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Bus Exportable Power Supply (BEPS) System Use Strategy: Investigating the Use of Transit Buses as Emergency Generators

NOVEMBER 2019

FTA Report No. 0146
Federal Transit Administration

PREPARED BY

Jason Hanlin, Center for Transportation and the Environment
Ashley Wargo, Hagerty Consulting
Michael Lewis, University of Texas, Center for Electromechanics

BEPS

Bus Exportable Power System

U.S. Department of Transportation
Federal Transit Administration

COVER PHOTO

Courtesy of Hagerty Consulting

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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The Center for Transportation and the Environment (CTE) partnered with the University of Texas Center for Electromechanics and Hagerty Consulting to develop a Bus Exportable Power Supply (BEPS) System that will give hybrid buses the capability to act as on-demand, mobile electrical-power generators. This technology will be especially useful in emergency disaster response and recovery when traditional power supplies are not reliable. The project team is responsible for system design, demonstration, and a documented recommended methodology for implementation in real-world applications. This project received funding under the FTA Innovative Safety, Resiliency, and All-Hazards Emergency Response and Recovery Demonstrations program.

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ABSTRACT

The Center for Transportation and the Environment (CTE) partnered with the University of Texas Center for Electromechanics and Hagerty Consulting to develop a Bus Exportable Power Supply (BEPS) System that will give hybrid buses the capability to act as on-demand, mobile electrical-power generators. This technology will be especially useful in emergency disaster response and recovery when traditional power supplies are not reliable. The project team is responsible for system design, demonstration, and a documented recommended methodology for implementation in real-world applications. This project received funding under the FTA Innovative Safety, Resiliency, and All-Hazards Emergency Response and Recovery Demonstrations program.

EXECUTIVE SUMMARY

When Hurricane Irma hit Florida in September 2017, it was accompanied by power outages across the state. When backup generators failed, the health and the safety of vulnerable communities was threatened. A designated special needs shelter in Southwest Florida lost power, which significantly impacted its operations. The facility was equipped with a backup generator, but it had only enough power for the oxygen tanks required by some shelter guests, and the site struggled to function, as the generator fitted to the site did not meet the true needs of the facility. During Hurricane Irma, local government workers in Southwest Florida risked their lives to fix a generator that failed at another medical shelter. During Hurricane Maria in 2017 that impacted Puerto Rico and the US Virgin Islands, the Federal Emergency Management Agency (FEMA) dispatched 250–300 generators from its inventory. Responders then supplemented them with leasing/renting an additional 1,150 generators to augment the shortfall in generator requirements, but this still was not enough.

Even without a disaster, electric power service interruptions occur once or twice a year for every individual electric utility costumer in the US, completely independent of any major event. When electrical power goes out, critical infrastructure in local communities, including schools, healthcare facilities, government offices, and businesses, cannot maintain their required operations, which can directly impact the safety of the community's population. When electricity goes out at hospitals or nursing homes with vulnerable populations, death from heat exposure is a distinct possibility when air conditioning systems are no longer operable.

The lack of mobile generators is a significant capabilities gap for local, state, and regional communities. However, communities potentially could use hybrid-electric transit buses that are operated by transit agencies in many US urban areas as a mobile generator source to fill in this gap. Hybrid bus powertrains already contain all the key elements required for mobile power generation, including an ample fuel tank, a diesel or fuel cell engine, and a generator. The development and deployment of additional power electronics equipment, referred to here as the Bus Exportable Power Supply (BEPS) system, transforms hybrid buses into mobile generators by exporting power using the buses' primary power supply within the hybrid propulsion system. Through collaboration between local transit agencies, who would own and maintain the BEPS system, and local emergency management agencies, who provide temporary backup power to communities, this technology can be put to work throughout the country. The implementation of a BEPS system can provide communities with a powerful, accessible, well-maintained, and cost-effective mobile generator alternative in disasters and emergencies.

This project investigated how hybrid electric transit buses can be used as on-demand, mobile electric-power generators during emergency response and recovery. Together, the project team provide the foundational expertise to investigate how a BEPS system can be developed and used most effectively. Objectives to this project were to assess aspects related to use of a BEPS system in practice, including the need, optimal use, technical feasibility, value, challenges, procurement, challenges, and recommendations for BEPS use. To accomplish these objectives, the project team assembled a panel of experts to provide subject matter expertise across multiple industries on aspects related to the development and utilization of BEPS. This included representatives from transit agencies, emergency management agencies, private sector partners, the American Red Cross, the National Guard, and the US Army Corps of Engineers (USACE).

The team and panel quickly discovered that although Federal resources exist to assist local and state communities with their generator needs, these resources are not readily available for a small-scale, localized power outage. The gap currently hindering local communities' abilities to respond to an immediate need for backup power lies in the lack of locally-available mobile generators and quick access to them. As of 2016, there were 8,367 hybrid buses across 178 transit agencies in the US covering the northeast and coastal areas of the country. Project team simulations showed that a single bus or multiple buses can be used up to the full hybrid system's rated power upon the bus without negatively impacting the bus powertrain or cooling systems. Thus, it is feasible to power loads in excess of 100 kW, and possibly up to 200 kW or more, depending on the rated power output of the hybrid system onboard the bus. In situations where the load exceeds the power rating, multiple BEPS-equipped buses can be run in parallel to service the load. Facility needs during an outage range as low as 15 kW for call centers to more than 250 kW for full emergency shelters. Results from a physical BEPS demonstration carried out by the project team showed that a hybrid transit bus that incorporated BEPS electronics equipment could provide backup power needs for a facility that serves as an emergency shelter. The BEPS system was able to power up seamlessly and follow the facility loads, even with an unbalanced load on the three-phase power.

In most local jurisdictions, the emergency management agency and the transit agency have established relationships because the transit agency assists with moving citizens during evacuations. The use of BEPS could build off this relationship to give transit agencies the additional role in emergencies of providing back-up power. Emergency management would request and coordinate the resource, similar to how the two agencies communicate for evacuations. During deployment of a BEPS-equipped bus, the transit agency would be the owner and operator of the bus. Agency operators would drive the bus to the identified location, and a certified electrician would connect the BEPS bus to the facility or equipment. Transit agencies reported a preference for keeping an agency-staffed driver or maintenance technician with the bus throughout the deployment to monitor and provide security for their property.

The intrinsic value of BEPS lies in its ability to simplify and expedite the resource deployment process for backup power. Having the BEPS component added to the bus eliminates the need to procure a separate generator. It also eliminates the need to identify and locate the corresponding transportation needed to deploy and return the generator. Even in a situation when Federal resources are available, it can take days before the resources arrive and are operational. BEPS being readily available in the community provides the jurisdiction with the ability to provide power while awaiting Federal assistance. A secondary value of BEPS is the increased reliability of power generation at the time of need. With BEPS, the component would be maintained along with the already-established bus maintenance schedule as well as more regularly in use as the bus operates on its day-to-day routes.

To help quantify the potential value of BEPS, the project team developed a model that compares the response timeframe and cost of generators under three scenarios: (1) Jurisdiction Owned and Provided, (2) Third-Party Rental, and (3) BEPS. The model was used to complete a baseline analysis based on assumptions developed from the project team, the expert panel, and industry stakeholder input. The simulations showed that the BEPS approach provides the fastest response time and best cost-benefit within the first week of response, and its quick response time can relieve cost associated with the loss of power.

Some challenges related to using a BEPS-equipped bus are common to using existing generators. These include the need to properly size the power output and connections to the facility and the need for refueling during extended operation. However, other challenges are unique to a BEPS-equipped bus:

- Since BEPS equipment integrates with the buses, the responsibility for procuring, maintaining, and controlling this equipment lies with the transit agencies. The lack of incentives for transit agencies to assume this cost and responsibility can be a challenge.
- The size and weight of a bus presents a challenge for operations in urban areas without a substantial amount of additional space.
- During an emergency, there can be competing interests for using the bus that include providing regular transit service for and evacuation of people.
- Commercial availability of BEPS systems is lacking.

All of these challenges can be overcome with proper planning, coordination, and policies.

The project team recommends the following initiatives to help accelerate product development and incentivize adoption:

- A transit bus manufacturer should develop and demonstrate an exportable power system.

- An industry committee should be formed to develop standard system specifications.
- FTA should exclude buses equipped with exportable power systems from spare ratio calculations.
- BEPS should qualify for funding through the same programs that currently fund the procurement and deployment of traditional emergency generators.
- Federal and local agencies should develop new funding programs for BEPS technologies.

Ultimately, stakeholders agree that buses equipped with exportable power systems can make communities more resilient to emergency events and make local municipalities less dependent on State and Federal resources during disaster response and recovery. The initiatives described above will drive adoption and overcome challenges associated with the new technology. The lack of mobile generators is a significant capabilities gap during emergencies and power outages, and communities can use the vast number of hybrid-electric transit buses that are operated by transit agencies today as mobile generator sources to quickly and cost-effectively fill that gap.

SECTION 1

Introduction

When an emergency or a disaster impacts a community, the community looks to its local emergency management office to coordinate the response to the event. Depending on the nature of the event, that could be anything from establishing a cooling station during a heat wave to coordinating a large-scale evacuation and sheltering mission.

Whatever the mission, a frequent need is temporary backup power, which frequently is also a resource shortage. Even when plans for temporary backup power exist, a disaster can still hinder those plans. When Hurricane Irma hit Florida in September 2017, the storm was accompanied by power outages across the state. When backup generators failed, the health and the safety of vulnerable communities was threatened. A designated special needs shelter in Southwest Florida lost power, which significantly impacted its operations. The facility was equipped with a backup generator, but it had only enough power for the oxygen tanks required by some shelter guests and little else. This meant that shelter guests did not have air conditioning. Additionally, the building did not have any water pressure, so restrooms became inoperable.[1] Despite the presence of an onsite generator, the site struggled to function, as the generator fitted to the site did not meet the true needs of the facility. Another challenge commonly faced is that generators, like many other pieces of equipment, are not infallible. During Hurricane Irma, local governments workers in Southwest Florida risked their lives to fix a generator that failed at a medical shelter.[2] Generators must be regularly maintained so they are ready to operate in case of an emergency at all times, but maintenance is frequently a pitfall for generator users.

Even without a disaster, electric power service interruptions occur once or twice a year for every individual electric utility costumer in the US, completely independent of any major event.[3] When electrical power goes out, critical infrastructure in local communities, such as schools, healthcare facilities, government offices, and businesses, cannot maintain their required operations, which can directly impact the safety of the community's population. When electricity goes out at hospitals or nursing homes with vulnerable populations,

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[1] https://www.naplesnews.com/story/weather/hurricanes/2017/09/11/hurricane-irma-special-needs-shelter-evacuees-dealt-extra-blow/656091001/.

[2] http://www.govtech.com/em/disaster/After-Hurricane-Irma-Many-Ask-How-Safe-are-Shelters.html.

[3] US Energy Information Administration, Annual Electric Power Industry Report (EIA-861) 2015.

death from heat exposure is a distinct possibility when air conditioning systems are no longer operable.[4] When an outage causes a loss of traffic lights, police services then expend limited resources to aid in directing traffic.[5]

As utility providers work to restore power, coordination of a community's response to a power outage typically falls to the local emergency management agency. Across the country, there is a notable shortage of readily-available mobile power generation sources for immediate response during a power outage, which leaves local communities unable to provide temporary power to facilities in need. For example, during Hurricane Maria in 2017 that impacted Puerto Rico and the US Virgin Islands, the Federal Emergency Management Agency (FEMA) dispatched 250–300 generators from their inventory. They then supplemented this with leasing/renting an additional 1,150 generators to augment the shortfall in generator requirements, but this still was not enough.[6]

The lack of mobile generators is a significant capabilities gap. However, communities could potentially use hybrid-electric transit buses that are operated by transit agencies in many US urban areas as a mobile generator source to fill in this gap. The hybrid bus powertrain contains all the key elements required for mobile power generation, including an ample fuel tank, a diesel or fuel cell engine, and a generator. The development and deployment of additional power electronics equipment, referred to herein as the Bus Exportable Power Supply (BEPS) system, transforms hybrid buses into mobile generators by exporting power using the buses' primary power supply (the engine) within the hybrid propulsion systems. Through collaboration between local transit agencies, who would own and maintain the BEPS, and local emergency management agencies, who have a role to play in providing temporary backup power to communities, this technology can be put to work throughout the country. The implementation of a BEPS system can provide communities with a powerful, accessible, well-maintained, and cost-effective mobile generator alternative in disasters and emergencies.

The BEPS concept started to become a reality in 2013, when the Federal Transit Administration (FTA) sponsored a grant to develop, evaluate, and plan the deployment of a BEPS system by an interdisciplinary project team[7] as part of the agency's Innovative Safety, Resiliency, and All-Hazards Emergency Response and Recovery Research Demonstrations initiative.

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[4]https://www.npr.org/2017/12/24/573275516/after-deaths-during-hurricane-irma-florida-requiring-changes-for-nursing-homes.
[5]http://www.tampabay.com/news/weather/hurricanes/pinellas-officials-grateful-for-limited-damage-hoping-for-beaches-access/2337067.
[6]US Army Corps of Engineers (USACE).
[7]The project team consisted of the Center for Technology and the Environment (CTE), Hagerty Consulting, and the University of Texas Center for Electromechanics (UT-CEM).

This study explores the necessary background to understand the system's relevance in the US, including the associated costs, technologies, and need for this resource in greater detail. The report includes 1) the project methodology undertaken by the project team to determine the BEPS system's most applicable uses and use strategies and to identify relevant constraints to the system; 2) how the conceptualized system was verified through simulation and demonstrated using a hybrid fuel cell bus to power the back-up circuits at building that has been designated as an emergency shelter site; 3) the results and analysis gleaned from the building and demonstration of BEPS; and 4) the identification of pertinent policy implications that when realized will help spur the implementation of BEPS as a viable emergency response asset in the United States.

SECTION

2

Project Methodology

Funded through an FTA research grant, the Center for Transportation and the Environment (CTE) partnered with the University of Texas Center for Electromechanics (UT-CEM) and Hagerty Consulting to investigate how hybrid electric transit buses may be used as on-demand, mobile electric-power generators during emergency response and recovery. Together, the project team provided the foundational expertise to investigate how a BEPS system can be developed and used most effectively.

Project Objectives

There were nine objectives for this project:

1. Identify the need for backup power during an emergency or disaster.
2. Determine the technical and logistical capabilities to transform a hybrid bus into a mobile generator.
3. Create a component that facilitates the conversion of a hybrid electric bus into a backup power generator.
4. Demonstrate the bus generator's capabilities through a controlled simulation.
5. Investigate the value a BEPS-equipped bus adds during an emergency.
6. Describe the most plausible, best-use option for the BEPS technology.
7. Predict obstacles upon introducing BEPS technology.
8. Determine procurement, operation, and ownership options for the BEPS system.
9. Theorize potential next steps for the BEPS system upon its actualization.

To accomplish these objectives, the project team assembled a panel of experts to provide subject matter expertise across multiple industries on aspects related to the development and utilization of BEPS. Panelists were identified based on establishing a geographically-diverse group of stakeholders and who represent those who would be involved in the system's actual use. This included representatives from transit agencies, emergency management agencies, private sector partners, the American Red Cross, the National Guard, and USACE.

The panelists convened twice in person and periodically via conference calls during the project. A summary of the two in-person meetings is shown in Table 2-1.

Table 2-1

Meeting Summaries

Meeting	Focus
April 2016	Educate panelists on relevant hybrid-electric bus technology and emergency management strategy. Review project objectives. Confirm task schedule. Identify problem to be solved. Discuss potential constraints. Discuss ideal technical configuration of BEPS.
July 2016	Identify procurement/ownership options. Address liability concerns. Introduce operations developments. Discuss connection needs. Classify supervision needs and configurations. Identify fueling needs and processes.

Concurrently, the project team of CTE, UT-CEM, and Hagerty conducted research and designed, simulated, and built the BEPS system. A use strategy for BEPS was developed from the panelist meetings and subsequent research.

SECTION

3

Background

Emergency Management

When a disaster or emergency occurs in the United States, communities depend on first-response agencies and local emergency management to protect their well-being and restore order to their communities. Power outages are a frequent and problematic disruption of normalcy that can render critical functions inoperable. Several such notable examples include loss of power to traffic lights, loss of power in a nursing home or other critical care healthcare facility, loss of power to emergency services systems such as 9-1-1 call centers, loss of power at temporary shelters, and loss of power to businesses upon which communities depend, such as pharmacies, grocery stores, and gas stations. The cascading impact on this power loss can be financially burdensome to a community and may risk lives. Without power to traffic lights, more dangerous road conditions are generated, and law enforcement becomes necessary to fill the traffic direction gap until the lights are restored. In the case of critical healthcare facilities, residents and patients face the loss of oxygen therapy, dialysis machines, and other crucial life-supporting devices, in which case, without backup power, immediate evacuation is necessary (albeit risky in and of itself). If 9-1-1 centers go down, redundancies in place may limit capabilities in response altogether and response time. Pharmacies and grocery stores depend on electricity to refrigerate medications and perishable foods, and gas stations are unable to supply gas to consumers without a source of power.

An emergency does not need to be disastrous in nature, such as a major hurricane or a catastrophic earthquake, to cause problematic power outages. Statistically, less than one of every four power outages in the US is attributed to a major event.[8] In all emergencies, the responsibility of coordinating a local jurisdiction's assets and response is designated to the local emergency management agency.

For various reasons including geography, demography, infrastructure, governance, and others,[9] emergency management in the US employs a "bottom-up approach" to managing emergencies. This means the initial and primary responsibility is positioned in the hands of local first-responders and the local emergency management agency. Therefore, when a local jurisdiction needs emergency backup power in the form of a mobile generator, the local jurisdiction attempts to fill the request first. If a local jurisdiction is unable to supply a source of backup power, it may look to existing standby contracts with private generator supply

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[8]US Energy Information Administration, Annual Electric Power Industry Report (EIA-861) 2015.
[9]National Academies (2012), Disaster Resilience, A National Imperative.

companies or to memoranda of understanding (MOUs)/memoranda of agreement (MOAs) established with neighboring local jurisdictions as means to obtain the needed generator(s).

When a resource request cannot be filled through any of these means, the local jurisdiction requests assistance from its corresponding State emergency management agency. If a State cannot internally meet the needs requested, it may request resources through state-to-state mutual aid agreements, such as the Emergency Management Assistance Compact (EMAC). An EMAC is a mutual-aid compact established among all states and territories of the US to provide personnel and/or equipment during larger emergencies. For EMAC to be an option, the governor must declare a state of emergency before a request for supplemental resources can be initiated.[10] Correspondingly, if a State is unable to fulfill a request through in-state resources or mutual aid, it requests Federal assistance via a Presidential Disaster Declaration, governed by the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act), thereby invoking Federal emergency response support and coordination via FEMA and other federal agencies.[11] In instances of power outage, FEMA works with the USACE 249th Engineer Battalion to conduct facility assessment, deploy resources, and perform the installation of the generators.[12]

Average deployment timelines for these resources to be requested, deployed, and installed are listed in Table 3-1.

Table 3-1

Average Resource Deployment Timelines

Internal Resource Deployment	Standby Contract Supplier	State Resource Deployment	State Mutual Aid Deployment	Federal USACE Deployment
12 hours	24 hours	24–36 hours	48–72 hours	72 hours

Backup Generators

Backup generators are electrical supply systems independent of the electrical grid that provide power to corresponding structures or equipment when power is unavailable. During brief power outages, backup generators provide a source of reliable and cost-effective electricity to ensure continuity of operations and diminish the likelihood of economic losses and social hardship. Generators rely on an internal combustion engine, typically fueled by diesel fuel or natural gas, to create mechanical energy through a crankshaft, which is then converted into electrical energy using electromagnets. When powering equipment, buildings, and structures, backup generators connect to a transfer switch, an electrical switch

[10] http://www.emacweb.org/.
[11] Robert T. Stafford Disaster Relief and Emergency Assistance Act, Public Law 93-288, as amended, 42 U.S.C. 5121 *et seq.*
[12] http://www.usace.army.mil/Media/News-Archive/Story-Article-View/Article/475308/power-teams-rapidly-deploy-to-help-east-coast-communities/.

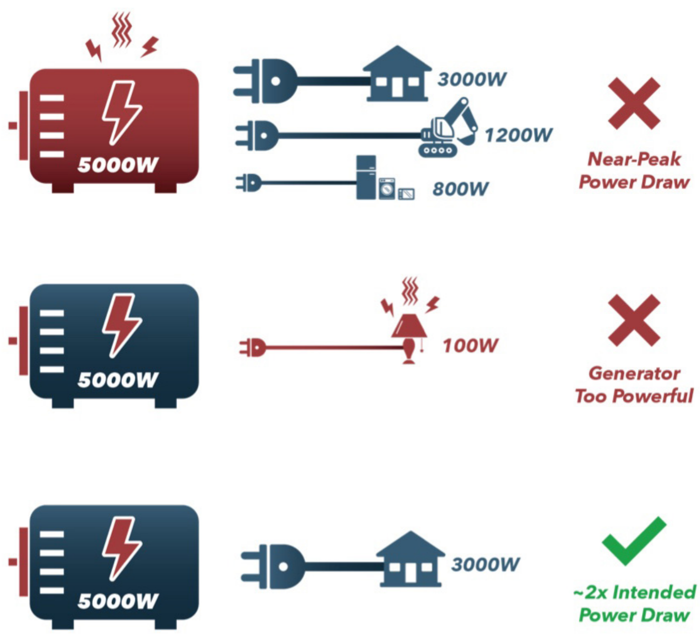
that facilitates the transference of electricity to that corresponding load through its electrical panel or subpanel.

Mobile or stationary, backup generators come in multiple sizes and electrical outputs, ranging from a few hundred watts up to multiple megawatts for industrial-sized generators. A generator's output capabilities must be selected and sized to support the electrical load demanded by its corresponding recipient of electrical power. When larger generators are used to power smaller electrical loads or when generators are powering loads at their peak output power rating, this can lead to inefficient operation and increased wear and shorter life. It is preferred to select a generator whose output power rating is approximately double the intended load to ensure efficient operation. In some cases, multiple generators are paired together to safely power larger electrical loads in unison.

Designed for short-term use until power is restored, backup generators generally contain fuel tanks with enough capacity to remain operational for 8–12 hours before refueling. Generators must be regularly tested, occasionally at full power output, and maintained to ensure their reliability. If properly maintained, a 100+ kW generator can have a lifespan of up to 30 years. Often, generator owners avoid testing at full power to preserve the longevity of the generator.[13] This practice, while done with the good intentions of preservation, can result in operational failures at full-demand when attempting use in a real event. A full power capacity test should be conducted on a yearly basis to decrease the potential of system failure and identify any maintenance needs before an actual power outage.[14]

Figure 3-1

Importance of matching generator output



[13]http://www.asne.com/standby-generator-maintenance-prepared-power-outages/.
[14]http://www.csemag.com/home/single-article/load-bank-testing-ensures-performance-reliability/78a658bfd0e96c9542373bf983f028d6.html.

For a generator to be deployed, installed, and run, irrespective of the scope of the emergency and the issuing agency, there are several key components that must be addressed.

Using knowledgeable, certified personnel to make facility connections is critical to ensure that the grid is not back-powered to protect linemen working on power lines. Additionally, generator "cold starts" can damage electronics and all breakers should be open to allow the supplied power to settle before turning on the generator loads. (Regulations covering safe operation of power generation can be found in 29 CFR Part 1910: Occupation Safety and Health Standards.) Coordination of the electrician and facility representatives would be accomplished by the emergency management agency in a similar manner to existing generator deployment. The successful deployment and operation of a mobile generator requires cooperation and coordination among many agencies and individuals, regardless of the level of government deploying the generator.

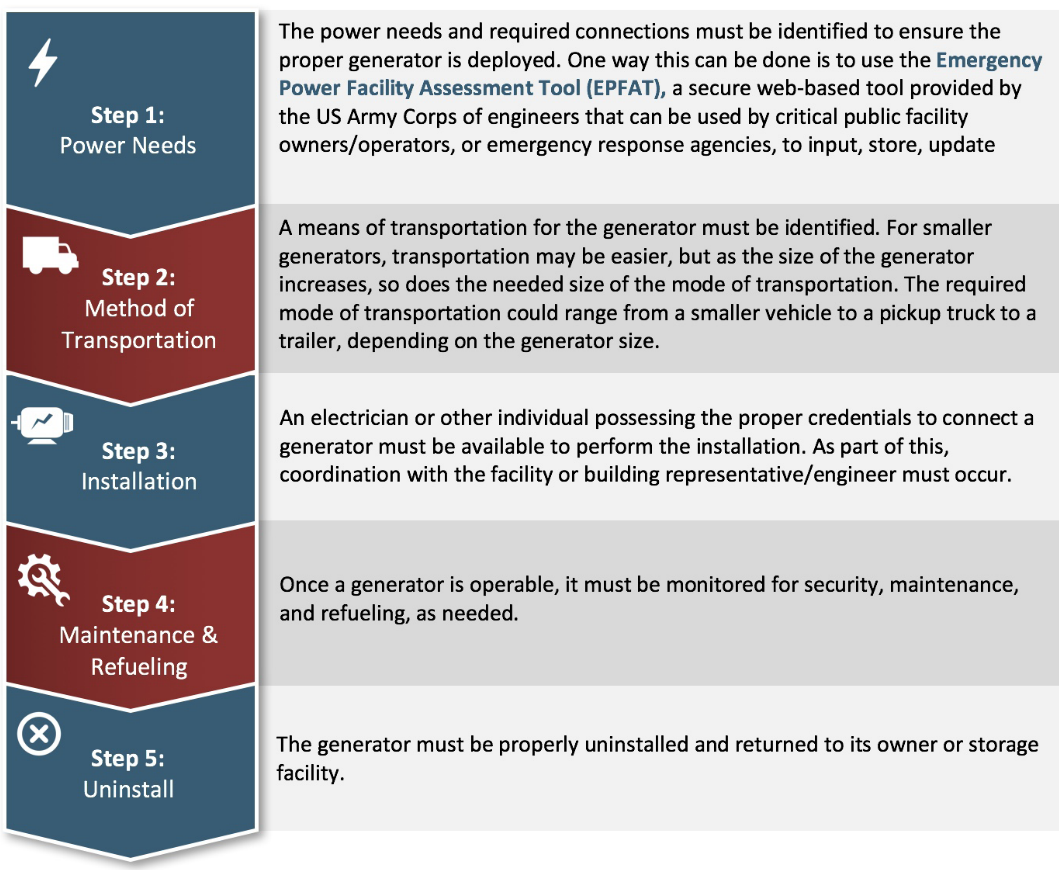


Figure 3-2

Emergency backup generator process

Generator Consumption Rates

When deploying a generator, the size of the generator and the building or facility load will have a direct impact on the fuel cost to operate the generator. Table 3-2 shows fuel consumption rates for different size generators under a variety of load cases.[15] It can be important to consider fuel consumption when matching the generator to the load.

Table 3-2

Generator and Fuel Consumption Rates

Generator Size (kW)	1/4 Load (gal/hr)	1/2 Load (gal/hr)	3/4 Load (gal/hr)	Full Load (gal/hr)
20	0.6	0.9	1.3	1.6
30	1.3	1.8	2.4	2.9
40	1.6	2.3	3.2	4
60	1.8	2.9	3.8	4.8
75	2.4	3.4	4.6	6.1
100	2.6	4.1	5.8	7.4
125	3.1	5	7.1	9.1
135	3.3	5.4	7.6	9.8
150	3.6	5.9	8.4	10.9
175	4.1	6.8	9.7	12.7
200	4.7	7.7	11	14.4

Cost of Generators

Jurisdictions may adopt several different generator procurement options at the local level before receiving State or Federal assistance. These options include ownership, standby contracts with private companies for generator rentals, and mutual aid agreements with neighboring jurisdictions through MOUs/MOAs.

- *Ownership* – Purchasing a mobile generator is the costliest option for a jurisdiction. A 150 kW mobile generator costs $30,000, on average, and up to $60,000 for a trailer-mounted model,[16] with an annual maintenance cost of approximately $800. Manual transfer switches (MTS), in which an operator begins the transfer by throwing the switch, are typically used with most mobile generators. Automatic transfer switches (ATS), which automatically are triggered upon detection that a power source has lost or gained power, are typically used with permanent backup generators. An industrial MTS capable of handling larger electrical loads can cost around $6,000, plus another $10,000 for installation.[17] Fuel purchase is necessary for each use. To deploy a procured generator, typical personnel needs include a person to deploy the generator, an electrician to hook up the generator, a person

[15] http://www.dieselserviceandsupply.com/Diesel_Fuel_Consumption.aspx.
[16] Based on national survey of current generator prices.
[17] http://www.csemag.com/single-article/comparing-permanent-and-portable-backup-generators/2c5dd3520606f7955efbdd0ea9ec55dd.html.

to fuel the generator throughout its use, and a person to ensure the security of the generator. Depending on the jurisdiction, there may also be associated storage costs if there is not an established storage facility.

- *Rental Agreements* – Rented generators can be obtained via standby contracts or through contracts established at the time of an incident. Typically, rented generators have specific limitations governing their terms of use, such as standard eight-hour operational periods per day with fees for additional hours beyond that threshold. Maintenance costs, storage costs, and transportation costs for rental generators typically are accounted for in the overall lease costs. Rental generators still require installation, MTS equipment, and fuel to be supplied. Given the temporary nature of power outages, rental generators typically have a daily or weekly fee agreed upon prior to their deployment. Rental fees may differ by locality depending on local competition and deployment distance. Jurisdictional personnel attributed to rented generators includes a person to oversee installation, a person to ensure security of the generator, and a person to fuel and operate the generator. However, a common risk associated with rented generators is that there may not be enough available. Vendors enter agreements with multiple entities and, depending on the situation, may not have a cache available when needed.
- *Mutual Aid* – MOUs and MOAs to access mobile generators may be established in advance of an incident in which backup power would be needed. Partners entering the MOU/MOA predetermine prices for services, equipment, and personnel to be reimbursed after the MOU/MOA is enacted. Specific costs vary by MOU/MOA, dependent on the exact resources, rates, and services provided. In the case of providing backup power by MOU/MOA, costs need to be agreed upon for the deployment, installation, and operational duration of a specific size generator as well as any additional costs that the provider and recipient consider related to these services, such as fuel or personnel. However, similar to rented generators, there may not be enough available from nearby jurisdictions if it is a large event, and generators from jurisdictions outside the impacted area may take longer to arrive or have challenges reaching the impacted area.

In more severe circumstances or when a State makes a request for Federal support, FEMA and USACE act together to deploy and install generators; this support is available only when a Presidential Disaster Declaration has been issued. FEMA deploys generators in packs of 54 units of varying sizes and capacities, ranging from 15 kW to 800 kW.[18] The overall power mission costs including the USACE Infrastructure Assessment (IA) Planning and Response Team (PRT), the 249th Engineering Battalion, USACE Advanced Contracting Initiative (ACI) support, and additional support costs vary greatly depending on the resource requested. Table 3-3 shows representative costs for three possible configurations.[19]

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[18] https://www.fema.gov/blog/2011-02-03/why-generators-are-critical-supporting-local-and-state-response-efforts.

[19]USACE; based on FEMA Regions I–III costing.

Table 3-3

Cost Comparison of Generators

	Type II (Second Largest)	Type III (Mid-Range)	TYPE IV (Second Smallest)
Pre-declaration operations (4 days)	$1,524,000	$1,024,300	$502,100
Daily	$317,000	$298,900	$100,250
Qualifying event factors	• Significant event (i.e., CAT III + hurricane, major earthquake, etc.) • 24/7 operations • Greater than 100 generators • High demand on generators	• CAT II or less tropical event • 24-hour operations, with most installs completed during daytime • 50–100 generators	• CAT I or tropical event • Any event in which FEMA generators deployed (5–10 per day/50 total) • Day operations only

Needs Assessment

Many local jurisdictions do not own mobile generators that could be easily and quickly deployed. Many of these jurisdictions rely on MOUs, MOAs, standby contracts, and/or on their State emergency management agency in severe circumstances. Local agencies that have generators on hand frequently find themselves unable to match the needed size.

For local communities that maintain a generator cache, the most prevalent generator sizes in their inventory range from 5–60 kW; a typical nursing home would require a 100–200 kW generator.[20] During Hurricane Maria, the most challenging need to fill was the overwhelming number of facilities needing a 200 kW generator or higher; this challenge was after assistance from multiple Federal agencies and emergency procurement of additional generators. Even with a larger reserve of generators, there is still a challenge to meet the needs of these critical facilities in an emergency.

Although Federal resources exist to assist local and state communities with their generator needs, these resources are not readily available for a small-scale, localized power outage. The gap currently hindering local communities' abilities to respond to an immediate need for backup power lies in the lack of locally available mobile generators.

Hybrid Transit Technology

Conventional transit buses use internal combustion engines powered by diesel or gasoline fuel. The torque produced by the engine goes through a transmission to a rear differential and finally to the wheels that propel the bus. By modifying the same general components with an electric propulsion system, hybrid diesel-

[20] USACE.

electric transit buses combine a diesel engine with an electrical generator to produce electricity as a power source. When stationary or decelerating, these buses also store the electricity they produce in batteries or capacitors for future use.

Hybrid diesel-electric transit buses, the most common hybrid bus technology used by transit agencies nationwide, come in two main drivetrain variations—parallel and series (see Figures 3-3 and 3-4). Parallel diesel-electric hybrids operate through a balance between their internal combustion engine and electric motor mediated by a computer to control output as they work in tandem to generate power that moves the bus. Series diesel-electric hybrids rely directly on their electrical motor as the primary source that powers the bus, and their internal combustion engine drives an electric generator that supplies energy to the battery that powers the motor.

Of the two powertrain variations, series hybrid-electric transit buses contain the more optimal configuration to maximize the capabilities of the BEPS system with the least amount of disruption to the original bus design. By using an electrical generator fueled by a diesel engine or a fuel cell as their main power source rather than as part of two distinct power sources, series hybrid-electrics are essentially already high-powered generators that function to move the bus rather than externalize power. The addition of BEPS equipment transforms series diesel-electric hybrid buses into mobile generators through an additional component attached to the internal computer and battery that facilitates the export of power that would have otherwise been used to move the bus.

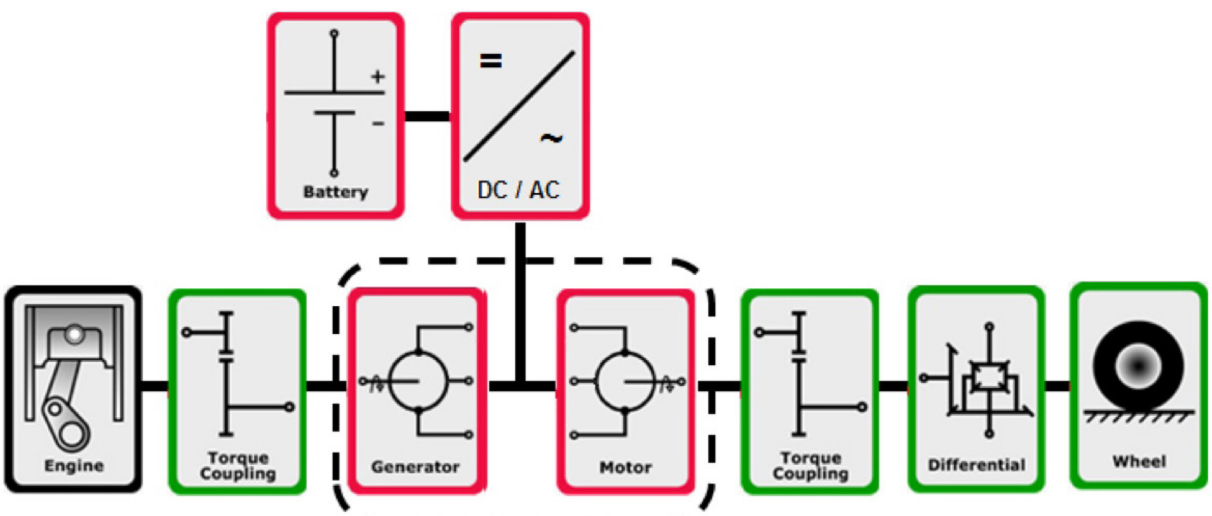


Figure 3-3

Series hybrid

Figure 3-4

Parallel hybrid

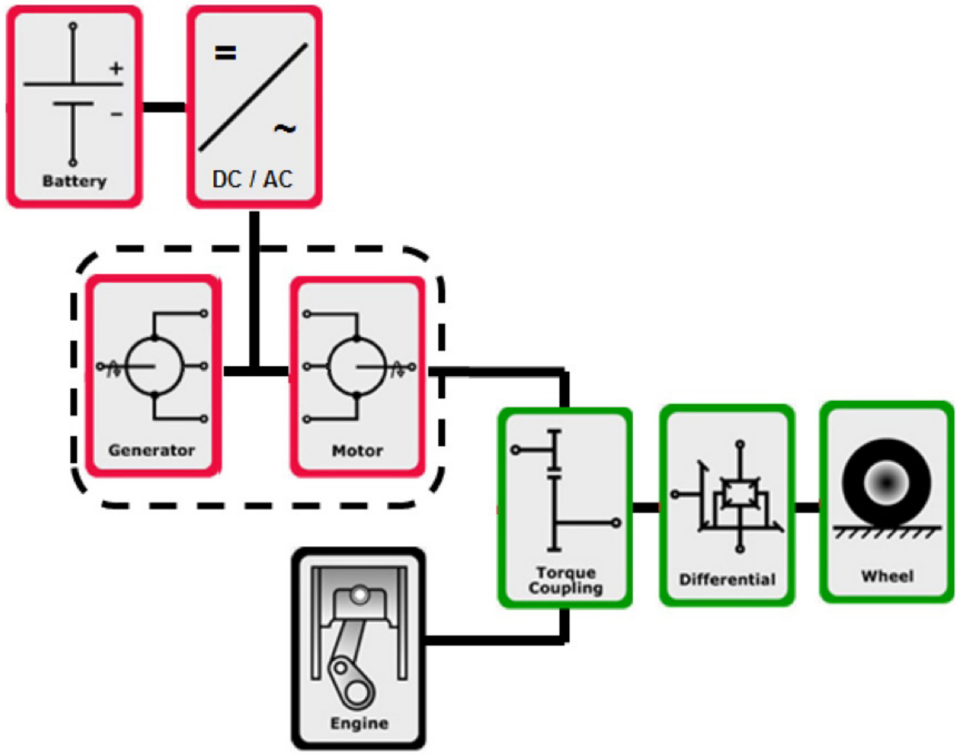
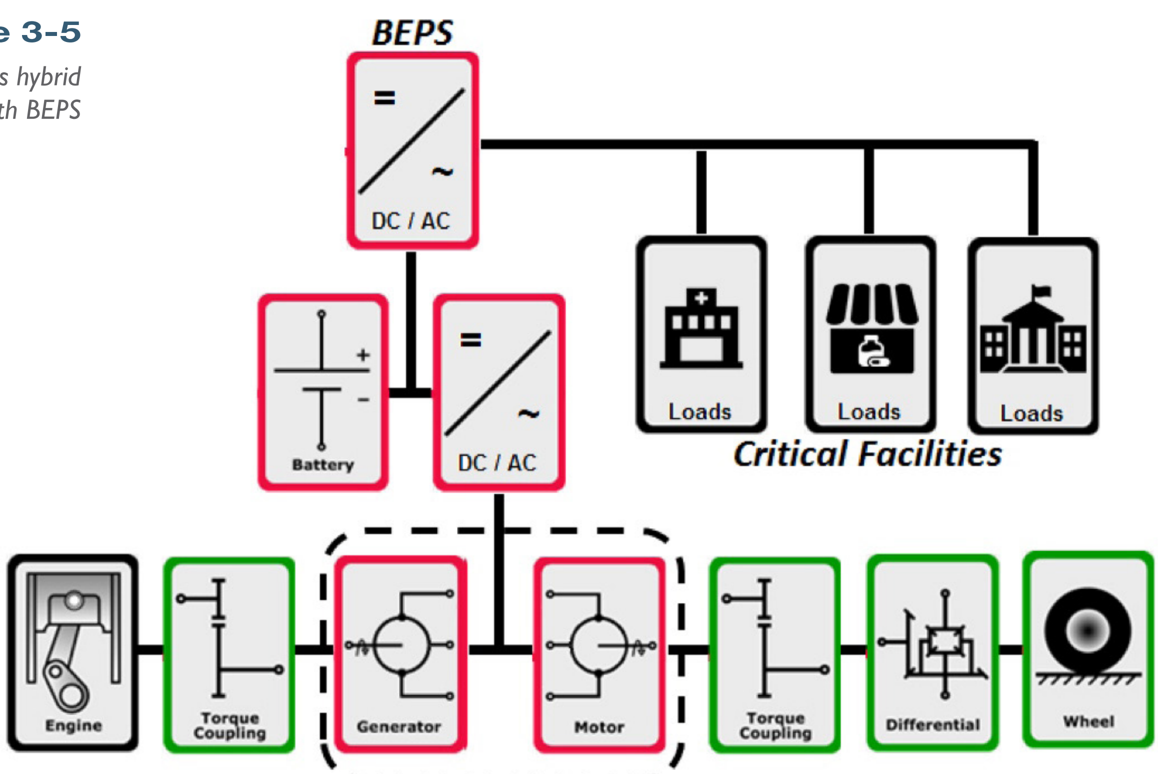


Figure 3-5

Series hybrid with BEPS



Hybrid transit buses are currently available with either internal combustion engines that use diesel as fuel or fuel cell engines that use hydrogen as fuel. Both hybrid systems are capable of using BEPS equipment to exportable power. However, diesel fuel is currently more readily available and transportable than hydrogen fuel. Local jurisdictions are more experienced with supplying diesel as a generator fuel in emergency needs. However, as the demand and regulatory requirements for zero-emission vehicles grows and the cost for the technology decreases with scale, the widespread use of fuel cell vehicles and hydrogen fuel is also expected to grow. Both hybrid configurations should be considered as a potential for supplying back-up power for extended durations at a single location.

All-electric transit buses also are technically capable of acting as a generator with BEPS technology installed; however, the batteries must be replenished with electricity from an external source. Electricity cannot be efficiently stored and transported to a discretionary location in a practical manner. Therefore, the limited energy capacity provided by the on-board battery of an all-electric bus must supply all energy needs for back-up power and to reliably get the vehicle to and from a charging location. The longer the distance from the depot or charging station, the less energy will be available for BEPS use at a needed site. For instance, if an all-electric bus has a 440 kWh energy battery, then 90% of that may be usable for a total of 396 kWh. Of that available energy, a 40-mile round trip to a needed emergency response site would require approximately 80 kWh of energy in normal operational conditions. This situation would leave 316 kWh for BEPS use, or just over 2 hours of use at a facility with a 150 kW load. For extended back-up power needs at a single location, all-electric buses may not be practical.

Overview of Hybrid Transit Buses in the US

According to the latest FTA National Transit Database (NTD) revenue vehicle inventory,[21] 178 transit agencies in the US (16% of all US transit agencies) have hybrid buses in their fleet.[22] As shown in Figure 3-6, the majority of these agencies are located in urban areas. Shaded circles in the figure show the area within a 100-mile radius of each agency. The range of a typical hybrid bus is several hundred miles. Not shown are agencies in Hawaii and Puerto Rico, which have 156 hybrid buses combined.

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[21] 2016 Annual Database Revenue Vehicle Inventory, July 2018, retrieved from https://www.transit.dot.gov/ntd/data-product/2016-annual-database-revenue-vehicle-inventory-0.

[22] Hybrid buses include vehicles categorized as Buses, Articulated Buses, Double Decker Buses, Over-the-Road Buses, or School Buses with the following FTA NTD fuel type: hybrid diesel, hybrid gasoline, and hydrogen fuel cell.

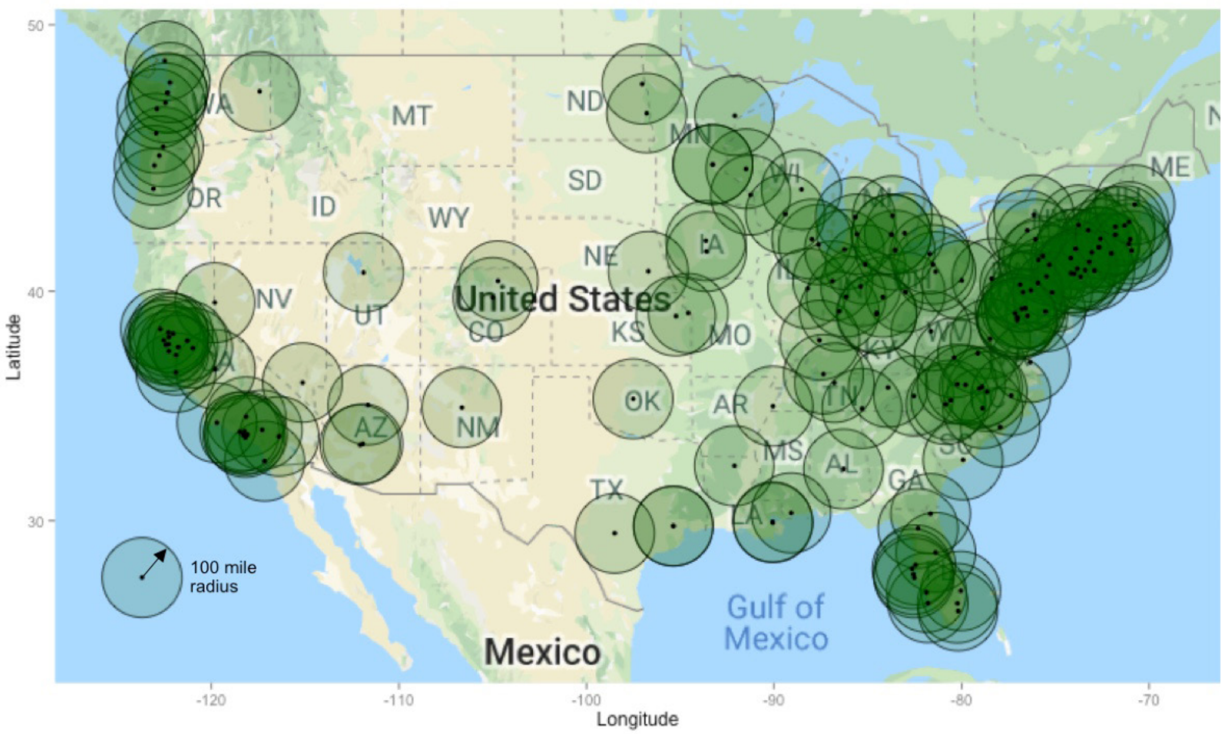


Figure 3-6

Location of transit agencies with hybrid buses in continental US

As of 2016, there were 8,367 hybrid buses in US transit fleets.[23] MTA New York City Transit has 1,200+ hybrids, more than any other agency. The 20 agencies with the most hybrids are listed in Table 3-4.

[23]FTA NTD 2016 Annual Database Revenue Vehicle Inventory, July 2018, retrieved from https://www.transit.dot.gov/ntd/data-product/2016-annual-database-revenue-vehicle-inventory-0

Table 3-4

Top 20 US Transit Agencies with Most Hybrid Buses

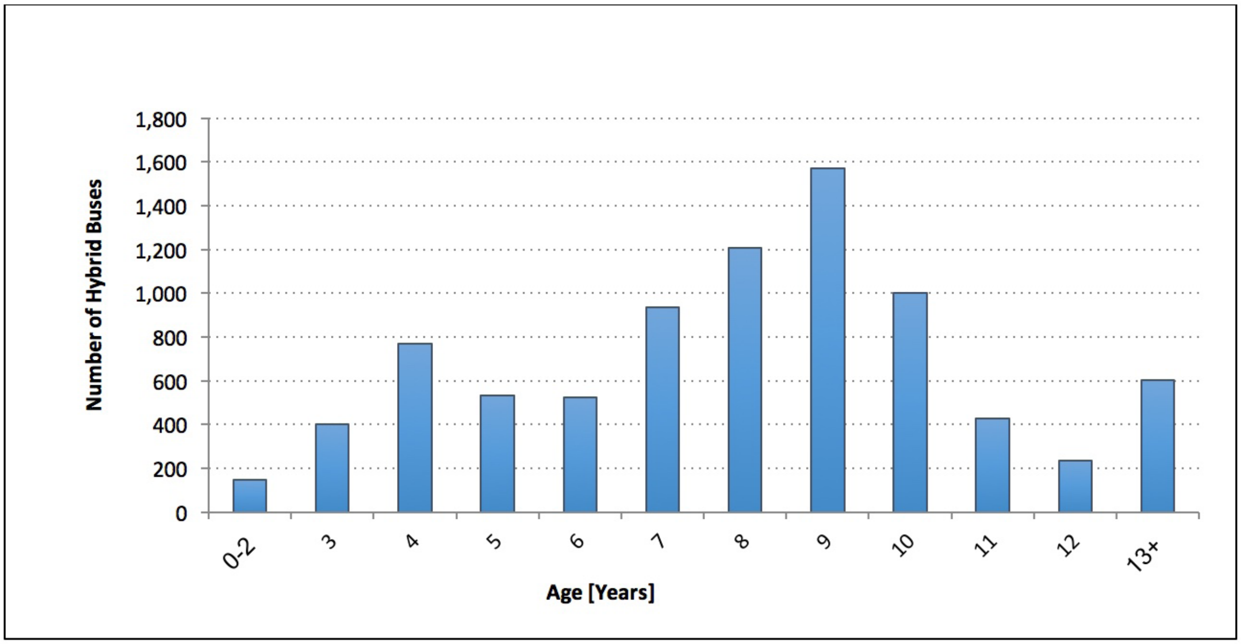
Rank	Agency Name	Location	Hybrid Buses	Total Buses	% of Fleet
1	MTA New York City Transit	New York, NY	1,287	5,392	24%
2	Washington Metropolitan Area Transit Authority	Washington, DC	905	2,045	44%
3	Southeastern Pennsylvania Transportation Authority	Philadelphia, PA	747	1,416	53%
4	King County Department of Transportation	Seattle, WA	725	1,478	49%
5	Metropolitan Transit Authority of Harris County, TX	Houston, TX	494	1,430	35%
6	Maryland Transit Administration	Baltimore, MD	404	1,012	40%
7	Chicago Transit Authority	Chicago, IL	218	2,125	10%
8	Regional Transportation Commission of Southern Nevada	Las Vegas, NV	188	657	29%
9	Santa Clara Valley Transportation Authority	San Jose, CA	134	511	26%
10	Miami-Dade Transit	Miami, FL	121	854	14%
11	City of Albuquerque Transit Department	Albuquerque, NM	115	156	74%
12	Westchester County Bee-Line System	Mount Vernon, NY	99	329	30%
13	City and County of Honolulu DOT Services	Honolulu, HI	92	564	16%
14	Central Puget Sound Regional Transit Authority	Seattle, WA	90	288	31%
15	Long Beach Transit	Long Beach, CA	89	249	36%
16	Broward County Transit Division	Plantation, FL	86	351	25%
17	Toledo Area Regional Transit Authority	Toledo, OH	78	244	32%
18	Capital District Transportation Authority	Albany, NY	73	211	35%
19	Ride-On Montgomery County Transit	Rockville, MD	68	352	19%
20	Clark County Public Transportation Benefit Area Authority	Vancouver, WA	64	189	34%

As of 2016, the average hybrid bus in the US was age 8, as shown in Figure 3-7; about 840 hybrid buses in the US are more than age 12. Assuming that all buses were purchased with a 12 year expected useful life as required for Federal assistance,[24] more than 3,700 hybrid buses will be scheduled for replacement by 2022. It is not currently known if these buses will be replaced with new hybrid buses or buses equipped with a different powertrain.

The number of hybrid buses as a percentage of the total number of buses in the US public transportation system has increased over the last decade (Figure 3-9). From the American Public Transportation Association (APTA) *2017 Public Transportation Factbook:*

> The fuel distribution of the bus fleet has evolved dramatically in the past two decades. Electric hybrid buses saw their market share increase from 1 percent in 2005 to over 17 percent in 2015.

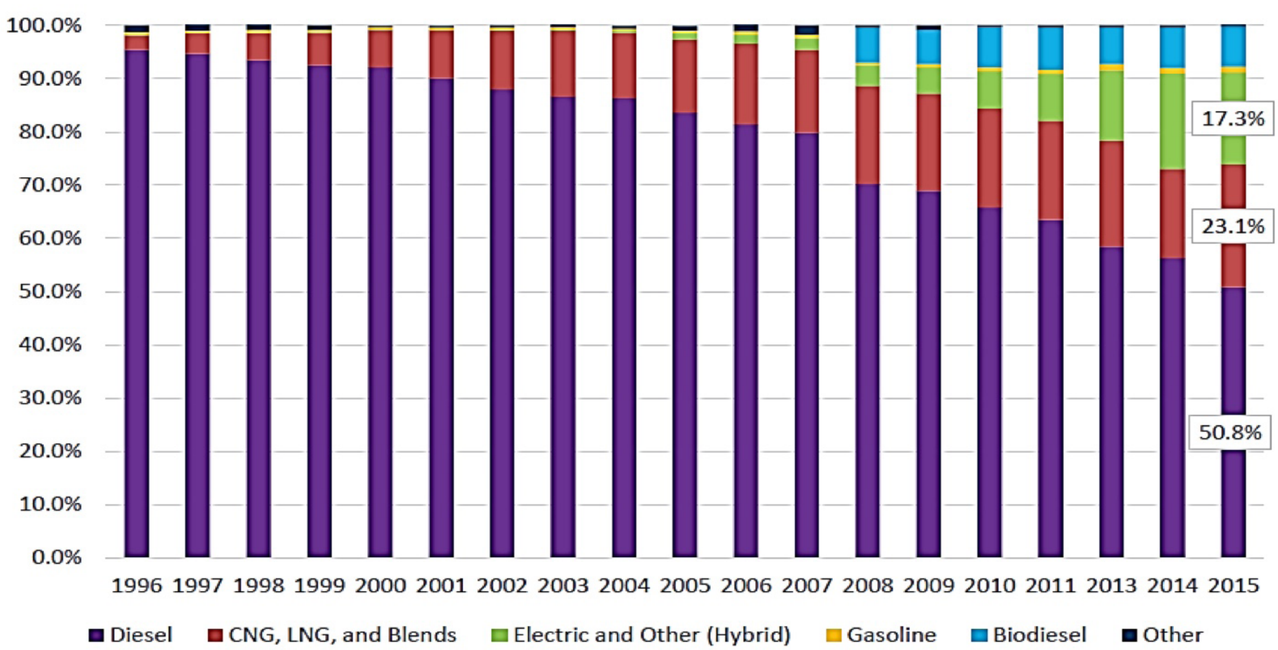
[24]Federal requirement for "Minimum Useful Life" in FTA C 9300.1B Capital Investment Program Guidance and Application Instruction, at www.fta.dot.gov



Source: FTA NTD 2016 Annual Database Revenue Vehicle Inventory

Figure 3-7

Age of hybrid buses in US fleets, 2018



Source: *APTA 2017 Public Transportation Handbook*

Figure 3-8

Percentage of buses by fuel type

SECTION

4

BEPS Technical Validation

Simulation Verification

Once the basic needs and design requirements of the technology were established, the project team began simulations as initial tests of the conceptualized prototype. To accomplish this, a computer model of the bus power train, including the diesel engine, motor/generator, and battery energy storage, was constructed in Matlab® and Simulink®. Loads for various emergency response scenarios, such as hospitals, shelters, and/or other critical infrastructure, gathered from the expert panelists throughout the project were used as inputs to the computer simulation. The team relied on bus manufacturer specifications to build the bus powertrain model and existing databases for infrastructure loads. The computer model/simulation was exercised to determine the ability of the BEPS system to respond to a power outage. The model also served to address the feasibility of using multiple BEPS buses in parallel to power a single building load.

The simulation showed that a single bus or multiple buses can be used up to the full hybrid system's rated power upon the bus without negatively impacting the bus powertrain or cooling systems. Thus, it is feasible to power loads in excess of 100 kW, and possibly up to 200 kW or more, depending on the rated power output of the hybrid system onboard the bus. In situations where the load exceeds the power rating, multiple BEPS-equipped buses can be run in parallel to service the load. Control schemes for this can vary and will largely depend on the application's requirements. This objective demonstrates the bus generator's capabilities through a controlled simulation. Details of the simulation are presented in Appendix A: Simulation Verification.

Building and Design

Several sites were considered for the demonstration, with the team ultimately deciding to use a facility located at the University of Texas (UT) Pickle Research Campus. The Commons building on the research campus is a designated emergency and medical shelter and recently was employed during Hurricane Harvey, which hit the Texas coast in 2017. The demonstration plan would power the emergency power circuits with BEPS during normal business hours. A block diagram of this circuit on the research campus is shown in Figure 4-1. During normal operation, the emergency power loads are serviced by the utility grid; during a power interruption, an automatic transfer switch switches these loads to an emergency generator. For the BEPS demonstration, the team simulated a grid power failure at the Commons while using the bus to power the critical emergency loads rather than the campus back-up generator system.

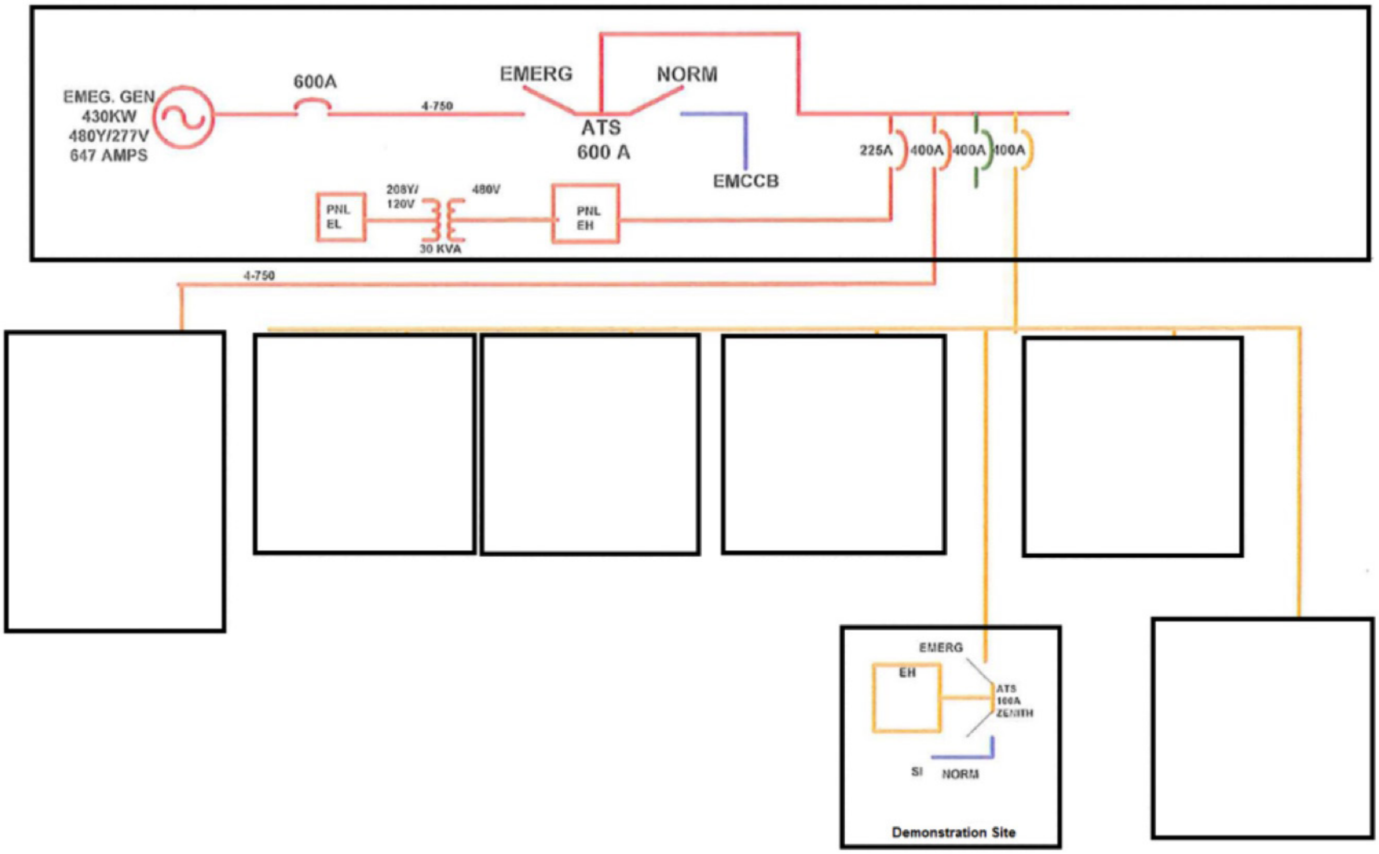


Figure 4-1

One-line back-up power electrical circuit diagram for potential demonstration site at UT Pickle Research Campus (several sites blocked out for confidentiality)

Demonstration

As part of the project, the research team, led by UT-CEM, performed a demonstration of the BEPS technology. The intent of the demonstration was to prove the feasibility of powering critical infrastructure during emergency response and recovery using the BEPS system.

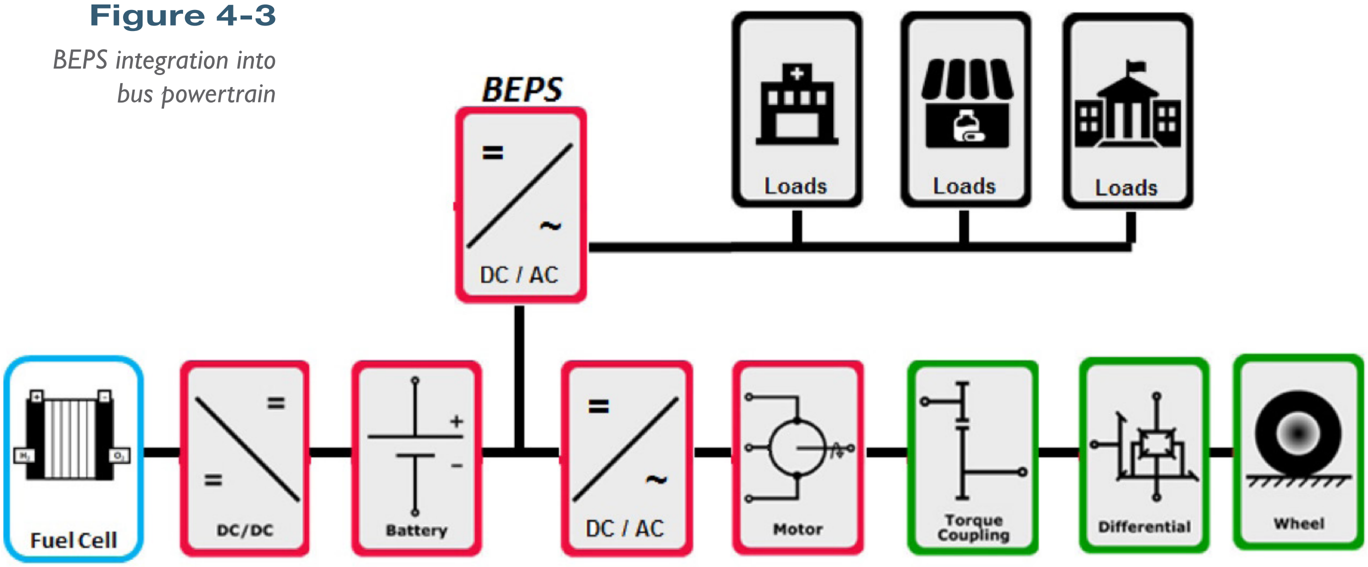
While planning for the demonstration, the team reached out to several industry partners and bus manufacturers to garner support and use of one of their existing diesel hybrid buses for integration of the BEPS system and demonstration. The industry partners were intrigued by the concept and supportive of the project, but logistical and programmatic hurdles for acquiring a bus for the demonstration could not be overcome in a timely manner. This led the team to select an early-generation fuel cell hybrid E-bus that currently resides at UT-CEM for the demonstration (Figure 4-2). This bus includes a 19-kW fuel cell with a 60-kWh battery operating at a nominal 300 VDC. The BEPS would integrate into the bus powertrain, as shown in Figure 4-3 to power critical facilities.

Figure 4-2

UT E-bus used for BEPS demonstration

Figure 4-3

BEPS integration into bus powertrain



The UT-CEM researchers procured a commercially-available inverter that would convert the bus's DC power into AC building power and act as the exportable power device tied into the vehicle powertrain. The input power from the bus is a nominal 300 VDC with an output of 480 VAC from the inverter. Due to internal current limitations, the inverter was power-limited to approximately 16 kW, which was adequate for the demonstration since the building emergency loads did not exceed 10 kW. In addition to the inverter, the setup included a test stand with appropriate power disconnects and a transformer to connect the inverter's 480 VAC to the buildings 208 VAC emergency power circuit. Figure 4-4 shows the hardware used in the demonstration, and Figure 4-5 shows the demonstration setup outside the Commons building.

Outside of Ideal Power inverter

Inside of Ideal Power inverter

Test stand assembly with fuse panels and disconnects

Ebus high voltage battery electrical connection interface

Figure 4-4

Images of demonstration hardware installation alongside E-bus at UT-CEM

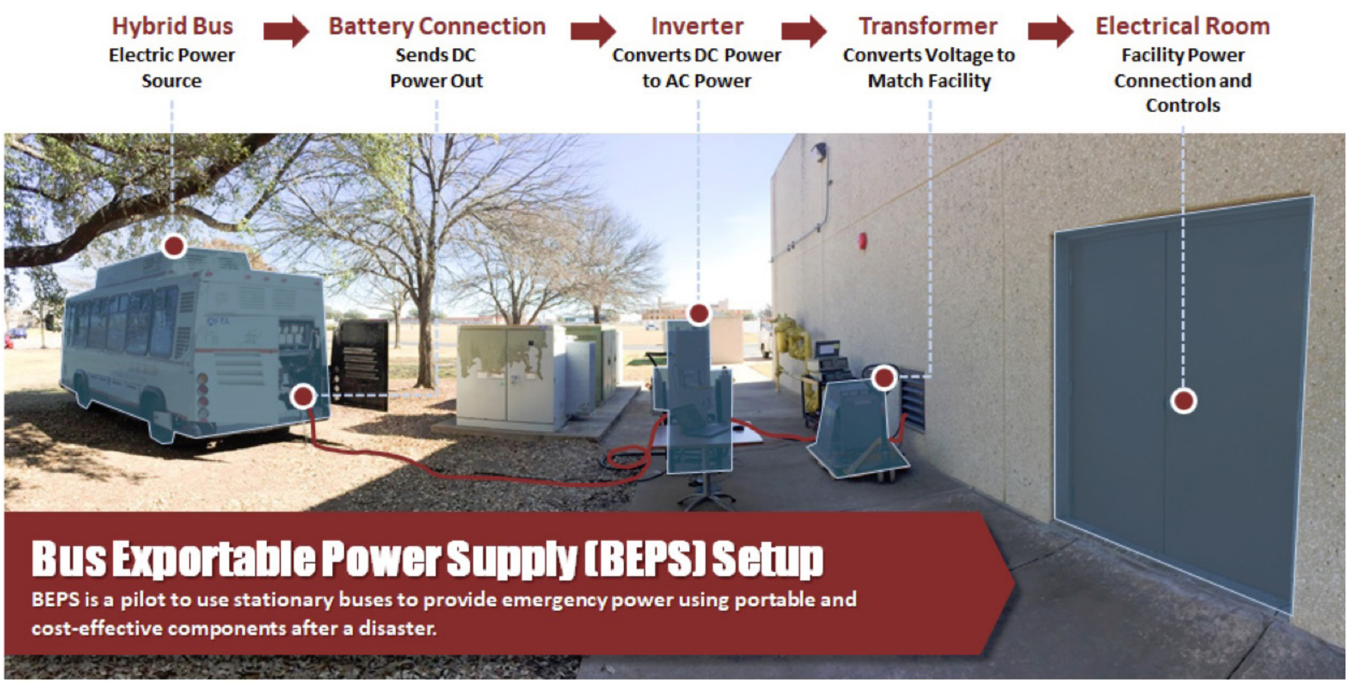


Figure 4-5

BEPS demonstration setup

For this BEPS demonstration, the connection to the vehicle consisted of a simple two-wire interface to the plus and common terminals of the battery energy storage system. These are shown in Figure 4-4 with blue and red connectors and orange cabling. The connection to the building was a four-wire, three-phase connection with a neutral/ground. For this particular inverter and building setup, it was necessary to install a transformer to convert the power from 480 VAC to 208 VAC. This transformer may not be required in practice, depending on the output capabilities of the BEPS inverter and the building power requirements. However, one advantage to the transformer is that it helps to filter and isolate power between the building and the vehicle, which may be a useful feature in future commercial applications. Furthermore, a key aspect of the setup that should not be overlooked was the need to ensure the correct phase sequence of BEPS matched the normal power for correct rotation of some machinery and equipment.

The demonstration was performed on January 30, 2018. Results from the demonstration proved that exportable power from a bus could be used to power a facility in a power outage event. The BEPS was able to power up seamlessly and follow the facility loads, even with an unbalanced load on the three-phase power. Appendix B: Demonstration Data presents data from the demonstration.

SECTION

5

Use Strategy

Ownership and Procurement

Two possible arrangements with transit agencies are envisioned for the ownership and procurement of a BEPS system. The most likely scenario is that the BEPS is provided onboard a new hybrid bus by the manufacturer and purchased and owned by the transit agency. The BEPS-equipped bus would follow a typical transit bus preventive maintenance plan to keep the BEPS operational for the 12-year life of the bus. Therefore, this system is advantageous because the upkeep on the part of the transit agency is minimal, routine, and tracked and ensures that the system is ready for use in an emergency.

An alternative scenario would employ BEPS as on off-board system purchased separately from the bus as a retrofit, although in conjunction with the specific bus since proper interfaces and control systems would need to be part of the vehicle to use BEPS. The advantage of this approach is that a transit agency could likely use a single BEPS system for multiple buses on an as-needed basis. Therefore, not each bus has to be procured with a fully functioning BEPS and overall costs would be less for the transit agency. However, in this approach, the preventive maintenance advantages of the onboard approach are not realized.

Given that traditional 100 kW generators cost approximately $25,000, it is reasonable to expect this to be the top end for a BEPS add-on to a hybrid bus since a BEPS system would not need the motor, generator, and fuel system that are packaged in a typical generator. Similar systems being offered by bus manufacturers as auxiliary power units for electric accessories cost about $1,000 per kW of output power. The cost of BEPS is difficult to quantify at this time when many critical aspects regarding the preferred system configuration, such as power rating and voltage, have yet to be determined for a commercial product. Manufacturers and users ultimately will define the market and the acceptable price point and power capability.

Typical Use

In most local jurisdictions, the emergency management agency and the transit agency have established relationships because the transit agency assists with moving citizens during evacuations. The use of BEPS could build off this relationship to give transit agencies the additional role in emergencies of providing back-up power. Emergency management would request and coordinate the resource, similar to how the two agencies communicate for evacuations. During deployment of a BEPS-equipped bus, the transit agency would be the owner and operator of the bus. Agency operators would drive the bus to the identified location, and a certified electrician would connect the BEPS bus to the facility or equipment. Transit agencies report a preference for keeping an agency-staffed driver or maintenance technician with the bus throughout the deployment to monitor and provide security for their property. A built-in benefit of BEPS over traditional generators is that most transit buses have video surveillance systems and emergency assist (EA) buttons for additional security during deployment.

The envisioned ownership and deployment configuration was developed from conversations with the panelists assembled for the project to represent a best practice for implementing BEPS. Jurisdictions may examine other collaborations and team configurations based on the needs and corresponding capacities. From panelist consensus, the critical elements for composing a personnel team to complement BEPS are a bus operator, an electrician, and security.

Table 5-1
Personnel Need Comparison

Personnel Needed	BEPS	Traditional Generator
Bus Operator	✔	
Electrician	✔	✔
Security	✔	✔
Transportation		✔
Refueling Personnel	✔	✔

In a disaster, numerous types, sizes, and functions of facilities lose power. However, there are certain facilities that, to minimize long-term impact of the incident to the community, are determined to be critical in nature and, therefore, may be prioritized to have power by local leadership over others.

Table 5-2
Facility Need

Type of Facility	Typical Demand*
Emergency shelters/evacuation centers	250 kW**
Emergency operations center	15–25 kW
Police/fire emergency call centers	15–25 kW
Communication infrastructure	35–75 kW
Nursing home	100–200 kW
Transit depots	100–300 kW

*Source: USACE, unless otherwise noted.
**Source: NYCEM.

Modern hybrid transit buses use electric motors with power ratings at 200 kW or greater. Thus, it is feasible that a single BEPS-equipped bus could power each of the facilities listed in Table 5-2. However, in cases where the load is too great for a single bus, multiple buses could power the facility in parallel.

Location

Due to several factors, the effectiveness and cost of deploying a BEPS during a disaster is likely most practical in urban areas because transit systems, particularly those procuring hybrid-electric buses, are located in more urban areas. This proximity allows for quick deployment and use, reducing the deployment timeframe. In addition, once no longer needed, a BEPS-equipped bus may go back into routine operation almost immediately. (See Figure 3-7 for a map of transit agencies with hybrid buses and their proximity to other locations around the US.)

Value

Reliability and availability of backup power options pose the greatest threat to crippling local jurisdictions' ability to get power where it is needed when it is needed. BEPS offers a solution to both issues and enables local government agencies to more quickly and efficiently meet the needs of the community.

The intrinsic value of a BEPS system lies in its ability to simplify and expedite the resource deployment process for backup power. Having the BEPS component added to a bus eliminates the need to procure a separate generator. It also eliminates the need to identify and locate the corresponding transportation needed to deploy and return the generator. Availability of BEPS-equipped buses can further accelerate resource deployment into a local jurisdiction's resource cache. Even in a situation when Federal resources are available, it can take days before the resources arrive and are operational. BEPS being readily available in the community provides the jurisdiction with the ability to provide power while awaiting Federal assistance.

A secondary value of BEPS is the increased reliability of the generative functions being operational at the time of need. A common hindrance of generators is a lack of proper maintenance, resulting in failure when the system is needed most. With BEPS, the component would be maintained along with the already-established bus maintenance schedule, as well as more regularly in use as the bus operates on its day-to-day routes.

To help quantify the potential value of BEPS, the project team developed a model that compares the response timeframe and cost of generators under three scenarios: 1) Jurisdiction Owned and Provided, 2) Third-party Rental, and 3) BEPS. The model is constructed in Microsoft Office Excel and is a tool that may be used by emergency response and transit stakeholders to evaluate the value of BEPS. All inputs to the model are variable and can be modified for various response situations according to local conditions and available assets.

The model was used to complete a baseline analysis based on assumptions developed from the project team, the expert panel, and industry stakeholder input. Appendix C: Value of BEPS provides the details for the analysis; Figure 5-1 shows the results. The Jurisdiction Owned generators included those owned and provided by local, State, or Federal authorities specifically for emergency response. They represent a great power generation solution in the time of need, but the protocols for requesting a generator and having it installed can take several days. Third-party rental generators typically can be provided more readily, especially if the business or institution needing power contracts the generator vendor directly. But if the request goes through governmental processes, the response can take several days. The rental and setup fees are the biggest drawback to this solution. BEPS generators would likely be a local source for response and could be onsite within hours. Their maintenance costs are covered by the transit agency but would incur fuel and operator costs. The BEPS approach provides the best cost-benefit within the first week of response where its quick response time can relieve cost associated with the loss of power. However, after approximately 1–2 weeks, the other generator options become a better solution based on cost. This is largely driven by the assumption that a BEPS-equipped bus would require a paid driver at all times. If this requirement was relieved, then BEPS operating expenses would be similar to the other generator options.

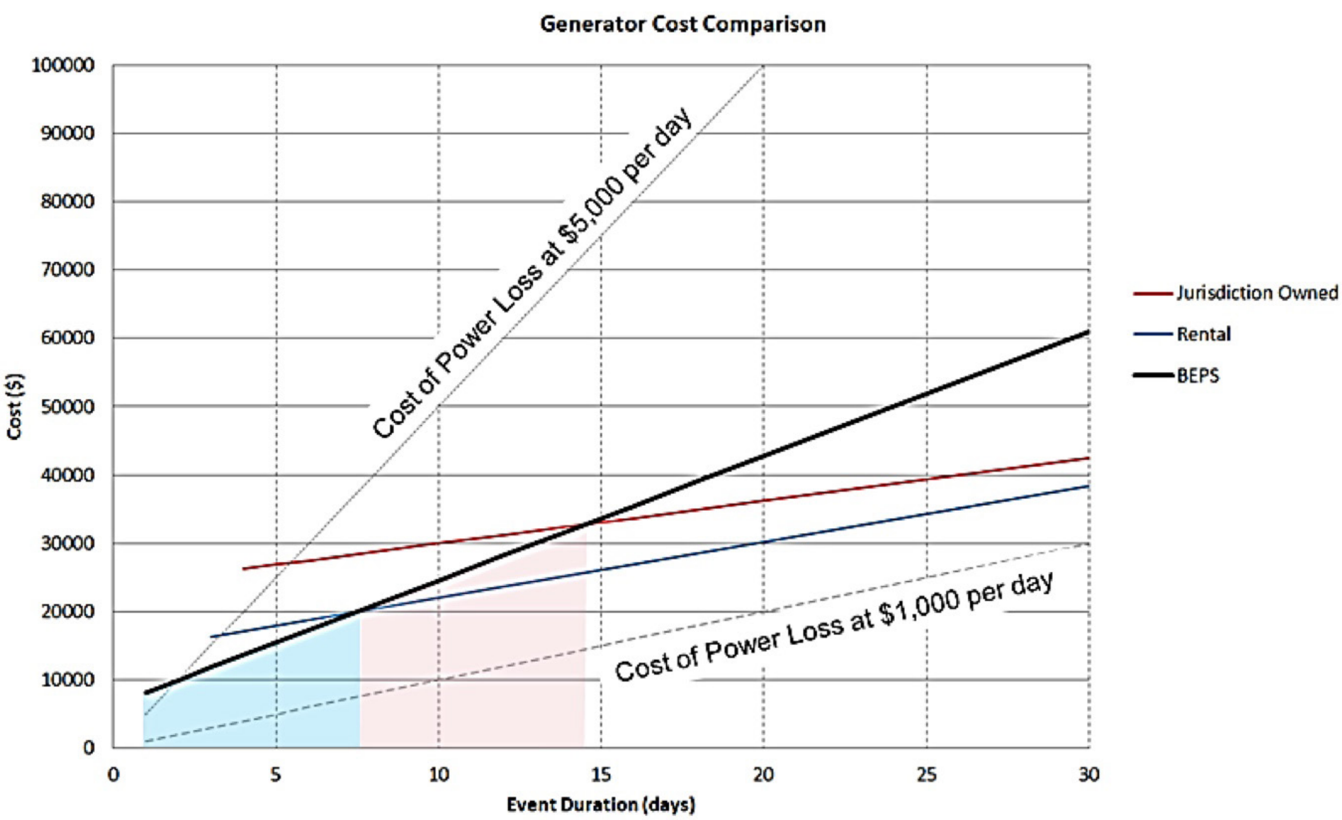


Figure 5-1

Response Benefit Model results with baseline assumptions

There are additional unquantified benefits that the BEPS system has over traditional generators. First, buses have emissions controls and mufflers so mobile generation should be cleaner and somewhat quieter. Second, BEPS has flexibility to serve multiple purposes throughout day; for instance transport and evacuations during day and power generation at night.

Identified Challenges

The value of BEPS is evident, but there are several challenges identified that should be addressed to realize its optimal utilization and value. Several of these of constraints are inherent to provision of backup power in general, and several are more unique to BEPS.

A fundamental challenge is where and when the BEPS technology will be available for deployment. BEPS is best suited for areas where there is a local transit agency that is operating hybrid transit buses and has enough resources to spare for this type of use. During larger-scale emergencies, there may be modifications in the agency's route operation schedule opening up the availability of fleet not traditionally available. However, during smaller localized outage incidents, deploying a BEPS resource would need to occur by using a bus not needed for daily route operations. During a large-scale emergency, there may be competing interests for the transit buses, including transportation of evacuees. Coordination of resources must be addressed as the events occur.

The size of a bus presents a challenge for operations in urban areas without a substantial amount of additional space. Although transit buses are frequently operated in urban areas with narrow streets, for BEPS, the bus also needs to get close enough to a building to be able to connect or have supplemental equipment that ensures connectivity is possible even at distances. Typical cable runs for backup generators are reported to be 75–100 feet. A standard transit bus is approximately 40 feet long, 8.5 feet wide, 10–11 feet tall, and weighs 30,000+ pounds.[25] In many instances, this would not be an issue, but if the facility in need was in an area with high building density, without readily-available space to park one or more buses, the bus may not be able to get close enough to the building to connect. With long-enough connections, this challenge may be able to be avoided, but extensive cabling would be heavy and expensive.

Similar to the deployment of traditional generators, BEPS will also be susceptible to refueling, proper facility connection requirements, including provision of transfer switches, matching the generator's output to the facility's needs, and acquiring an electrician to perform the connection of the system to a facility. A BEPS-equipped bus is projected to use fuel at a rate of 7 gallons per hour; with a 100-gallon tank and a theoretical 10-mile trip to the facility location, this means

[25] http://deldot.gov/information/business/drc/pd_files/plan_development/dtc_bus_dimensions.pdf.

BEPS can power a building for nearly 14 hours before needing to be refueled. If the facility needed power for longer than 14 hours, the users of the system would need to configure a plan for allowing the bus to be refueled. If not being refueled, users would have to plan to leave enough fuel for the return trip to the fueling station.

Other challenges commonly faced when deploying and connecting a generator are correctly matching the generator to the building, both in the needed size/output and the proper corresponding connections. These are matters to which BEPS will not be immune and that will need to be considered when a jurisdiction moves to obtain and operate a BEPS system. However, any type of BEPS configuration that requires special instructions for use would provide a significant barrier since the potential user base is broad and use could be infrequent. Special training and/or instructions would be difficult, if not impossible, to roll out. In the near term, BEPS equipment should be configured to connect and operate similar to existing generators to take advantage of user-familiarity with that equipment.

Since BEPS equipment integrates with the buses, the responsibility for procuring, maintaining, and controlling this equipment lies with the transit agencies. The lack of incentives for transit agencies to assume this cost and responsibility could be a challenge, especially when the emergency response community and the general community realize the benefits. The primary incentive for transit agencies for owning and providing a BEPS system is the positive attributes of providing assistance to its community in times of need (similar to providing evacuation services). There may be some minimal internal benefits to use exportable power (in lieu of portable generators) in an agency's day-to-day operations; however, in general, there is an up-front financial outlay necessary for transit agencies to procure the equipment and little to no financial pathways to recoup those investment costs. Pathways for providing incentives or subsidies for the procurement and maintenance of BEPS equipment should be considered by the local, State, and Federal communities that would ultimately receive the benefits of the equipment.

SECTION

6

Summary and Recommendations

Summary and Recommendations

Stakeholders agree that buses equipped with exportable power systems can make communities more resilient to emergency events and make local municipalities less dependent on State and Federal resources during disaster response and recovery. For these systems to become a reality, bus manufacturers must commit resources to system design and development, and their customers (e.g., transit agencies) must express a desire to add the technology to its fleet. To date, product development has been stifled by lack of demand. Demand has been low because a bus manufacturer has not yet presented a product. Furthermore, some transit agencies are hesitant to adopt a technology that is not related to their primary objective of safe and efficient transportation for members of their community. Addressing these issues are the most important next steps. The project team recommends the following initiatives to help accelerate product development and incentivize adoption:

1. **A transit bus manufacturer should develop and demonstrate an exportable power system**. FTA should support an exportable power system design and demonstration project that includes multiple major transit bus manufacturers. Transit agencies are more likely to be interested in exportable power systems if the systems are offered by the bus manufactures, instead of third-party organizations. Financial support from FTA can encourage companies like New Flyer and GILLIG to get involved.
2. **An industry committee should be formed to develop standard system specifications.** Developing standard system specifications will streamline and simplify design, procurement, and deployment activities. Emphasis should be given to standards that describe how the bus is connected to the facility and/or other auxiliary system(s) and that describe user interface and operation. Additionally, industry stakeholders should encourage the adoption of language in APTA's Standard Bus Procurement Guidelines that provide specifications for the optional provision of BEPS equipment. This would provide agencies both the awareness of the technology as well as accessible language for reliable exportable power from the buses. Further, it would help drive commonality among systems and interoperability on the outlet side of the bus.
3. **FTA should exclude buses equipped with exportable power systems from spare ratio calculations**. FTA places restrictions on the number of "spare" buses that public transit agencies can keep in their fleet inventory.

The restrictions apply to transit agencies that receive Federal assistance for the purchase of revenue service vehicles and are described in FTA Circular C 5010.1E, "Award Management Requirements." The number of spare buses in the active fleet for recipients operating 50 or more fixed-route revenue vehicles should not exceed 20% of the number of vehicles operated in maximum fixed-route service.[26] This requirement prevents transit agencies from stockpiling subsidized buses and ensures that Federal funds are being used effectively and efficiently. However, agencies often have a need for their spare ratio to be greater than 20%. Buses often are out of service for scheduled and unscheduled maintenance, which reduces the number of fleet vehicles available for passenger service. Additionally, agencies often are asked to deploy their fleet vehicles into irregular service, such as for a local special event shuttle, evacuation assistance, warming/cooling centers during extreme temperatures, and, if BEPS becomes a reality, for power generation support. These irregular operations further complicate the agency's ability to provide its regular passenger service without having a greater number of spare buses in its fleet. A bus equipped with an exportable power system would likely be one of the first buses pulled out of passenger service and deployed in irregular service. Additionally, to establish market demand for BEPS technology, agencies need to be incentivized to procure, operate, and maintain the equipment.

To assist with these resource limitations and to help incentivize transit agencies to purchase BEPS technologies, it is suggested the FTA consider excluding BEPS-equipped buses from an agency's spares ratio calculations. To further encourage use of the technology during emergencies or disasters, the spares ratio exemption could require that BEPS equipped buses be made available to support emergency response when requested by local jurisdictions.

4. **Bus exportable power systems should qualify for funding through the same programs that currently fund the procurement and deployment of traditional emergency generators**. Several existing FEMA and FTA programs allow grant recipients to use Federal funds to purchase and/or operate emergency generators. FEMA's Hazard Mitigation Grant Program (HMGP) is authorized under Section 404 of the Stafford Act to help communities implement identified hazard mitigation projects following a presidentially declared disaster.[27] Hazard mitigation is defined as any action taken to reduce or eliminate long-term risk to people and property from natural disasters.[28] As funding becomes available, grantees and sub-grantees may submit mitigation projects as part of this grant. To receive grant funds, a jurisdiction must have developed a hazard mitigation plan with

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[26]FTA Circular C 5010.1E, "Award Management Requirements."
[27]https://www.fema.gov/hazard-mitigation-grant-program.
[28]https://www.fema.gov/hazard-mitigation-assistance.

established mitigation projects. State and Federal officials must approve the mitigation project before funds are distributed. Mitigation projects that included traditional emergency generators have been funded in the past. Mitigation projects that include buses equipped with exportable power systems should qualify for HMGP funding in future.

One form of potential funding that does not require a presidential disaster declaration is FEMA's Pre-Disaster Mitigation Grant Program (PDM). Generators and related equipment (e.g., hook-ups) are eligible provided that they are cost effective, contribute to a long-term solution to the problem they are intended to address, and meet all other program eligibility criteria. A generator that is a stand-alone project can be considered for PDM funding if the generator protects a critical facility. Generators and/or related equipment purchases (e.g., generator hook-ups) are eligible when the generator directly relates to the hazards being mitigated and is part of a larger project.[29] To be eligible, the project must be cost-effective, which equates to a ratio of 1.0 through the use of a benefit-cost analysis (BCA) with FEMA software.[30]

Traditional emergency generators have also been procured through the alternative procedures of the FEMA Public Assistance (PA) program. In 2013, the Stafford Act was amended by the Sandy Recovery Improvement Act (SRIA), which added Section 428 to the Stafford Act, authorizing alternative procedures for Permanent Work projects for the FEMA Public Assistance (PA) program.[31] If an applicant (jurisdiction, transit agency, or others defined as applicants by FEMA) has experienced significant damage from a disaster, it may be eligible to apply for and receive PA funding. Under Section 428, fixed-cost recovery grants can be made based on mutually agreed upon cost estimates, cost underruns can be retained for hazard mitigation, and the 10% penalty usually applied to Alternate Projects is waived. The Alternative Procedures offer two potential paths for procurement of emergency generators:

- *Cost Underruns* – If a facility within a jurisdiction eligible for PA funding has been damaged and the applicant and FEMA agree on a cost estimate for repair in kind, but, ultimately, repairs cost less due to alternate construction means and methods or changes to design, the jurisdiction or applicant is left with a cost underrun. That underrun can then be used for hazard mitigation measures, such as procuring a generator.
- *Alternate Projects* – Alternatively, if the applicant chooses to not repair the damaged asset or facility, it can declare an Alternate Project. These projects must receive prior FEMA approval and require an

[29]https://www.fema.gov/media-library-data/1424368115734-86cfbaeb456f7c1d57a05d3e8e08a4bd/FINAL_Generators_JobAid_13FEB15_508complete.pdf.
[30]https://www.fema.gov/media-library-data/1424368115734-86cfbaeb456f7c1d57a05d3e8e08a4bd/FINAL_Generators_JobAid_13FEB15_508complete.pdf.
[31]https://www.fema.gov/alternative-procedures.

environmental assessment and usually incur a 10% reduction to eligible scope. This penalty is waived if the project is completed using the Section 428 Alternate Procedures. In theory, that Alternate Project can include procuring a generator. Like procuring a generator, equipping a bus with an exportable power system should be an allowable PA Alterative Procedure expense.

FTA's Emergency Relief (ER) program is authorized by Congress and enables FTA to reimburse public transit operators in the aftermath of an emergency or major disaster to help pay for protecting, repairing, or replacing equipment and facilities that may suffer or have suffered serious damage. ER Program funds can also fund the operating costs of evacuation, rescue operations, temporary public transportation service, or reestablishing, expanding, or relocating service before, during or after a declared emergency. ER program funds should be available to reimburse agencies for the use of buses and staff when buses equipped with BEPS are deployed in an emergency response activity.

5. **Federal and local agencies should develop new funding programs**. Most of the programs described above provide funding following an emergency and may or may not allow for BEPS specific technology. There remains a need for both specific and proactive, or resilient, funding streams for bus exportable power technologies. Communities and agencies that can benefit from exportable power systems should consider development of new funding programs to encourage the development and adoption of such systems.

APPENDIX

A

Simulation Verification

Once the basic needs and design requirements of the technology were established, the project team began simulations as initial tests of the conceptualized prototype. To accomplish this, a computer model of the bus power train, including the diesel engine, motor/generator, and battery energy storage, was constructed in Matlab® and Simulink®. Loads for various emergency response scenarios, such as hospitals, shelters, or other critical infrastructure, gathered from the expert panelists throughout the project were used as inputs to the computer simulation. The team relied on bus manufacturer specifications to build the bus powertrain model and existing databases for infrastructure loads. The computer model/simulation was then exercised to determine the ability of the BEPS system to respond to a power outage. The model served to answer questions regarding parallel BEPS use and transfer switching when grid power becomes available.

The system configuration of the BEPS is shown in Figure A-1. The system includes a diesel engine, generator, battery energy storage system (ESS), inverter, ac grid load, and accessory load. In the current BEPS bus system model, the traction motor, transmission system and vehicle dynamics are not modeled, but these components could be easily included in the developed model if required.

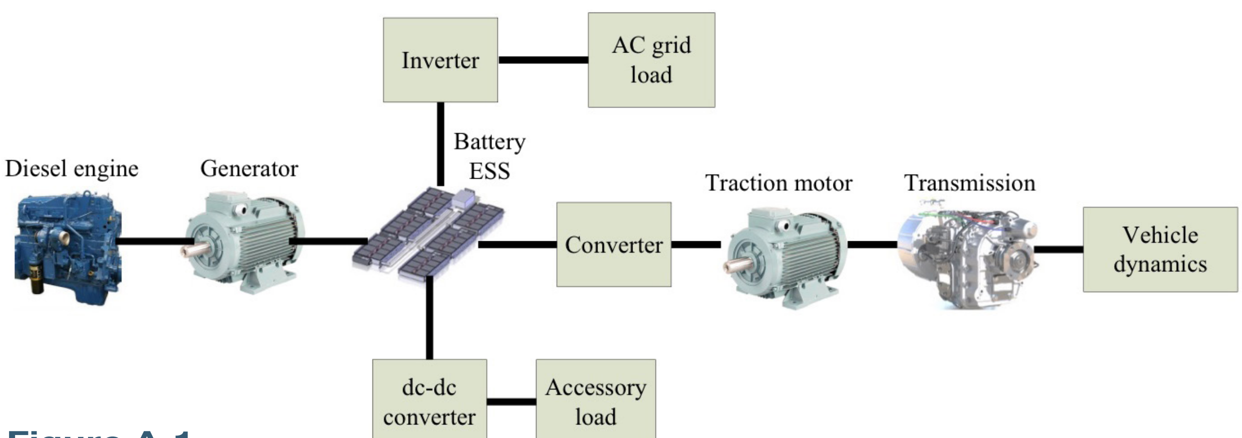

Figure A-1

System configuration of BEPS

All the model parameters are included in a user-friendly data file using either vendor available data or data obtained from literature. The data files can be updated as component specifications change. A summary of the model data is listed below.

- *Diesel engine* – data includes torque curves and fuel map. Fuel map is used to determine fuel consumption. Data obtained from literature for typical diesel engines.

- *Generator* – uses available efficiency data from literature and vendor toque-speed curves for similar size and type generators that would be found on a transit bus.
- *Battery ESS* – specifications obtained from vendor data for cell resistance and voltage.
- *Power converters* – modeled as ideal voltage transformers with constant efficiency.

In addition, energy estimations for heat transfer to ambient, inter-cooler power, coolant energy, and exhaust energy were added in the BEPS diesel engine model. These losses were included to quantify the amount of heat rejection that would be required by the radiator to sustain the loads that may be seen by BEPS.

Simulations were performed to study the ability of BEPS to power a critical facility load and a large (>200 kW) load with multiple buses. Of particular interest was the control methodology for the multi-bus scenario, in which a droop or isochronous control strategy could be implemented. The load for this study was taken from real-world measured power data from an aggregated neighborhood ac power grid of 24 residential houses with 22 photovoltaic units with a peak load demand of approximately 500 kW. The three-bus model was implemented to test the coordination of local controllers and tune the parameters of the controllers. In the droop controller study, all buses automatically share the load with no master controller to maintain system frequency. Although a common control strategy, steady-state frequency deviation may exist, which can be improved by regulating the power set-point of each bus droop controller. In the isochronous controller scheme, one of the buses acts as a master controller by regulating the AC grid frequency, while the other buses are controlled with the droop method using constant power set-points. Figure A-2 shows a comparison of each control method.

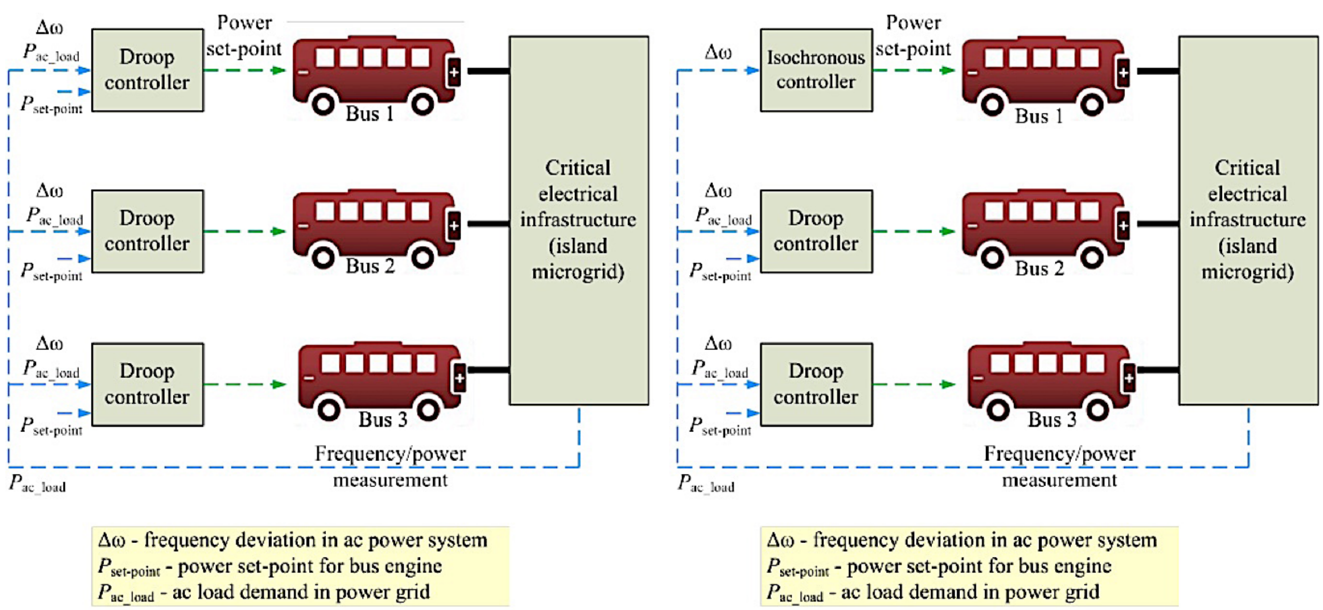

Figure A-2

Proposed control structure for multiple-bus BEPS system (droop control on left, isochronous control on right)

The simulation results show that both proposed controller methods were able to synchronize the power sharing of each BEPS bus and feed the load demands on the AC power grid. As expected, frequency response of the isochronous controller was better than the all-droop controller method, but response of the all-droop controller could be improved by regulating the power set points.

Figure A-3 shows the results of three varying power set points for the all-droop controller. Spikes in the frequency response occur with sudden load changes. It can be seen that as the power set point is adjusted from a constant power setting to an adjustable setting, averaging the power output over the last 30 minutes or 3 minutes, the frequency response is greatly improved.

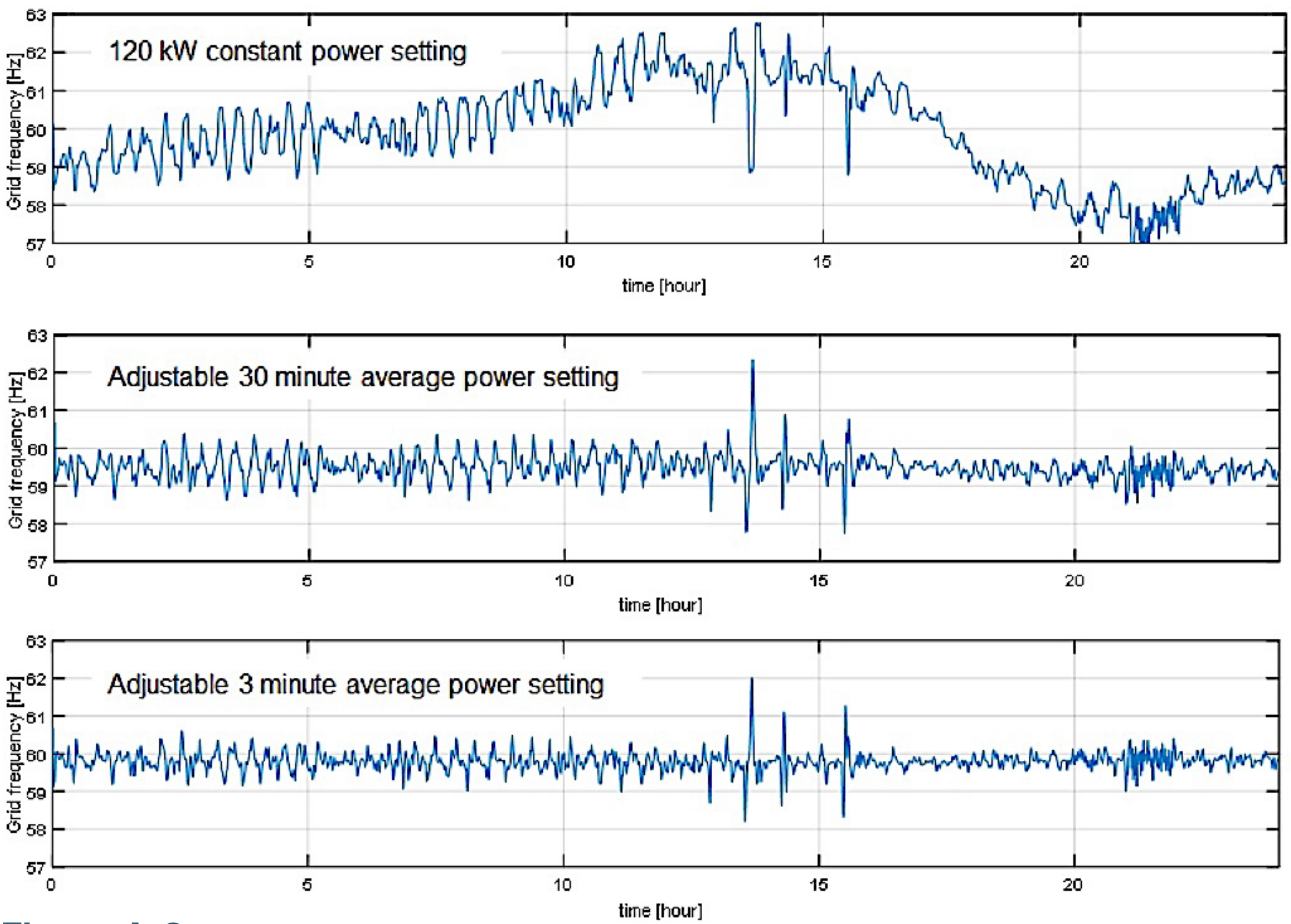

Figure A-3

Frequency response of three power set point cases for all-droop controller

In comparison, Figure A-4 shows the frequency response of the isochronous control method, with one bus acting as a master providing frequency regulation. Such a control methodology provides much tighter control of frequency output.

For most loads and applications, the all droop controller may be adequate, but for more sensitive loads, such as hospitals, the isochronous method may be preferred.

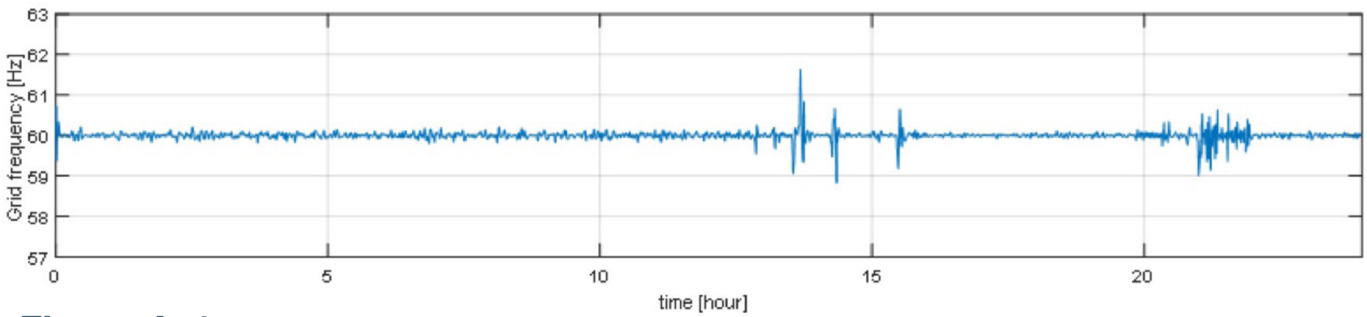

Figure A-4

Frequency response of isochronous controller

For each simulation, the fuel consumption rate and losses in the engines were computed. Figures A-5 and A-6 show the results for the isochronous case, which were very similar to the droop controller cases as the control methodology had only a small effect on efficiency.

In discussions with bus manufacturers, the cooling requirements for the radiator are not anticipated to be a problem for implementing BEPS on hybrid buses while running the generator at full power with the bus idling. Bus manufacturers have said that the radiators are designed to accommodate continuous full power heat loads at a standstill. The simulations showed that the max losses seen by the coolant/radiator are about 40 kW, whereas a maximum heat load would be on the order of 200 kW for each engine.

In conclusion, the simulation showed that a single bus or multiple buses can be used up to the full hybrid system's rated power upon the bus without negatively impacting the bus powertrain or cooling systems. Thus, it is feasible to power loads in excess of 100 kW and possibly up to 200 kW or more depending on the rated power output of the hybrid system onboard the bus. In situations where the load exceeds the power rating, multiple BEPS-equipped buses can be run in parallel to service the load. Control schemes for this can vary and will largely depend on the application's requirements.

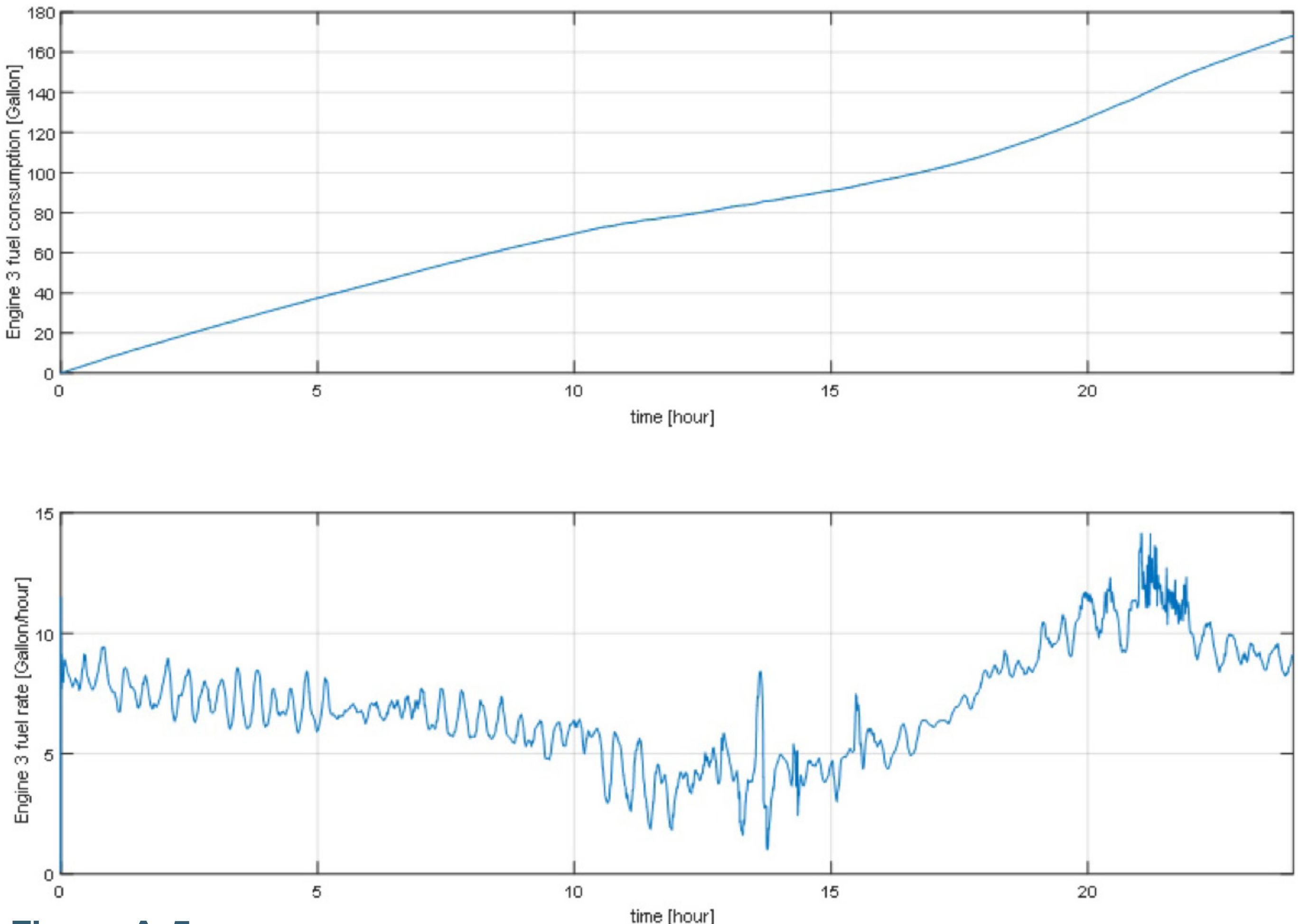

Figure A-5

Fuel consumption for single engine of three-bus BEPS simulation

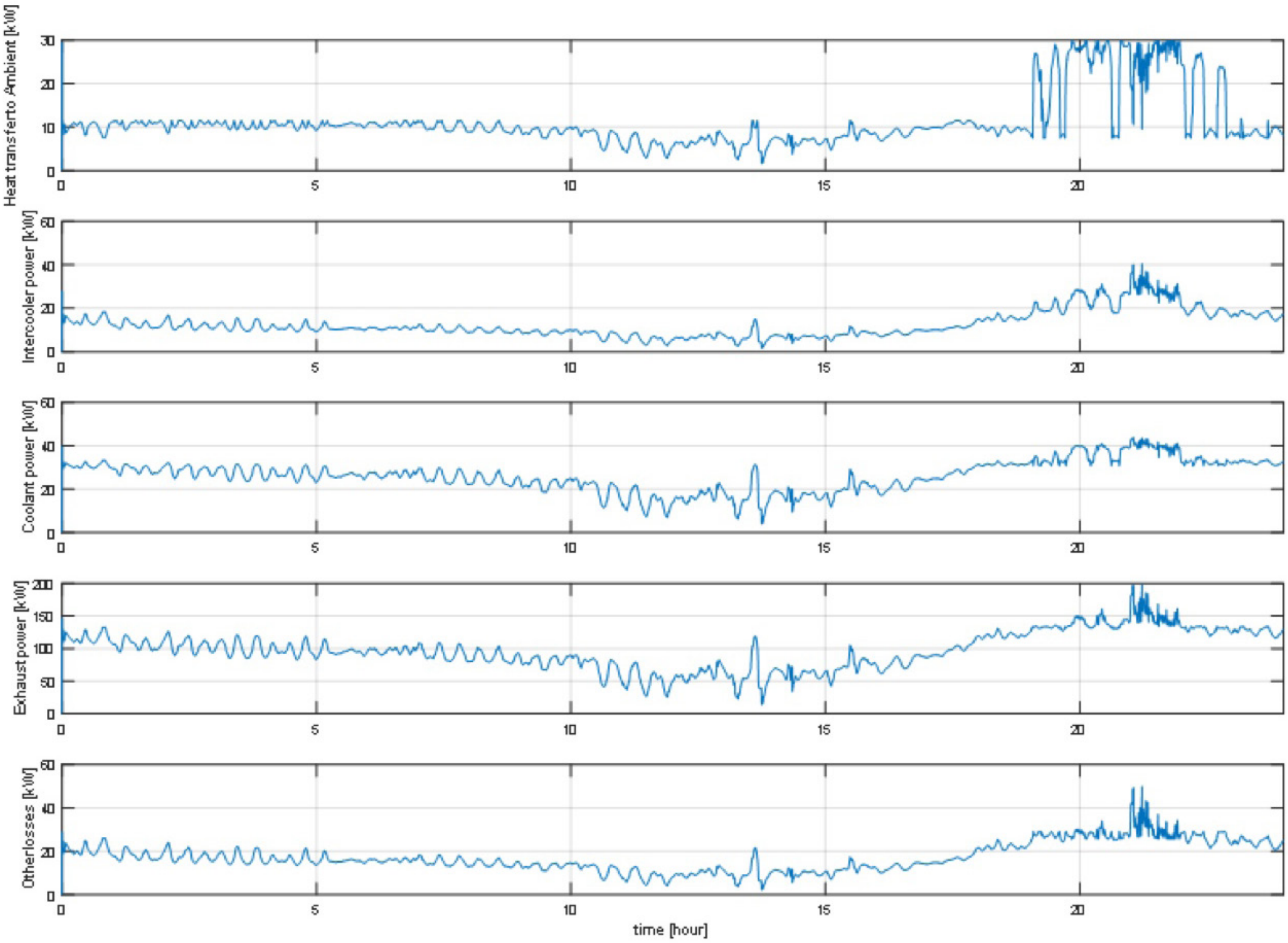

Figure A-6

Engine losses for single engine of three-bus BEPS simulation

APPENDIX B

Demonstration Data

The demonstration was performed on January 30, 2018, and results proved that exportable power from a bus could be used to power a facility in a power outage event. The BEPS was able to power up seamlessly and follow the facility loads, even with an unbalanced load on the three-phase power. Figures B-1 and B-2 show the input battery current and output voltage and current waveforms from the demonstration, noting that the load (current) varies greatly between the phases. The demonstration was monitored with National Instruments LabVIEW™ software through a panel depicted in Figure B-3, tracking input battery voltage, current, and power and output inverter voltage, current, and power.

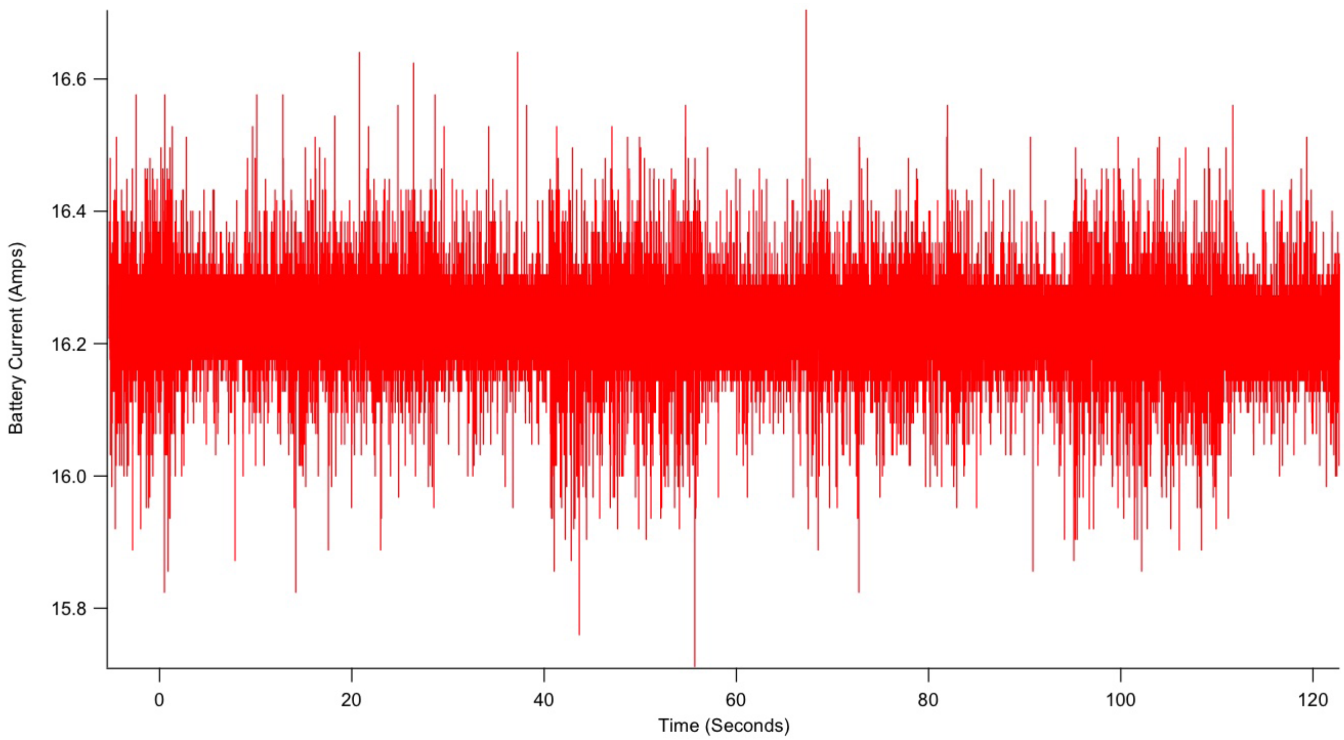

Figure B-1

Input battery and current waveform during BEPS demonstration

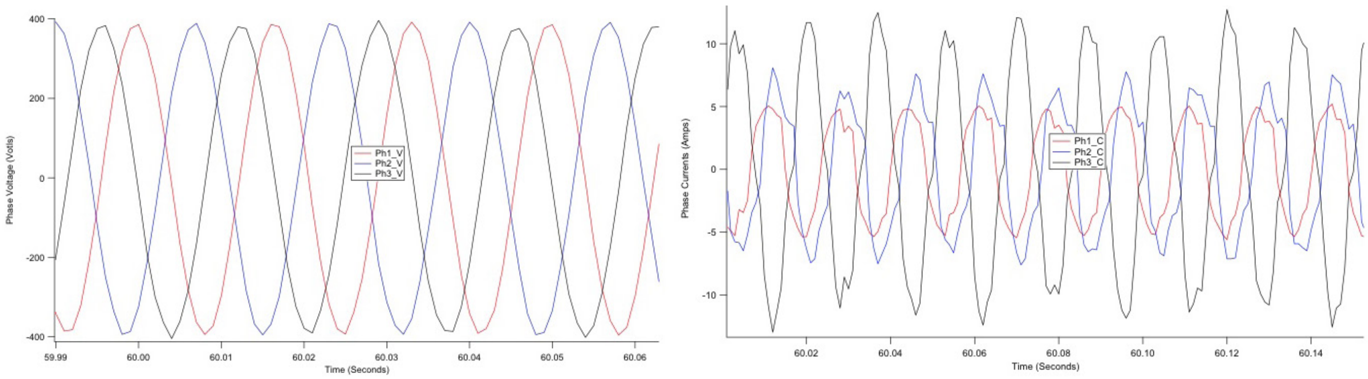

Figure B-2

Output voltage (left) and current (right) waveforms during BEPS demonstration

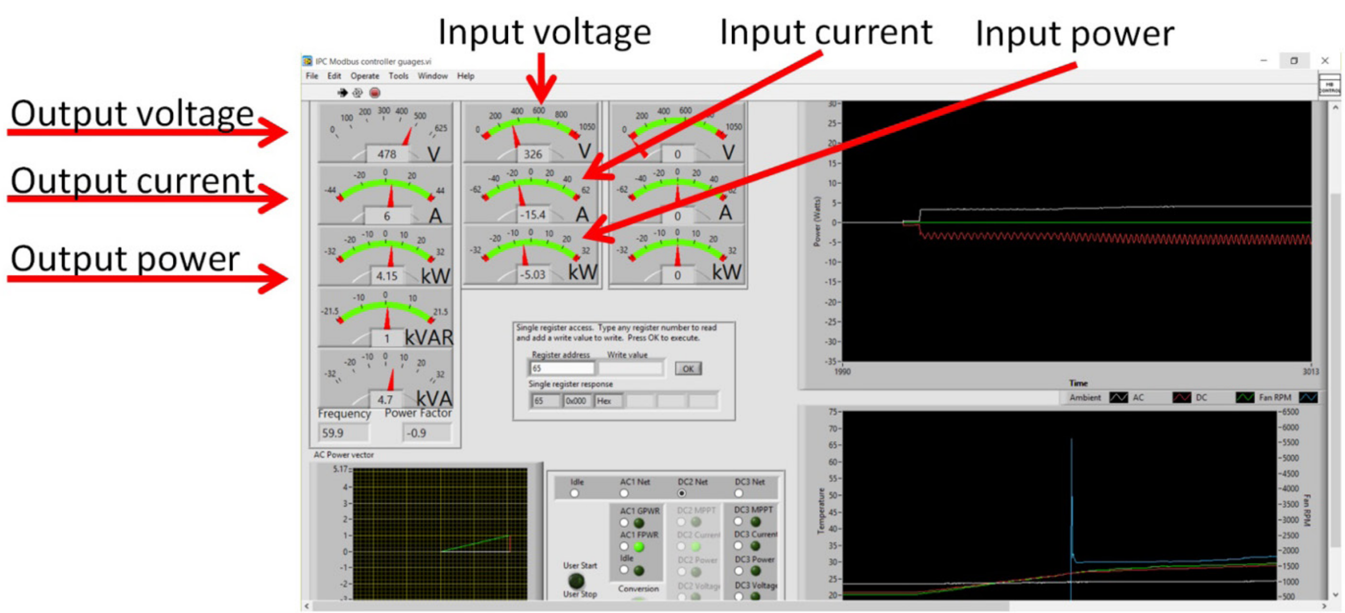

Figure B-3

Power for BEPS demonstration monitored during testing

APPENDIX

C

Value of BEPS

To help quantify the potential value of BEPS, the project team developed a model that compares the response timeframe and cost of generators under three scenarios: (1) Jurisdiction Owned and Provided, (2) Third-party Rental, and (3) BEPS. The model was constructed in Microsoft Office Excel and is a tool that may be used by emergency response and transit stakeholders to evaluate the value of BEPS. All inputs to the model are variable and can be modified for various response situations according to local conditions and available assets.

The Jurisdiction Owned generators included those owned and provided by local, State, or Federal authorities specifically for emergency response. These generators are purchased, maintained, and provided by these authorities. They typically are stored in central warehouses distributed throughout the country and represent a great power generation solution in the time of need, but the protocols for requesting a generator and having it installed can take several days.

Third-party rental generators typically can be provided more readily, especially if the business or institution needing power contracts the generator vendor directly. If the request goes through governmental processes, then response can take several days. The rental and setup fees are the biggest drawback to this solution.

BEPS generators would likely be a local source for response and could be on site within hours. Their maintenance costs are covered by the transit agency but would incur fuel and operator costs.

Table C-1 shows baseline assumptions and break down the cost associated with each style of emergency response power solution for a 100-kW generator.

Figure C-1

Baseline Assumptions

Back Up Power Solution*	Purchase Cost ($)	Facility Cost ($)	Annual Maintenance Cost ($/yr)	Rental Fee ($/day)	Installation Cost ($)	Fuel Cost ($/day)	Operator Cost ($/day)
Jurisdiction Owned	25,000	0	10,000	N/A	5,000	620	N/A
Third-Party Rental	N/A	0	N/A	200	5,000	620	N/A
BEPS System	20,000	0	N/A	N/A	5,000	620	$1,200

* All values assume power generation level at 100 kW.

- *Purchase cost* – A typical 100 kW generator costs approximately $25,000, which would be a cost incurred by the government jurisdiction in such case. Any purchase costs associated with a third-party rental are assumed to be accounted for in the rental fee. The purchase cost of the BEPS solution would be incurred by the transit agency with possible subsidies from FTA. It is likely that the BEPS feature will be less than a full 100 kW generator cost, assumed to be $20,000 for this exercise.
- *Facility cost* – For some generator installations, additional costs may be incurred at the facility, such as transfer switches. This requirement is not a necessity for the operation of BEPS or the other cases under consideration, but the model as constructed provides for the possibility. In the baseline assumptions, the model assumes these costs are zero for all three scenarios. The cost associated with an automatic transfer switch is about $7,000.
- *Annual maintenance cost* – Annual maintenance for a 100 kW generator is approximately $10,000. A jurisdiction that owns a generator would incur these costs each year. It is assumed that any maintenance fees for a rental generator are covered in the rental fee; the BEPS maintenance costs are negligible, as they will be part of the transit agency's routine maintenance for the bus.
- *Rental fee* – Rental fees for a 100 kW generator are $1,400 per week or $200 per day.
- *Installation cost* – A generator installation can be costly and time-consuming. The building damage and power requirements must be assessed by an electrician. The appropriate generator must then be selected and installed, also by an electrician. At times, the installation also may require long runs of cables to reach the building's power feed. This cost can vary greatly per site, but for this case $5,000 is assumed. In the case of BEPS, a similar installation cost would be incurred.
- *Fuel costs* – Since all generator solutions are assumed to be the same power level, the daily fuel cost to operate each.
- *Operator cost* – The only solution that likely would require an operator or mechanic would be the BEPS solution since transit agencies typically require a driver to be with the bus at all times. The cost presented in Table C-1 assumes $50 per hour at 24 hours per day.

The Response Benefit Model was constructed with these cost parameters as variable inputs so that variances in costs can be studied. Additional factors considered in the model were response time, generator life, generator load, fuel cost, and number of response events per year, and power outage cost per day. Each of these parameters is also variable within the model so that variances can be studied, but typical values are discussed below.

- *Response time* – The response time for a Jurisdiction Owned solution involves a series of requests starting at the local government level and continuing through State and Federal levels as needed. In such a request, the responding jurisdiction will be on site within 24 hours to assess the building and then assign a generator. Generator delivery and installation then occurs over the next 48 hours, and in some cases can take longer, making a typical response time for a Jurisdiction Owned asset on the order of three days up to one week. When considering a third-party Rental solution, the response time can be within a day if the facility affected contracts directly with the generator vendor; however, if requests are made through governmental channels, the same three-day response seen with a Jurisdiction Owned asset would be typical. The potential benefit of BEPS is that the response time can be 24 hours or less when used as a local asset.
- *Generator life* – Generator life factors into the Response Benefit Model by amortizing the upfront generator cost over the life of the system. Typical generator life is 20 years; a heavy-duty bus life is required to be 12 years (although some buses operate for 15 years or more). Thus, the Jurisdiction Owned solution has a life of 20 years, whereas BEPS is considered for only 12 years. For the third-party rental solution, up-front generator cost is considered to be rolled into the rental fee and, thus, generator life factors are as well.
- *Generator load* – Generator load plays a factor in the model when considering fuel consumption, as discussed earlier in this report. The Response Benefit Model uses the same generator load assumption for each solution.
- Fuel cost – Similar to generator load, the model also includes a fuel cost input, which is treated the same for each response solution.
- *Number of events per year* – Since the initial cost of the generator or BEPS is a factor in the overall value benefit, the number of times the system is used in a year and over its life is necessary to estimate when trying to consider the cost on a per-response event basis. This variable is treated the same for each response solution within the model; however, as with generator life, this parameter is not a factor for the third-party rental solution and has a role only in the Jurisdiction Owned and BEPS solutions. In the examples presented below, the model assumed two events per year.
- *Power outage cost per day* – This parameter is included in the Response Benefit Model to include the cost of not having power to the facility during such an event. This cost can be difficult to quantify and varies from one facility to the next. This cost is treated the same for each solution and can be varied in the model. The results shown below assume the average cost of a power outage is $5,000 per day, which would be expected for a small business.

The Response Benefit Model was exercised using the baseline assumptions discussed for cost and other factors. Figure C-1 shows the common input parameters for each solution, and Figures C-2, C-3, and C-4 show inputs for each of the generator solutions. Note these baseline assumptions can be exercised to study variances within the model.

Figure C-1

Common input parameters for Response Benefit Model

Average Events per Year	2	
Power Outage Cost	5000	$/day
Generator Load	100	%
Diesel Fuel Cost	3.50	$/gal

Figure C-2

Jurisdiction Owned generator input parameters for Response Benefit Model

Generator Size	100	kW		
Generator Cost	25000	$		
Installation and setup cost	5000	$		
Response time	3	days		
Annual Maintenance Cost	10000	$		
Generator Life	20	years		
Fuel Consumption	2.6	diesel gal/hr at	25	% load
	4.1	diesel gal/hr at	50	% load
	5.8	diesel gal/hr at	75	% load
	7.4	diesel gal/hr at	100	% load

Figure C-3

Third-party rental generator input parameters for Response Benefit Model

Generator Size	100	kW		
Generator Rental Fee	1400	$/week		
Installation and setup cost	5000	$		
Response time	2	days		
Fuel Consumption	2.6	diesel gal/hr at	25	% load
	4.1	diesel gal/hr at	50	% load
	5.8	diesel gal/hr at	75	% load
	7.4	diesel gal/hr at	100	% load

Figure C-4

BEPS input parameters for Response Benefit Model

BEPS Size	100	kW
BEPS Cost	20000	$ - to transit agency, not facility
Automatic Transfer Switch Cost	0	$ - to facility
Installation and Setup Cost	5000	$ - to facility at time of incident
Response time	0	days
Annual Maintenance Cost	1000	$ - to transit agency
Operator Salary	50	$/hr
BEPS Life	12	years
Fuel Consumption	2.6	diesel gal/hrs at 25 % load
	4.1	diesel gal/hrs at 50 % load
	5.8	diesel gal/hrs at 75 % load
	7.4	diesel gal/hrs at 100 % load

Using these inputs, the Response Benefit Model calculates the daily cost of operating each of the generator solutions. Figure C-5 shows the results of the baseline assumptions with an assumed power outage cost of $5,000 per day. The cost of daily power outage can vary depending on the site and business associated with it. For reference, Figure C 6 includes a line representing a daily power outage cost of $1,000 per day and another at $5,000 per day. The results in Figure C-5 show that BEPS has value within the first week of deployment, where its quick response time can relieve cost associated with the loss of power. However, after approximately 1–2 weeks, the other generator options become a better solution based on cost. This is driven largely by the assumption that a BEPS-equipped bus would require a paid driver at all times. If this requirement was relieved, then BEPS operating expenses would be similar to the other generator options.

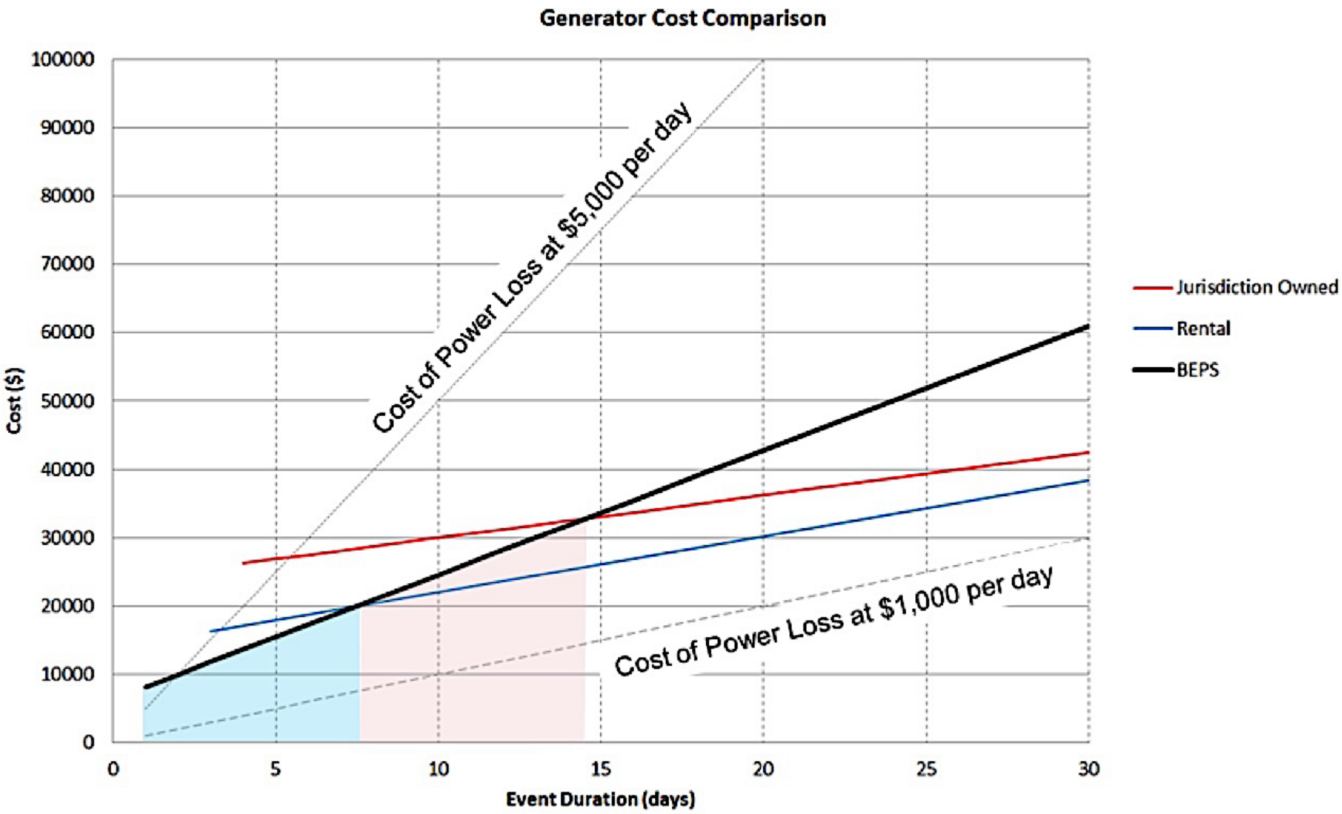

Figure C-5

Response Benefit Model results with daily power outage cost

APPENDIX

D

Independent Evaluation

An independent review and evaluation of the methodology and findings of this report was conducted by Richard Boothe of Embedded Power Control, Inc. (EPC), a Senior Design Engineer with EPC with 48 years of professional experience in the field of electrical and electronics engineering. The purpose of the independent evaluation was to review the project findings and evaluate the overall effectiveness of the research and demonstration. The evaluation includes:

- Assessment of the Technology Readiness Level (TRL) of the BEPS system
- Comparison of the BEPS system with existing alternatives, including an availability assessment, cost benefit analysis, and the value of safety improvements and risk reduction associated with the technology
- Assessment of the ability of BEPS hardware to meet the use cases defined by expert panel
- Evaluation of the overall effectiveness of the research and demonstration.

Introduction

The project final report, "Bus Exportable Power Supply [BEPS] System Use Strategy," is well- organized and readable. The case is presented for the development and deployment of the BEPS. Hardware and control strategies necessary for deployment are simulated and demonstrated. BEPS is compared to other options already available. The specific area in which BEPS is most applicable is determined by cost and technology analysis

The project team assembled an impressive panel of experts to provide expertise across multiple industries. A comprehensive study was made that determined the principles needed for the development and utilization of BEPS. The panel included representatives from transit agencies, emergency management agencies, private sector partners, the American Red Cross, the National Guard, and USACE.

The expert panel determined that the prevailing method for procuring emergency power uses the "bottom up" approach. This is key to establishing the potential role for BEPS.

Technology Readiness Level (TRL) of BEPS

This project's final report provides strong evidence that developing BEPS-specific hardware will result in a successful product. Computer simulations show that adding a BEPS to the hybrid bus design is viable without impacting the basic design of the hybrid bus already in production.

A demonstration of the overall concept was carried out using an existing fuel cell (one possible hybrid configuration) bus, an off-the-shelf power converter for the BEPS, and a building load that normally would be powered by a stand-by generator in the event of an emergency. The demonstration was successful, as evidenced by the data presented in Figures B-1 and B-2.

The Ideal Power Stabiliti Series Microgrid power converter was a good choice for the demonstration. It has several features that are essential to the BEPS:

- Boost converter in DC link to allow connection to a range of bus battery voltages
- Ability to produce smooth sinusoidal output voltages undistorted by switching ripple
- Ability to operate with unbalanced phase currents
- Ability to maintain frequency and voltage regulation when the output load is rapidly increased (step change)

One aspect of technical readiness is ease of use. The final report points out this may be critical to BEPS acceptance. A desirable facet of ease of use is similarity with the existing emergency generator interface. Standardization is critical with the need for an Industry Standards committee specifically mentioned.

A single BEPS may be able to power 100 to 200KW emergency loads. In cases in which more power is needed, multiple BEPS may be readily paralleled for larger facilities without de-rating, as shown by the project computer simulations.

Another important finding from the simulations is that no changes in the basic design of the hybrid bus are required. This includes the radiator cooling systems for the prime mover.

Further Research Needed

Single Phase Applications

Many potential applications below 25KVA total power will be single phase, 240VAC RMS with center tap for 120VAC. For single phase applications, power is drawn from the system as a 120HZ rectified sine wave (as opposed to DC in the 3-phase balanced load application). The unbalanced nature of the power drawn adds additional stress to components in the BEPS DC link. This needs to be accounted for in the system design.

Although the peak to average power ratio is essentially 1:1 for the three-phase configuration, the peak power for single phase is approximately 1.57 times the average power. The design of the bus battery may be impacted by this requirement or the allowable power draw may be limited.

Paralleling with a Generator

The project team investigated paralleling BEPS systems. Another possible use for the BEPS system is paralleling with a permanent or emergency backup generator. Over time, the power loading of an installation tends to grow and the permanent backup generator may no longer be adequate. A BEPS in parallel with the generator may be a solution. Simulations to determine the means of synchronization and power sharing should be done.

Developing Specifications for Power Converter/Inverter (Need for Filters)

Specifications unique to the BEPS system application should be developed. Modeling and actual testing should be done to validate the specifications. Some of the attributes that should be considered include:

- Ambient temperature of operation (could be higher than normal due to on-road application)
- Shock and vibration specifications
- Ability to operate single phase
- Hardware filters or other means of removing switching voltage transients from output voltage waveform.
- Power electronics to allow matching various voltage levels of bus battery system to the necessary output AC voltage
- Networking to bus system (and / or external control).
- Hardware interface to external power system per standards developed
- The requirements for on-board (hybrid bus) versus off-board location may affect the BEPS system specification.

Customer Power System Configuration including Safety Ground

The power systems to which the BEPS may connect will vary. Typical examples are as follows:

- 3-phase 480VAC with grounded neutral
- 3-phase 208VAC (line-to-line) with grounded neutral; 120VAC is supplied from phase to ground
- 1-phase 240VAC (line-to-line) with grounded center point; 120VAC is supplied from center point to phase

Using the BEPS demonstration of the issues involved, the Ideal Power inverter was capable of providing only 3-phase 480VAC whereas the requirement was for 3-phase 208VAC. The solution was the addition of a three-phase transformer to match the input 480VAC to the output 208VAC. This is a perfectly viable solution, but other options are available with a more versatile design-specific BEPS inverter. As an example, the DC link voltage could be reduced from approximately 800V to 400VDC. This is adequate to reproduce the output 208VAC with fidelity equal to that provided at the higher level. The drawback is that the current is doubled for the same power rating.

Although not specifically detailed in the report, it is likely the transformer configuration was delta – wye with the secondary neutral point grounded. This provides the necessary grounding for the user configuration and allows the 120VAC circuitry to be powered as normal. The transformer for a 20KVA application likely costs $5,000 and weighs 200 lbs. Therefore, it would be desirable to eliminate it.

The potential to design power electronics for the BEPS system such that the center point of the DC link can be regulated and connected to ground should be investigated. This allows a 4-wire (as opposed to 3-wire) output configuration for 3-phase systems and 3-wire output with center point ground for single-phase systems.

On-board vs. External Location of BEPS

The location of the BEPS needs further study. If the BEPS is located integrally with the bus, then transportation to the site is not an issue. In addition, the electrical connections from the bus to the BEPS system are already in place, and safety considerations are reduced. On the other hand, space in the bus is likely at a premium and some compromise in functionality may be required.

If the BEPS is designed as a separate piece of equipment, there are added environmental, security, and transportation concerns not present as on-board equipment.

Comparison of BEPS with Existing Alternatives

Options for portable emergency power include:

- Jurisdiction-owned backup generators
- Leased backup generators
- BEPS

Availability Assessment

The project team determined that emergency generators are procured and distributed using a "bottom up" approach. A need is first presented to local authorities, then State, then Federal (usually FEMA). The number of generators available varies with the location and the number of requests. The number of requests is usually proportional to the magnitude of the disaster. An option for procurement is leasing from a private company. The project team determined that leasing was generally the faster option with local, then State, then Federal as slower options.

The BEPS approach potentially creates a valuable source of locally-available emergency generators. At the time of the writing of this report, there were approximately 8,367 hybrid buses scattered throughout the US (see Figure 3-6). These are more highly-concentrated along the coastal regions more prone to natural disasters. If these buses are eventually replaced with hybrid buses that include BEPS systems, a new, large pool of emergency generators will be available to supplement those emergency generator resources already in place.

Cost Benefit Analysis

The major benefit of the BEPS approach is described by the project team as follows: "The intrinsic value of the BEPS lies in its ability to simplify and expedite the resource deployment process for backup power…. A secondary value of BEPS system is the increased reliability of the generative functions being operational at the time of need."

The project team suggested that an industry committee be formed to develop standard system specifications. With standards in place, cost of the BEPS systems can be reduced. Standardization should reduce the time for initial connection when the bus arrives on site which, in turn, also impacts safety in a positive way.

The method of cost comparison between the options is described in Appendix C. An Excel spreadsheet was developed by the project team that can be employed as a tool by the business or agency that has access to data specific to the particular emergency power loss event.

The project team researched the various areas of associated cost. Some items, such as initial generator cost by size, fuel usage, fuel cost per gallon and BEPS driver cost, were readily quantified. Other items such as delay time from request to installation were bounded. Still other items such as installation cost and power outage cost vary across different types of end applications.

The report acknowledges that some data, such as the power outage cost, varies between applications and is difficult to quantify in a generalized way. The amount of $5,000 per day was selected as representative of a large number of possible applications. Response time is difficult to predict but can be estimated and categorized.

Plots for the optional approaches are shown in Figure B-14. This supports the stated result in the report that the BEPS approach is most effective in the first 5–7 days of the outage. As time goes on, the additional cost of the bus driver makes the BEPS less cost effective relative to the other researched approaches.

The initial advantage is largely due to the fast response time and the lower maintenance cost of the BEPS approach.

Value of Safety Improvements and Risk Reduction Associated with the Technology

The deployment of BEPS systems will contribute to the overall ability to provide emergency power when disaster or other electric power service interruptions occur. As summed up in the project final report, "When electrical power goes out, critical infrastructure in local communities, such as schools, healthcare facilities, government offices, and businesses cannot maintain their required operations, which can directly impact the safety of the community's population. When electricity goes out at hospitals or nursing homes with vulnerable populations, death from heat exposure is a distinct possibility when AC systems are no longer operable."

Ability of BEPS Hardware to Meet Cases Defined by Expert Panel

The project team assembled a panel of experts to provide subject matter expertise across multiple industries on aspects related to the development and utilization of BEPS systems. Representatives from transit agencies, emergency management agencies, private sector partners, the American Red Cross, the National Guard, and USACE provided input.

The expert panel defined the best niche for BEPS operation by the following statement from the final report: "Resources are not readily available for a small-scale, localized power outage. The gap, currently hindering our local communities' ability to respond to an immediate need for backup power, lies in the lack of locally available mobile generators and quick access to them."

Appendix C provides strong evidence that BEPS is the superior approach to providing the fastest response time and best cost-benefit within the first week where it can relieve cost associated with the loss of power.

Appendix A presents data results of modeling multiple systems in parallel without de-rating. The necessary control techniques are demonstrated. Displays of voltage and frequency while in operation are shown. The simulations also confirm that the addition of the BEPS function has little impact on the design of the hybrid bus—an important consideration in initial deployment.

Figure 3-1, "Importance of Matching Generator Output," provides guidelines for matching a generator to the loads powered. It is general practice to include a safety margin of approximately 2:1 in order to allow for some unaccounted-for load as well as transients caused by starting motors and other devices. The addition of the battery into the BEPS system should allow the safety margin to be reduced to approximately 1.5:1. This is because the battery is capable of providing the transient power requirement whereas the hybrid bus motor-generator set needs to provide only the average power. This is not specifically mentioned in the report but is a logical extension of the data provided.

Appendix B contains the results from an actual demonstration of BEPS using off-the-shelf hardware. The Commons building at The University of Texas Research Campus was chosen for the demonstration. This building is a designated emergency and medical shelter. The demonstration hardware replaced a permanently-installed backup generator. The data in Appendix B show that the loads were powered without incident. The results from the demonstration and simulations make a good case that a follow-up project for design and deployment of BEPS systems will be successful.

Further recommendations by the project team state that "developing standard system specifications will streamline and simplify design, procurement, and deployment activities. Emphasis should be given to standards that describe how the bus is connected to the facility and/or other auxiliary system(s), and to standards that describe user interface and operation."

A summary of the project team's position on BEPS system deployment is repeated below.

> Ultimately, stakeholders agree that buses equipped with exportable power systems can make communities more resilient to emergency events and make local municipalities less dependent on State and Federal resources during disaster response and recovery. The initiatives described above will drive adoption and overcome challenges associated with the new technology. The lack of mobile generators is a significant capability gap during emergencies and power outages and communities can use the vast amount of hybrid-electric transit buses that are operated by transit agencies today as a mobile generator source to quickly and cost-effectively fill that gap.

Overall Effectiveness of Research and Demonstration

There were nine objectives stated in the final report. Comments related to each of the nine are stated below.

"Identify the need for backup power during an emergency or disaster" – The project team studied the availability and deployment of the existing backup generator options. It was determined that the ability to rapidly deploy a BEPS backup generator would provide extensive savings in lost powered time to users. BEPS technology is especially applicable to localized power outages since it is available nearby.

"Determine both the technical and logistical capabilities to transform a hybrid bus into a mobile generator" – The project team studied the technical capabilities necessary to transform a hybrid bus into a mobile generator. Hardware to be added was identified and characterized. It was determined that few changes were required in the series hybrid bus to accommodate BEPC. A fuel-cell hybrid E-bus was used in the demonstration virtually without modification. Logistically, the question of funding the cost of the BEPS is still unresolved. This is related to the question of BEPS' physical location. Funding sources may vary depending on whether the BEPS is actually located on the bus. Several reasonable suggestions for funding of the BEPS are enumerated in the final report. The project team recommended forming a Standards Committee for BEPS. The committee findings will likely simplify the logistics of deployment.

"Create a component that facilitates the conversion of a hybrid electric bus into a backup power generator" – The project team identified the general attributes of the BEPS component. Off-the-shelf hardware was used to demonstrate successfully the efficacy of the overall concept.

"Demonstrate the bus generator's capabilities through a controlled simulation" – MATLAB and Simulink computer models were constructed to demonstrate the operation of the bus components, BEPS, and electrical load. The models were used to investigate control strategies. Successful strategies for paralleling of BEPS units to increase the available power were tested.

"Investigate the value a BEPS-equipped bus adds during an emergency" – The BEPS has the fastest response time of all options investigated by the project team. It is also capable of providing >200KVA loads with paralleled systems.

"Describe the most plausible, best-use option for the BEPS technology" – The BEPS approach provides the best cost-benefit within the first week of response where its quick response time can relieve cost associated with the loss of power.

"Predict obstacles upon introducing BEPS technology" – The project team had these related findings:

- The transit authority purchasing a hybrid bus has little incentive to provide the additional funds for BEPS technology since the benefits are external.

- The use of BEPS effectively will require collaboration between the transit authority (bus owners) and emergency power users.
- There may be a conflict of interest between possibly using the bus for evacuation and BEPS.

"Determine procurement, operation, and ownership options for the BEPS" – If the BEPS hardware is not on the hybrid bus, then the bus exportable power systems should qualify for funding through the same programs that currently fund the procurement and deployment of traditional emergency generators. If BEPS is on the hybrid bus, then it could be purchased with the hybrid bus with FTA funding. Other options were presented, but the question of procurement, operation, and ownership was not definitively established.

"Theorize potential next steps for the BEPS upon its actualization" – The project team presented reasonable next steps for actualization:

- A transit bus manufacturer should develop and demonstrate an exportable power system.
- An industry committee should be formed to develop standard system specifications.
- FTA should exclude buses equipped with exportable power systems from spare ratio calculations.
- Bus exportable power systems should qualify for funding through the same programs that currently fund the procurement and deployment of traditional emergency generators.

Conclusion

The project team determined that emergency management in the US employs a "bottom-up approach" to managing emergencies. Therefore, when emergency backup power is needed, the local jurisdiction attempts to fill the request first. When deployed, BEPS will be available nearby and can quickly fill the local need.

The project team has shown, through the demonstration and computer simulations, that the technology is available to produce a BEPS product. Whether the BEPS should be separate or integrated with the hybrid bus remains an open question.

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