Assessing Components and Systems Related to Low and No Emission Transit Buses

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Prepared by CALSTART
in partnership with
Ohio State University

CALSTART

THE OHIO STATE UNIVERSITY

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List of Acronyms

BEBs	Battery Electric Buses
BTUs	British Thermal Units
CAR	Center for Automotive Research
CNG	Compressed Natural Gas
DOT	Department of Transportation
FAST Act	Fixing America's Surface Transportation Act
FCBs	Fuel Cell Buses
FTA	Federal Transit Administration
GTI	Gast Technology Institute
HVAC	Heating, Ventilation, and Air Conditioning
LNG	Liquefied Natural Gas
LoNo buses	Low or No-emission Buses (inclusive of many types of technologies)
LoNo CAP	Low or No-emission Component Assessment Program
NOx	Nitrogen Oxide
OEMs	Original Equipment Manufacturer, also known as bus manufacturer
TAC	Technical Advisory Committee
TRC	Transportation Research Center
ZEBs	Zero Emission Buses (inclusive of BEBs and FCBs)

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Executive Summary

Since 2013 the Federal Transit Administration (FTA) has provided funding to state and local government to purchase low or no emission (LoNo) transit buses across the country. This program has made great strides in recent years leading to orders and deployment approaching 2,000 zero emission buses. In the process transit agencies along with bus manufacturers have reported some challenges with the internal components and systems in these buses.

Ohio State reached out to CALSTART to spearhead a survey of the LoNo bus industry and identify what critical issues are preventing transit agencies from fully utilizing their LoNo buses. CALSTART contacted 39 transit agencies, bus manufacturers, and component suppliers that had experience with battery electric and hydrogen fuel cell buses. The roughly one-hour interview asked several questions about what components had problems with reliability, maintainability, performance, structural integrity, efficiency, and noise.

CALSTART identified industry concerns distributed across individual components, systems, and vehicle-wide issues. There was no single overwhelming issue identified but rather a multitude of differing issues.

Component level concerns included energy storage, reliability and durability, and heating issues. Charger design and integration are not fully understood by users and there were concerns that a mismatch between the components of charging systems could cause inefficiencies or even safety hazards. Respondents also voiced concerns about the potential for mismatches between the charging capacities of the onboard battery and the off-board charger.

Systems level concerns included off-bus topics including charging infrastructure and hydrogen fueling stations along with on-bus software and HVAC systems. Concerns were raised about the impacts that environmental factors, like temperature and pressure, can have on hydrogen fueling. The fuel cell stacks performed well, but other auxiliary components such as the compressor or hoses were not durable for 20,000 hours of operations.

Vehicle-wide issues centered primarily on fuel and energy economy questions during daily in-use operation. In most climates, the heating, ventilation, and air conditioning system (HVAC) directly competes with the propulsion system for energy and does not efficiently keep passengers at a comfortable temperature.

Background

Since the creation of the Clean Air Act, the federal government has been working with public and private organizations to reduce the amount of pollution released into the atmosphere. Urban transit buses have always been a major issue for policymakers and environmental advocates alike because buses have traditionally operated on diesel fuel. However, over the last few decades transit agencies have made great strides in adopting cleaner technology. In 2015 almost half of all buses used a cleaner alternative fuel other than diesel[1]. It is crucial that all diesel-powered buses are replaced in the future because they produce a significant amount of air pollutants including black carbon, carbon monoxide, and nitrogen oxides (NOx). While bus riders produce less pollution per capita than cars, they are much more likely to be exposed to poor air quality[2]. Considering that many bus riders (22%) have no other transit options except for buses[3], reducing and eliminating the amount the air pollutants emitted by this public transportation mode has been a major goal for the federal government.

Figure 1: A bus that uses compressed natural gas as its fuel, which produces significantly less emissions.

Types of Low and No Emissions Bus Technologies

There has been a revolution in the automotive world over the last 25 years in terms of controlling, reducing, and ultimately eliminating tailpipe emissions. Most people today are familiar with electric cars like the Tesla Model S or the Nissan Leaf. The lessons learned by Tesla and Nissan in developing these state-of-the-art vehicles has been passed onto other automakers and related industries, including the bus market.

Today, there are four major types of technologies available to public transit fleets. The first two types attempt to reduce the amount of emissions. Electric hybrid buses utilize diesel fuel to power an electric drivetrain, not unlike a Toyota Prius and other variations of hybrid cars. Another approach is to use a different fuel altogether, such as compressed natural gas or liquefied natural gas. CNG and LNG buses, as they are known, produce less emissions that diesel buses. Both hybrids and natural gas buses have been commercially available for many years now.

Figure 2: Types of LoNo Bus technologies. Beginning clockwise from upper left: An Electric Hybrid bus, a CNG-powered bus, a Battery Electric Bus (BEB), and a Fuel Cell Bus (FCB).

The second two types of bus technologies have emerged quite recently. Battery electric buses (also known as BEBs) are simply oversized electric vehicles not unlike a Tesla Model S or Nissan Leaf, and produce no emissions and has no tailpipe. Similarly, hydrogen fuel cell buses (FCBs for short) replace the diesel fuel tank and engine with a hydrogen gas tank, a fuel cell, and electric drivetrain. The FCB combines the hydrogen with oxygen from the atmosphere inside the fuel cell to create electricity and water. Newer models of FCB are occasionally called hybrids because they store their energy in an onboard battery which then propels the bus forward identically to a BEB.

In this report, all four types of buses will be referred to as “LoNo buses” because they produce low or no emissions.

State of the LoNo Bus Industry

As of 2015, 40.4% of all transit buses used one of the four types of LoNo bus technology, with the majority of these being natural gas powered or hybrids[1].

To accelerate the adoption of zero emission buses, Congress passed the FAST Act in 2015. Among many other transportation related goals, a provision of this law enabled the Federal Transit Administration (FTA) to oversee a competitive grant to help public transit agencies purchase LoNo buses. This grant program is called the “Low or No Emission Vehicle Program,” and it is chiefly targeted for public transportation agencies on the local and state level.

Between 2013 and 2018, the FTA has distributed over $271 million dollars for LoNo buses through this program. Although all types of LoNo buses qualify for funding, the selection process has heavily favored buses that produce no emissions despite being much more expensive than the low emission type. Thanks to this aggressive funding, the cost of these technologies has significantly decreased since the beginning of the program. In 2013, 33 LoNo buses were subsidized for over $54 million. In 2017, 206 LoNo buses were awarded for virtually the same amount funding.

As of August 17th, 2018, there were 1,650 zero emission buses either operating on the road, on order, or awarded funding[4].

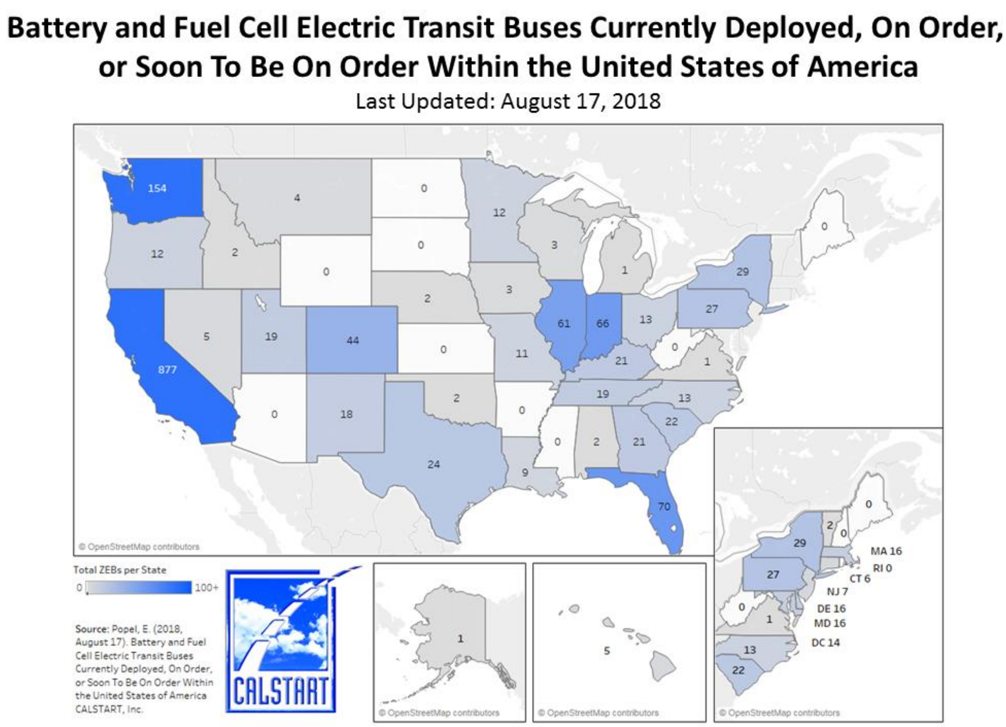

Figure 3: Distribution of Zero Emission Buses across the US

Low or No-emission Component Assessment Program

In 2016, Congress created a new program that would more rigorously test the internal parts of LoNo bus, specifically individual components, systems, and the entire vehicle. This program, called the Low or No-emission Component Assessment Program (LoNo CAP for short), would insure that these buses are no longer an experimental mixture of technologies and that they are as safe, efficient, and reliable as any traditional bus technology.

In April 2017, the FTA officially announced that the Ohio State University and Auburn University would receive funding to develop their own versions of LoNo CAPs. Both universities will conduct testing, evaluation, and analysis of LoNo components. They were selected because they best met the evaluation criteria, including their demonstrated capacity to carry out transportation-related advanced component testing and evaluation as well as effective facilities, laboratories, and partnerships.[5]

Ohio State LoNo CAP

The Ohio State LoNo CAP team is composed of three highly qualified research centers.

Figure 4: Research Centers participating in the Ohio State LoNo CAP

On Ohio State campus is the **Center for Automotive Research** (CAR). CAR spearheaded the initial proposal process and is already well equipped to do component testing. The Commercial Vehicle Research and Testing Laboratory within this department has several powerful tools, including a heavy-duty chassis dynamometer, energy storage laboratory, and an advanced powertrain laboratory.

In East Liberty, Ohio, is the **Transportation Research Center** (TRC). TRC is the largest independent vehicle test facility and proving grounds in the United States. In addition to their secured 7.5-mile-long oval test track, TRC brings to the table expertise in crash avoidance and crashworthiness testing, emissions testing, dynamic testing and durability testing. They have also made significant investments into testing emerging technologies, such as autonomous vehicles. TRC has the respect of the entire automotive industry, including federal agencies like the National Highway Traffic Safety Administration.

Lastly, but not least, is the **Gas Technology Institute** (GTI). GTI has been the leading research, development, and training organization for gaseous technologies for over 75 years. In addition to providing expertise on all things related to natural gas fuel, GTI has unique testing equipment that can be applied to hydrogen fuel cell vehicles, including fuel quality and storage, fuel cell performance, and environmental scenarios.

Armed with three world class testing facilities, the Ohio State LoNo CAP is well positioned to perform component tests on LoNo buses. At this point in time, the program must resolve two major questions: what kinds of component tests does the industry want, and what's the best way to attract "customers" from bus manufacturers and component suppliers?

CALSTART

Ohio State has reached out to CALSTART to assist with marketing the LoNo CAP program. CALSTART is an environmental nonprofit organization with a mission to accelerate the growth of the clean transportation industry. It has been very successful over the last 25 years and has worked with everything from light duty vehicles, buses, medium- and heavy-duty trucks, and even airplanes. The nonprofit is also supported by over 185-member companies across the industry, including transit agencies operating LoNo buses.

CALSTART conducted this study to identify technological issues that are preventing transit agencies from fully utilizing their LoNo buses. Specifically, this study aims to identify existing components on current LoNo buses that need improvement, especially in terms of maintenance, reliability, efficiency, noise, and cost. To accomplish these goals, CALSTART developed a series of open-ended interview questions targeting the LoNo bus industry, including transit agencies, bus manufacturers, and component suppliers. These interviews formed the basis of the Zero Emission Component Survey.

Zero Emission Component Survey

Scope of Survey

Given the historical emphasis for zero emission buses by the Low or No Emission Vehicle Program[4], CALSTART decided to limit the scope of the survey to two types of bus technologies: battery electric buses (BEBs) and hydrogen fuel cell buses (FCBs). While CNG and diesel electric hybrids components qualify for testing at LoNo CAP, the technologies for these types of buses are significantly more developed and have been available for decades. Zero emission components, in contrast, are likely to have many more "low hanging fruits" that Ohio State LoNo CAP could immediately begin investigating and producing valuable results.

Methodology

CALSTART reached out to 39 different transit agencies, bus OEMs, and suppliers that are known to work with BEBs and FCBs for anonymous interviews about their experience. Of these, 19 organizations agreed to be interviewed. These organizations formed the **Technical Advisory Committee**, or TAC for short. A full list of the TAC is available in the appendices.

While there are 1,650 BEBs and FCBs across the US, many of these exist only on paper as orders for new buses or funding awarded to a transit agency[4]. The population of operational buses could be less than a third of this size. As a result, most transit agencies, bus manufacturers, and suppliers in the LoNo bus industry do not have a significant amount of experience with these vehicles. Transit agencies' experience may range from a single, experimental demonstration of the technology to a fleet of less than 40 vehicles. Manufacturers and suppliers have very different perspectives compared to transit agencies, as their focus is on pre-commercial activities. There are relatively few people who are subject matter experts on everything under the hood of both BEBs and FCBs – most are experts in a single aspect of the technology.

But there are a few people who are a jack of all trades when it comes to zero emission buses. Early on in survey, CALSTART decided to invite these individuals to join the **Steering Committee** for the survey, along with Ohio State's CAR, TRC, and GTI. The Steering Committee played a role in developing the interview questions. Their inputs were invaluable and allowed CALSTART to calibrate its early results based on their real-world experience.

Throughout the survey, CALSTART followed these steps:

- Develop a series of interview questions, specifically for transit agencies, bus manufacturers, and component suppliers.
- Reach out to transit agencies, bus manufacturers, and component suppliers to join the TAC.
- Interview TAC members.
- Extract data from interview transcript and aggregate with other interviews.
- Present preliminary results to Steering Committee and gather their feedback.
- Adjust results based on feedback, then present results to TAC.

Results

Framework

CALSTART discovered that while specific, individual components need to be improved, there are also systems and vehicle-wide issues that need to be improved.

Systems refer to a collection of components working together for a specific task. While there may be individual components in a system that need to be improved, the intangible quality of how the components are connected is the real issue.

Vehicle issues are similarly focused on how components and systems interact with each other as a single unit – the entire bus. While the issues discussed under this heading may sound like pure basic research rather than component evaluations, it is imperative to understand how a single component or system would impact the overall capabilities of the bus.

The vehicle level testing is different from what is currently performed at the Larson Transportation Institute's Bus Research and Testing Center in Altoona, Pennsylvania, which certifies buses for safety, durability, fuel economy, and other criteria before it can be available to transit agencies. Ohio State's LoNo CAP would be capable of swapping one or more components or systems on the bus to understand how the vehicle's performance changes.

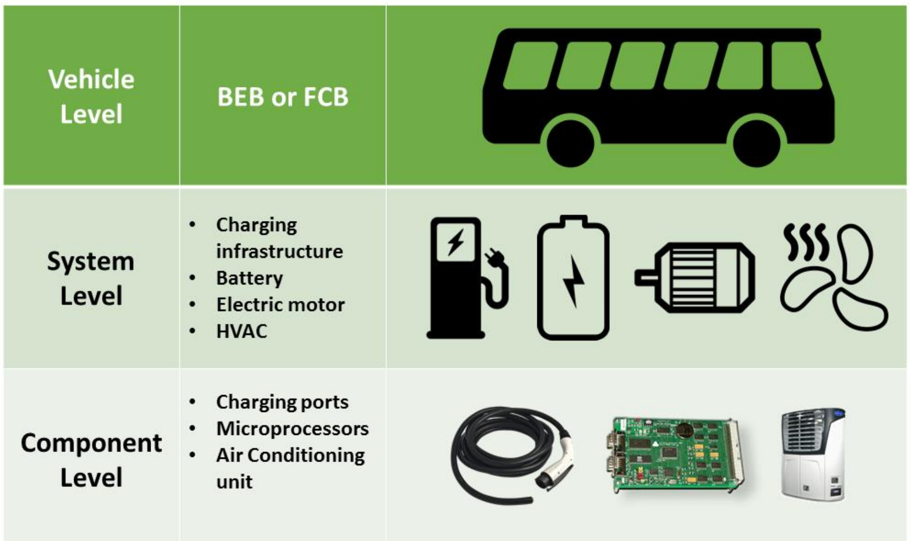

Figure 5: Vehicle, System, and Component Level Framework

It is important to understand that no component or system exists in isolation on a zero emission bus. When all electronics are hooked up to the same battery that the electric bus uses to propel itself with, the energy draw of each device will impact the effective range of that bus. This is fundamentally different from diesel-powered buses and even CNG-powered and diesel electric hybrid buses, where components are not tied to each other in this unique way.

With this framework established, here are the result of the survey, categorized by components, systems, or vehicle level issues.

Component Level

The following Component Level issues were identified.

Reliability and Durability

1. On selected (not all) FCBs, the oxygen and hydrogen compressor and blower are not durable for the 20,000 hours of expected operations.
2. On FCBs, hoses transferring oxygen or hydrogen are not durable for the 20,000 hours of expected operations. Leaks are hard to detect, and gases evaporate away without indicating where the leak is located.
3. On FCBs, an interruption in either oxygen or hydrogen immediately reduces the range of the bus. This can be caused by a variety of issues, including the above.
4. On BEBs, charger plugs are not guaranteed to work for 12 years. Chargers for heavy duty electric vehicles simply haven't existed for that long, and users expressed a concern in their wear and tear/durability.
5. Electronic controllers regulating components unique to zero emission vehicles are not durable. This is the same as the above issues.
6. In cold weather climate, a variety of components unique to zero emission vehicles experience corrosion due to ice, salt on the road, and other environmental factors. One example of this is mud kicked up by the tires invariably land on the oxygen intake of FCBs, which could lead to problems. Users expressed concerns about wear and tear.

Energy Storage

1. The charging rate of the onboard battery and the discharge rate of the offboard charger are poorly understood by transit agencies. Fleet managers want tests validating that batteries and chargers are well matched with each other.
2. The full lifespan of batteries is poorly understood. No one is sure whether batteries on buses will last the full 12-year lifespan. Many transit agencies operate buses for several years beyond that as well, but they are unsure if the batteries will be useful at that point.

3. Many transit agencies are unsure of what to do if the battery is unexpectedly destroyed. This ranges from fire and rescue procedures to hazardous waste disposal.
4. On FCBs, onboard hydrogen storage could be optimized for transit bus operation. This includes factors likes temperature, pressure, dispensing rate, etc.

Heating Issues

1. The electric HVAC unit limits the bus's range and fuel economy, as it is competing with the propulsion system for energy. This effect is noticeable even in relatively mild climates.
2. In extremely cold weather, the electric HVAC unit does not efficiently create enough BTUs of heat. The bus does not maintain passengers' comfort and the previous issue is further aggravated.
3. On FCBs, the fuel cells stack produces a significant amount of waste heat. This heat is vented out of the bus and is not captured in any meaningful way. BTUs of heat must be created by the HVAC unit despite a "free" source of heat already existing on the bus.

System Level

The following System Level issues were identified.

Charging Infrastructure

1. The overall design and integration of components related to DC fast chargers, wireless chargers, overhead pantograph chargers, and depot chargers are not well understood by users. There is a concern that a mismatch between components (i.e. the depot box, electrical cabinet, and transformer) could lead to inefficiencies, longer charging time, or safety hazards.
2. Interoperability of charging ports is a major concern of transit agencies planning to use multiple BEBs made by different manufacturers. Transit agencies want to avoid being "locked" into a specific technology or manufacturer because of an early decision in their charging infrastructure plan.

3. The spatial requirement of charging infrastructure is a major concern. Transit agencies have limited space as is before adding infrastructure for each bus.

Hydrogen Fueling Station

1. The conditions of compression, storage, and dispensing systems for hydrogen at fueling station is a major concern. The quantity of fuel available to FCBs fluctuate with temperature and pressure, and the ambient environmental conditions seem to impact the quantity of fuel that is transferred to the buses.
2. Some transit agencies expressed concern with long term storage of hydrogen. They want tests on how much fuel would be available if kept in storage for several days (i.e. a day with no bus service) or for several months (i.e. an emergency reserve).

Software Systems

1. Error messages do not adequately inform drivers and mechanics about the severity of the problem or the correct response. In some cases, drivers have returned to the bus yard early for minor problems. In other cases, a major malfunction occurred with no warning.
2. Telematic systems are not always calibrated for BEBs or FCBs. There is a concern that the industry is focused on the wrong data, or that data is collected incorrectly. Transit agencies need guidance on understanding what data to focus on.
3. Several components within a system may have mismatched "level of authority" over each other. This is an increasing concern as traditionally mechanical components are replaced by digital equivalents, and these new components are expecting outdated commands or feeding unreadable data to each other. There is a need to validate computer programming across the system

HVAC System

1. The HVAC system (including the primary HVAC unit and associated components) should be validated for high efficiency and low weight in addition to the BTUs of

heat produced. The concern is that a high BTU output requires a significant amount of energy, which drains the battery or hydrogen fuel tank.

2. The insulation and seals of windows and doors across the entire vehicle should be examined and accounted for when testing HVAC components. There are cases where a low performing HVAC component does better than high performing equivalent due to air leaks.
3. Innovative designs, such as air curtains, window glazing, and doors, should be accounted for when testing HVAC systems.

Vehicle Level

The following Vehicle Level issues were identified.

Fuel and Energy Economy

1. When testing the entire bus's performance, the vehicle needs to be evaluated with a realistic set of operational components. Systems that would not ordinarily be activated during Larson Transportation Institute's bus testing (such as the HVAC system) need to be activated to better understand the vehicle's fuel economy.
2. Likewise, the bus performance needs to have a realistic simulation of passenger weight. Most zero emission buses are heavier than traditional buses, and some transit agencies have noticed significant wear and tear on the suspension system as well as the asphalt of bus stops and bus yards.
3. Hilly terrain poses a difficult challenge for zero emission buses, as well as the heating challenges discussed previously. Both conditions need to be considered when testing bus performance.

Summary of Results

As mentioned before, no component or system exists in isolation on a zero emission bus. The battery or hydrogen fuel tank has a set amount of energy stored in it, and as components increasingly become digitally controlled they need to tap into the same supply of energy that drives the entire vehicle. First, LoNo CAP testing centers should ensure that unique components are rated for the 12+ years lifespan of the vehicle or are supportable with spare parts and periodic maintenance for 12+ years. Second, the test centers should carefully consider how a component would fit within a system, both on and off the vehicle. Lastly, testing centers should consider heat management across the entire vehicle

Discussion

Throughout the Zero Emission Component Survey, responses seem to coalesce around three distinct themes. These themes include 1) components, 2) systems, and 3) vehicle design.

Components are the most obvious theme. The industry wants to ensure that components perform well, are reliable, and are compatible with the rest of the bus.

The most surprising result of the survey was that the industry is not very concerned about major LoNo bus-specific components such as the electric motor, battery, or fuel cell stack. Despite every BEB and FCB having an electric motor and a battery, few interviewees voiced a concern about their capabilities. The few that wanted more assurances that the battery would last 12 years and have a predictable charging rate, rather than proof of how many kWh it contains.

Most interviewees thought that other “minor” components had more critical issues, with the HVAC unit featuring very prominently. CALSTART came to learn that the reason for this was because the interviewees’ expectations of the HVAC unit had changed drastically when applied to a LoNo bus. On traditional diesel-powered bus, the HVAC unit consumes diesel to keep the cabin at the appropriate temperature. Weight and efficiency are not high priorities when diesel is plentiful, but LoNo buses do not have this luxury. To be useful on a BEB, the HVAC unit needs to keep passengers comfortable, be relatively light weight, and use a limited amount of energy regardless of how extreme the ambient environment may be. Because most HVAC units used on LoNo buses are selected for performance, rather than weight or efficiency, interviewees have had a lot of challenges related to this single component. The HVAC unit design needs to evolve to fit on a LoNo bus. CALSTART believes that while the HVAC unit is a major issue that needs to be addressed, many other components that are identical between LoNo and non-LoNo buses may have similar problems.

Fuel cell ancillary components face a simpler problem – they are just not durable for the 20,000 hours of bus operation over a 12 to 15-year lifespan. Because there are relatively few FCB across the country, most fuel cell-related components are drawn from preexisting designs meant for light duty vehicles. The downside of this approach is that these components are rated for the 5,000 hours of operation, rather than the 20,000 hours of transit bus operations. Hoses, compressors, and blowers share this durability problem.

The HVAC and fuel cell ancillary component issues identified in this report are important challenges that would accelerate the adoption of LoNo buses if solved.

The second major theme is **bus systems**. In this case, the industry is asking whether individual components are combined in a manner that maximizes LoNo bus performance.

On LoNo buses, many unique components are brought together for the first time. Both bus manufacturers and component suppliers have done a reasonable job at anticipating shortfalls and ensuring that all the hardware on the bus works well together, but our survey has shown that there are problems with the more intangible aspect of bus operations. Small mismatches between several different offboard components, such as the charging infrastructure or hydrogen fueling station, can slow refueling efforts and limit the time that the bus could be operating. Communication between different component software can lead to unusual errors that require the bus manufacturer to troubleshoot. Air leaks and insulations have been identified as major sources of heat loss on the bus and addressing these would enable a lower performing HVAC unit to keep passengers much more comfortable. Individually the component may work perfectly fine on its own, but how it is integrated and expected to work with other components is the barrier preventing success. These qualities are not being actively investigated by bus manufacturers or during standardized testing but would have a significant impact on the bus utility.

The last major theme identified was **vehicle design**. In this case, the industry is asking whether the vehicle will meet their expectations in terms of performance and operation.

Simply put, transit agencies want a vehicle that will perform as advertised, including performance, range, and maintenance requirements. However, because LoNo buses are fundamentally different from traditional diesel-powered buses there are a lot of questions about the basic capabilities of these vehicles that have never been asked before. For example, because LoNo buses are much more sensitive to ambient temperature and hilly terrain, no one is quite sure what the kWh per mile rate of a BEB driving uphill is in cold weather. While this might be considered a niche application useful to only a handful of transit agencies today, the lack of understanding on this issue could prevent other transit agencies in cold mountainous environments, such as the entire Rocky Mountain region, from purchasing LoNo buses. Validating that the LoNo bus can perform all the same actions that a regular bus can do would settle a lot of the confusion in this industry.

kWh per Mile Rates			
	2.50	3.25	3.75
	2.33	3.00	3.50
	2.75	3.50	4.00

Figure 6: An example of additional information that would be useful to LoNo bus stakeholders.

This matrix shows a hypothetical vehicle' kWh per mile rates based on climates and terrain conditions. Note that Altoona would normally supply the middle value in the 1st column (2.33 kWh per mile) because they test in mild weather and on a flat test track. Transit agencies in mountainous terrain or colder climates would benefit from this matrix.

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Appendices

Appendix A: TAC Members and Steering Committee

Appendix B: Results of TAC Interview

Appendix A: TAC Members and Steering Committee

The following agencies were members of the Steering Committee

Steering Committee Member	Category
CALSTART	Research
National Renewable Energy Laboratory (NREL)	Research
Ohio State University	Research
Santa Barbara Metropolitan Transit District	Transit Agency
Stark Area Regional Transit Authority	Transit Agency

The following transit agencies agreed to participate in the Zero Emission Component Survey.

Interviewee	Category
AC Transit	Transit Agency
Anaheim Resort Transportation	Transit Agency
IndyGo	Transit Agency
LA Metro	Transit Agency
Montebello Bus Transit	Transit Agency
New York City Transit	Transit Agency
Santa Barbara Metropolitan Transit District	Transit Agency
Stanford University	Transit Agency
Stark Area Regional Transit Authority	Transit Agency
Sunline Transit Agency	Transit Agency
Utah Transit Authority	Transit Agency
Complete Coach Work	OEM
El Dorado National	OEM
New Flyer Industries	OEM
BAE Systems	Component Supplier
Ballard Power Systems	Component Supplier
Thermo King	Component Supplier
National Renewable Energy Laboratory (NREL)	Research
Utah State University Sustainable Electrified Transportation Center (SELECT)	Research

Appendix B: Results from TAC Interview

From the beginning, the Zero Emission Component Survey was designed to be an open-ended interview process to encourage candid response from the TAC member. CALSTART developed a standard script that was applied to all interviews equally. CALSTART took detailed notes and wrote a complete transcript with the names of the participant and their organization omitted to ensure anonymity. The anonymous nature of these transcripts allowed the participants to speak freely with CALSTART.

After the interviews have been completed, the transcripts were reviewed. Any issues relating to a component, system, or vehicle design was flagged and aggregated in Microsoft Excel. There was a total of 98 individual responses across 25 separate topics. CALSTART took the top 11 aggregated responses for closer examination, culminating into the Result section of this report.

The “raw” data is provided in this appendix.

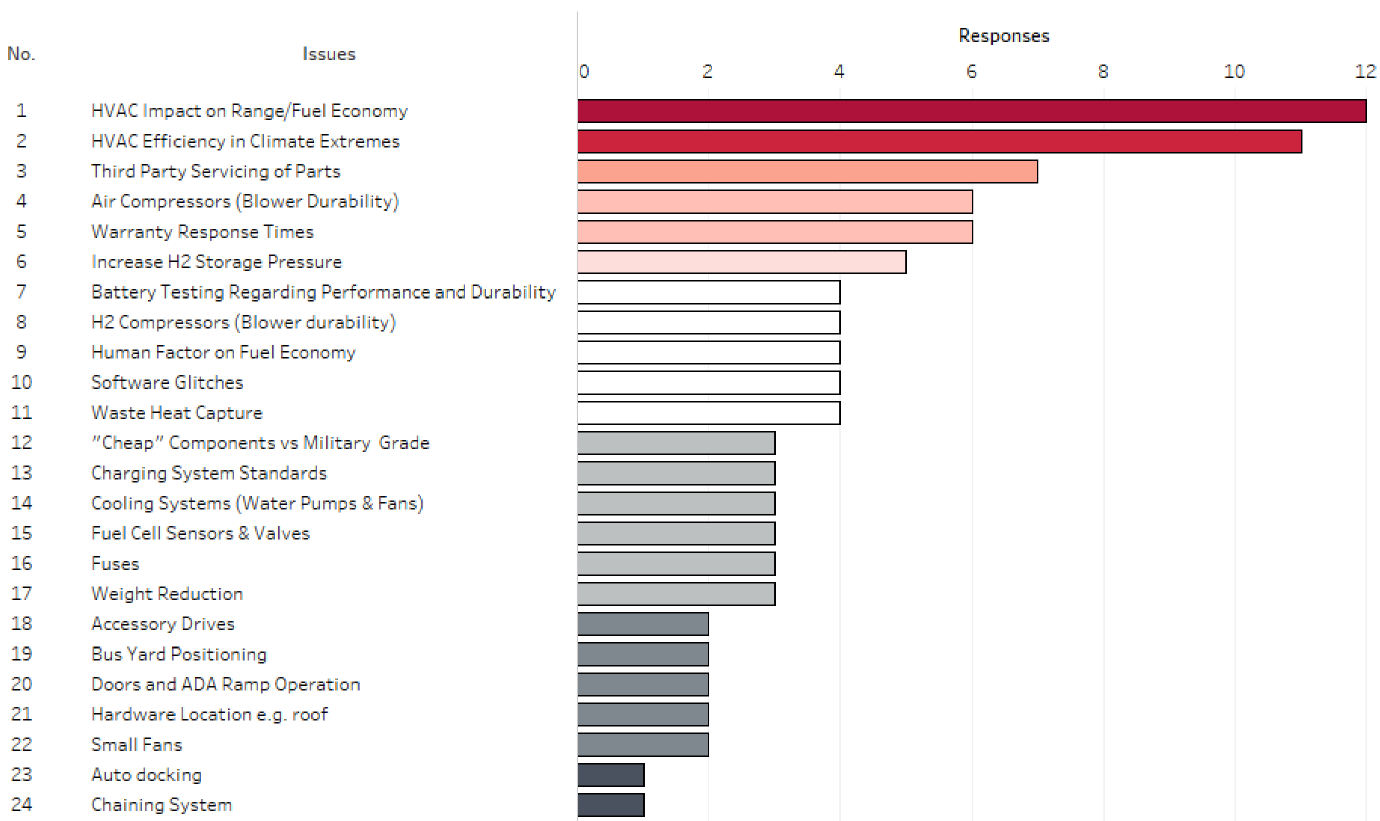

Figure 7: TAC Survey Responses

Several of the issues obtained from the Survey did not make it into our report. These are largely responses related to issues like “Third Party Servicing of Parts” or “Warranty Response Time.” In these two cases, the problem has more to do with the lack of replacement parts or a reasonable turn-around time on delivering that component to the transit agency. CALSTART believes that these issues will disappear once there are significantly more LoNo buses on the road and the manufacturing of these components scale up to meet the demand.