White Paper

Fuel-Fired Heaters:

Emissions, Fuel Utilization, and Regulations in Battery Electric Transit Buses

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List of Acronyms

BEB	Battery Electric Bus
CARB	California Air Resources Board
CNG	Compressed Natural Gas
CO	Carbon Monoxide
EPA	U.S. Environmental Protection Agency
FCEB	Fuel Cell Electric Bus
g/bhp-hr	Grams Per Brake Horsepower Hour
g/kW-hr	Grams Per Kilowatt Hour
g/mi	Grams Per Mile
GVWR	Gross Vehicle Weight Rating
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Innovative Clean Transit
kW	Kilowatt
kWh	Kilowatt Hour
kWh/mi	Kilowatt Hour Per Mile
LEV	Low Emission Vehicle
MHDV	Medium- and Heavy-Duty Vehicle
NMHC	Nonmethane Hydrocarbon
NMOG	Nonmethane Organic Gas
NOx	Nitrogen Oxides
OEM	Original Equipment Manufacturer
PM	Particulate Matter
PPM	Parts Per Million
R122	Regulation No 122 of the Economic Commission for Europe of the United Nations

ULEV	Ultra Low-Emission Vehicle
Wh/kg	Watthour Per Kilogram
Wh/l	Watthour Per Liter
ZEB	Zero-Emission Bus

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Section I

I. Fuel-Fired Heaters: The Current Landscape

Introduction and Background

As of 2021, there are 3,364 full-sized transit battery electric buses (BEBs) in the United States, with more on the way (Hamilton et al., 2021). An increasing number of states and transit agencies are making a commitment to zero-emission buses across the country. Cold climate regions, such as the Midwest or Northeast, that adopt BEBs may experience significant range limitations in cold weather due to the energy needed to keep the cabin heated throughout the day.

Fuel-fired heaters (FFHs) are traditionally used to provide engine preheat, supplemental heating for passenger comfort in buses, and heating for a Class 8 truck’s sleeper cab (e.g., to keep a driver warm while resting). These burners have a combustion chamber that transfers heat to the coolant loop, or alternatively function as direct air heaters depending on the application. **Figure 1** illustrates a coolant heater that supplies heat in a water-to-air configuration (i.e., water circuit with a glycol mixture is connected to heat exchangers). In California, the California Air Resources Board (CARB) defines an FFH as “a fuel burning device that creates heat for the purpose of warming the passenger compartment of a vehicle but does not contribute to the propulsion of the vehicle.”

Figure 1. Hydronic L-II Coolant Heater

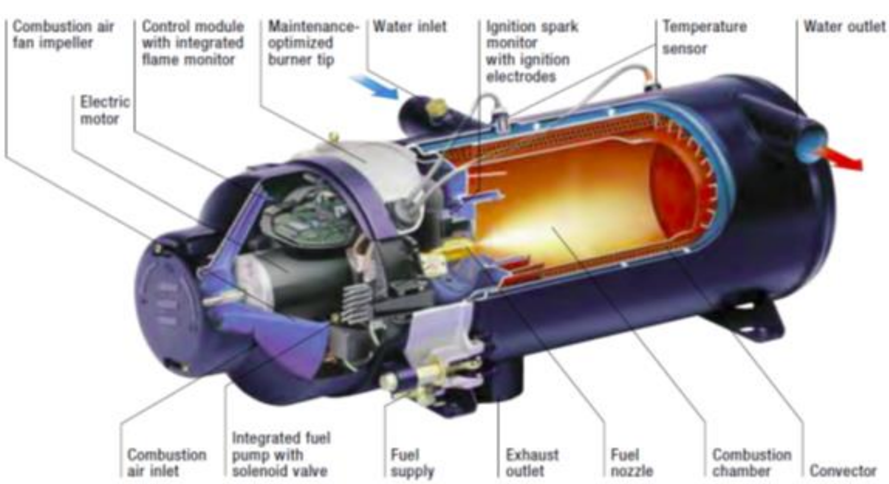


Image credit: Eberspächer North America

Using an FFH in a Class 8 truck mitigates the necessity of idling the main engine for heat. FFHs are generally diesel-powered but use only about 1/20th of the amount of fuel compared to idling the main diesel truck engine (Roy & Windover, 2015), thus reducing diesel emissions and saving fuel. In California, Class 8 berth trucks are not allowed to run an FFH unless the ambient temperature is 40 degrees Fahrenheit or below. California's Advanced Clean Truck rule, which requires all new truck sales to be zero-emission starting in 2045, will allow the installation of FFHs in vehicles if they comply with the current FFH emissions regulations (CARB, 2020b). The U.S. Environmental Protection Agency (EPA) does not have specific runtime requirements; however, the EPA does classify FFHs as non-road engines and has a voluntary verification process to assure FFHs use less fuel compared to idling the main diesel engine.

BEB manufacturers have caught on to the benefits of installing FFHs to improve vehicle range. One company, Valeo, states on their website that they have installed over 450,000 FFHs into buses after more than 40 years in business (Valeo Thermal Bus, n.d.). FFHs are a proven product for Class 8 trucks and diesel and compressed natural gas (CNG) buses that may need supplemental heating or engine preheating. Due to increased efficiencies in diesel engines, many diesel buses in cold weather locations are also outfitted with FFHs as there is less waste heat from the engine to repurpose for cabin heating. Cold weather operation can be incredibly detrimental for a BEB due to the limited battery capacity and heating energy requirements. Additionally, transit buses have relatively poor insulation and are prone to lose heat quickly due to frequent stops for on-and off-boarding passengers. To help combat this, a 30kW (on average) diesel heater is available as an add-on when purchasing a BEB. Having an FFH installed reduces the energy demand for heating required of the traction battery, but the main issue with this solution is the inevitable diesel emissions.

Per California's Innovative Clean Transit (ICT) regulation, buses with FFHs do not qualify as zero-emission buses (ZEBs). Fifteen states and the District of Colombia are following California's leadership by signing an agreement to sell only zero-emission buses by 2050 (CARB, 2020a). The states that are adopting similar ICT regulations may have to allow FFHs in their ZEBs to meet the transit agency range demands due to cold climates and harsh winters. Without CARB or other federal guidance, these states could have difficulties setting an appropriate emission limit and test procedure for existing FFH solutions.

To assist in the transition to zero-emission vehicles, California has created the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project to reduce the cost of innovative, clean trucks and buses. ZEBs can receive funding under this program. However, if the bus has an FFH installed, it cannot receive funding (Mobile Source Control Division, 2019). On the other hand, the similar New York Truck Voucher Incentive Program allows FFH buses with a caveat: the funding cannot be used to purchase or install an FFH, but the funds can be used to purchase a bus with a pre-installed FFH (NYSERDA, n.d.).

Presently, the CARB FFH emission regulations do not apply to ZEBs; ZEBs cannot have FFHs installed to qualify under the ICT regulation. As the CARB ICT regulation is being adopted by other states operating transit buses in colder climates, CARB could consider changing the ICT regulation to allow FFHs under specific, harsh cold climate conditions. As new zero-emission heating solutions should be developed, more research should also be conducted to understand the annual or seasonal FFH emissions and emissions variations per route and driver preferences. This would not only help California accurately account for their transportation emissions but may also help other states make an informed decision about their ZEBs.

Fuel-Fired Heaters for Approved Routes

California's ICT regulation requires transit agencies in the state to transition to a 100 percent ZEB fleet by 2040. The regulation includes a provision for granting exemptions for transit agencies with routes that a BEB cannot service due to daily mileage or gradeability needs (Air Resources Board-Mobile Sources Control Division, 2020). CARB requires extensive supporting documentation such as monthly mileage reports, ZEB requests for procurement, topography information, conventional vehicle performance information, and energy use data (if available) for an exemption. Upon approval, the transit agency may purchase a fossil fuel-powered bus. Because the ICT regulation requires large agencies to begin purchasing ZEBs in 2023 and therefore purchase requirements have not yet taken effect, it is unknown how many agencies will apply for and have their exemption approved. Currently, an auxiliary heating source such as an FFH will, in many cases, be needed for a BEB to complete its route in cold climates. On-route BEB charging can add additional range and partially mitigate the increase in energy needed to maintain cabin heat; the charging infrastructure and electricity demand charges, however, can be detrimentally expensive. Fuel cell electric buses can add additional hydrogen storage tanks to account for the increase in heating energy. It is important to point out that from a system approach, a ZEB with an FFH that operates during the cold weather months may still be better from an emissions standpoint compared to an alternative fossil fuel-powered bus in operation year-round and may itself be equipped with a supplementary heater.

Another factor impacting the use of FFHs is the pull-up heater requirement for transit buses in cold conditions. The American Public Transit Association states that the transit bus heater must warm the bus up to 70 degrees Fahrenheit from an ambient temperature of –20 degrees Fahrenheit within 70 minutes (American Public Transportation Association, 2013). More heat than an electric heater can provide may be necessary to warm a bus within 70 minutes. A BEB could also deplete too much of its battery and render it unable to complete its prescribed duty cycle.

Due to California's climate, barring FFHs from ZEBs is not often detrimental, but transit agencies and bus manufacturers have noted cabin heating is a non-trivial issue that they should be aware of when purchasing and designing ZEBs. Transit agencies in the Midwest and Northeast are in colder climates and would benefit from offboarding their heating demand to help with passenger comfort and conserve the battery for the bus route. There have been some instances of the HVAC heater using more of the battery pack energy than the traction motor in cold conditions (Göhlich et al., 2018).

Emissions Data Collection

To understand how ambient temperature and weather conditions impact FFH emissions, real-world vehicle data should be collected and analyzed. Looking at how transit agencies operate and use their bus fleet can lead to informed policy decisions. Quantifying FFH emissions can help regulatory agencies understand how these emissions are impacting climate goals.

The EPA classifies an FFH as an idle reduction technology. The goal of the EPA's SmartWay program is to reduce fuel use when idling the main engine (U.S. EPA, n.d.). The SmartWay program verifies that the emissions of the idle reduction technology are less than idling the diesel engine, and confirms the technology can operate properly as needed. The list currently includes FFHs for school buses only, not transit buses.

Fuel consumption data for FFHs are readily available and listed on manufacturers' respective factsheets (see **Table 1**). On average, a 30kW FFH can consume around one gallon of diesel per hour. The total consumption is heavily dependent on ambient temperature, heat losses, and temperature setpoints for the heater. Furthermore, the direct emissions associated with the heaters are dependent on usage. The transit agencies listed rely on FFHs to offboard the heating demand to complete routes and maintain passenger comfort. Without the FFH, the vehicles may otherwise be unable to complete a route in the winter months and thus do not represent a feasible option for the transit agency.

Table 1. Example of FFH Manufacturers

FFH Heater Manufacturer	Valeo	Proheat	Eberspacher
Bus OEM(s)	BYD, New Flyer	New Flyer	Proterra
Model(s)	Spheros Thermo (230/300/350)	Proheat X30	Hydronic L30
Example of Transit Agency Usage	• Link Transit – Washington State • Metro Transit – Minneapolis/St. Paul • Utah Transit Authority (UTA) – Salt Lake City (Electric buses)	Utah Transit Authority (UTA) – Salt Lake City (Diesel buses)	Chicago Transit Authority (CTA) – Chicago
Fuel Consumption	• Thermo 230: .79 g/h • Thermo 300: 1.05 g/h • Thermo 350: 1.18 g/h	0.1 – 0.31 gal/hr	0.96 gal/hr
Heat Output	• Thermo 230: 23 kW • Thermo 300: 30 kW • Thermo 350: 35 kW	2.9 – 9.1 kW	30 kW

Stronger Regulations

From the U.S. EPA, there are no definitive FFH emissions regulations. They could be regulated by the EPA nonroad compression ignition engine standards or spark ignition standards (US EPA, 2016a, 2016b). However, the heat output from an FFH comes from a combustion chamber that is connected to a heat exchanger and thus does not directly resemble the mechanics of a compression ignition engine; FFH could also be treated as a small turbine or open flame device, but none of the EPA's standards completely encompass the FFH. Depending on the rated power output (kW), varying exhaust regulations exist (see **Table 2**). Some of the exhaust standards have not been updated for more than 10 years. When an FFH is installed on a battery electric vehicle, the emissions are not accounted for in the vehicle's performance credits.

Table 2. EPA Nonroad Compression Ignition Engine Emission Standards

Rated Power	Model Year	NMHC + NOx (g/kW-hr)	PM (g/kW-hr)	CO (g/kW-hr)
kW < 8	2008+	7.5	0.40	8.0
8 ≤ kW < 19	2008+	7.5	0.40	6.6
19 ≤ kW < 37	2013+	4.7	0.03	5.5

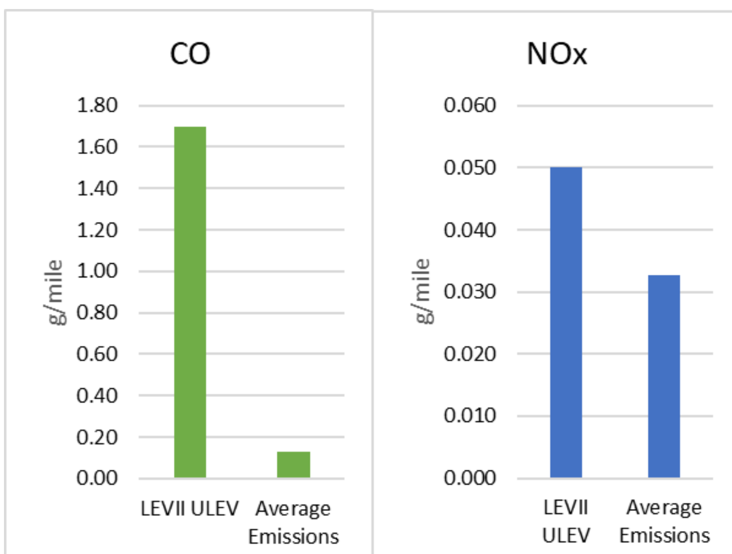
CARB currently regulates FFHs under the Low Emissions Vehicle (LEV) II regulations (see **Table 3**). CARB's 13 CCR 1956.8(a)(6)(D) regulates the emissions of FFHs to be installed and operated on all heavy-duty diesel-fueled vehicles with a gross vehicle weight rating (GVWR) over 14,000 pounds and all diesel-fueled commercial motor vehicles with a GVWR over 10,000 pounds. This regulation states "the fuel-fired heater must meet LEVII ULEV (ultra low-emission vehicle) standards for passenger cars and light-duty trucks less than 8,500 pounds GVW." Common vehicles that fall under this regulation are diesel-powered school buses, transit buses, and long-haul trucks. Notably, most FFHs are diesel powered, but there is no requirement for particulate matter (PM) testing. The regulation as written applies only to diesel-powered vehicles (i.e., FFHs installed on other alternatively powered vehicles are not regulated). All units in Table 3 below are grams per mile (g/mi).

Table 3. CARB FFH Emission Standards

(g/mi)	NOx	CO	Formaldehyde	NMOG
LEV II ULEV	0.050	1.70	0.0080	0.0400

CALSTART received FFH emissions data from FFH manufacturers to understand how BEB FFH emissions compare with CARB's standard. An average of FFH nitrogen oxide (NOx) and carbon monoxide (CO) emissions data (see **Figure 2**) show that FFHs are far below the standard CARB has set in LEVII. The FFH emission standard is the same as passenger vehicle engines, even though FFHs are small, only produce heat, and are not responsible for vehicle movement.

Figure 2. LEVII ULEV Standard vs. Average Emissions of FFH



As it stands, FFHs must be emissions tested only if installed in diesel vehicles. For example, if a medium- or heavy-duty vehicle is battery-powered, the installed FFH would not have to be tested under CARB's regulation. This is a loophole that could be exploited as alternative fuel vehicles become more common. Creating more stringent FFH regulations based on fuel type can steer manufacturers away from diesel FFHs and toward other fuels such as CNG, propane, or hydrogen.

Another CARB regulation is the Low NOx standard, which is intended to reduce NOx emissions in heavy-duty diesel vehicles (Miller, 2020). Using a few logical assumptions for a transit bus route and heating demands, a comparison was made between the Low NOx standard and the current FFH standard (see **Table 4**). The ULEV standard, per its design for smaller engines, is more stringent than the Low NOx standard; as **Figure 2** demonstrated previously, the emissions from FFHs are still far below the standard.

Table 4. Low NOx Standard Compared to FFH LEVII Standard

	Current	2024-26	2027+
Low NOx Standard (g/bhp-hr)	0.200	0.050	0.020
Low NOx Standard (g/mi)*	0.483	0.121	0.048
FFH NOx Standard (LEVII ULEV)	0.050		
% Difference	866%	141%	-3%

*Assuming 30 kW heater running for 6 hours on a 100-mile route.

Europe has enacted specific testing and emissions requirements for FFHs in all passenger vehicles, transit vehicles, trucks, and semi-trucks (Economic Commission for Europe of the United Nations, 2010). In the R122 standard, units are reported in parts per million (ppm) and Bacharach, an optic unit measuring exhaust color (see **Table 5**). One manufacturer's results show that their FFH emissions are well below the standard.

Table 5. R122 Standard Compared to Example FFH Emissions

	CO (ppm)	NOx (ppm)	Hydrocarbons (ppm)	PM (Bacharach)
R122 Standard	1000	200	100	4
Company A	35	98	1	1
% Difference	-2757%	-104%	-9900%	-300%

CARB and the EU have set standards for FFH emissions in g/mi and ppm, respectively. Due to current recording, collecting, and reporting methods, it is unfortunately not possible to compare the standards' stringency. Being able to compare these standards would allow for a more holistic view of the policy landscape for FFHs. In addition, CARB's unit to measure emissions is g/mi; by definition, an FFH "does not contribute to the propulsion of the vehicle." Furthermore, the EPA measures emissions in g/kWh, adding another unit that is difficult to compare to the g/mi and ppm values mentioned above.

Section II

II. Technology Demonstrations

Cold weather has not stopped some transit agencies from adding BEBs into their fleets. By reviewing operational data for BEBs, it has been possible to better understand how heating the bus impacts efficiency. The transit agencies have been made anonymous to ensure the integrity of the data provided.

- With funds from the Federal Transit Authority, CALSTART collected BEB data in collaboration with a large Midwestern transit agency in a cold-weather climate. Charging and vehicle usage data from their fleet of 60-foot BEBs produced by a legacy OEM was collected over 12 months of service. The BEB fleet consumed an average of 235 gallons of diesel per month for their FFHs; this is about 30 gallons per bus per winter month. Assuming the FFHs are 80 percent efficient, this is equivalent to almost 1,800 kWh per bus per month needed to run the heaters while the buses are in service. The FFH reduced the energy draw of the bus by 0.71 kWh/mi. Without the diesel heater, it is estimated that the electric heater would have to draw an additional 0.71 kWh/mi to satisfy the heating needs of the bus. One bus would need approximately 60kWh additional battery pack energy to compensate for the additional heating energy required on the route without the auxiliary heater. The larger, heavier battery pack would lead to a longer charge time and lower overall bus efficiency throughout the year, while the additional stored energy would be required only during the winter months.

  To support and extend the buses' battery ranges, the 60-foot BEBs have a switch on the dashboard to activate the FFH as needed. The transit agency configured their heaters to run the electric heater first and then use the diesel FFH when necessary. Depending on the heating needs and setpoint, a transit agency can configure the FFH as the primary source of heat, which would maximize the battery's energy to be used for the electric motor. It is unclear how much control the transit agency and driver have to change the FFH settings after the bus has been delivered, such as if the agency or OEM decided to make the e-heater the secondary source of heat at a later date.

- CALSTART was able to look at two days of BEB usage from another transit agency in a cold climate region: one day with the FFH (ambient temperature below freezing) and one solely relying on the electric heater (ambient temperature in the mid-50 degrees Fahrenheit). On average per trip, only about 3 percent of the battery energy went to heating when the FFH was active. When using only the electric heater, 25 percent of the battery energy was dedicated to heating. Seventy-seven percent of the trips on the warmer day utilized the electric heater. The cold day had the electric heater running for only 50 percent of the trips and at a very low energy use; the remaining heating demand was made up by the FFH. There could be additional factors impacting the heating demand on the energy breakdown such as driver and route characteristics or the cabin temperature setpoint that were not reported. As such, any heating energy needs by the battery has a significant impact on the vehicle's range.

- Information from one original equipment manufacturer (OEM)'s operating manual explains that the BEB's diesel heater has been programmed to operate only at temperatures less than 40 degrees Fahrenheit and to shut off when the ambient temperature is above 45 degrees Fahrenheit. It also states the diesel FFH is used to condition the battery and for cabin heat. Conversely, a different BEB OEM has programmed their FFH to be solely used for passenger cabin heating. Inconsistent FFH usage and variable cabin temperature setpoints can make it more difficult to understand the use frequency, range impact, and overall emissions impact of FFHs. It is unclear how the heating energy is split between cabin heating and battery thermal management.

Göhlich et al's academic study (Göhlich et al., 2018) found that heating a BEB from an ambient temperature of 14 degrees Fahrenheit (-10 degrees Celsius) to a cabin temperature of 63 degrees Fahrenheit (17 degrees Celsius) can increase energy consumption by 2.09-3.22 kWh/mi depending on the prescribed driving cycle. Using 1.93 kWh/mi as the energy demand for traction and other non-HVAC auxiliaries, heating in cold weather can total to 4.02-5.15 kWh/mi energy demand. Anecdotally, it has been witnessed that in some extremely cold regions, heating and traction energy demand can reach 6 kWh/mi or more, with the total heating energy having 2-3 times the impact compared to energy used by the traction motor.

These current examples of transit agencies deploying BEBs in cold regions support the need for FFHs to complete routes with current BEB technology that would otherwise be difficult, or even impossible.

Section III

III. Conclusions and Future Work

Diesel FFHs are becoming more prominent as BEBs are deployed in cold climate areas. Using the Midwestern cold-climate transit agency as an example, cabin heating in cold weather could lead to an increase in energy of 37 percent in order to maintain service. BEBs cannot have FFHs installed to qualify under California's ICT regulations, but FFHs and other technologies can help maintain passenger comfort in cold climates. The ICT regulation could consider an exception to allow FFHs under specific conditions, such as in cold or hilly regions. To reduce the heating demand of BEBs and thus the need for FFHs, other technologies could be implemented, such as air curtains, heat-pumps, heated passenger seats, increased insulation, and/or driver climate zones.

Zero-emission FFH technology needs to be explored so more regions of the United States can easily add BEBs to their fleet. Off-boarding the heating demand means buses can devote the maximum amount of energy to completing a route. Two potential technologies that can provide heating for a bus with zero emissions are heat pumps and fuel cell heating; however, zero-emission FFH technologies have not been explored and are not commercially available seemingly due to the predominance of the tried-and-true diesel FFH. Hydrogen FFHs are near zero-emission and seem feasible; burning hydrogen to produce heat has been used in industrial practices and would require industry engagement, funding, testing, and moderate modifications to function in a BEB. Hydrogen FFHs would produce a small amount of NOx but would have zero carbon emissions.

As battery capacities and prices continue to improve, it could be argued that the heating load can be satisfied with larger battery capacities in the future. However, taking into consideration the highly variable heating needs that can easily require a 50-100 percent increase in battery capacity (i.e., 200kWh-400kWh), the current estimated price improvements from $156/kWh to $80/kWh would still result in a significant increase of the total vehicle cost (DNV GL, 2020).

Despite projected improvements in gravimetric (Wh/kg) and volumetric (Wh/l) energy densities, doubling battery capacity would still have a substantial impact on the design and weight of a transit bus. The United States Advanced Battery Consortium has, in March of 2021, set new lithium electrode cell goals of 450Wh/kg and $50/kWh. Current lithium-ion chemistries can achieve around 350Wh/kg on the cell level as measured at the beginning of life (Masias et al., 2021). However, overall end system gravimetric efficiencies are between 0.484-0.742 of the cell values depending on the cell type used (i.e., pouch, prismatic, or cylindrical) (Löbberding et al., 2020). Despite the steady improvements in battery capacities and the introduction of new disruptive technologies such as solid-state batteries, it is difficult to project when it would be feasible to cover the heating demand with a battery both from a technical and financial standpoint.

Larger battery capacities that can satisfy heating needs would also require significantly longer charging times with currently available charging power levels. With limited information and real-world performance data of new storage technologies, such as solid-state batteries, it is difficult to project what the total weight and design implications could be when accounting for total propulsion and heating loads of a bus operating in severe cold climates.

From the research and case studies presented in this white paper, CALSTART has identified two key recommendations when considering the future development and implementation of FFH technology:

- **Testing and Reporting Standardization:** FFH testing and reporting should be comparable across regulating bodies. The current mismatch has made it difficult to compare emission stringencies and does not allow for a comprehensive view of the FFH policy landscape. The regulatory agencies should work together to understand the relative strengths of their standards; FFHs are an international product that could become more prominent as ZEBs continue to increase market share.

- **Alternative Heating Research:** Further research is needed into the emissions implications and use frequency of FFHs, and alternative heating techniques should be thoroughly evaluated. It is important to understand annual or seasonal FFH emissions to try to obtain an accurate account of emissions coming from the transit sector. Phasing out diesel FFHs should be considered, and alternatives need to be explored and tested to fully divest transit buses from fossil fuels. A growing number of transit agencies that operate in cold climates have or will install diesel FFHs to overcome adverse weather. In the future, other transit agencies should have zero-emission heating options when purchasing BEBs for their fleet. FFHs are currently a necessity for many transit agencies, but this legacy technology's emissions need to be mitigated to allow ZEBs to be truly zero-emission. New zero-emission heating solutions can also be broadly adopted in other segments of the industry, such as in heavy-duty sleeper cabins. The feasibility for alternative zero-emission heating solutions, such as hydrogen FFHs, should be further evaluated.

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