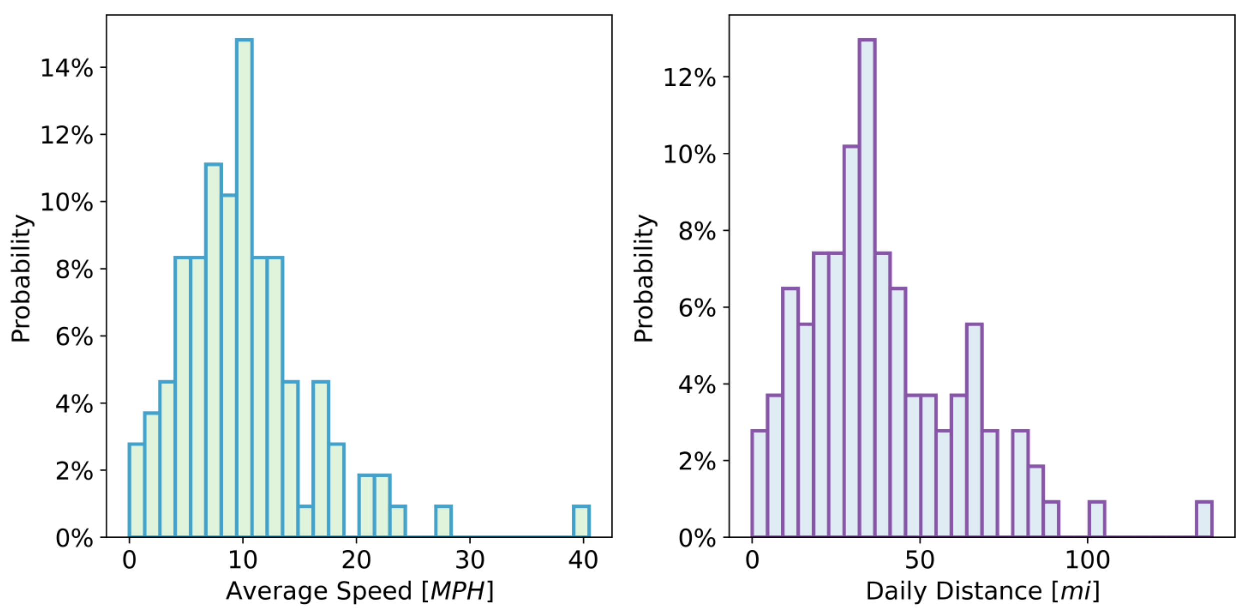

Figure 3. Average speed and daily distance distributions

2.3.5 Fuel Economy Distributions

Fuel economy distributions in miles per gallon (MPG), as well as gallons per hour, were computed to understand the energy demands of the vehicle over the total operational days, as demonstrated in Figure 4. The fuel usage was translated into typical daily energy requirements, which was then extrapolated into electric powertrain requirements to understand electrification potential.

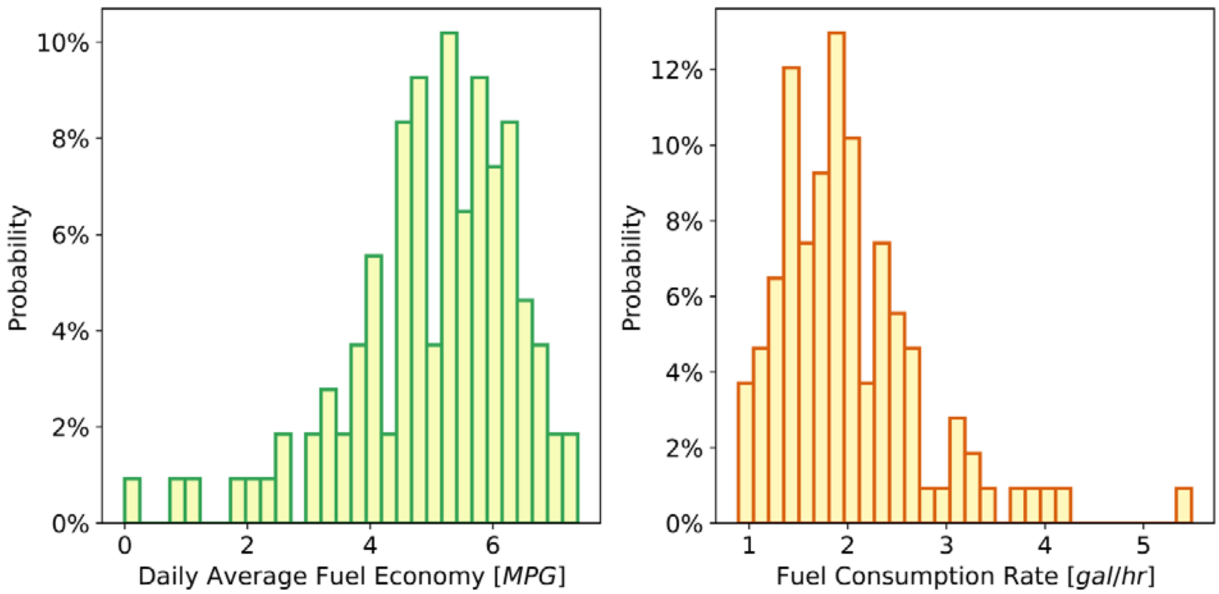

Figure 4. Fuel economy distributions

2.3.6 Engine Idling Distributions

Engine idling was defined as the engine being on while the vehicle speed was zero. The amount of time in hours the engine spent in idle conditions, along with engine-on time distributions, determine the total time of engine use throughout the day. Therefore, it is helpful to evaluate both, as depicted in Figure 5. Large durations of idling may be conducive for electrification given that EVs typically use less energy at idle as they are only powering accessory loads, such as air conditioning or power steering, and the idle time might be an opportunity for charging.

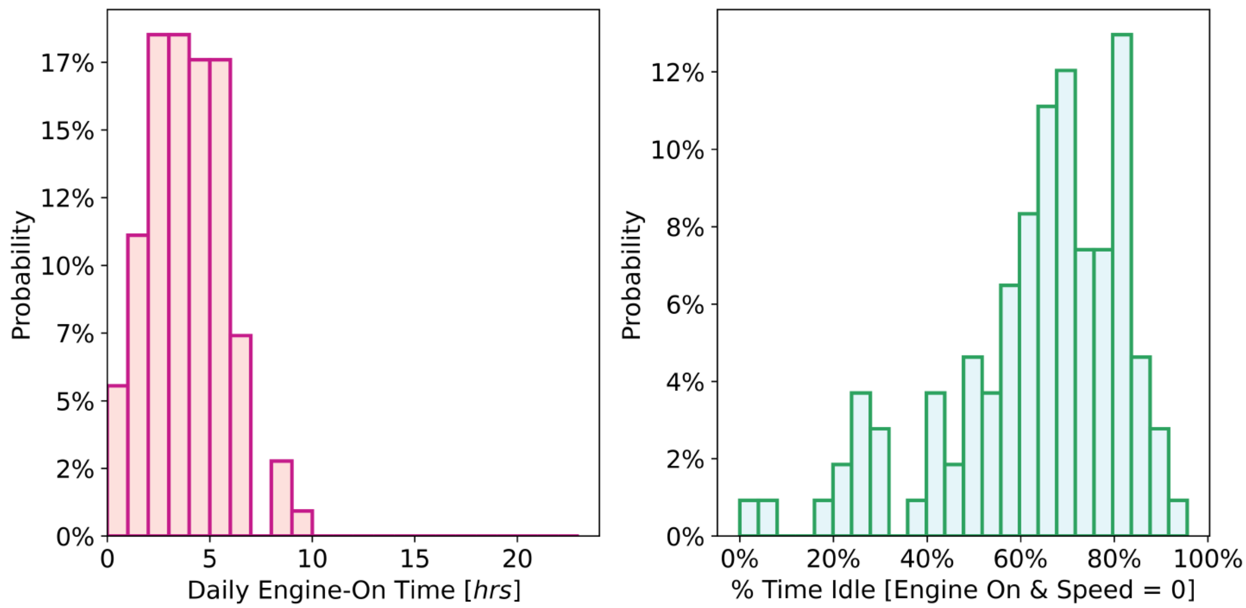

Figure 5. Engine-on time and idling distributions

2.3.7 Brake Energy Distributions

Brake energy is the mechanical energy required to complete the vehicle's daily work and is a calculation derived from the engine power signal. Similar to daily energy calculations, brake energy distributions model the range of daily brake energy required, as well as the frequency throughout the day. In addition, the idle energy distribution shows the amount of mechanical energy spent on idling when the vehicle was not working. These plots illustrate the amount of energy required to complete their daily activities, as shown in Figure 6.

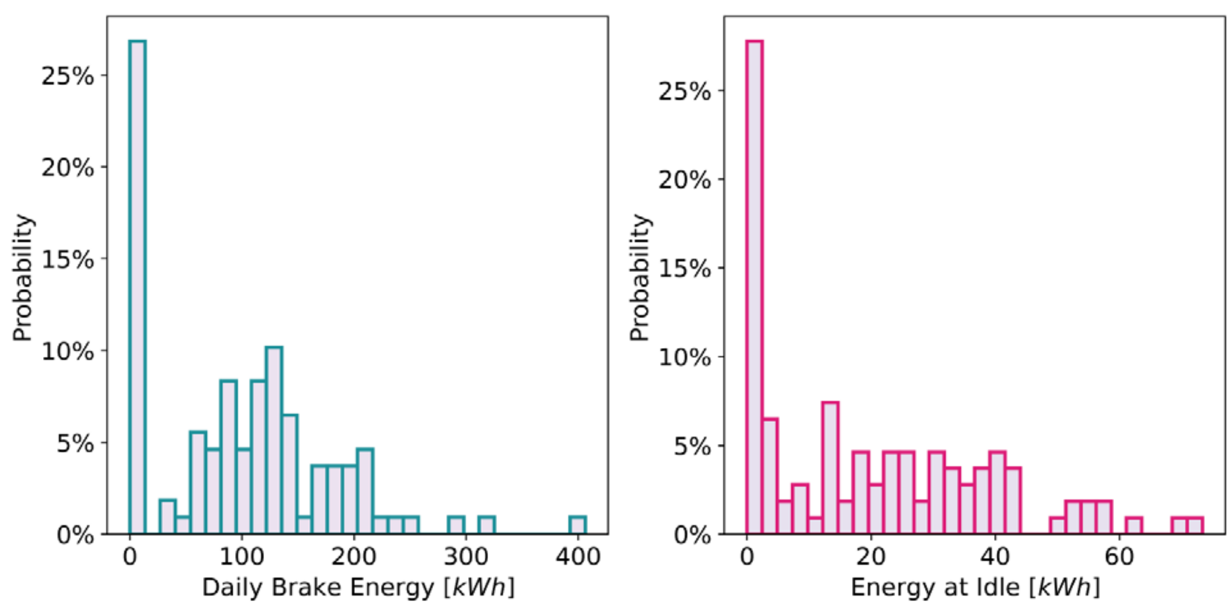

Figure 6. Brake energy distributions

2.3.8 Kinetic Intensity

Kinetic intensity is the ratio of characteristic acceleration to aerodynamic velocity (O'Keefe, Simpson, and Kelly 2007). Kinetic intensity greater than or equal to 1 mi^{-1} usually indicates a vehicle duty cycle with a lot of stop-and-go driving which results in more opportunities for regenerative braking. The higher the kinetic intensity of a duty cycle, the greater the benefit of hybridization. Plots of each of these metrics from a vehicle's daily work are illustrated in Figure 7. This metric indicates the hybrid advantage of a vehicle, where the fuel used in idle and vocation loads is less than the fuel used to fulfill road loads. It determines the aggressiveness of the driving style by measuring the changes in vehicle speed. The advantages of utilizing a hybrid powertrain are generally reduced total fuel usage and associated costs.

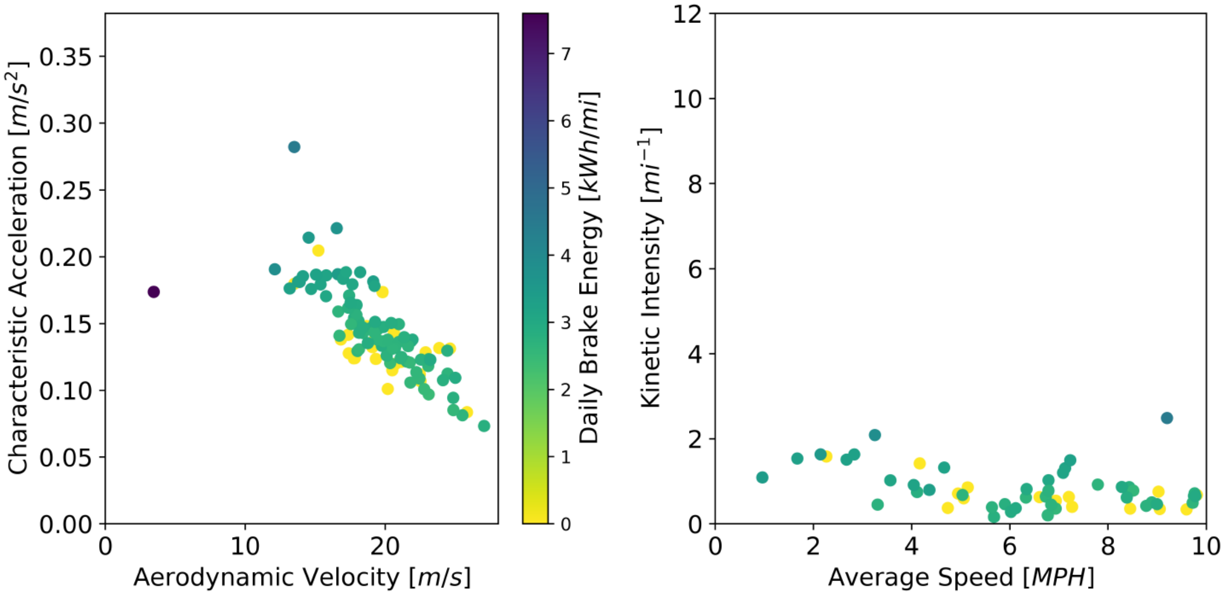

Figure 7. Kinetic intensity inputs and resulting kinetic intensity with respect to average vehicle speed

The calculated ratios of characteristic acceleration (m/s^2) to aerodynamic velocity (m/s) are represented at average speeds throughout the day.

2.3.9 Dwell Periods

An aspect of assessing the electrification potential of the application was to understand the availability of the vehicle to charge based on typical operating characteristics. To assess the charging periods available for a potential EV, all time gap periods between logged data events and idling durations were computed. These periods are defined as dwell periods as may include events such as being parked overnight and engine-on while remaining stationary etc. Dwell periods less than 5 minutes yield no opportunity for charging. Dwell periods between 5 minutes and 1 hour provide an opportunity for direct-current (DC) fast charging, and dwells greater than 1 hour yield opportunities for either DC fast charging or Level-1 and Level-2 alternating-current (AC) charging. An example of dwell analysis is illustrated in Figure 8.

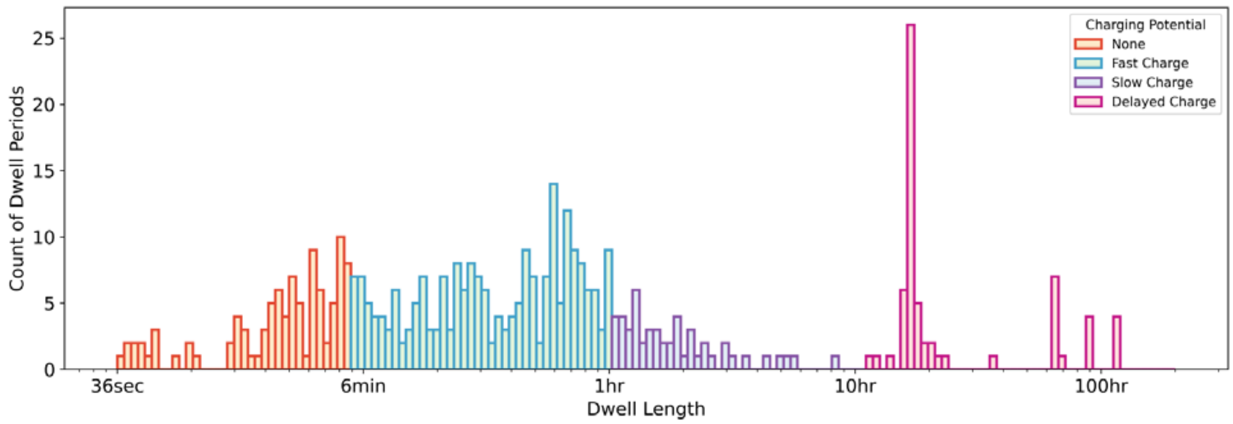

Figure 8. Dwell periods

3 Data Analysis Summary Report

The aggregated analysis of the vehicles' in-use performance was translated from the specific calculations to metrics more distinguishable to fleet managers in a single-page summary. This provided a concise conclusion of results and a reference for recommendations that may result in cost savings or improved environmental impacts for fleets.

The vehicle make, model, VIN, vocation, and logger number were identified mainly for documentation purposes. The summary highlighted key performance indicators such as the number of days logged, total distance, average daily distance, total fuel consumption, average daily fuel consumption, and total CO_2 emissions, as these metrics are good indicators of both the daily work conducted by the vehicle and the resulting fuel impacts and environmental effects. An example of these captured data is shown in Figure 9.

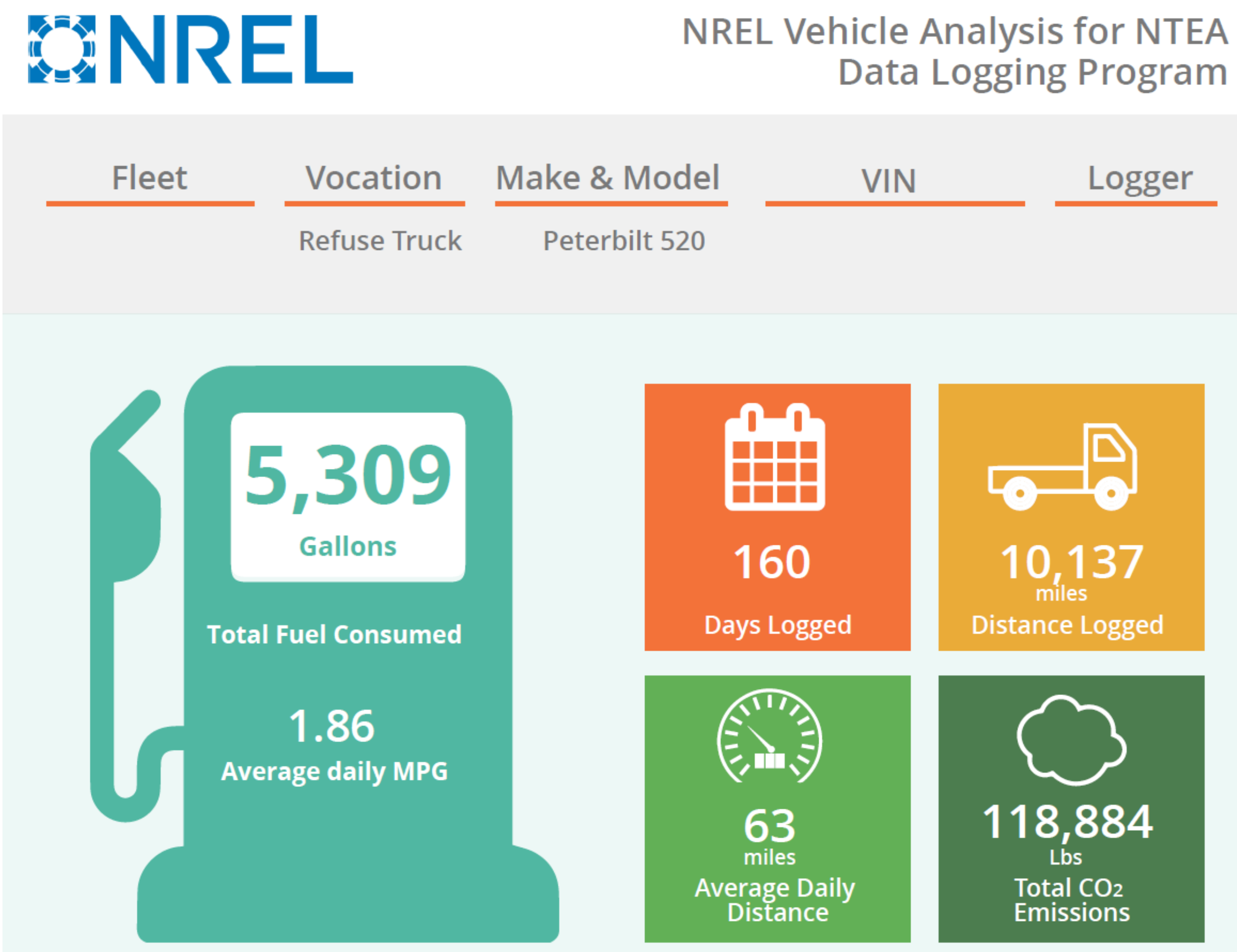

Figure 9. Vehicle details and key performance indicators

The percent of time spent idling, amount of fuel used due to idling, and percent of time spent high idling were additional indicators of operational behaviors that tend to impact fleet costs. Therefore, these figures were also specifically illustrated, as exampled by Figure 10.

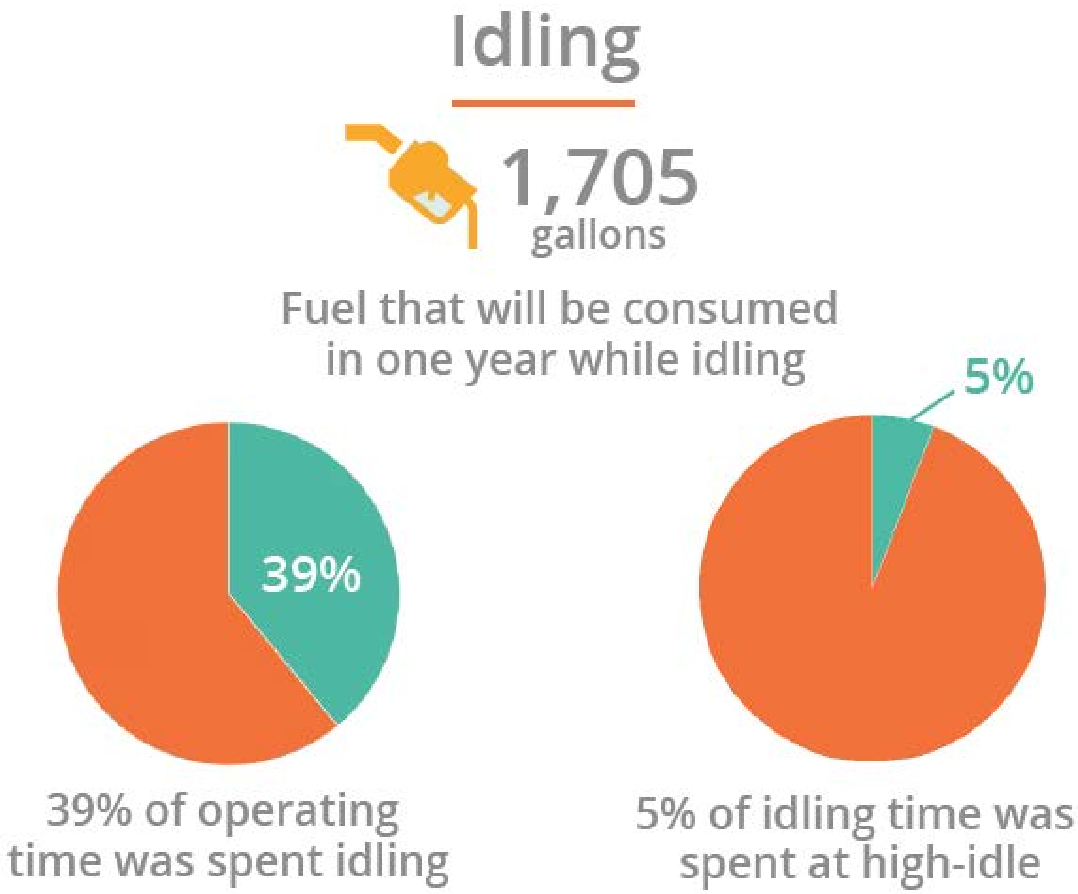

Figure 10. Idling details

In addition, the annual distance and annual fuel consumption were projected based on the vehicle's behavior, as illustrated in Figure 11. This provided additional insight into the impacts of the performance extrapolated over a year of operation to better understand the financial implications of such behaviors.

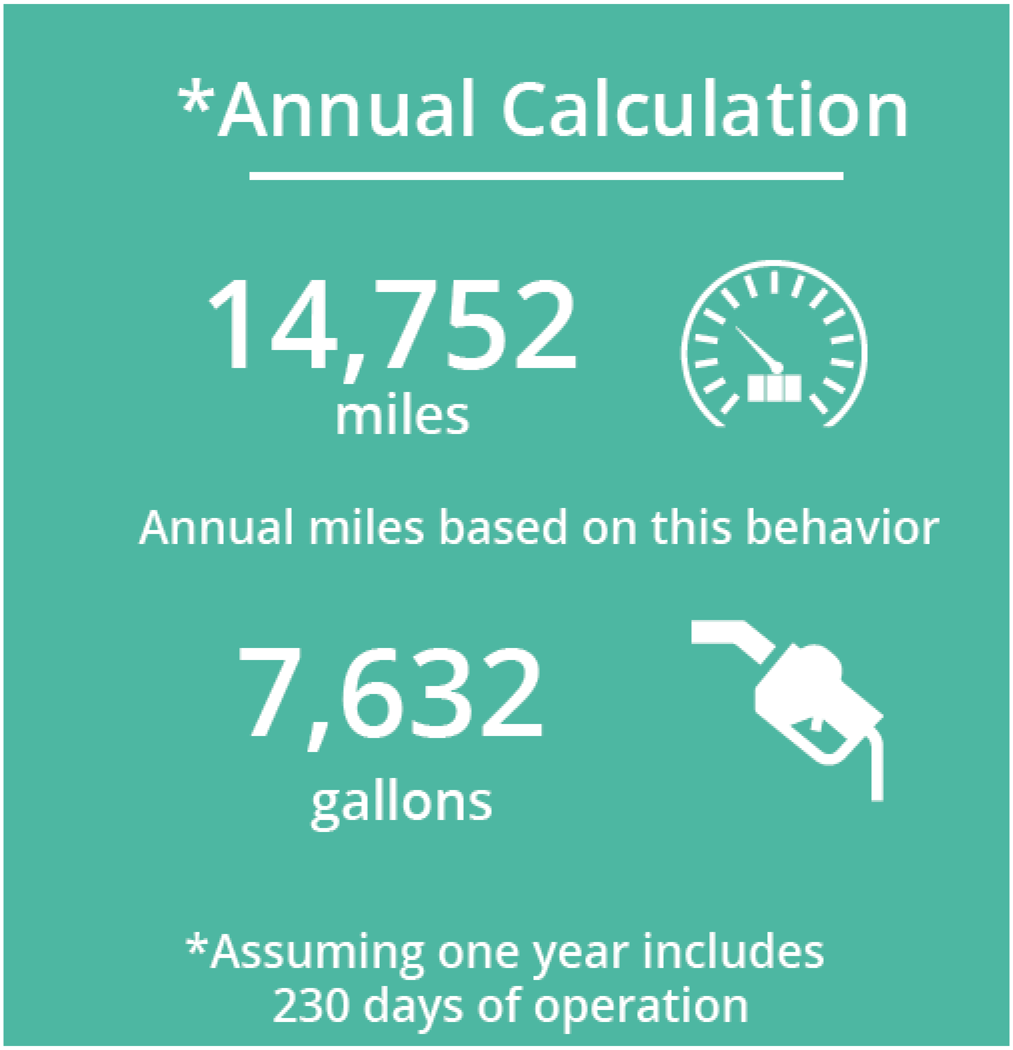

Figure 11. Annual projections

NREL also depicted the daily fuel consumed in a calendar illustration, as shown in Figure 12, to visually portray fuel usage per day to help fleets identify specific days of high usage. The maximum and average daily fuel consumed were also shown to help understand the peak of fuel consumed compared to the average rate.

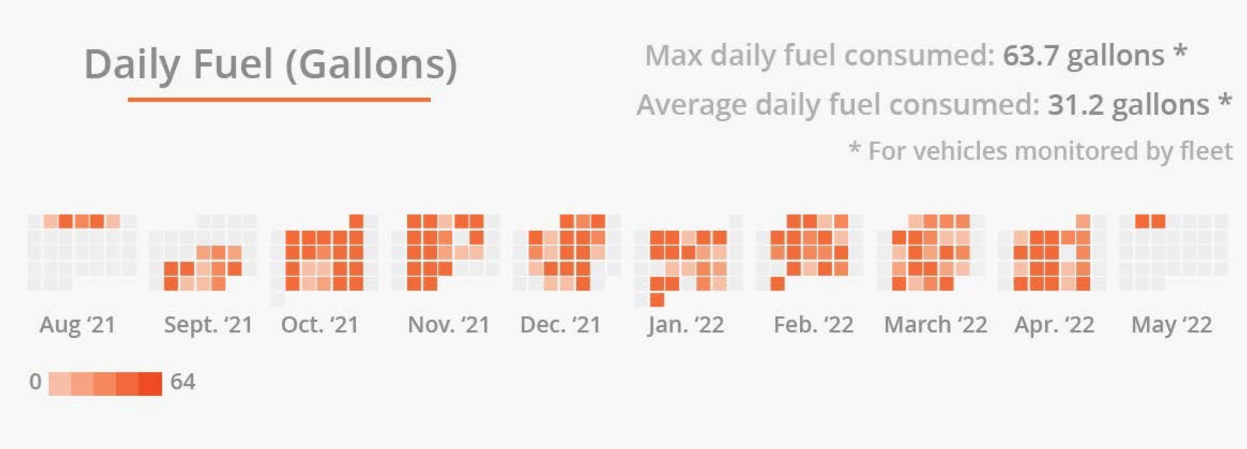

Figure 12. Daily fuel usage

An "Alternative Fuel Scorecard," as shown in Figure 13, provided a high-level assessment of the potential to utilize an EV for the application. The electrification potential was based on the charge time availability determined from the dwell analysis, brake and acceleration behavior as indicated by the kinetic intensity analysis, average daily distance driven, and average daily speed. These were high-level considerations for electrification but additional vehicle analysis was recommended to confirm the electrification potential and technology trade-offs.

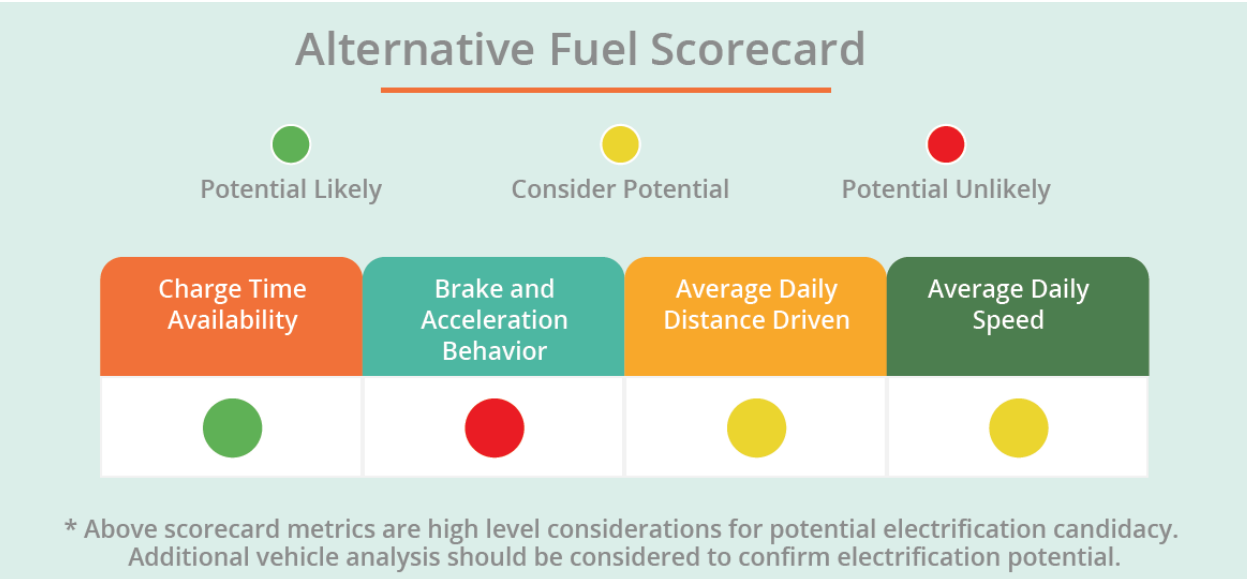

Figure 13. Alternative Fuel Scorecard

4 Conclusion

NREL successfully leveraged the collaboration of the DOE Technology Integration program and NTEA to implement a vehicle and fleet analysis project that assisted GTA fleet members in identifying opportunities to save energy, improve efficiency, reduce costs, and meet environmental goals based on short-term data logging and analysis. NREL worked with NTEA to establish a process that included initial data acquisition, provided data storage, and developed analytic methods to assess fleet vehicles' in-use performance and inform fleets of areas of opportunity. A summary report of the statistical analysis was translated into key performance indicators for fleets based on the operational data. NREL also derived recommendations that would likely result in reduced costs and environmental impacts for the fleet.

This analysis practice was demonstrated utilizing a range of data collected per vehicle. The shortest data collection period was approximately 30 days of in-use vehicle performance data, and the longest was approximately 10 months. A long-standing goal is to create an anonymized data set large enough to provide greater observations of vehicle performance per vocation. These data would then be available via a public dashboard where users would be able to select specific data sets of interest. The project will require additional data and development to produce more complex analysis and maintain the data sharing platform. Until then, such data gathering, storing, and analysis will continue to contribute to other efforts both within NREL and across DOE national laboratories.

Glossary

Term	Definition
Fleet DNA	A secure, online clearinghouse of commercial fleet vehicle operating data maintained by the National Renewable Energy Laboratory, consisting mainly of fleet telematics data recorded with SAE International protocol Controller Area Network (CAN) logging devices.
hybrid advantage	The percent reduction in fuel consumption of a hybrid electric vehicle over a conventional vehicle.
kinetic intensity	The ratio of characteristic acceleration to the square of aerodynamic speed.

References

O'Keefe, Michael, Andrew Simpson, and Kenneth J. Kelly. 2007. "Duty Cycle Characterization and Evaluation Towards Heavy Hybrid Vehicle Applications." Presented at the 2007 SAE World Congress and Exhibition, 16–19 April 2007, Detroit, MI. NREL/CP-540-40929. https://www.nrel.gov/docs/gen/fy07/40929.pdf.