US Army Corps of Engineers®
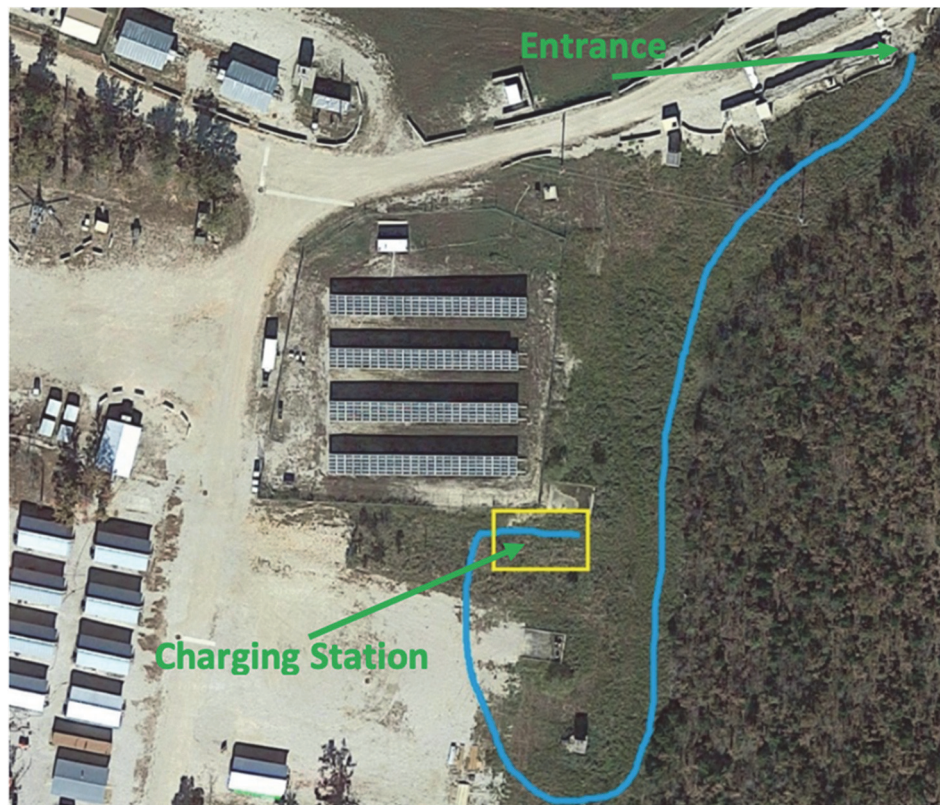Engineer Research and
Development Center

Integration of Autonomous Electric Transport Vehicles into a Tactical Microgrid

Final Report

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Final Technical Report (TR)

Abstract

The objective of the Autonomous Transport Innovation (ATI) technical research program is to investigate current gaps and challenges and develop solutions to integrate emerging electric transport vehicles, vehicle autonomy, vehicle-to-grid (V2G) charging and microgrid technologies with military legacy equipment. The ATI research area objectives are to: identify unique military requirements for autonomous transportation technologies; identify currently available technologies that can be adopted for military applications and validate the suitability of these technologies to close need gaps; identify research and operational tests for autonomous transport vehicles; investigate requirements for testing and demonstrating of bidirectional-vehicle charging within a tactical environment; develop requirements for a sensored, living laboratory that will be used to assess the performance of autonomous innovations; and integrate open standards to promote interoperability and broad-platform compatibility. This final report summarizes the team's research, which resulted in an approach to develop a sensored, living laboratory with operational testing capability to assess the safety, utility, interoperability, and resiliency of autonomous electric transport and V2G technologies in a tactical microgrid. The living laboratory will support research and assessment of emerging technologies and determine the prospect for implementation in defense transport operations and contingency base energy resilience.

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1   Introduction

1.1   Background

The Army needs a realistic testing area to test developing autonomous vehicle technology for use on Army installations and contingency operations. The military is slow to take advantage of government, academic and industry expertise to accelerate the integration of unmanned vehicle technologies into defense and civilian transport operations until the technology is tested and proven safe and reliable for transportation on post. Autonomous vehicles offer the opportunity to reduce personnel (drivers), reduce the environmental footprint and demand for individual vehicles and associated parking, and increase mobility for military and civilian personnel. Research is needed to integrate large autonomous electric vehicles into a microgrid in a way to enhance the resiliency of the installation and surrounding community.

There is a requirement to prototype the integration of unmanned vehicle technologies into defense and civilian transport operations. The ability to test and demonstrate how a variety of autonomous transportation systems could be integrated into an installation transportation network and microgrid is required to build confidence in these technologies. How can autonomous electric vehicles be integrated into contingency base operations to enhance energy security while reducing reliance on vulnerable resupply operations that put Soldiers at risk.

This effort responds to DoD research needs to accelerate the adoption and use of intelligent ground vehicle systems for military operations; and find innovative opportunities to enhance both installation and contingency basing energy resilience.

1.2   Objective

Develop an operational "living laboratory" on a military base to research and demonstrate the value of autonomous transportation systems in real-world, non-hostile environment. A prototype bench scale testing area will be developed to include paved and non-paved areas plus a microgrid charging capability. The goal is to be able to attract and test autonomous

systems, monitor their performance, and identify reliability problems or safety risks to the military before the autonomous systems are exposed to civilian or military personnel at a larger scale.

Investigate how Army installations can integrate large autonomous electric vehicles into a microgrid to enhance the resiliency of the installation and surrounding community. Results will help Army installations and surrounding communities plan adoption of unmanned vehicle technologies. Research how autonomous electric vehicles can be integrated into contingency base operations to enhance energy security while reducing reliance on vulnerable resupply operations that put Soldiers at risk.

Fort Leonard Wood is a partner to the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) in demonstrating Autonomous Vehicle technologies. Fort Leonard Wood is the host installation for all 88M truck driver training for Army, Navy, Air Force, and Marine Corps; this provides:

- a large secure space for vehicle testing including paved, unpaved and off-road environments; and

- a realistic demonstration of technologies with Soldiers, Airmen and Marines to best assess the utility of these systems in operational environments.

1.3   Approach

The team members will research and demonstrate the safety and utility of autonomy-enabled vehicles in various scenarios and environmental conditions. Incorporate a demonstration microgrid that will integrate electric vehicles, charging stations, and renewable power to power adjacent facilities. The electric vehicle batteries will provide energy storage for the microgrid. The microgrid will be scalable to allow for growth as additional electric vehicles are added to the program. The center will expand to include civilian transport research applications, including autonomous commercial freight movement, underground mining equipment, and transit operations. Research results will also inform and accelerate driverless vehicle policy development.

The purpose of the Autonomous Transport Innovation (ATI) RDTE project is to develop a roadmap for a sensored, living laboratory to integrate autonomous transport vehicles into a tactical microgrid.

The scope of the ATI technical research program is as follows:

1. Identify military-unique requirements for autonomous transport technologies
2. Identify existing technologies that can be adapted for military applications, conduct technology gap analysis and identify need gaps
3. Identify research and operational tests for autonomous transport vehicles
4. Investigate requirements for testing and demonstrating vehicle charging within tactical microgrid environment
5. Develop requirements for a sensored living laboratory to assess performance of autonomous innovations
6. Integrate open standards to promote interoperability.

1.4 Worldwide threat assessment

The Worldwide Threat Assessment of the U.S. Intelligence Community was presented to Congress by the Director of National Intelligence on January 29, 2019. The presentation identified threats to U.S. national security that will both expand and diversify as "development and application of new technologies introduce both risks and opportunities" to the U.S. economy. Of the global threats identified, "our adversaries and strategic competitors will increasingly use cyber capabilities—including cyber espionage, attack, and influence—to seek political, economic, and military advantage over the United States and its allies and partners." These cyber capabilities are used to attack and hold at risk the nation's critical infrastructure.[*] Moreover, the U.S. Department of Homeland Security (DHS) Cybersecurity and Infrastructure Security Agency (CISA), identified "16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any

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[*] Coats, Daniel R. "Global Threats: Cyber." *Worldwide Threat Assessment of the U.S. Intelligence Community,* 29 Jan. 2019, p. 5., https://www.dni.gov/files/ODNI/documents/2019-ATA-SFR---SSCI.pdf.

of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications."[*]

1.7   Electric transportation as a distributed energy resource

The shift from fossil fuel-reliant transportation to electric transportation presents a new paradigm in the transportation and energy sectors. The onboard energy storage electric transport vehicles provide introduces the potential to access an additional and distributed electric power supply through bidirectional power flow. V2G charging equipment, an emerging technology, is essential in enabling a bidirectional flow of electric power between electric transport and energy systems. It is this connection that allows electric transportation to provide ancillary energy and assurance to local energy generation resulting in improved reliability, flexibility, and resilience.

1.8   Autonomy

Electrified transport systems, coupled with V2G technologies, are being evaulated for future deployment and benefit to the modernized grid. These benefits have potential to carry over to U.S. military defense transportation operations as well as contingency and enduring base energy applications. The U.S. Department of Defense (DoD) and Army have invested in research-developing technologies designed to reduce risks to the warfighter and decrease reliance on vulnderable resupply operations. This objective can be achieved through integrating autonomous technologies with electric transport.

The DoD and the Army understand the potential importance of autono-mous vehicles (AVs) as illustrated by this commentary from the Army website:

> The Department of Defense has been researching the use of autonomous vehicles since 2004, when the Defense Advanced Research Projects Agency (DARPA) funded specific research and technology and sponsored its first autonomous vehicle competition. While the most recent technical

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[*] National Institute of Standards and Technology, U.S. Department of Commerce. "Purpose and Scope: Overview and Background." *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0*, Sept. 2014, p. 14., https://www.nist.gov/system/files/documents/smartgrid/NIST-SP-1108r3.pdf.

> emphasis has undoubtedly been on front-line functions such as un-
> manned tactical vehicles or light maneuver capabilities such as bomb dis-
> armament, those assets are not technically autonomous vehicles. Autono-
> mous vehicles present opportunities to improve logistics, security, base
> operation and maintenance, transport, and eventually warfighting. As
> such, they represent a significant advancement in how we conduct all
> phases of the military mission.[*]

Army leadership realizes the potential of AVs. Unmanned systems will en-
able the Army of the future. To achieve its vision for 2028, the Army has
identified equipment modernization as a key objective with efforts focused
on "… experimenting with and developing autonomous systems, artificial
intelligence and robotics to make our Soldiers more effective and our units
less logistically dependent."[†]

The number of applications and potential benefits for AVs are wide rang-
ing. For use in forward areas, AV potential benefits are:

- Autonomous logistics operations could reduce the number of casualties
  associated with transport. According to the DoD, "Fifty-two percent of
  battlefield casualties occur when sustainers are delivering needed sup-
  plies to and from the battlefield."[5]
- Supporting continuous (24 hours a day, 7 days a week) supply opera-
  tions in theatre, efficiently creating and improving overall supply and
  resupply operations.
- Support security for convoys and forward-operating bases (FOB)
  through increased reconnaissance capacity and, eventually, warfighting
  capability.

Initial AV development and testing is well suited for various military in-
stallations—and, as such, is where initial testing and development will oc-
cur. In addition to supporting forward operations, there are various poten-
tial installation operations and maintenance benefits that AVs could pro-
vide to the military:

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[*] Henry, Capt. Matthew P. "Autonomous Transportation: Combat Power in the 21st Century." U.S. Army,
1 Nov. 2018, army.mil/article/213078/autonomous_transportation_combat_power_in_the_21st_century.

[†] General Mark Milley, Army Chief of Staff, Honorable Mark Esper, Secretary of the Army. "Army 2028
Mission and Vision Statement."26 March 2019, pp. 7.

- Reduced cost and streamlined routine or continuous, high-capacity personnel transit by reducing the number of vehicles and staff used to bus personnel—for example, a basic training Army base, such as Fort Leonard Wood, provides in excess of 1.5 million soldier trips a year[*] in support of basic training. Many of which are recurring transit operations that could be automated.
- Improved transit scheduling and delivery results in reduced training-time losses associated with current systems.
- With emerging AVs, reduced costs (personnel time, contract labor, equipment, fuel, etc.), routine mowing, and land maintenance in training areas and ranges. Installations can spend millions of dollars annually in various land management activities.[†]
- AV land management activities in training areas and ranges that can be conducted when training is not occurring (day or night) reduces loss of areas for routine maintenance, which increases effective availability of training areas and ranges.
- AV point-to-point logistics systems used to establish bidirectional transportation whereby vehicles always travel hauling materials to or from storage and supply areas.
- AV systems that conduct routine road maintenance (sweeping, plowing, etc.) and unpaved trail maintenance and repair—all reducing the cost while providing improved access in support of the mission.

The development, deployment, and implementation of AVs offers a myriad of potential benefits. A report, prepared by Compass Transportation and Technology (CTT) for Securing America's Future Energy (SAFE), notes that economic benefits of AVs include: improved access to labor and jobs, access to new markets and larger markets, a reduction in public-financing capital required for traditional transportation investments, stimulated growth in shared-mobility markets, changed land use, and reduced costs for long-haul freight transportation. The report posits that, excluding economic productivity gains, the adoption of AV adoptions provides a benefit cost ratio of 8 to 1, or about $6 trillion–$8 trillion. Further research from SAFE notes that "significant economic benefits from the widespread

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[*] "ARIBO: Fort Leonard Wood." *Robotic Research, LLC*, roboticresearch.com/programs/aribo-fort-leonard-wood/.

[†] Barghout, Jeff, et al. Joint Base "Lewis-McChord Feasibility Study for the Application of Automated Vehicles." pp. 1–39, Joint Base Lewis-McChord Feasibility Study for the Application of Automated Vehicles.

adoption of AVs could lead to nearly $800 billion in annual social and economic benefits by 2050."[*]

In a report prepared and delivered to DOE Secretary Rick Perry and U.S. Department of Transportation (DOT) Secretary Elaine Chao, that in their own previous commissioned studies, research, and analysis found the cumulative consumer and societal benefits of AVs would add $3 trillion–$6 trillion to the U.S. economy and, that annually, the full deployment of AVs could realize $800 billion in economic and societal benefits.[†] Additionally,

> In 2016, U.S. annual vehicular fatality rate was 37,461; 94% of crashes are due to human error. AVs have the potential to remove/reduce human error and decrease deaths. Depending on adoption and vehicle characteristics, AVs have the potential to reduce crashes by 90%, potentially saving approximately $190 billion per year. Potential AV benefits include improvements in safety and public health; increased productivity, quality of life, mobility, accessibility and travel, especially for disabled and elderly; reduction of energy use, environmental impacts, congestion and public and private costs associated with transportation; and increased adoption of car sharing."[‡]

1.9 Interoperability among devices

The rapid evolution and convergence of state-of-the-art technologies in autonomy, energy, and transportation yield uncharted technical challenges and gaps. As new and emerging technologies come online, industry standards are increasingly behind the curve. Widespread deployment of systems with onboard energy storage and cyber-based communication within the grid underscores the urgency for modernized interconnection, interoperability, and cyber security standards to achieve interoperability among grid devices and systems.[§] As new technologies, applications, and sources of value continue to emerge, the adopting of interoperability

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[*] SAFE, Fuel Efficiency Standards Should be Modernized to Expand the Use of Advanced Fuels, Promote Driverless Technologies, and Strengthen U.S. Energy Security, Oct 2018, https://avworkforce.secureenergy.org/.

[†] http://secureenergy.org/wp-content/uploads/2018/10/Securing-Americas-Future-EnergyComments-on-EPA-HQ-OAR-2018-0283-0756.pdf.

[‡] University of Michigan Center for Sustainable Systems, Autonomous Vehicles factsheet, accessed 31 Oct 2019, http://css.umich.edu/factsheets/autonomous-vehicles-factsheet.

[§] "Smart Grid." NIST Engineering Laboratory, U.S. Department of Commerce, 21 Nov. 2019, www.nist.gov/el/smart-grid.

standards is paramount to enable efficiency and reliability in today's increasingly complex energy sector.

As new DER technologies and capabilities emerge, the shift to a modernized grid yields new engineering challenges. The establishment of interoperability standards is fundamental for this transformation. Interoperability, as defined by the GridWise™ Architecture Council, is the

> capability of two or more networks, systems, devices, applications, or components to work together, and to exchange and readily use information—securely, effectively, and with little or no inconvenience to the user. The modern grid will be a system of interoperable systems, which are different systems able to exchange meaningful, actionable information in support of the safe, secure, efficient, and reliable operations of electric systems. The systems will share a common meaning of the exchanged information, and this information will elicit agreed-upon types of response. The reliability, fidelity, and security of information exchanges between and among modernized systems must achieve requisite performance levels.[*]

Advances in technologies, such as smart metering, demand response, distributed generation, ESSs and EV supply equipment, are developed to offer bidirectional flows of energy and two-way communication and control capabilities. Competitive and individualized manufacturing of multilevel components drives diversity in the market and postures the need for standardize interoperability requirements. In the absence of standards, there is a risk that diverse, modern grid technologies will become prematurely obsolete or be implemented without adequate security measures.[†]

Recognizing the necessity, federal and state agencies, utilities, stakeholders, and industry leaders are actively working to develop policies, protocols, and standards to promote system interoperability. The joint agencies of California: California Public Utilities Commission (CPUC), California Energy Commission (CEC), California Air Resources Board (CARB), and

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[*] GridWise™ Architecture Council, "GridWise Architecture Council Interoperability Constitution Whitepaper," October 2005 https://www.gridwiseac.org/pdfs/interoperability_path_whitepaper_v1_0.pdf.

[†] National Institute of Standards and Technology, U.S. Department of Commerce. "Purpose and Scope: Overview and Background." *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0,* Sept. 2014, https://www.nist.gov/system/files/documents/smartgrid/NIST-SP-1108r3.pdf.

California Independent System Operator (CAISO), collaboratively make up the vehicle-grid integration working group to develop policies that support V2G integration. The initiative, to align EV charging with the needs of the electric grid, is slated to assess communication protocol necessary to enable EVs with capabilities to support bidirectional charging while economically participating in electricity markets at scale.[*] The challenge: standardized connection and communication between the vehicle and the grid, optimization and price signaling, and mitigating impacts to the grid.

The Institute of Electrical and Electronics Engineers Standards Association (IEEE SA) facilitates standard development for a high-quality, market- relevant standardization environment that is respected worldwide.[†] Standard 1547-2018 provides standards for interconnection and interoperability of DERs with associated electrical power systems interfaces:

> The standard provides universal requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection. It also includes general requirements, response to abnormal conditions, power quality, islanding, and test specifications and requirements for design, production, installation evaluation, commissioning, and periodic tests.[‡]

Formerly, the original equipment manufacturer (OEM) designed and had complete control of EV onboard charging equipment operation, the rise in direct current (DC) fast charging with bidirectional capabilities creates a new challenge. The 2030.1.1-2015—IEEE SA help OEM engineers address the challenge of controlling an external power device in EV supply equipment. "This interoperability standard specifies the design interface of EVs and DC bidirectional chargers that utilize battery EVs as power storage devices."[§]

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[*] "DRIVE OIR Vehicle-Grid Integration Working Group." *Vehicle-Grid Integration Communications Protocol Working Group*, California Public Utilities Commission, www.cpuc.ca.gov/vgi/.

[†] "IEEE SA – Strategy." *IEEE SA,* https://standards.ieee.org/about/strategy.html.

[‡] "1547-2018 – IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces." *IEEE SA*, 6 Apr. 2018, https://standards.ieee.org/standard/1547-2018.html.

[§] "2030.1.1-2015 – IEEE Standard Technical Specifications of a DC Quick Charger for Use with Electric Vehicles." *IEEE SA*, 5 Feb. 2016, https://standards.ieee.org/standard/2030_1_1-2015.html.

1.10 DoD 2016 Operational Energy Strategy

In alignment with U.S. grid modernization initiatives and policies, the military has concentrated efforts to improve future energy security, resiliency, and reliability through policies, including the DoD 2016 Operational Energy Strategy and the Army's Energy Security and Sustainability (ES^2) Policy. The DoD 2016 Operational Energy Strategy (Figure 1) identifies three objectives to ensure consistent delivery of energy in support of the warfighter:

Figure 1. U.S. DoD policy driver to reduce energy vulnerabilities.

1. Increase future warfighting capability by including energy throughout future force development.
2. Identify and reduce logistics and operational risks from operational energy vulnerabilities.
3. Enhance the mission effectiveness of the current force through updated equipment and improvements in training, exercises and operations.[*]

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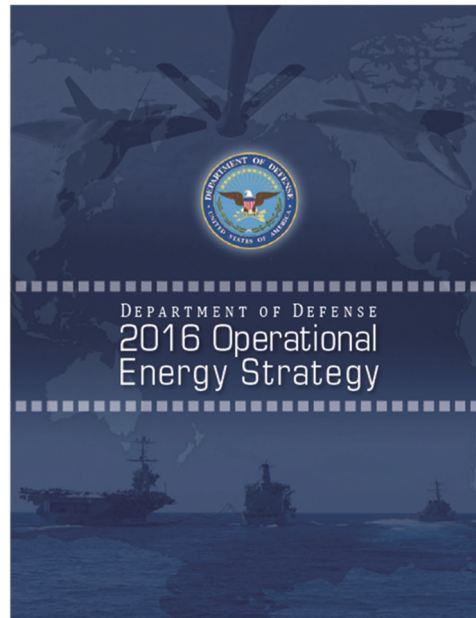
[*] U.S. Department of Defense 2016 Operational Energy Strategy, February 2016

1.11 U.S. Army's Energy Security and Sustainability Policy

Pursuant to the DoD Operational Energy Strategy, the Army's ES² Policy (Figure 2) defines a vision of "A ready and resilient Army, strengthened by secure access to the energy, water and land resources to preserve future choice in a rapidly changing world."* To achieve this vision, the ES² Policy identifies five strategic goals in an effort to provide broad direction for the integration of improved energy and water use into the Army capabilities:

Figure 2. U.S. Army policy driver to strengthen energy resiliency.

1. Inform decisions
2. Optimize use
3. Assure access
4. Build resiliency
5. Drive innovation.
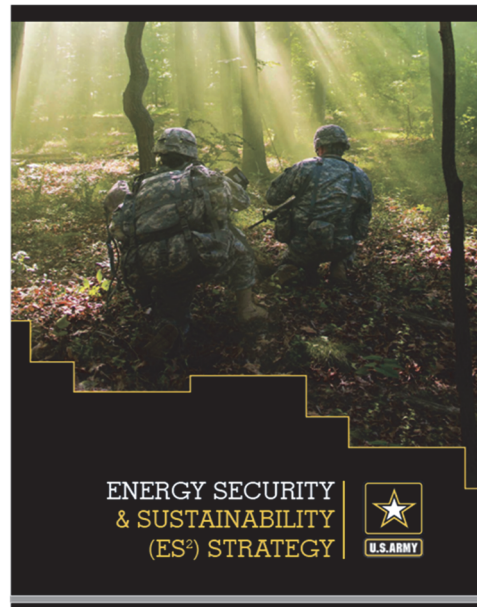
Numerous Army initiatives and programs are underway that focus on supporting this vision. They include net-zero, large-scale renewable energy, and developing energy resilient power systems for FOBs.

1.12 Tactical microgrid standards consortium

The Tactical Microgrid Standards Consortium (TMSC) is actively developing a standard to establish "requirements for tactical microgrids (TM), including the interoperability and interfaces of the hardware and software relevant to tactical microgrid design as well as considerations of intelligent control, stability and performance, safety of personnel, security, and protection." The standard defines an open architecture to facilitate tactical microgrid source ability to communicate, provide, and use services and information between systems, regardless of manufacturer or version, without the need for operator intervention. Progress is slated "to establish

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* U.S. Army Energy Security & Sustainability (ES²) Strategy, May 2015

open standards supporting a modular, highly cohesive system structure with full design disclosure to leverage the collaborative innovation of industry, academia, and government participants and stakeholders."

USACE ERDC-CERL provided a working definition of the tactical microgrid as a:

> Warfighter operated and maintained, mobile, flexible group of interconnected sources and loads that acts as a single controllable entity, which can be organized as a system, intended to be self-contained, readily deployable that may utilize alternative-energy resources and power storage, and is capable of interfacing with other grids.[*]

The tactical microgrid standard supports the development of advanced power systems that can bring energy resiliency to the warfighter through a tactical microgrid that:

- Consists of interoperable devices
- Uses a resilient, open architecture that is modular and scalable
- Accommodates mission-based equipment configurations
- Enables single-component upgrades and interactions instead of forcing system upgrades
- Utilizes multilevel cybersecurity.

Policy drivers, the emergence of new technologies, and the push to develop open standards underscore the need to develop a living laboratory to conduct tests, evaluate, and demonstrate advanced technologies to assess prospect for potential incorporation into the military. A living laboratory will promote the investigation of device interoperability and allow researchers to develop an approach to bridge the gap between new technologies and standards.

1.13 Definition of a living laboratory

The European Network of Living Labs (ENoLL) defines a living laboratory as "user-centered, open innovation ecosystems based on a systematic user

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[*] Tactical Microgrids Standards Consortium, Tactical Microgrid Interoperability Standardization, May 2018, U.S. Army Engineer R&D Center (ERDC), U.S. Army Communications-Electronics RD&E Center (CERDEC) and MIT Lincoln Laboratory

co-creation approach integrating research and innovation processes in real-life communities and settings."[*] The living laboratory is a platform for "sensing, prototyping, validating and refining complex solutions in multiple and evolving real-life contexts."[†] This research environment embodies "five key elements: innovation settings, operating environments, influence on innovation processes, user engagement, and expected outcomes."[‡]

The living laboratory, an increasingly popular research and development (R&D) concept, has gained momentum since 2006.[§] While some studies suggest the concept originated from Professor William Mitchell of the Massachusetts Institute of Technology,[**] the first historical reference of the term 'living laboratory' was used by Thomas Knight in 1749.[††] Since then, the novel concept has modernized into a multifaceted, experimental environment in real-life context.

1.14 The CERL mission

The CERL mission is to "develop and infuse innovative technologies to provide excellent facilities and realistic training lands for DoD, the U.S. Army and many other customers while also supporting ERDC's R&D mission in geospatial research and engineering, military engineering, and civil works."[‡‡] In support of this mission, the Paragon research team set out to design a roadmap for an innovative sensored, living laboratory with the capacity and capability to evaluate a nexus of emerging technologies in the fields of electric transport vehicles, vehicle autonomy, V2G, and microgrid technologies integrated with military legacy equipment. The fundamental concept of the Contingency Basing Integration Technology Evaluation Center (CBITEC) living laboratory is to serve as a testbed to facilitate real-time research and joint innovation across autonomy and microgrid

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[*] "What Are Living Labs." *About Us*, European Network of Living Labs, enoll.org/.

[†] Hossain, Mokter, et al. "A Systematic Review of Living Lab Literature." *Journal of Cleaner Production*, 1 Mar. 2019, pp. 976–988., doi:0.1016/j.jclepro.2018.12.257.

[‡] "European Network of Living Labs." *European Network of Living Labs*, enoll.org/.

[§] Hossain, Mokter, et al. "A Systematic Review of Living Lab Literature." *Journal of Cleaner Production*, 1 Mar. 2019, pp. 976–988., doi:0.1016/j.jclepro.2018.12.257.

[**] ibid.

[††] Knight, Thomas. *Reflections Upon Catholicons, Or Universal Medicines: With Some Remarks on the Natural Heat That Is in Animals, and the Luminous Emanations from Human Bodies*. Vol. 1, T. Osborne in Gray's-Inn., 1749, books.google.com.

[‡‡] "Mission Statement." *CERL Missions*, U.S. Army Corps of Engineers Engineer Research & Development Center Construction Engineering Research Lab, www.erdc.usace.army.mil/Locations/CERL/Missions.aspx.

technologies in realistic settings. An immersed, yet structured, exhibition of technologies in action will allow research and assessment of interoperability and operational performance between systems.

The CBITEC Living Laboratory roadmap facilitates an understanding of how state-of-the-art technologies can interoperate within a spectrum of possible scenarios and aid in determining the prospect for implementation to advance the military mission. This concept will support the CERL mission and posture innovation across private and public sectors where no similar applications and capabilities coexist.[*]

1.15 The Paragon Team

To develop a living laboratory roadmap, Paragon leveraged leading technical experts' ideas, knowledge, and experience in the fields of transportation, autonomy, and energy solutions. This unique collaboration led to communal information sharing and open innovation across technology borders that would have otherwise been siloed. The living laboratory is therefore a platform for the convergence of leaders across fields of interest to cocreate innovation, prompting an acceleration of technological advancement, and innovation across individualized industries. The industry experts that developed this Research, Development, Test and Evaluation (RDT&E) project are:

1.15.1 Paragon Business Solutions, Inc.

Paragon Business Solutions, Inc. provides project management, quality systems, and strategic energy expertise to improve the success and resilience of our customers. Paragon's processes create a framework that is repeatable and proven to reduce risk, improve efficiency, and deliver desired results. Founded in 1997, Paragon is a U.S. Small Business Administration (SBA) Women-Owned Small Business (WOSB).

Angela Rolufs, Vice President for Strategic Energy Initiatives, and the project proponent for the ATI project, led the Paragon team by providing program management and project delivery.

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[*] ibid.

1.15.2 Robotic Research, LLC

Robotic Research, LLC focuses on in-ground robotics, especially in locali-zation, sensor processing, and intelligent command and control. Robotic Research has extensive experience with developing robotic systems for various vehicles types, ranging from the man-portable Talon to small elec-tric shuttles and large Army Palletized Load System (PLS) trucks.

Bryan Brilhart, Senior Program Manager at Robotic Research, led the R&D efforts for improving autonomous transport technologies in a tactical envi-ronment.

1.15.3 TechFlow, Inc.

Founded in 1995 with deep operational roots in the bi-coastal innovation hubs of California and Washington D.C., TechFlow applies innovative en-gineering, technology, and integration solutions to the government's most demanding mission and business challenges, delivering impactful ingenu-ity on a government scale. TechFlow' s Energy and Mobility Solutions business unit employs subject matter experts (SMEs) with decades of proven performance in the area of program managing, engineering, energy effectiveness, as well as V2G/microgrid applications/demonstrations, en-ergy storage, technology transition, RDT&E, and resilience.

Clark Boriack, Director of Engineering for Energy and Mobility at Tech-Flow, led the research and demonstration efforts for the integration of V2G charging into a tactical microgrid.

1.15.4 The Center for Sustainable Solutions (CS2)

The Center for Sustainable Solutions (CS2) is a non-profit organization that works to advance sustainable practices throughout society by con-ducting education and outreach efforts on sustainable technologies, com-munity systems development, long-term planning, and sustainable ap-proaches to problem-solving within communities. CS2 works primarily with military installations and their surrounding communities to coordi-nate and promote sustainable technology demonstrations and validations that will advance and support state-of-the-art emerging technologies and the companies that have developed them. CS2 works to identify,

document, and promote sustainable technology R&D through needs identification and transition of technologies from research to use.

Kevin Palmer, Founder and Director of CS2, leveraged his knowledge of military installations and emerging technologies to lead the identification of military transport operations that can be improved through automation. He, and the Paragon research team, engaged with military and civilian stakeholders to define requirements and identify need gaps. Palmer also contributed to the quality-assurance effort to ensure that all deliverables meet the standards set forth in the contract.

1.15.5 Paul Brubaker, LLC

Paul Brubaker, CEO and president of Paul Brubaker, LLC, supported the Paragon team by engaging AV SMEs to advise and provide input into the latest AV technologies that the team considered for tactical operations. He acted as a technical reviewer of the reports prepared by Paragon team members to ensure high standards are met as Paragon requires and ERDC- CERL expects.

1.16 Autonomous Transport Innovation

Paragon developed the ATI RDTE project in support of the Army's ERDC-CERL innovative energy efficiency and energy security and contingency basecamp operational energy initiatives.

Paragon partnered with leaders in the field of electric transport vehicles, vehicle autonomy, V2G, and microgrid technologies to deliver the ATI RDTE project to advance the state-of-the-art of autonomous tactical vehicles and contingency-basing energy resiliency. The technical issues that have the potential to impede integrating autonomous electric transport vehicles into a microgrid were investigated and solutions documented in this report for future application. Research, results, and methodologies established can be implemented to assist ERDC-CERL in the strategic integration of new and emerging energy and resilience technologies.

The ATI technical research program investigated current gaps and challenges and develop solutions to integrate emerging electric transport vehicles, vehicle autonomy, V2G, and microgrid technologies alongside military legacy equipment. Research performed resulted in a roadmap to

develop a sensored, living laboratory with operational testing capability to assess the safety, utility, interoperability, and resiliency of autonomous electric transport and V2G technologies in a tactical microgrid. The living laboratory will support ERDC-CERL research and assessment of emerging technologies and determine the prospect for implementation in defense transport operations and contingency base energy resilience.

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The scope of the ATI technical research program is as follows:

1. Identify military-unique requirements for autonomous transport technologies
2. Identify existing technologies that can be adapted for military applications, conduct technology gap analysis and identify need gaps
3. Identify research and operational tests for autonomous transport vehicles
4. Investigate requirements for testing and demonstrating vehicle charging within tactical microgrid environment
5. Develop requirements for a sensored living laboratory to assess performance of autonomous innovations
6. Integrate open standards to promote interoperability.

2   Identify Military-Unique Requirements for Autonomous Transport Technologies

The objective of Research Area 1 is to identify military transport activities that can be automated to the benefit of the government. This research was informed through the review of government programs, standards, and practices and engagement with stakeholders.

The Paragon team identified vehicle-dependent Military Support Activities, the vehicles used to enable the activity, and the specific transport system requirements for each support activity. This information was distilled to develop specific use cases for a list of candidate transport systems that can be automated to the benefit of the military mission.

2.1   Military support activities and associated transport systems

The objective of this research was to identify military transport systems that have potential to benefit from automation. This was carried out by evaluating routinely conducted support activities performed by the military.

2.1.1   Vehicle-dependent Military Support Activities

Military Support Activities (MSA) routinely conducted in Continental United States (CONUS) installation operations were studied to document transport-dependent activities and observe transport systems used. Paragon's team engaged with stakeholders and conducted a review of literature including a thorough review of military programs, standards, and practices. CSS used a significant portion of the 46 Army Installation Strategic Plans, National Guard, Reserve, and community strategic sustainability plans that have been developed since 2000 to identify a list of common military activities that are vehicle dependent (Figure 3). These strategic plan documents included weaknesses and threats identified by a stakeholder-developed SWOT analysis. See **Appendix A: Military Strategic Planning Resource Documents** for detailed information on results from the planning done at Army Installations across the world used in identifying significant military activities for this study. In addition, a review of the Joint Base Lewis-McChord (JBLM) Feasibility Study for the Application of Automated Vehicles[7] identified and validated vehicle-dependent military activities that represent opportunities for autonomous

operation. Session notes from the JBLM Scoping Session were referenced for installation stakeholder discussion around Military Support Activities that would be most useful to conduct autonomously as part of the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) Applied Robotics for Installation and Base Operation (ARIBO) program.[6,*]

Figure 3. Military installation strategic plans reviewed.

Based on reviews of strategic plans and the JBLM session, the following Military Support Activities were identified as candidates for further review and research:

- **MSA 1**—Personnel transport
- **MSA 2**—Land management
- **MSA 3**—Logistics
- **MSA 4**—Security monitoring

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* Steucke, Paul. "Joint Base Lewis-McChord (JBLM) Autonomous Vehicle Scoping Session Summary." *Internal Meeting Summary with Installation Stakeholders to Identify Military Support Activities That Could Be Performed Autonomously*, 31 Oct. 2014, pp. 1–4.

- **MSA 5**—Land preparation
- **MSA 6**—Road maintenance.

Our team analyzed all of the content to document transport dependent Military Support Activities that were routinely identified in strategic plan documents as resource intensive, inefficient, costly, or poorly functioning to the point of adversely impacting or having the greatest potential to impact the mission. Transport-dependent Military Support Activities, the missions each could impact, along with the transportation system used for the Military Support Activity are provided in Table 1.

Table 1. Vehicle-dependent Military Support Activities.

MSA No.	MSA Type	Mission Supported	Vehicles
1	Personnel Transport: transport (1–4 people)	Installation Management Command (IMCOM)/Army Materiel Command (AMC) missions for logistics in support of installation operation—personnel transport supports all CONUS housing, training and deployment functions.	Automobile
	Personnel transport (5–20 people)		Shuttle
	Troop transport for training (platoon to company size—up to 250 Soldiers)	Mass transit is more common at basic training installations. FLW provides 2.5 million round trips annually to move Soldiers to training areas, ranges, and dining facilities.	Buses (40–80) and tractor with personnel trailer (125)
2	**Land Management:** grounds maintenance—beautification and security cutting	IMCOM/AMC installation operation —grounds maintenance can include grass cutting, snow removal, dirt removal, wood clearing (with workers), tree removal (with workers), etc.	Tractors and mowers
	Land Management: range maintenance	Two types of ground maintenance are common: grass cutting in cantonment areas and less frequent grass cutting in range and training areas. This effort would be focused on large-scale mowers and earth movers that can be used to maintain CONUS range areas (and possibly cantonment areas).	Large/farm tractors with cutting decks, plowing
3	**Logistics:** materiel transport—food, water, munitions, fuel, municipal solid waste	IMCOM/AMC Installation Operations directly supporting training (TRADOC), Garrison (FORSCOM) missions, and deployment (all installations that deploy personnel). Convoys used to support all forward-operating areas.	Delivery trucks and vans, tractors with trailers, specialty trucks (tankers, refrigeration unit, waste hauler, bucket truck), secure trucks (munitions)
	Logistics: material management and warehousing— delivery, storage and distribution		Forklifts, indoor and outdoor tugs, material handling equipment
	Logistics: airfield activities—ground support vehicles (GSVs)		Various GSVs—fuelers, pallet loaders, aircraft tugs, small loaders, munitions movers and loaders (security), deicers, plows
3	**Logistics:** vehicle and equipment hauling	Vehicle and equipment recovery and delivery—supports IMCOM/AMC operations.	Tow trucks, vehicle lifts and haulers, tractors with trailers
4	Security Monitoring	Reconnaissance in forward areas, as well as installation security monitoring.	Drones, reconnaissance vehicles

MSA No.	MSA Type	Mission Supported	Vehicles
5	**Land Preparation:** earth moving, plowing, digging	IMCOM/AMC grounds maintenance, as well as combat engineering operations and training.	Engineering equipment—scraper, crane, dozer, plow, hauler, dump truck, grader, loader, backhoe, crawler, hydraulic excavator (HYEX)
6	**Road Maintenance:** maintenance, repair, snow removal	IMCOM/AMC installation maintenance and clearing, development, and maintenance of new and existing roads in forward areas.	Grader, sweeper, dump truck, asphalt paver, compactor, roller, snowplow

2.1.2 Military Support Activity transport requirements

The military transports a variety of personnel, including Soldiers and civilian staff, for a variety of activities, such as training, dining, and Garrison support duties. Transport requirements for Military Support Activities identified in the previous section are summarized in Tables 2 to 7.

Table 2. Military Support Activity 1: Personnel transport.

Transport System	Transport Requirements
Automobile, shuttle buses (40–80), **tractor** with personnel trailer (125)	• On-post transit requirements can range from moving individuals to company-sized units (up to 250 people) around a post to train, eat, attend medical appointments, etc. • Soldier transport is accomplished by bus (40 people with packs): hauling capacity (lb.) • Distances will be a function of the demonstration: distance (burdened and unburdened [mi.]) • A Class 6–8 tractor (truck) pulling a trailer accommodating up to 100 people: towing capacity (lb.) • Personnel transport in forward areas will depend on the specific mission • Vehicle might need to traverse unpaved roads (gravel or dirt trails): ground clearance (in.)
Performance Attributes: Vehicle capacity, seating configuration, storage area, No. of egress points, rough terrain suitability	

The Army maintains over 9 million acres of land,[*] including cantonment, training, and range areas. A majority of this acreage requires management. Cantonment area management can include grass cutting, snow removal, and grounds maintenance. Land management in training areas and ranges is required to maintain operational capacity. Grass-cutting periods depend on climate and land-use schedule. Range and training maintenance can include grass cutting, invasive species removal (bush hogging), removal of foreign materials (concertina wire), revegetation, plowing, and grading.

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[*] Vincent, Carol Hardy, and Laurel Hanson. "Federal Land Ownership: Overview and Data." *Congressional Research Service*, 3 Mar. 2017, p. 6, fas.org/sgp/crs/misc/R42346.pdf.

Table 3. Military Support Activity 2: Large-scale land, training area, and range maintenance.

Transport System	Transport Requirements
Tractors and mowers: large and farm tractors with cutting decks, plowing	• Maintain thousands to hundreds of thousands of acres* • Continuous operation to mitigate invasive species and rapid growth • Systems to detect and remove foreign materials that would otherwise damage the unit (concertina wire) • Systems to detect and notify unexploded ordnance (UXO) • Systems to support land rehabilitation • Ability to work in undeveloped: ground clearance (in.) • Capacity to support land-grading and earth-moving functions
Performance attributes: Rough terrain suitability, number of attachments, sensing features (foreign objects, terrain, etc.), towing capacity	

Materiel transport has application to all military activities and is a resource-intensive activity. Logistics in forward areas represent significant risk to all personnel involved with the receipt, transport, and delivery of materiel used in operations. Transported materiel includes food, water, munitions, fuel, solid waste, warehoused materials, mail, and medical supplies.

Table 4. Military Support Activity 3: Materiel transport.

Transport System	Transport Requirements
Delivery trucks and vans; tractors with trailers; specialty trucks (tankers, refrigeration unit, waste hauler, bucket truck); secure trucks (munitions); forklifts, indoor and outdoor tugs, material handling equipment various GSVs	Towing vehicles must be able to tow at least 3 tons: towing capacity (lb.) Delivery vehicles should have sufficient capacity to provide routine materiel deliveries Vehicles should be able to function at minimum required speeds (25–45 mph) Vehicle should be able to function on gravel road: ground clearance (in.) Specialized functions should be operable by wire
Performance attributes: Towing capacity, hauling capacity, availability of specialized functions (e.g., refrigeration)	

Security is a critical consideration at CONUS and Outside Continental United States (OCONUS) installations. It is a critical function for FOBs and operations.

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* Vincent, Carol Hardy, and Laurel Hanson. "Federal Land Ownership: Overview and Data." *Congressional Research Service*, 3 Mar. 2017, p. 6, fas.org/sgp/crs/misc/R42346.pdf.

Table 5. Military Support Activity 4: Off-road, transport-based security monitoring.

Transport System	Transport Requirements
Drones, reconnaissance vehicles	• Host surveillance equipment and other platforms • Off-road capability required: ground clearance (in.) • Duration of operation in undeveloped areas: impact of geographic features on battery performance • Provide visual data to users: broadcast bandwidth (hertz [Hz])
Performance attributes: Rough terrain suitability, sensors, and monitoring capability	

Redistribution of land and materiel is a common activity that supports construction, land management, engineering operations, FOB development, and range and training area maintenance.

Table 6. Military Support Activity 5: Earth moving.

Transport System	Transport Requirements
Engineering equipment: scraper, crane, grader, dozer, plow, hauler, dump truck, etc.	• All land alteration functions associated with land maintenance and management, construction, and combat engineering
Performance attributes: Rough terrain suitability, available engineering functions (crane, dozer, dump truck, etc.)	

Establishing and maintaining surfaced, gravel, and dirt roads is a continuous and costly activity at CONUS, OCONUS installations and FOBs.

Table 7. Military Support Activity 6: Road maintenance.

Transport System	Transport Requirements
Grader, sweeper, dump truck, asphalt paver, compactor, roller, snowplow	• Maintain road condition • Grade and repair roads • Resurfacing • Plow snow
Performance attributes: Rough terrain suitability, available engineering functions (grader, resurfacing, dozer, dump truck, etc.)	

2.1.3 Vehicle performance metrics

Performance metrics can further define how well a specific vehicle can support a military activity.

Performance metrics considered include the following:

- Acceleration (burdened and unburdened)
- Battery capacity and average performance time (before batteries are empty)
- Broadcast bandwidth (Hz.)

- Distance on a full charge (burdened and unburdened)
- Efficiency (%)
- Ground clearance (in.)
- Handling (lb./ft²)
- Hauling capacity (lb.)
- Impact of geographic features on battery performance (e.g., how hills impact time between charges)
- Power (hp)
- Power to weight (hp/lb.)
- Safety ratings
- Traction (psi)
- Top speed (loaded and unloaded: lb.)
- Torque (ft-lb)
- Towing capacity (lb.)
- Traction (psi)
- Turning radius (in.).

2.2 Autonomous transport vehicle military use cases

Six vehicle-dependent Military Support Activities were evaluated to identify the current transport system used and the requirements necessary to maintain or improve effectiveness if automated. The following use cases demonstrate the value of AVs in logistics/supply, security/reconnaissance, and construction support activities. Each use case provides the basic flow of a support activity from receipt of request to delivery of needed support. Alternative scenarios are included to demonstrate how autonomy adds value that would not be available with a human-operated vehicle.

2.2.1 Use case for an autonomous vehicle supply convoy

The objective of this research is to use autonomous and EVs to move people and goods within tactical operating environments.

An FOB requires replenishing fuel and supplies to sustain military operations. The logistician receives the requisitions for supplies including fuel, food, water, munitions, ammunition, equipment, and other necessities. Supplies are loaded into autonomously operated, adequately charged electric trucks. The destination is programmed into the vehicles, which successfully navigate both paved and unpaved roads from the supply depot to the FOB. Once at the FOB, the trucks are unloaded, charged, and

autonomously return to the supply depots with any materiel required to be returned.

Subject Area: Logistics and Supply

Actors: logisticians, supply clerks, supply specialists

Stakeholders: commanders and Soldiers

Trigger: Supply clerks request supplies from the supporting supply depot.

Precondition 1: The supply clerk orders all of the needed supplies to support the operations of the FOB.

Precondition 2: The logisticians at the depot have the materiel, fuel, and autonomous transport vehicles to supply the FOBs.

Precondition 3: Vehicles can be successfully charged.

Basic Flow:

- The supply clerk orders necessary supplies from the depot.
- The supply depot receives the order.
- Supply specialists select and load the supplies onto pallets.
- Pallets are loaded onto an autonomous and adequately charged electric truck.
- The destination is programmed into the truck(s), and the truck(s) depart(s) for the FOB.
- Drone escorts are deployed to provide additional situational awareness.
- AV/EV trucks navigate the route from the depot to the FOB transmitting location data as well as video from the vehicle to the command center that is accessible to the FOB supply clerk.
- AV/EV trucks arrive at the FOB and then are unloaded by supply specialists.
- Vehicles are charged while being loaded with any materiel required to leave the base.

- Depot destination is programmed into the truck(s), and the truck(s) depart(s) for the depot.
- Trucks navigate back to the depot.
- Trucks arrive at the depot.
- Supply specialists unload the trucks.
- Trucks are cleaned, inspected, maintained, and charged for next trip.

Alternative Path 1: A vehicle in the convoy fails during the trip to the FOB (Table 8).

This scenario describes the situation where a critical component, required for the safe and/or continued operation of the AV/EV, is failing or has failed.

Table 8. Alternative Path 1: A vehicle in the convoy fails during the trip to the FOB.

Description
- Loaded truck begins to fail in route to the FOB.   - The loaded truck, its contents, and the nature of the failure are identified through onboard sensors and diagnostics.   - Diagnostics determine whether the truck can make it to the depot, reverse course, and return to the depot or if it should stop in route and await a repair crew.   - Other trucks on the supply mission continue to the FOB.   - If necessary, an additional drone is dispatched to observe and protect the disabled vehicle.   - If required, a manned repair crew is dispatched, necessary repairs are made, and truck resumes it supply mission.   - If the truck cannot be repaired in a timely manner, a new truck is dispatched to the location, supplies are transferred to the operating vehicle, and the supply mission resumes.
Postcondition/outcome: The supplies are delivered to the FOB.

Alternative Path 2: Vehicle is destroyed (Table 9).

This scenario describes when a supply vehicle is attacked by the enemy and destroyed.

Table 9. Alternative Path 2: Vehicle is destroyed.

Description
- A supply vehicle and its contents are attacked by an enemy and subsequentially destroyed.   - The escort drone is dispatched to the supply vehicle. It provides situational awareness of the incident to the depot command center.   - The level of threat is assessed by the command center.   - If necessary, the command center recommends a kinetic response to the threat.   - Once the threat is neutralized, the command center determines if ground supply can continue to be performed.   - If necessary, and when safe, a disposal unit is deployed to remove the vehicle from the road, and any blocked vehicles resume their supply mission.   - The supplies on board the destroyed vehicle are recorded at the depot, and an identical supply order is selected and loaded onto a secondary AV/EV and dispatched to the FOB.   - The mission resumes.
Postcondition/outcome: The supplies are delivered to the FOB.

Alternative Path 3: Multiple vehicles are destroyed (Table 10).

This scenario describes when multiple vehicles are destroyed after an enemy attack.

Table 10. Alternative Path 3: Multiple vehicles are destroyed.

Description
• Multiple supply vehicles attacked by an enemy and are subsequentially destroyed.
• The escort drone is dispatched to the supply vehicles. It provides situational awareness to the command center at the depot.
• The level of threat is assessed.
• If necessary, the command center recommends a kinetic response to the threat.
• Once the threat is neutralized, the command center determines whether ground supply can continue.
• If ground supply cannot continue within a reasonable timeframe, designated emergency supplies are airlifted to the FOB.
• When appropriate and safe, a disposal unit is deployed to remove the vehicles from the road, and any remaining vehicles may resume their supply mission or return to the depot.
• The supplies on board the destroyed vehicles are recorded at the depot, and identical supply orders are selected and, if appropriate, are loaded onto secondary AV/EVs where they are then dispatched to the FOB.
• The ground supply mission resumes.
Postcondition/outcome: • Needed supplies arrive at the FOB. They are unloaded and charged, allowing vehicles return to the supply depot. • Business rules: • Supply requirements are predictable and well anticipated based on historical analysis. • Depots have sufficient supplies, reserves, and vehicles to meet FOB requirements. • When ground supply operations are disrupted, airlift is possible.

2.2.2 Use case for an autonomous vehicle reconnaissance mission (command, control, communications, computing, intelligence surveillance reconnaissance)

The objective of this research is to use autonomous and EVs as platforms for forward reconnaissance missions.

AV/EVs can be used as reconnaissance and intelligence gathering platforms to increase military command's situational awareness. These vehicles can be operated fully autonomously, or remotely, depending on the mission situation. The platform can patrol the areas surrounding an FOB or a variety of terrain, including urban areas, to observe potential hostile or suspicious activity and/or provide desired situational awareness. The platform collects and transmits situational awareness from onboard sensors to include cameras, radar, radio signal, air quality, and/or chemical sensors. The platform is expected to calculate remaining battery life and return to the FOB for charging, as necessary. When necessary, multiple platforms can operate simultaneously to provide full-spectrum intelligence and offer resilience in observation without risk to human life.

Subject area: Command, Control, Communications, Computing, Intelligence, Surveillance, and Reconnaissance (C4ISR)

Actors: commanders, mission planners, and platform specialists

Stakeholders: commanders, observers, intelligence analysts, mission planners

Trigger: desire for situational awareness

Precondition 1: The FOB commander requires situational awareness within AOR.

Precondition 2: The FOB has the communication capacity to receive process and monitor situational awareness data from the AV/EV C4ISR platform.

Precondition 3: The observable area is within the EV range of the FOB to allow vehicles to perform the mission and return to the FOB.

Precondition 4: There are sufficient numbers of AV/EV platforms on the FOB to perform the required C4ISR missions.

Basic Flow:

- The commander desires situational awareness within the AOR.
- Mission planners consult with the platform specialists to plan C4ISR missions to meet commanders need.
- The platform is charged and deployed on the mission.
- The platform performs the mission.
- The platform returns to the FOB.

Alternative Path 1: Pervasive situational awareness in the area surrounding the FOB (Table 11).

Table 11. Alternative Path 1: Pervasive situational awareness in the area surrounds the FOB.

Description
• The commander desires pervasive situational awareness around the FOB. • Mission planners consult with platform specialists to plan platform placement, patrols, and rotation of platforms to ensure the necessary charging and coverage around the FOB AOR to meet the mission requirements. • Platforms perform their missions and autonomously return to base when necessary to charge. • As platforms return to the FOB to be charged, they are replaced with freshly charged platforms.
Postcondition/outcome: • The commander achieves the desired level of situational awareness and security objectives are achieved.

Alternative Path 2: Platform malfunctions or is destroyed.

This scenario describes when a platform becomes inoperable or is destroyed (Table 12).

Table 12. Alternative Path 2: Platform malfunctions or is destroyed.

Description
• The platform specialist is alerted to the platform malfunction or destruction. • The specialist determines the nature of the malfunction and whether the platform can be repaired remotely or rescued. • If the platform is inoperable and cannot be repaired or rescued, the platform can be remotely destroyed. • Mission planners and analysts assess the condition to assess risks and determine alternative paths to continue situational awareness. • When possible, the platform is replaced.
Postcondition/outcome: • The mission may continue. • The mission might be interrupted. • Sensitive technology does not fall into enemy hands. Business Rules for the C4ISR Mission: • The systems required to support AV/EV-C4ISR platform operation are in place at the FOB. • All AV/EV platforms are continuously monitored for performance and return to the FOB, when possible, in the case of performance degradation. • Platforms are destroyed if there is a risk of capture.

2.2.3 Use case for an autonomous vehicle construction support mission

The objective of this research is to use autonomous and electric platforms to support the military construction mission.

A commander decides to construct an FOB. AV/EV platforms are deployed to support land clearing, grading, site preparation, construction of perimeter fencing, security, and initial buildings.

Subject Area: Military Construction

Actors: commanders, military construction engineers, construction support

Stakeholders: commanders and Soldiers

Trigger: commander give the order to establish an FOB at a particular location.

Precondition 1: The commander and planners have selected a site for the FOB.

Precondition 2: U.S. Army Corps of Engineers have AV/EVs capable of performing autonomous construction tasks.

Precondition 3: AV/EVs can be transported to the FOB location with generators along with a tactical microgrid for charging vehicles.

Basic Flow:

- The commander orders the construction of the FOB.
- Clearing and grading specifications are determined and programmed into the AV/EV construction platforms.
- Computer-Aided Design (CAD) designs are developed, and construction plans and staging order requirements are programmed into the control center. Instructions are provided to the robotic construction systems and AV/EV platforms.
- USACE leverages AV/EV supply vehicles to transport AV/EV construction platforms, robots, and automated construction systems as needed to the FOB site.
- A temporary generator, fuel, and charging equipment is transported to the site to support the AV/EV clearing and grading equipment.
- AV/EV construction equipment begins clearing and grading the site for barracks and support facilities construction.
- A tactical microgrid, EV, and robotic charging stations are transported to the FOB site and set up inside the FOB perimeter, per the CAD site design.
- AV/EV robotic platforms drill holes to inject concrete and fence posts around the perimeter of the FOB and install fencing.
- Off-site automated prefabrication systems, such as additive manufacturing and building component manufacturing equipment, arrives.

- Onsite automated and robotic systems, such as single-task construction robots for steel-truss assembly, welding, installation, cinder block laying, and concrete pouring, arrive on site.
- Robotic systems and AV/EV construction platforms begin construction of the FOB facilities, per the CAD specifications.
- All platforms and robotic systems are charged as needed.
- As tasks and construction is complete, specific AV/EV platforms, construction robots, and systems are loaded onto AV/EV and then returned to depots for the next assignment.

Alternative Path 1: The Only AV/EV Support is for Site Clearing and Grading (Table 13).

This scenario describes what happens when site clearing, and grading are the only available autonomous systems.

Table 13. Alternative Path 1: The only AV/EV support is for site clearing and grading.

Description
• The commander orders construction of the FOB.
• Clearing and grading specifications are determined and programmed into the AV/EV construction platforms.
• CAD designs and construction plans are developed.
• USACE leverages AV/EV supply vehicles that are used for transport. AV/EV clearing and grading equipment, traditional construction equipment, fuel, and supplies are transported as needed to the FOB site.
• A temporary generator, fuel, and charging equipment are transported to the site to support the AV/EV clearing and grading equipment as well as the traditional construction equipment.
• AV/EV construction equipment begins clearing and grading the site for barracks and support facilities construction.
• A tactical microgrid equipment and EV charging stations are transported to the FOB site and installed inside the FOB perimeter, per the CAD site design to support future AV/EV missions, such as supply and C4ISR.
• Traditional construction equipment begins construction of the FOB facilities, per the CAD specifications.
• As tasks and construction are complete, the AV/EV clearing and grading equipment and traditional construction equipment are loaded onto AV/EV transport vehicles. They are returned to depots for the future assignment.
Postcondition/outcome: • The FOB is built with limited autonomous support and requires more personnel support.

Alternative Path 2: Construction Robots Malfunction or are Otherwise Inoperable (Table 14).

Table 14. Alternative Path 2: Construction robots malfunction or are otherwise inoperable.

Description
• The commander orders the construction of the FOB.
• Clearing and grading specifications are determined and programmed into the AV/EV construction platforms.
• CAD designs are developed, and construction plans and staging order requirements are programmed into the control center. Instructions are provided to the robotic construction systems and AV/EV platforms.
• USACE leverages AV/EV supply vehicles to transport AV/EV construction platforms, robots, and automated construction systems as needed to the FOB site.
• A temporary generator, fuel, and charging equipment are transported to the site to support the AV/EV clearing and grading equipment.
• AV/EV construction equipment begins clearing and grading the site for barracks and support facilities construction.
• A tactical microgrid, EV, and robotic charging stations are transported to the FOB site and set up inside the FOB perimeter, per the CAD site design.
• AV/EV robotic platforms drill holes to inject concrete and fence posts around the perimeter of the FOB and install fencing.
• Off-site automated prefabrication systems, such as additive manufacturing and building component manufacturing equipment, arrives.
• Onsite automated and robotic systems, such as single-task construction robots for steel-truss assembly, welding, installation, cinder block laying, and concrete pouring, arrive on site.
• Single-task robot(s) fail to function as performed.
• Robotic system software and systems are remotely examined and, if necessary, repaired if possible.
• Other work continues if possible until the robotic system can be either repaired remotely or in person or a replacement robotic system arrives.
• Robotic systems and AV/EV construction platforms resume construction of the FOB facilities, per the CAD specifications.
• All platforms and robotic systems are charged as needed.
• As tasks and construction is complete, specific AV/EV platforms, construction robots, and systems are loaded onto AV/EV and returned to depots for the next assignment.
Postcondition/outcome:
• The FOB is built with minimal disruption to the construction schedule.

Alternative Path 3: Site is Attacked as Construction Begins (Table 15).

Table 15. Alternative Path 3: Site is attacked as construction begins.

Description
The commander orders the construction of the FOB. • Clearing and grading specifications are determined and programmed into the AV/EV construction platforms. • CAD designs are developed, and construction plans and staging order requirements are programmed into the control center. Instructions are provided to the robotic construction systems and AV/EV platforms. • USACE leverages AV/EV supply vehicles to transport AV/EV construction platforms, robots, and automated construction systems as needed to the FOB site. • A temporary generator, fuel, and charging equipment are transported to the site to support the AV/EV clearing and grading equipment. • AV/EV construction equipment begins clearing and grading the site for barracks and support facilities construction. • A tactical microgrid, EV, and robotic charging stations are transported to the FOB site and set up inside the FOB perimeter, per the CAD site design. • AV/EV robotic platforms drill holes to inject concrete and fence posts around the perimeter of the FOB and install fencing. • The site is attacked. • All transport to the FOB stops until the enemy is engaged and neutralized. • Once neutralized, the damage is assessed, and replacement equipment and supplies are ordered, if necessary. • Deliveries of equipment and supplies resume. • Off-site automated prefabrication systems, such as additive manufacturing and building component manufacturing equipment, arrives. • Onsite automated and robotic systems, such as single-task construction robots for steel-truss assembly, welding, installation, cinder block laying, and concrete pouring, arrive on site. • Robotic systems and AV/EV construction platforms begin construction of the FOB facilities, per the CAD specifications. • All platforms and robotic systems are charged as needed. • As tasks and construction is complete, specific AV/EV platforms, construction robots, and systems are loaded onto AV/EV and returned to depots for the next assignment.
Postcondition/outcome: • The FOB is built with limited disruption to the construction schedule. • Outcome: FOB is constructed with minimum personnel placed at risk, and construction can occur 24 hours a day. • Business Rules: • AV/EV construction and robotic construction equipment is deployed to the maximum extent practicable. • If AV/EV construction equipment, or robotics construction equipment, is not available for required construction roles, traditional construction equipment will be used. • CAD drawings, supply staging, and construction plans are modified based on the mix of AV/EV, robotic equipment, and traditional construction equipment.

2.3 Conclusion

Research conducted in Research Area 1 resulted in the identification of vehicle-dependent Military Support Activities, the transport system requirements for each activity, and military transport systems that are candidates for automation. Use cases further defined the value of autonomy for specific Military Support Activity scenarios. The research conducted in this first phase of the project set the parameters for the development of a prioritized list of transport systems for automation. Research Area 2 provides an analysis of current and emerging electric vehicle technologies that can support these transport systems and Paragon's research goals of integrating the vehicles into a tactical microgrid.

3   Research and Identify Existing Technologies That can be Adapted for Military Applications

The objective of this research is to identify existing transport systems that can be automated to benefit the military mission. For the purpose of this research, only existing electric transport systems were considered. These systems were cataloged in accordance with support activity application, resulting in a preliminary list of categorized candidate electric transport systems that have automation potential. Additionally, the Paragon team identified autonomous vehicle OEM and kit manufacturers that might have compatibility with identified EVs.

3.1   Transport systems that can be automated to the benefit of the military

Initial, broad internet searches were conducted to identify existing manufacturers and companies that develop electric transport systems. Identified electric transport system websites were recorded and analyzed for basic, available information. Reviewed websites for electric transport system manufacturers are provided in **Appendix B**. **Appendix C** summarizes addition EV and AV technology, industry, research, and DoD sources and websites reviewed for information on existing and emerging technologies. These sources (**Appendices B** and **C**) served as the foundation for this research and allowed for a more narrowed research approach going forward. Electric transport systems were then researched through review of literature—publications, journals, forums, associations, resources, journals, forums, associations, resources, and websites were—for objectivity of research and the development of a comprehensive collection of data. The validity of manufacturers or electric transport company claims were cross-referenced through review of secondary and tertiary sources. A practical limitation impacting the collection of data was the availability of information on public websites. In-depth data were gathered from priority manufacturers during the engagement process.

The literature search did not identify an available EV for the following Military Support Activities:

- **Heavy engineering equipment**: scraper, crane, dozer, plow, hauler, dump truck, grader, loader, backhoe, crawler, HYEX
- **Large grounds maintenance tractors**—no fully EVs were identified; however, smaller EV tractors are coming onto the market as well as hybrid EV (HEV) farm tractors
- **Specialty trucks**, such as bucket trucks, pump trucks, etc. HEVs are available but not fully EV versions.

In general, for these cases, the activity was not considered further in the information gathering and evaluation process. In addition, many automobile manufacturers have established AV research, design, and development (RD&D) efforts. Further, the Army Combat Capability Development Center—Ground Vehicle Systems Center (CCDCGVSC) is the lead for all research and demonstration activities conducted with automobile manufacturers. As such, automobiles were excluded from additional research, information gathering, and consideration for this effort. Future autonomous automobile demonstrations might be warranted in conjunction with the lead Army organization.

3.1.1 Candidate electric transport systems

Based upon the literature evaluation, Table 16 lists candidate electric transport systems that can be automated to benefit the military mission. These systems are categorized by Military Support Activity transport systems. A preliminary list of these systems identified from the initial literature search is provided in **Appendix D**.

Table 16. Candidate EVs.

Model	Manufacturer
Shuttles and Transit Buses (MSA 1)	
EV22, EV27, EV3 shuttle buses	AVM
e.Cobus shuttle	COBUS Industries
3000 shuttle	COBUS Industries
K7, K95, K9, K11 shuttles	BYD
C6, C9 & C10 buses	BYD
eBus	eBus
Transit EV	Ford

Model	Manufacturer
Transit PHEV	Ford
EV250, EV300, EV350, EV400 & EV550 shuttle buses	GreenPower Bus
Xcelsior	New Flyer
Catalyst	Proterra
All American RE, Microbird G5	Blue Bird
LEV Repower	Lightning Systems
Ford E-450 shuttle	Lightning Systems
Ford Transit Passenger	Lightning Systems
Synapse bus	GreenPower
EVStar shuttle	GreenPower
Axess	ENC
EZ-Rider II	ENC
LFS HEV	Nova Bus
Tractors and Mowers (MSA 2)	
eDrive tractors	Autonomous Tractor Corporation (ATC)
Class 6 & 8 Refuse	BYD
SESAM tractor	John Deere
eUtility tractor	Solectrac
eFarmer tractor	Solectrac
Nemesis mower	Mean Green Mowers
CXR-52/60 mower	Mean Green Mowers
Stalker mower	Mean Green Mowers
FL Electric & FE Electric refuse	Volvo
LR Electric refuse	Mack
Trucks and Vans (MSA 3 and MSA 4)	
Newton	Utilimaster/Smith Electric
Newton	Utilimaster/Smith Electric
e-100	Workhorse
NGEN 1000 van	Workhorse
E100 van	Workhorse
W-15 truck	Workhorse
Class 6 step van	BYD
Super Duty F Series	XL Fleet/Ford
eVito	Mercedes-Benz
Vocational, medium- & heavy-duty Trucks (MSA 1 and MSA 3)	
Class 8 Day cab	BYD
Terminal tractor	BYD
Class 5 & 6 truck	BYD
T-Series Terminal trucks	Orange
eM2 box truck	Freightliner
eCascadia semi	Freightliner
Class 8 semi	Tesla

Model	Manufacturer
ZeroTruck	Zero Truck
V8011 refrigerated van	Chanje/Thermo King
Ecantor van	Fuso
220EV, 520EV, 579EV	Peterbilt
Class 6 box truck	Lightning Systems
Ford E-450 Cutaway	Lightning Systems
Ford Transit Chassis cab	Lightning Systems
Ford F-59	Lightning Systems
NikolaTwo	Nikola
Specialty Vehicles (MSA 3, MSA 5 and MSA 6)	
Mobile Power System (MPS) Disaster Response Platform	Dannar
Burden carrier hauler	Johnson Industries
Airport carrier	Johnson Industries
Ground support utility truck	Johnson Industries
Large ground support truck	Johnson Industries
Airport GSVs	Johnson Industries
Customized hauler	Johnson Industries
Platform carrier	Johnson Industries
Indoor outdoor towing/lifting	Linde Material Handling
Warehousing	Taylor-Dunn (Polaris company)
ECB Series forklift	BYD Motors
HyPower	Terex Utilities
Heavy-duty Vehicles (MSA 1 and MSA 3)	
EC15 & EC27 compact excavators	Volvo Construction Equipment
L20 & L28 wheel loaders	Volvo Construction Equipment
LX2 compact wheel loader	Volvo Construction Equipment
EX2 compact excavator	Volvo Construction Equipment
988K XE wheel loader	Caterpillar
D6 XE dozer	Caterpillar
V8011 refrigerated van	Chanje/Thermo King
Ecantor van	Fuso
220EV, 520EV, 579EV	Peterbilt
Class 6 box truck	Lightning Systems
Ford E-450 Cutaway	Lightning Systems
Ford Transit Chassis cab	Lightning Systems
Ford F-59	Lightning Systems
NikolaTwo	Nikola

3.1.2 Research project compatibility

Research identified several types of vehicles that could provide benefits to the military but were not further considered for one or more of the following considerations:

- Could the Military Support Activity rely on an EV of sufficient battery capacity that it can support V2G and microgrid R&D objectives? If not, are there additional considerations that could result in that activity (and its class of vehicles) being further considered as part of this initial research? Of the Military Support Activities identified in Table 1, small-scale grounds maintenance (security, grass cutting, and beautification), airfield activities, and ground service vehicles (GSV), security monitoring conducted by electric drones, warehousing activities and unmanned logistics (excluding point-to-point delivery), and vehicle towing do not offer sufficient battery storage capacity (50 kilowatt-hours [kWh]) to support tactical microgrid demonstrations envisioned for the ATI. As such, these activities were excluded from further consideration.
- To provide a charge/discharge capacity of 50 kilowatts (kW), a usable energy storage rating of 50 kWh is needed for most battery technologies (also referred to as a 1c rating in the battery industry). The team is targeting a 50-kW charge/discharge capacity because a 50-kW charger can be tested as a reasonable replacement for the standard 60 kW Advanced-medium Mobile Power Source (AMMPS) generators that are to be included in the microgrid. Fifty kW is also the rating of the bidirectional chargers that are located at Los Angeles Air Force Base (LAAFB) that CERL would like to use in the future and enables using the charger at full capacity. A vehicle with less than a 50-kWh rating will require multiple vehicles and chargers to be tested as a 60-kW AMMPS replacement, further increasing overall cost.
- Can testing be suitably simulated at CBITEC/FLW? The team members are familiar with the facilities and configuration of FLW and have determined that the environment would allow operation of the test vehicles and tactical microgrid and V2G infrastructure in a realistic, simulated environment. Specifically, the varied terrain and diverse topography of the FLW installation allows for testing in various environments that will simulate forward-operating environments.

Any Military Support Activities targeted for demonstration should be able to perform in this environment to provide realistic simulation scenarios that can translate to use in forward areas. No remaining Military Support Activities were precluded based upon this consideration.

- Is there ongoing R&D in the private sector to obviate need for the program to focus on this operation? Could the Army, in the near future, purchase an AV system that is functional and commercially available and performs target mission support activity? Paragon's research revealed that while billions of dollars are being invested in RD&D of electric and AVs, virtually all of this activity is aimed at simulating and testing in environments that mimic public roads and urban traffic environments. As such, the team eliminated from further consideration, personnel transport supported by passenger vehicles (commercially available electric sport utility vehicles [SUVs]/pick-up trucks were included for further research for use in off-road situations, which is not being as thoroughly researched by the automotive sector).

Several technology gaps, potential developmental areas, and project concepts were identified and/or formulated throughout this research effort. While they were not immediately germane to this specific effort, EVs that support mission activities in the context of microgrid operation, they do represent potential, future lines of effort that could be of interest to the military. **Appendix E** identifies and describes future lines of inquiry based upon gaps and emerging technologies/concepts related to HEVs, EVs, and AVs even though they were not directly germane to this effort.

SMEs collaboratively discussed project requirements necessary for autonomous electric transport systems to be the subject of research, testing, and demonstration for this project. This discussion resulted in a detailed set of project compatibility requirements and metrics for autonomous transport systems. Project compatibility metrics, which are provided in **Appendix F,** were developed for uniformity in analysis and comparison of candidate systems considered to be integrated into our RD&D plan.

3.1.3 Candidate system screening criteria

The identified Military Support Activity requirements and SMEs recommendations informed the development of candidate system screening criteria. SMEs developed screening criteria with two objectives. The first

objective was to screen each candidate system to ensure systems maintained or exceeded identified military transport requirements. The second objective was to screen each candidate system to ensure systems were compatible with our research.

SMEs identified seven topics of interest utilized in the development of screening criteria and criteria thresholds. Screening criteria topics were technology readiness levels (TRL), target cost, location of assembly, battery capacity, complementary research, Military Support Activity requirements, and General Services Administration (GSA) availability. Screening criteria thresholds set baseline requirements to prioritize candidate systems.

SMEs collaboratively screened each candidate electric transport system utilizing the identified screening criteria. Candidate systems were prioritized by the number of thresholds met. Nomenclature used to document systems obtaining threshold requirement was labeled "Y" for "yes." Nomenclature used to document systems not obtaining a threshold requirement was labeled "N" for "no." Candidate systems were sorted by the number of Ys obtained.

The seven screening criteria and criteria threshold variables are described as follows:

1. **Technology Readiness Levels**

   TRLs are utilized for estimating the maturity of technologies during the acquisition phase of a program. Using TRLs enables consistent, uniform discussions of technical maturity across different types of technology. A technology's TRL is determined during a Technology Readiness Assessment (TRA) that examines program concepts, technology requirements, and demonstrated technology capabilities. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology. The DoD has used the scale for procurement since the early 2000s. For this assessment, the team assigned a TRL value based upon the following:

   1—Basic principle

   2—Concept formulated

3—Proof-of-concept

4—Valid in laboratory environment

5—Valid in relevant environment

6—Demonstration in relevant environment

7—Demonstration in operational environment

8—System completed and tested

9—System proven successful.

The threshold for these criteria was a TRL 7–9. This threshold requirement was necessary to obtain to facilitate the testing and demonstration of the candidate system. Systems meeting this criterion were assigned a value of "Y."

2. **Target Cost**

    Paragon SMEs agreed to set a ceiling of $450,000 to acquire the candidate system. The higher the cost, the less likely a system will fit within early demonstration budgets. This ceiling does not include the cost associated with retrofitting the system for autonomous operation, bidirectional charging (if modification is required) or establishing additional charging capability within the test location. A system with a published manufacturer's suggested retail price of $450,000, or less, was identified as meeting the cost screening threshold and assigned a value of "Y."

3. **Location of Assembly**

    Manufacturer's assembly systems located in the United States were used as indicators of countries of origin. At this stage in our research, available system data did inform whether Buy American Act requirements were met. A system that is manufactured or assembled in the United States were assigned a value of "Y."

4. **Battery Capacity**

    Paragon's team of SMEs recommend 50-kW charge and discharge capacity for microgrid utility because:

* A 50-kW charger can be tested as a reasonable replacement for the standard 60-kW AMMPS generators that are to be included in the microgrid.
* 50 kW is also the rating of the bidirectional chargers that are located at the LAAFB that CERL would like to use in the future and enables the use of the charger at full capacity.
* A vehicle with less than a 50-kWh rating will require multiple vehicles and chargers to be tested as a 60-kW AMMPS replacement, further increasing overall cost.

A system with a battery rating greater than, or equal to, 50 kWh was assigned a value of "Y."

5. **Complements Ongoing Government Research**

SMEs' knowledge of current or planned research was identified as a useful screening criterion because of the potential to form partnerships to leverage funding. Systems that were identified as part of an ongoing research effort were assigned a value of "Y."

6. **Military Support Activity Requirements**

System data confirming the aptitude to meet at least one Military Support Activity application requirement, as outlined in Section 2.2, were identified as meeting the screening criteria and assigned a value of "Y."

7. **Available on GSA Schedule**

Manufacturer documentation is available to verify the system meets requirements for purchase by the federal government. If documentation is accessible, and stating the system is currently available on the GSA schedule, the system was assigned a value of "Y."

3.1.4 Prioritized categorized list of candidate systems

The Y/N screening, employing the criteria provided above, was applied to EV technologies to prioritize the previously identified systems (Table 17) for further consideration. Screening was applied to stratify systems that resulted in a prioritized, categorized listing of candidate systems enabling the identification of optimal candidate systems to be integrated into this program. To apply the system, each of the EVs were evaluated with respect to the seven Y/N criteria. If the system met the criteria, it was scored with

a "Y" (otherwise "N"). Each system was then assigned a score based on the number of criteria met. The initial Y/N scoring for identified systems is provided in **Appendix G**.

Table 17. Prioritized electric transport systems.

Total No. of Y:	TRL (7-9)	Cost ≤ $450,000	Assembled In U.S.	Battery Capacity ≥ 50 kWh	MSA	Related Research	Available through GSA
7	Mobile Power System (MPS) by: Dannar						
	Y	Y	Y	Y	Y	Y	Y
	9	$200–400K	IN	125–630 kWh	2, 4, 5, 6	DHS	
MPS is designed to support rescue operations in emergency response and disaster mitigation operations. The system can generate power and clear debris (with attachments). This system can perform in severe conditions, in up to 4 feet of water. The drive-by-wire system should support autonomous use. This system presents a unique opportunity to support several military operations including the Maneuver Support Center of Excellence (MSCoE) Mission (Prime Power School Engineering School) as well as routine land management functions. This robust system is designed to function in standing water and can use various attachments for recovery, debris removal, lifting, moving/towing vehicles, and structures. Power generation could also support resilience requirements in that the system can provide power to remote grids.							
6	Cargo Van, Chassis Cab, Cutaway Cab, Shuttle Van, Step Van by: Zenith Motors						
	Y	Y	Y	Y	Y	N	Y
	9	$100K	CA	52–100 kWh	1, 3		
Zenith Motors provides a variety of customizable EV trucks and shuttles developed on truck platforms (Dodge). The system can be ordered through DHS to meet specific function. Cost will vary depending on features. The company supports government purchase, but lag time can be long; the company cues production once order is received.							
6	Medium-duty Trucks, Shuttles, and Buses by: Zero Truck						
	Y	Y	Y	Y	Y	N	N
	9	$60–100K	CA	53–80 kWh	1, 3		
The company offers customized vehicle platforms based on three different chassis and two power plants. It is flexible in terms of designing system to meet needs. Cost will depend on nature of specialization requested.							
6	Zeus Electric Shuttle bus, Utility vehicle, Flatbed truck by: Phoenix Motorcars						
	Y	Y	Y	Y	Y	Y	N
	9	$240,000+	CA	105 kWh	1, 3	EPA, CA	
The company offers a shuttle, utility vehicle, and flatbed trucks. Utility truck and flatbed are not commonly to eTruck manufacturers and could provide a demonstration for installation maintenance functions including facility and grounds maintenance. The company is working to develop autonomous as well as microgrid (V2G) capabilities.							
5	T-Series Yard Hostler by: Orange Motors						
	Y	Y	Y	Y	Y	N	N
	9	$200–300K	MO	80–160 kWh	1, 3		
The T-series is manufactured by Orange Motors in Missouri. The company seems well established and provides an electric hauler that could serve low-speed purposes at an installation. Passenger transport would only be accomplished using troop trailers—Silverside design. It is common to training installations. Heavy hauling capacity increases potential for direct logistical support in terms of deployment and training material marshalling activities. Orange produces two versions of a heavy hauler. While the system can be used on roads, it has a top speed of 25 mph, and it can haul 81,000 lbs. Vehicles are Missouri-built, and the company can also retrofit older diesel frames to electric, reducing cost by approximately $50,000.							
5	Reckless by: Nikola						

Total No. of Y:	TRL (7-9)	Cost ≤ $450,000	Assembled In U.S.	Battery Capacity ≥ 50 kWh	MSA	Related Research	Available through GSA
	Y	N	Y	Y	Y	Y	N
	9	$480K/year lease	CA	52–100 kWh	4	U.S. Marine Corps (USMC)	
The system is currently part of U.S. Marine Corps (USMC) demonstration and could provide potential for integration with tactical microgrid development portion of ATI. The system is only an EV that currently under evaluation for tactical use.							
eBus by: eBus							
5	Y	Y	Y	Y	Y	N	N
	9	$400K	CA	130 kWh	1		
This commercially available system is used in mass transit. eBus is an electrification conversion service for existing buses. Cost is for electric motor, battery and charging systems. It provides a repurposing alternative and can result in vehicles configured to specific use scenarios. The company offers inductive charging system for use on routes, and it offers drive-under and drive-over charging systems. This service requires the government to provide a bus that would be converted.							
Xcelsior Charge (multiple versions) by: New Flyer							
5	Y	N	Y	Y	Y	Y	N
	9	$700–1,200K	AL	160–466 kWh	1, 3	Private sector	
The company offers a variety of buses with varying capacity. Autonomous operation system development is under way. Partnership to demonstrate bus at an installation with integration into a microgrid could provide demonstration partnerships with the manufacturer.							
R1T–EV Pick-u by: Rivian							
5	Y	Y	Y	Y	Y	N	N
	8	$70–100K	Y	IL	3, 4		
The R1T all-electric pick-up truck seats five passengers and is designed for urban and off-road use. It could provide a utility truck demonstration for small transport as well as material delivery.							
Saf-T-Liner C2 Jouley Electric School Bus by: Thomas Built							
5	Y	Y	Y	Y	Y	N	N
	8	$450K	NC	220 kWh	1		
This long-time bus manufacturer has gasoline vehicles traditionally used by government for student transport. Traditional units are available through GSA. Electric versions are likely to be offered, eventually, through GSA. A partnership with the company could support its effort to demonstrate vehicle as useful for government use.							
Edrive Tractor by: ATC							
5	Y	Y	Y	Y	Y	N	N
	9	$250K	MN	250 kW	2, 5, 6		
ATC offers a land-maintenance system designed for agricultural use. The system can be modified to provide foreign object detection and invasive species identification and removal. Large cutting deck provides wide-area processing. The system can be purchased with digging and earth-moving attachments. It does not have batteries (no large equipment does because of weight consideration); rather it has electric motors powered by on-platform power generation. As such, it provides power generation capacity that can augment microgrids. The company can retrofit existing vehicles or new frames. The system provides cost-beneficial options for land management operations.							
eCargo, eTruck drayage—Class 8 Tractor by: US Hybrid							
4	N	Y	Y	Y	Y	N	N
	6	$250K	CA	240 kWh	1, 3		
Vehicles are not currently available. The system might offer better performance, as it is made available over the next 2 years.							
LFSe by: Nova Bus							
4	Y	N	Y	Y	Y	N	N
	8	$700K+	NY	152 kWh	1		

Total No. of Y:	TRL (7-9)	Cost ≤ $450,000	Assembled In U.S.	Battery Capacity ≥ 50 kWh	MSA	Related Research	Available through GSA
The vehicle does not meet cost requirements, but partnership (as sought with New Flyer) might yield cost effective opportunities for a future demonstration.							

In addition, Paragon's team developed information packets for each candidate system (provided in **Appendix H**). After reviewing the information packets, the SMEs gathered at the Robotics Research Laboratory in Clarksburg, MD. The team discussed at length each candidate system, its ranking, and the compiled information (**Appendix H**). The team further evaluated considered the research project compatibility metrics and screening criteria thresholds. Optimal candidate systems for continued research and engagement were collaboratively agreed upon. Candidate systems were prioritized by the total number of Ys according to the screening methodology outlined in **Section 3.4**. In some cases, systems were eliminated from further consideration because of significant violation of one or more of the screening criteria (i.e., assembled in China). In conducting this evaluation, the team considered all of the vehicles using the same (or very similar) platform as one system for the purposes of this evaluation.

This approach resulted in a list of 13 prioritized electric transport systems identified in Table 17.

3.1.5 Autonomous vehicle OEM and kit manufacturers

The Paragon team engaged AV SMEs who advised and provided input about the latest AV technologies that might have compatibility with the identified EVs. The list of AV OEM and Kit manufacturers is provided in **Appendix I**.

3.2   Engagement with EV transport manufacturers

The purpose of engagement with EV transport manufactures was to confirm identified system data from prior research and finalize research plans to collect new information for the development of SME transport system recommendation summaries. Additionally, engagement meetings allowed SMEs to assess a manufacturer's willingness to partner for future research, testing, and demonstration project.

Paragon SMEs identified the following manufacturers for engagement: Dannar, Zenith Motors, Zero Truck, Phoenix Motorcars, Orange Motors, Nikola, Ebus, New Flyer, Rivian, Thomas Built, ATC, US Hybrid (USH) and Nova Bus.

Call leads were assigned to each manufacturer. SMEs were assigned call lead roles on the basis of previously established relationships with manufacturers. "Cold calls" were documented to state that no prior relationship with the contacted manufacturer is established.

3.2.1 Process of engagement

Paragon and its SMEs developed a Process of Engagement to be used when contacting manufacturers. This process ensures a consistent communication approach for scheduling and execution of manufacturer informational meetings and research plans. The Process of Engagement is outlined in the Figure 4. flow diagram.

Figure 4. Process of engagement flow diagram.
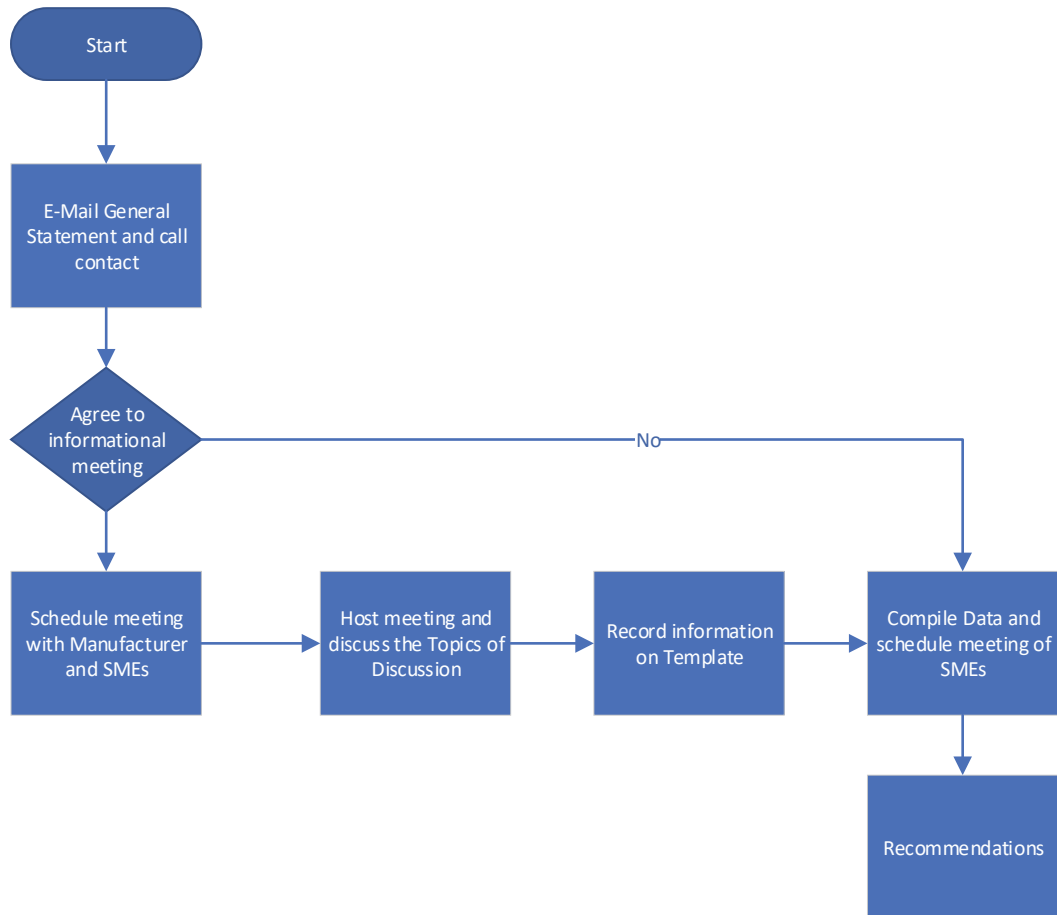
3.2.2 General statement

As outlined in the Process of Engagement, call leads initiated engagement with manufacturers by emailing the point of contact the following general statement:

> The Paragon team is researching the integration of Autonomous Electric Transport Vehicles as part of a technical program that will enhance energy resilience for military installations and contingency bases. This research will identify and recommend specific technologies related to electric transport vehicles, vehicle autonomy, and vehicle-to-grid (V2G) charging for future integration into a tactical microgrid.
>
> Could "insert company name" provide information about "insert vehicle(s)" to assist us with this research? Our team will follow up with a

phone call to schedule a time that is convenient for you. We appreciate
any assistance you can provide.

Call leads then followed up via phone call and email to coordinate a
meeting date and time. If manufactuers agreed to an informational
meeting with Paragon SMEs, call leads provided manufacturs with topics
for discussion and the meeting was scheduled. If manufacters declined an
informational meeting with Paragon SMEs, call leads documented
manufacters response for later consideration.

3.2.3 Topics for discussion

Topics for discussion were collaboratively developed by Paragon SMEs.
The team condensed Military Support Activity transport requirements and
research compatibility considerations to create a comprehensive and con-
cise set of topics. These topics were designed to effectively validate and fill
information gaps of prior research and effectively conduct comprehensive
research plans. Topics for discussion are:

1. Manufacturer and vehicle description
2. V2G charging readiness and effort implementation
3. Vehicle functions and capabilities
4. Testing and demonstrations
5. Autonomy readiness and effort to implement
6. Safety assessments
7. Pricing and warranties.

3.2.4 Manufacturer call documentation

For consistent documentation of manufacturer informational meetings,
call leads utilized a Manufacturer Call Notes Template. Manufacturer call
notes and manufacturer supplied information are listed in **Appendix J**.

3.2.5 Transport system recommendations

Documented call notes and any manufacturer supplied documents were
reviewed and discussed by Paragon SMEs to develop and agree upon
transport system recommendations.

Recommendations contemplate advantages and disadvantages of each identified transport system as well as the potential for manufacturer partnerships and transport system compatibility for this research.

3.3 Summary of conclusions and recommendations

3.3.1 Manufacturer outreach

Paragon SMEs wanted to gauge the willingness of candidate technology manufacturers to form partnerships to enable future ATI demonstrations. The SMEs contacted EV technology manufacturers that closely met the aforementioned research and demonstration project criteria. They requested interviews to secure additional information critical to making a comprehensive educated recommendation. Results from initial email and phone correspondence listed in Table 18.

Table 18. EV manufacturer interview correspondence.

Manufacturer	Correspondence Results
ATC	Not interested in participating
*Dannar	Notes in Appendix J
eBus	No response
First Priority Green Fleet	Not interested in participating
*New Flyer	Notes in Appendix J
*Nikola	Notes in Appendix J
Nova Bus	No response
*Orange Motors	Notes in Appendix J
*Phoenix Motorcars	Notes in Appendix J
Rivian	Not interested
Thomas Built	No response
*US Hybrid	Notes in Appendix J
Zenith Motors	No response
Zero Truck	No functional system to show at this time
*Manufacturers participated in interview and provided additional information	

The following is a list of the manufacturers that responded with interest and participated in interviews, providing additional information on technologies as they relate to the ATI testing and demonstration project:

- **Dannar**—MPS
- **New Flyer**—Xcelsior Charge (multiple versions)
- **Nikola** – Reckless

- **Orange Motors**—T-Series Yard Hustler
- **Phoenix Motorcars**—Zeus Electric Shuttle bus, Utility vehicle, Flat-bed truck
- **US Hybrid**—eCargo, eTruck drayage.

3.3.2 Manufacturer technology summaries and recommended research

After interview research plans were conducted, SMEs reviewed and analyzed manufacturer interview notes and held a meeting to discuss the information gathered to make recommendations for future testing and demonstration for six EV technologies in the ATI project. The EV technologies recommended for future research are listed below. Further detail of carried out research plans are provided in **Appendices J** and **K.**

3.3.2.1 Dannar

The Dannar MPS is an off-road energy platform with unique versatility in application that could support a wide range of military activities with a platform base that can be converted to a multitude of transportation systems. It meets all of the key operational and programmatic ATI testing and demonstration criteria to include autonomous and V2G capabilities with minimal implementation effort/cost. The system has full- remote capability, operating by onboard cab, x-box style remote control, or wireless supervision. Dannar is currently working to develop follow-the-leader autonomous function. The system has maturity and commercial availability, which pricing is in line with project parameters and the company is interested in participating in the ATI project.

Dannar manufactures systems for the U.S. governmental market and is located in Clemente, CA; San Jose, CA; and Muncie, IN (manufactured). The MPS is a direct current (DC) energy storage asset, to whose DC power bus, one can connect various power converters for export of energy. Dannar tends to focus first on MPS power export to islanded microgrids, such as those for remote worksites where grid power is not accessible. Supply to a utility grid involves additional hardware to ensure (i) both isolation of the ungrounded MPS from the grounded grid and (ii) synchronization of exported power with grid power. DANNAR's power electronics partner has supplied both unidirectional and bidirectional power converters for both DC-DC applications, such as EV charging, and alternating current (AC)-DC applications, such as either EV charging from grid or V2G transfer.

3.3.2.2 New Flyer

New Flyer manufacturers the Xcelsior Charge electric bus and has experience in the electric transport system industry making manufactured zero-emissions buses for more than 50 years. The Xcelsior Charge is a zero-emissions bus with a battery ESS ranging from 160 kWh to 460 kWh. While the Xcelsior Charge contains a large ESS, the New Flyer system does not have bidirectional charging capability.

New Flyer buses are interoperable with all heavy-duty vehicle charging equipment. New Flyer has partnered with Robotic Research to develop a proof-of-concept autonomous bus. Additionally, New Flyer has committed to additional autonomous bus programs with the Xcelsior Charge.

New Flyer has delivered several Xcelsior Charge buses to transit agencies across the United States and has a fleet of demonstration buses available for use. The Xcelsior Charge electric bus and the battery system is manufactured in the U.S. New Flyer warranties the ESS for 12 years and provides support and field service upon request.

The system is not a tactical vehicle but can be used on-post and even in foreign areas for transporting Soldiers and supplies. Because of its design for on-road use, testing would require paved roads and performance in conjunction with post activity. This could result in higher costs. Additionally, the entry cost of the electric bus is approximately $750,000. This technology would be a good candidate for electric and autonomous transport research in the future when the technology is more mature in its bidirectional and autonomous capabilities.

3.3.2.3 Nikola

The Nikola Reckless is a fully electric side-by-side utility vehicle that offers flexibility with the design of its open chassis. It offers off-road performance and can reach speeds of 100 mph in just over 3 seconds. The Reckless is estimated to have a range of 150 miles and more and a top speed of 75 mph, making it an appealing option for high-speed off-road use. The Reckless is available with powertrains ranging from 266–590 horsepower (hp) and is powered by a 400- volts of DC (VDC) battery system with 75–125 kWh of energy storage.

The Nikola Reckless is interoperable with a Remote Weapon Station and military drones. A variant of the platform has steer- and throttle-by-wire capabilities, and Nikola is working to develop more autonomous capabilities. The vehicle's onboard energy storage is large for the size of the vehicle and would be beneficial for bidirectional charging. The platform does not currently support bidirectional charging; however, the company has expressed interest in working toward this capability.

Potential challenges in testing the Reckless are a lack of commercial availability, deployment risk, and cost of the system. Currently only one known system is available and additional systems are limited to production prototype, raising concern on consistency of quality and performance. Additionally, the cost of the system could be prohibitive, the system has been quoted at a leasing cost of $40,000/month.

3.3.2.4 Orange Motors

Orange Motors—, based in Riverside, MO—, builds, sells, and services industrial EVs and is the leading OEM providing industrial fleets with heavy- duty electric trucks. The manufacturing location is approximately 200 miles from FLW, the recommended testing and demonstration site, FLW, which could allow for convenient operational and technical support.

The system is an electric hauler that could serve low-speed purposes at an installation. Passenger transport could be accomplished using troop trailers of a Silverside design, which is common at training installations. The trucks are purpose-built to site requirements and have heavy hauling capacity (81,000 lbs.) increases potential for direct logistical support in terms of deployment and training material marshalling activities. The system is DoD-certified for on- and off-road use, but maximum speed is currently 25 mph. The company can also retrofit older diesel frames to electric. Orange EV's trucks utilize a web-based telematics system that provides instant feedback, real-time performance statistics, and hard data, enabling fleets to understand system status, fuel efficiency, and cost savings.

The company seems well established with a mature technology that has good potential for autonomous capabilities and is priced within research project parameters. Concerns include a lack of bidirectional charging

capabilities and potentially significant cost to develop those capabilities from scratch.

3.3.2.5 Phoenix Motorcars

Phoenix Motorcars is a Southern California based company that manufacturers electric shuttle buses, flatbeds trucks, and work trucks. While its shuttle buses are most popular, Phoenix also provides electric utility trucks, with an enclosed steel body and service and maintenance trucks. They provide box trucks, delivery, flatbed, stake bed, to anybody who uses the e450 chassis. Their next phase extends to F550 platform in 2020.

This technology has several issues that could preclude it from being a candidate for the testing and demonstration project. Most significantly, it does not have bidirectional charging capabilities and the cost and timeline for development would be prohibitive.

3.3.2.6 US Hybrid

The USH Corporation specializes in the design and manufacture of power conversion systems for medium- and heavy-duty electric, hybrid and fuel cell commercial buses and trucks. USH's products utilize power converter topologies to provide integrated system solutions for OEM applications.

USH has built a number of prototype vehicles that can accommodate bidirectional charging and the company is currently providing a vehicle to the U.S. Air Force (Air Force) that is a 230-VDC charger for sustainable power on demand. The vehicle can power most of the required AC/DC load, and the operation is monitored using a GUI-driven dashboard. Time to produce a prototype proof-of-concept vehicle can vary depending on the complexity of the design, but it typically takes 6 months to design, build, and field a single proof-of-concept vehicle.

USH has a number of other demonstration projects underway demonstrating both EV and fuel cell capabilities. They are currently testing a 480-kW wide body tug for moving C-17s and a weapons loader. They have also electrified an 80,000-lb. truck capable of moving shipping containers. USH typically builds anywhere from one to 15 vehicles for demonstration projects, often in partnership with other OEMs or third parties (e.g., Textron or Oshkosh). The prototype vehicles have a minimum TRL of 5 and are

mostly TRL levels 6 or 7. USH is currently engaged with one such project with an R11 and R12 refuelers and is delivering jet fuel to fighter squadrons using these EVs.

USH offers all of their modified vehicles as drive-by-wire. USH has built the EV Mine Sweeper for Textron that is driven remotely through a virtual interface. USH is also supporting a number of other military related vehicles, some of which are focused on demonstrating autonomy readiness. USH does not have any autonomy capability on its own but is working on interfacing with another company's autonomous control system.

Currently all bidirectional charging has been done on prototype systems. The overall design of the technology could prove challenging with an initial modification of the base vehicle, then another modification to autotomize. For these reasons, this technology could be a good candidate for future research but currently has a high technical risk with a two- to three-year time frame for development activity.

3.4 Future evaluations

The EV market is constantly evolving with new and changing technologies. Even as this research was underway, transition was taking place and ongoing research reveals emerging products on a constant basis. One technology that was identified after manufacturer interviews had been conducted is Bollinger Motors. Preliminary research shows that the manufacturer offers fully EVs that support the tactical environment and are fast charging, with capabilities for transporting passengers and more (yet to be identified). Production is slated for 2Q2020 with price starting manufacturer's suggested retail price (MSRP) is $125,000. **Appendix L** provides additional information on this system.

3.5 Conclusion

Based on the research, there are several technologies that would be good candidates for testing and demonstration of electric transport systems with autonomous and bidirectional capabilities for Military Support Activities. The Dannar is an attractive technology for this project because it is commercially mature and has good versatility in platform design for a broad range of Military Support Activities. The technology currently has drive-by-wire operational capability and shows high probability for full

autonomous capability in the next few years. The Nikola Reckless provides an opportunity to explore high-speed EVs that will work in a tactical environment. The Orange EV system has a large hauling capacity that makes it appealing for testing logistics support in forward warehousing as well as on-post. The other technologies identified are potential candidates for future testing as they require additional development and overall maturity.

4   Research and Develop Operational Tests for Autonomous Transport Vehicles

The objective of Research Area 3 is to identify and research operational tests for autonomous transport systems. The purpose of this research is to develop autonomous-system operational test plans to be performed within the living laboratory at the CBITEC site.

Paragon SMEs identified required autonomous-system data and state-of-the-art technologies through a review of literature and engaged with leading industry experts.

4.1   State-of-the-art data capture and storage technologies

The objective of this research was to identify and verify autonomous-system data and to investigate state-of-the-art technologies for capturing and storing data required to develop operational tests. The ARIBO project was referenced to identify data types required to analyze and characterize the performance of autonomous-system operation.

In order to investigate state-of-the-art technologies for capturing and storing autonomous-system data, Paragon's team of SMEs conducted a review of literature through broad internet searches. This review resulted in a list of identified autonomy kits, sensors, and other technologies available today, which is found in **Appendix M**.

4.1.1   Data types

Raw-sensor data includes LiDARs (light detection and ranging), cameras, radars (radio detection and ranging), and navigation units. The data is typically in the form of Ethernet packets, and the autonomous-system is generally on a private or isolated network. The data structure in the Ethernet packets is organized and defined by the sensor manufacturer. The data structure format is provided to the end user in an Interface Control Document (ICD) for the individual piece of hardware. In order to capture and record this data, Wireshark—the network protocol analyzer—is used. Wireshark allows the user to collect a variety of network traffic in packet capture (pcap) files. This file format is basic, and saves captured network data, and has become the "de facto" standard of network captures. The

data is saved in a hexadecimal format and requires the user to post process, or parse, the log files to be human readable.

For the context of this report, post processing refers to the analysis and/or playback of data collected during autonomous operations after the operations have been completed.

Processed sensor data includes any of the aforementioned raw-sensor data above that has been transformed into a format usable by the autonomous-system. An example of this is a LiDAR point cloud that has been transferred into the system's reference coordinate frame to make a 3D-world model. This data is typically captured using Wireshark. Other data-recording tools, such as the Harris Jaqwire application, allow for LiDAR, radar, and video data to be recorded and disseminated to other users to view in real time or for post processing.

System data includes the commands, status, and control information necessary to make the system drive autonomously. Examples include obstacle detections, path-planning trajectories, velocity, steering commands, and system status information. This data can be in a variety of formats and is transferred over a Controller Area Network (CAN), serial network, or Ethernet. CAN data loggers, serial data loggers, and Wireshark are some of the common ways to collect system data. Additionally, the Robotic Operating System (ROS) command-line interface, rosbag, allows the user to create an Application Programming Interface (API) to write data into a bag file format.

Table 19 lists a set of expected generic data that would be expected to be collected during the operation of the autonomous-system. While there are many organizations designing autonomous-system software and hardware, the specific data recorded, and data formats used on platforms, are considered proprietary and unavailable without permission from the software or hardware provider. For the scope of this research area, the data types will be covered at a generic level.

Table 19. Example data collected during autonomous-system operation.

Type	Description	Format
LiDAR	3D point clouds: raw or processed	pcap
Radar	Radar range measurements: raw or processed	pcap

Type	Description	Format
Camera	Camera image data: raw or processed	pcap
Encoders	Quadrature wheel-encoder data	bag
Estop	Recorded when estop is pressed OR an event is tagged	bag
Localization	INS/GPS position and orientation data	pcap
CAN	Traffic on CAN Bus	CAN
Driving Commands	Speed and curvature commands to platform	CAN or pcap
System Status	System diagnostic data	CAN or pcap

4.1.2 Sensors

There are typically three types of sensors used on autonomous systems to sense objects: LiDAR, camera, and radar. LiDAR and radar both emit signals and receive returns from objects. The returns are collected over time in software to create the size, shape, and distance of the objects.

Radar uses radio waves to compute the range of the object and its velocity. Radars excel at detecting metallic objects but fail to see objects without a radar signature like a pedestrian. The radar sensor usually has a narrow-focused output that detects objects at a greater distance, up to 400 meters. This ability to see metallic objects at a greater distance makes the sensor well suited for detecting vehicles. An autonomous-system will typically have a forward-facing radar mounted on the front bumper area of the platform along with radars mounted on each corner of the platform. This configuration will detect vehicle traffic in the autonomous-system's direction of travel and cross traffic.

LiDAR behaves similarly to radar but uses a laser instead of radio waves to survey the environment. LiDAR usually does not have as long of a range, typically 100 meters, as radar but has a greater field of view that does not require the object's composition to be metallic. The set of LiDAR returns is referred to as a point cloud, and contains distance and angular position components and an angular position component relative to the sensor for each point. This can be thought of as spherical coordinate representation for each LiDAR return. The point cloud is transformed into the system's reference coordinate frame to create a 3D map of the system's environment, Figure 5 shows an example of a point cloud transformed into the system's reference frame. An autonomous-system will typically have at least one LiDAR to scan the primary direction of the system's travel. Depending on the use case, speed of operations, and need for redundant

sensing, more LiDARs may be added. For example, a system used on the road and in traffic might have LiDARs on each corner of the system whereas a system designed for lower-speed off-road use, might only have a forward-facing LiDAR.

Figure 5. Three-dimensional LiDAR scan example.
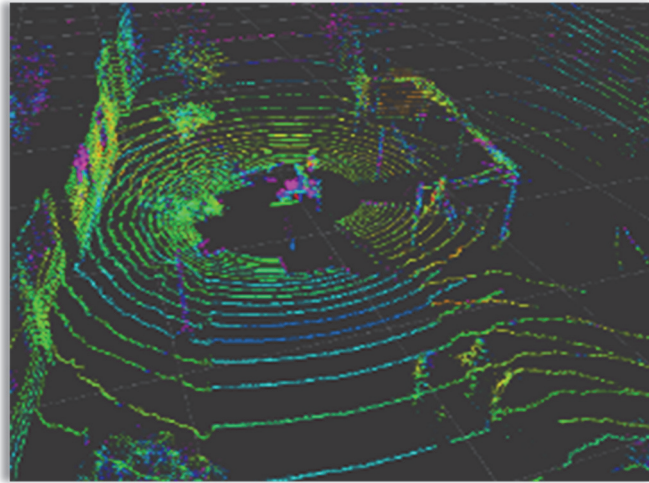
While radar and LiDAR work well for measuring an object's the range and velocity of an object, neither are not the best suited for capturing the details of an object. Because of this, cameras are a much better choice for classifying the type of object, whether it is a person, car, or the text on a road sign. Figure 6 shows of an example of a camera detecting and classifying an object as a vehicle. However, cameras have similar limitations to the human eye. For example, a camera will have a difficult time viewing the environment when looking into the sun. Sophisticated cameras can adjust to varying lighting conditions and still saturate during extreme conditions. Adding filters to the camera lens can improve camera performance but is not a viable solution for autonomous systems as lighting conditions can change rapidly and would require human interaction to change these filters.

Figure 6. Vehicle object recognition.

The use of stereo cameras or thermal imagers is considered beyond the scope of the report. These types of cameras are used in some robotic applications, but they generally do not perform well in the use cases described in this report.

In addition to object detection sensors, autonomous systems require a localization or navigation sensor. Most localization sensors combine a GPS sensor with an Inertial Measurement Sensor (IMU) to determine the coordinate position and the system's attitude (roll, pitch, and yaw). Localization sensors that include both GPS and IMUs are usually referred to as an Inertial Navigation System (INS).

4.2   Applications to interface with autonomous-system data

The tools listed in this section can capture most, if not all, the data necessary to analyze and characterize the autonomous-system's performance. The difficulty with capturing data across multiple tools is that a significant amount of post processing is needed to compare all the data against a reference timeframe. During regular operation, the autonomous-system consumes the aforementioned data, processes it, and makes decisions in real time. In order to analyze the data after it has been collected, a reference timeframe is needed to align captured data against a common timestamp. For example, it is important to compare a specific driving command to the system status message at any given position or orientation with respect to the LiDAR returns and camera images. Without a reference timeframe, it

is not possible to correlate the multiple data streams into a single timestamp.

Most of this data is recorded locally and unavailable for viewing and post processing via web or remote applications. This data is typically proprietary or requires the manufacture's ICD to interpret. Additional steps are needed to centralize this data into a single repository.

The Robotic Research engineering team is continuously searching for new, innovative ways to capture, store, and analyze data generated by autonomous systems. Common applications to interface with autonomous-system data are Wireshark, the CL2000: CAN Bus Logger, Jagwire, and nSight Data Logger.

4.2.1 Wireshark

Wireshark is an open-source network packet analyzing tool. It can analyze communication protocols similar to tcpdump, but with a Graphical User Interface (GUI). Wireshark comprehends the structure of different networking protocols and can parse and display the data in the intended protocol format (Figure 7.).

Figure 7. Wireshark capture setup.
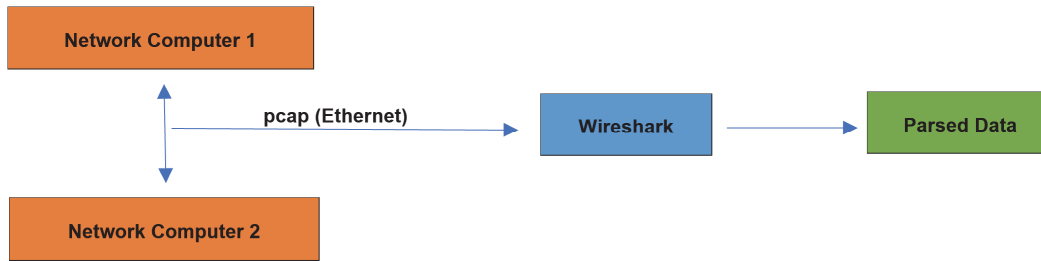
To use this tool, a computer running Wireshark must be plugged into the network being analyzed. The tool can be configured to search for user de-fined addresses, ports, messages, etc. It is recommended that Wireshark only be used on the private or isolated networks used by the autonomous-system.

Wireshark data is captured in the industry standard pcap format. Addi-tional parsing is required to put the pcap data into a human readable for-mat (Table 20)

Table 20. Wireshark data captured.

Item	Description
Sensor	• LiDAR • Radar • Camera • INS/GPS • Ethernet traffic
Data Format	• pcap
Features	• Capture data from live network connection or read from file • Captured data can be analyzed with GUI interface • Captured data can be filtered for specific inputs • Raw USB traffic can be captured
Pros	• Captures all Ethernet traffic • Base application is free
Cons	• Data requires parsing to be human readable • Might not be allowed on certain networks

4.2.2 CL2000: CAN Bus Logger

The CL2000 made by CSS Electronics records live CAN Bus traffic with timestamps to a locally stored memory card. The timestamping is per-formed with a real-time clock to ensure accuracy. The CL2000 can be plugged into any CAN interface on the CAN network to record bus traffic (Figure 8).

Figure 8. CAN Bus capture setup.

```
┌──────────────────┐
│   CAN Device 1   │
└──────────────────┘
         ↕        CAN (RS232)      ┌──────────┐          ┌──────────────┐
                        ──────────▶│  CL2000  │─────────▶│ Parsed Data  │
┌──────────────────┐               └──────────┘          └──────────────┘
│  CAN Device 2 2  │
└──────────────────┘
```
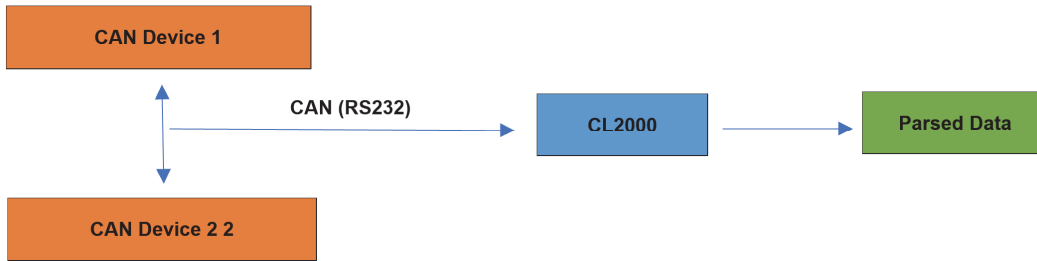
The CAN Bus traffic captures timestamped data with the CAN message header and 8-byte data field. The end user must compare the header and data field to the ICD to parse the data into a human usable format (Table 21).

Table 21. CL2000: CAN Bus Logger.

Item	Description
Sensor	• Vehicle bus (J1939, OBD2, etc.), command, and status
Data Format	• 11-bit identifier and 8-byte data message
Features	• Log data to SD card—no PC needed • Real-time clock timestamping • Stream data in Wireshark
Pros	• Captures all traffic on a CAN Bus network • Relatively low cost • Data is time tagged
Cons	• Requires manufactures interface control documentation to read messages • Limited to CAN/J1939/OBD2 traffic

4.2.3 Jagwire

Jagwire by Harris Geospatial Solutions is geospatial data management software that allows recording, retrieval, and playback of LiDAR, radar, and video data. The tool allows videos to be annotated or tagged for later review. Jagwire (Table 22) can save and display a variety of still imagery, such as NITF, GEOTIFF, and JPEG formats. It can also save and replay video formats including FMV and WAMI and LiDAR point clouds.

Table 22. Jagwire.

Item	Description
Sensor	• LiDAR • Radar • Camera

Item	Description
Data Format	- NITF - GEOTIFF - JPEG - FMV - WAMI - LiDAR point cloud
Features	- Manage data - Disseminate data at near real time - Play back data at multiple different bit rates
Pros	- Collects a wide range of sensors and data - Allows for search and replay of data
Cons	Requires licensing agreement

4.2.4 nSight data logger

Robotic Research developed a tool, nSight (Table 23), to capture multiple streams of data with a single data-logging device that both timestamps and performs post processing operations and analytics all in one location. It is Robotic Research's understanding that there is no other non-system proprietary product available that can capture, post process, and analyze all of the data on an autonomous-system in a single location.

Table 23. nSight data logger.

Item	Description
Sensor	- LiDAR - Radar - Camera - Wheel encoder
Data Format	pcap
Features	- Distribute the data to the various servers - Compare input command versus actual output value - Measure sensor performance and predict degradation
Pros	- Configurable for most autonomous systems - Collects raw and processed data from sensors and vehicle - Automatically uploads data to cloud storage devices - Hosts web application to analyze data
Cons	- Requires purchase of hardware to process and record data - Requires configuration based on autonomous-system - Might require large off-site storage dependent on amount of data collected (typically generates 50 gigabytes of data in an 8-hour day)

The nSight platform provides an end-to-end data collection and analysis solution. The nSight suite is composed of the nSight Recorder (Onboard data recorder), nSight Upload (Data disseminator to servers), nSight after-action review (AAR) (Server and Analysis Tool). Figure 9 illustrates Robotic Research's complete data collection, storage, and management process.

Figure 9. Proposed data management process flow using nSight tools.
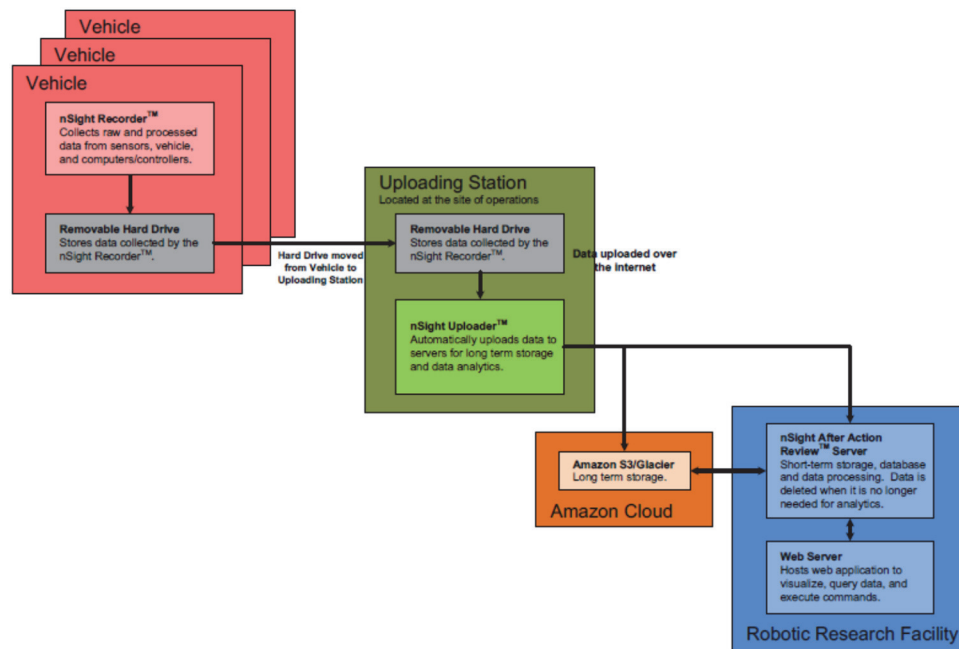
The sensor data is mostly captured in the industry standard pcap format. This is not only used for data communicated across Ethernet, but it also is used for serial data, such as CAN, USB, and RS-232. This includes sensors, such as LiDAR, radar, cameras, and wheel encoders. Processed data is outputted in ROS bag format, which was selected because it is a common format familiar to commercial and academic institutions. Robotic Research used these formats specifically to provide an open interface for data sharing.

The nSight data recorder can be installed on nearly any autonomous-system. The level of effort to install the system is based on the number of sensors, electrical signals to be recorded, and the availability of the manufacturer's ICD.

4.3   Operational tests to verify traffic safety

The objective of this research is to identify operational tests that can be applied to verify traffic safety of autonomous systems through analyzing and comparing human-driver behaviors to an AV system's steering-control behaviors in various traffic conditions.

4.3.1 Compare human drive behavior to autonomous-system behavior

In order to complete an analysis in human-driving behavior against autonomous-driving behavior, tests can be conducted to capture human-operational inputs and decisions and compare to the AV system's data during a defined timeframe. Human-driving behavior data during operation of the system is simultaneously generated and stored with AV system data. This methodology allows for human control of vehicle steering, braking, and acceleration while the output of the robotic system is stored. The result of the human's driving actions, and the actions the robotic system would have taken, is then post processed and compared. The differences between the two then create edge cases that can be independently assessed, determining whether the autonomous-system or the human behaved more safely and in compliance with road and traffic regulations.

A database with the rules of the road pertinent to the particular locale is necessary for this data collection. In general, there are between 40 to 60 rules drivers abide by on the road network. The existence of these rules is specifically designed to minimize accidents and, to a certain degree, minimize communication between the drivers. For example, in a two-way, two-lane road in the United States, the drivers will drive in the right-hand lane for each direction. In this case, both drivers, going in opposite directions, do not need to signal to one another which lane they will use. Instead, the rule of the road defines the behavior.[*]

For the purpose of this research, the test plan will focus on autonomous-system operations at the CBITEC site. The road network at CBITEC is considered unimproved and without markings. In order to evaluate and verify traffic safety of the autonomous-system, rules of the road will define expected autonomous-driving behaviors, such as driving on the right side of the road, stopping at intersections, and yielding to other traffic and pedestrians. Additional infrastructure, such as stop and yield signs, might be required.

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[*] Lacaze, Alberto. July 9, 2018. "System and Method for Verifying That a Self-Driving Vehicle Follows Traffic Ordinances."

Similar work was performed at Fort Bragg on the ARIBO project from 2014–2016.[*],[†],[‡] The objectives of this research are similar to the ARIBO project objectives:

- Socialize users and non-users with automated systems by creating trust and confidence
- Identify operational issues and develop mitigation strategies to offset technical risk through operational and policy adjustments
- Generate empirical data (e.g., performance, reliability, maintenance, etc.)
- Evaluate and improve reliability of AVs in a fail-safe environment
- Collaborate with industry and other agencies on autonomous systems R&D.

This effort aims to build upon the ARIBO project by introducing the use of unimproved roads, interacting with external hardware, such as charging stations, and expanding the analysis from simple rules of the road to more complex interactions in off-road environments.

Traffic safety operational tests will occur in three phases. Autonomous-system data will be collected using the nSight data recorder in each phase to evaluate characteristics of the human driver and the robotic vehicle. In Phase 1, a trained driver will operate the system in a manual driving mode. The autonomous-system and sensors, running in the background collecting data, will not control the system. In Phase 2, the driver becomes a safety operator. The autonomous-system will control the system, and the safety operator will be ready to take control in the event of an emergency. In Phase 3, the safety operator will be removed from the vehicle and perform safety operations from a remote location. Phase 3 will not occur until the data shows the autonomous-system is safe and reliable.

The recommended data to collect during operational tests are:

- Timestamp

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[*] Barghout, Jeffrey. July 12, 2018. "Autonomous Shuttle Technology Safety Review Fort Bragg, NC and Greenville, SC Deployments."

[†] Barghout, Jeffrey. Mottern, Edward. Putney, Joseph. Patel, Rashmi. March 27, 2017. "Fort Bragg, Autonomous Warrior Transport On-Base Automated Vehicle Evaluation Plan."

[‡] The University of Texas at Arlington Research Institute, September 30, 2014, "Applied Robotics for Installation and Base Operations (ARIBO) Roadmap"

- Safety operator/driver
- Vehicle state (on/off, charging, park, forward, reverse)
- Autonomous-system mode (manual/autonomous)
- Vehicle location (GPS coordinates—latitude, longitude, elevation)
- Relative left path border (GPS coordinates—latitude, longitude, elevation)
- Relative right path border (GPS coordinates—latitude, longitude, elevation)
- Odometer
- Vehicle speed
- Vehicle acceleration/deceleration
- Vehicle heading (instantaneous direction the vehicle is moving)
- Moving object proximity data**:** captures data on all moving objects, such as cars and people that are within 100 feet or, based on their speed and heading, are projected to come within 100 feet of the vehicle on its planned route
  - Distance From Vehicle
  - Speed Of Objects (Including Pedestrians)
  - Heading Of Objects (Including Pedestrians)
  - Time Until It Intersects Vehicle Route
  - Distance From Vehicle At Route Intersect
- Environmental/ambient conditions (temperature, humidity, pressure, light).

Using the discrete data subsets listed in Table 24, driving patterns during various scenarios will be captured and analyzed to compare human- to robot-driving modes. Driving pattern observations are detailed in Table 24.

Table 24. Driving patterns.

Scenario	Observation
Distance to Stationary Objects	The average, median, maximum, and minimum distance the vehicle comes to stationary object.
Pedestrian Reaction	The average, median, maximum, and minimum distance the vehicle initiates a response.
Intersection Entrance	The average, median, maximum, and minimum distance and estimated time to intersect oncoming cross traffic.
Critical-path Selection	The autonomous-system decision to or not to enter a designated clear area if an obstacle in the distance will force it to stop in an unsafe location, such as while crossing a road.
Human Control	Frequency and circumstances that a human took control of the vehicle that was in robot-mode.

Additional parameters for observation will be identified during Phase 1 of the autonomous-system traffic safety evaluation. As data accumulates, patterns will emerge, warranting deeper investigation of performance.

4.3.2 Route metrics

Route metrics for a designed scenario will be used for comparisons. For example, data will be captured that assesses the autonomous-system's response to pedestrians crossing the street in its planned path. Where possible, route metrics (Table 25) will be identified that can be captured in multiple route segments, which will strengthen the overall performance analysis by increasing the sample size of specific situations, with a variety of influential variables. These variables can then be evaluated to determine the autonomous-system's performance in the presence of those variables and compare them to human-driver performance.

While this report covers the types of data to collect and the general testing approach, Research Area 5A expands this concept and provides a detailed test plan for performing autonomous-system testing at the CBITEC site.

Table 25. Route metrics.

Scenario	Observation
Avoids Immediate Objects	The autonomous-system comes to a stop or alters route appropriately when an obstacle is detected in its path.
Objects Approaching Vehicle	Objects, such as pedestrians or vehicles, move toward the autonomous-system on the pedestrian roadway.
Approaching Objects from Behind	Objects, such as pedestrians or vehicles, move toward the autonomous-system from the crosswalk or in the major roadway (from a different route segment).
Following Other Objects	The robotic vehicle follows another vehicle in front of it at an appropriate distance even when the other vehicle is accelerating or decelerating.
Stopping/Stopped Object	The autonomous-system follows another vehicle and stops at an appropriate distance when the vehicle stops in front of it.
Impairs Pedestrians	Metric that ensures that autonomous-system does not block or interfere with pedestrians from crossing the street.
Sun Blinding	This observation evaluates conditions where the sun is positioned such that it might impair the driver (robot/human). Time of day and inclination of the sun can impact the robot/human drivers at certain points in the route. This metric can be layered on any route segment metric to evaluate if the sun had a significant impact on driver performance (robot/human). The position of the sun can be calculated based on date, time, and location of the vehicle. The **References** section provides links to calculation resources, including an MS Excel spreadsheet developed by National Oceanic & Atmospheric Administration (NOAA).
Cross Traffic Turn Left	The autonomous-system comes to a stop and then turns left onto a cross street.
Cross Traffic Turn Right	The autonomous-system comes to a stop and then turns right onto a cross street.

Scenario	Observation
Cross Traffic Straight	The autonomous-system comes to a stop and then proceeds across a street. When oncoming cross traffic is identified, the system waits or proceeds appropriately. Distance to oncoming vehicle, speed, estimated time, to intersection is collected.

4.3.3 Triggered events

Triggered events, outlined in Table 26, are scenarios where the autonomous-system operates in an unexpected or unsafe way. In the event that any of the following scenarios occur, the incident will be flagged for analysis into the mitigating circumstances. In addition to the standard data collected, audio and video will be saved for reference. For triggered events, data will be flagged for 15 seconds prior to and following the flagged event timestamp for a total of 30 seconds.

The data flagging is automatically triggered when the events listed in Table 26 occur or when the test observer requests thru a software interface. All of the data collected during the test is stored for later analysis, but the triggered or flagged events are highlighted in the dataset to locate the event more easily.

Table 26. Triggered events.

Scenario	Observation
Safety Operator Override	If at any time, while in robot-mode, the autonomous-system performs in an unsafe or undesirable manner, the safety operator should take control and override the autonomy. The safety operator should enter an explanation into the survey/log.
Emergency Stop/Pause	The safety operator can at any time hit the emergency stop or pause button located throughout the autonomous-system. When pressed, the vehicle comes to a rapid stop.
System Error/Failure	In the event that the autonomous-system senses a system error or failure, it will immediately initiate emergency stop procedures.
Path Following	Develop set of specific route boundaries that the AV is expected to use. This set should include the left- and right-side boundaries for the designated route. Any events, where the robotic vehicle crosses these boundaries, should be flagged automatically for closer study.

4.3.4 CBITEC autonomous-system route

Figure 10 shows a conceptual drawing of the route between the CBITEC entrance and the proposed location of the charging station. The autonomous-system will travel this segment in both directions. This is a low- to medium-vehicle traffic area with expected pedestrian traffic expected.

Figure 10. Example test track.
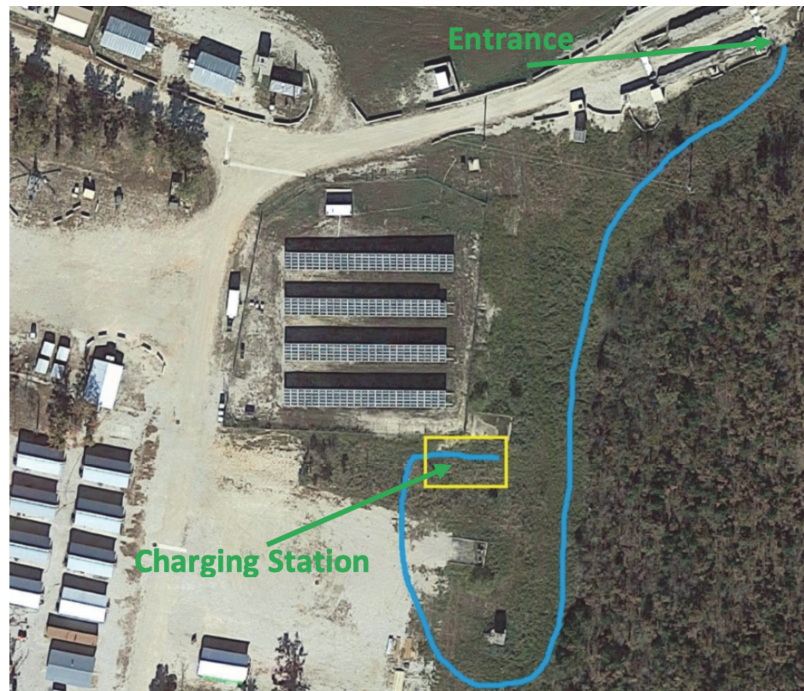
Specific observations are:

1. Vehicles turn around at the charging station area.
2. Pedestrians walk to and from the charging station area and are present in other areas of the CBITEC site.
3. There is vehicle traffic in and out of the dock area. This is the only access point to the charging station.

4.4   Monitoring autonomous component degradation

The objective of this research is to outline methodology for measuring autonomous component (sensor) degradation over time. For the scope of this research area, a sensor will be considered a LiDAR, radar, or camera. Just as human vision and reaction time change with age, the same is true for LiDARs, radars, and cameras, on which AVs rely.

The light intensity of a laser diode diminishing with time is an example of sensor degradation. After 3 years of operations, this intensity could be half of what it originally was. Another sensor degradation example is when the coatings of lenses and protective covers get scratched and subsequently less transparent over time, lowering the transmittivity and, therefore,

lowering the effective range of those same sensors. Cameras and laser detectors "burn in" with time, especially after exposure to bright lights and the sun, decreasing the sensitivity and creating more noise. As with humans, these changes in performance are not usually catastrophic; however, they gradually degrade the performance of the autonomous-system. To what degree this degradation happens depends on many factors that can be tested against road rules. For example, an old LiDAR might not be able to distinguish a person wearing a black velour suit 50 meters away, while the same LiDAR could have detected that same person with the same suit when it was new. If there is a traffic safety rule that says that the autonomous systems must stay 50 meters away from pedestrians, the aged system might not be able to comply with that rule. Like with humans, aging is not predictable. Some laser manufacturers use coatings that withstand elements better than others and exposure will be vehicle dependent. Testing the performance of the system is a way of understanding the current capabilities of the system.

4.4.1 Sensor degradation operational tests

To measure sensor degradation, a baseline must be established when the sensor is new. Data, which will be collected and stored during operational tests, will be used as a baseline for sensor degradation analysis. It is expected that certain features of the routes or scenarios will remain constant. These features include locations of buildings or other fixed structures. Sensor data is collected and recorded every time the autonomous-system is run. When the system is run over time, the collected data can be analyzed, and the sensor degradation can be characterized. Table 27 outlines sensor degradation operational tests.

Table 27. Sensor degradation operational tests.

Test	Observation
First Detection	The data-recording system continuously tracks the range measurements to objects and records the distance of the first detection. This data shows the overall health of the sensor and can be monitored over time to compare to a baseline. This test is used for LiDARs and radars.
Maximum Range	The maximum range measurement compares the sensors current capability to a baseline. This can be done by measuring the distance between the autonomous-system to a given feature when the feature is first detected. The distance can be recorded and tracked over a given time period. Captured data will show when the sensor's maximum range begins to decrease. This test is used for LiDARs and radars.
Range Measurement	The range measurement verifies whether the sensor is able to accurately measure distance. This can be done by measuring the distance between the autonomous-system to any given feature at a set location. This measurement can be recorded and tracked over time. The data will show if there is a deviation between what the sensor is currently measuring and the baseline. This test is used for LiDARs and radars.

Test	Observation
Object Shape/Size	This test will characterize the sensors ability to detect the shape of objects. This can be done by comparing the shape and size of a given feature over time. The data will show if the sensor has lost ability to sense finer details, such as corners or edges. This test is used for LiDARs, radars, and cameras.
Color and Focus	This test can characterize the overall health of a camera. This can be done by comparing image data of a given feature over time. The data will show if the camera has lost focus or color clarity. This test is used for cameras.

While sensor degradation operational tests can determine if a sensor is functional or not, the intent of the tests is to establish a baseline and characterize the sensor degradation over time. Sensor performance based on observed degradation is depended upon the autonomous operations use case. For example, a degraded sensor might not be usable in a high-speed application but would still be functional for lower-speed applications.

4.5 Autonomous-system terrain technologies

The objective of this research is to explore how current AV system terrain identification and estimation technologies can be improved.

Autonomous systems have an advantage when traversing complex or rough terrain. Without a person onboard, the system does not need to consider the driver's or passengers' comfort. However, platform shock and vibration limits need to be accommodated. The autonomous-system can use perception sensors to predict the upcoming terrain and navigation sensors to verify the prediction. This research will evaluate techniques that can be used to predict and verify the terrain and ways to use terrain data to improve the autonomous-system's planning algorithms.

4.5.1 Terrain identification

Most autonomous systems use LiDAR to detect the surrounding environment. LiDAR not only looks for obstacles in the system's path but also for the ground plane or support surface on which the vehicle drives. Determining the support surface is often a trivial task for on-road environments; however, in off-road environments, with the presence of vegetation, dust, and water, the operation is much more complex.

When LiDAR scans the environment, a hit occurs as the laser-range measurement contacts a surface that reflects the beam back to the LiDAR. In contrast, if the laser does not make contact with, and is not reflected, no

hit is recorded. The reflecting surface can be the ground, something attached to the ground, or something in the air like a bridge or an overpass. By collecting the number of hits in a given area, the autonomous-system can determine density and topography of the area surrounding the vehicle. A road surface will return several hits at a common elevation and will depict a smooth surface. A curb on the same road surface will show an abrupt elevation change. Similarly, a person or a car on the road surface will show attachment points to the ground.

Using the LiDAR information, the autonomous-system deciphers what the ground plane or support surface looks like. This becomes more challenging in areas with dense vegetation because the LiDAR might get hits off of tall grass, making the ground appear higher than it is. The autonomous-system must determine the density of those hits to better understand the surface.

Figure 11 depicts the support surface found using the detection method described above for a terrain with shoulder-height grass:

- The blue surface is the predicted support surface.
- The yellow line is the path of the vehicle.
- The green line in the middle picture is a row of hits from the grass.
- The white and red lines in bottom picture show the different density of hits returned from the grass.
- The darker red section are more dense returns where the white is less dense. The denser the vegetation, the harder it is for laser beams to penetrate, and, therefore, larger errors can be generated.[*]

By calculating the support surface using this methodology, the autonomous-system can predict the relative roughness of the terrain that the vehicle is about to cross. The planning system can then rate the rougher sections of terrain as less desirable to traverse or decrease the vehicle's speed to accommodate for the terrain.

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[*] Lacaze, Alberto, Murphy, Karl, DelGiorno, Mark. July 8, 2002. "Autonomous Mobility for the Demo III Experimental Unmanned Vehicles."

Figure 11. Support surface voxel generation.
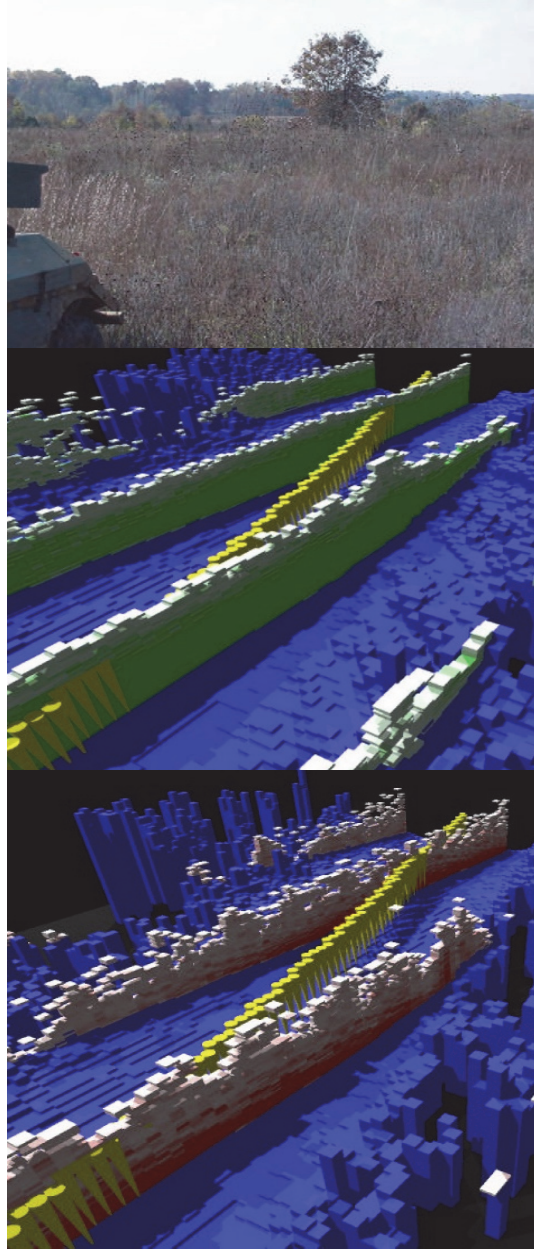
As perception sensors predict upcoming terrain, the inertial sensors can verify whether the predicted terrain equates to the platform's current attitude (roll, pitch, and yaw). This measurement can be made more accurately if the system is equipped with suspension sensors, as the tire-to-ground interaction will be damped by the suspension, and the GPS/INS will not sense the full roughness of the terrain. By adding the state of the suspension system to the system's current pose, terrain attributes can be better verified.

Post processing the LiDAR and navigation data will not only verify the accuracy of the terrain prediction but also allow the terrain prediction algorithm to be tuned for better results in the future.

More fidelity can be added to the navigation sensors ability to measure the current terrain interaction by adding smaller IMUs to each wheel. The system could then sense the overall vehicle pose and the dynamics happening at each wheel in real time.

4.5.2 Trajectory modeling

These detailed methods can be used to create simulated models of both the terrain and the autonomous-system's interaction with the terrain. If a system's behavior can be predicted with simulation and modeling, the planning algorithms in the autonomous-system can apply feed-forward control techniques that anticipate and correct for interaction with the terrain. This is useful when navigating complex terrain or when trying to achieve higher speeds in rougher terrain.

These simulations require precisely accurate modeling of the terrain and vehicle dynamics. While the modeling will result in a smoother ride for the autonomous-system, it would not be feasible to apply such a strategy to all systems. Complex models of the both the vehicle and terrain need to be created and verified. There are times where it is not possible to model all of the terrain, or the value of the autonomous-system might not warrant the added cost of the simulation.

Considerations for the feasibility of trajectory output software include:

• Cost of vehicle
• Number of vehicles in operation
• Complexity of the operating terrain/environment.

As the complexity of the terrain increases, the difficulty and cost to model the terrain also increases. Spreading across costs of the vehicle multiplied by the number of vehicles can offset this cost. It might not be cost effective to model complex terrain for a low quantity of inexpensive vehicles could be feasible for a larger quantity of expensive vehicles. Therefore, it is recommended that terrain modeling strategy be applied per Figure 12.

Figure 12. Feasibility of trajectory output software.
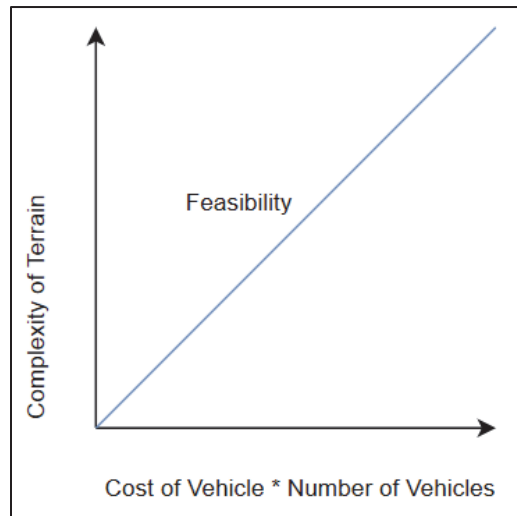
4.5.3 Autonomous docking with charging stations

The objective of this research is to define requirements for AV systems to autonomously dock with charging stations. Robotic Research team of engineers are SMEs in autonomous software and hardware development and integration. The following list of requirements (Table 28.) Robotic Research's engineering team developed define the high-level operations and behaviors necessary for an autonomous-system to autonomously dock with a charging station. It is expected that more specific sub-requirements will need to be defined based on the robotic vehicle selected for the operation and the final layout of the CBITEC site.

Table 28. Autonomous docking requirements.

Operation	Docking Requirement
Localization	• **Requirement 1:** The autonomous-system will be able to calculate its absolute position within 0.1 meters. • **Requirement 2:** The autonomous-system will be able calculate its relative position within 0.1 meters. • **Requirement 3:** The autonomous-system will calculate its attitude position (roll, pitch, and yaw). • **Requirement 4:** The autonomous-system will be able to receive differential GPS (DGPS) corrections. • **Requirement 5:** The autonomous-system will be able to visualize odometry data for localization. • **Requirement 6:** The autonomous-system will be able to use wheel-encoder odometry data for localization. • **Requirement 7:** The autonomous-system will be able to operate without GPS.
Perception	• **Requirement 8:** The autonomous-system will be able to operate in varying lighting conditions, such as full daylight, dusk, and night. • **Requirement 9:** The autonomous-system will be able to detect the position of objects within the sensor's field of view. • **Requirement 10:** The autonomous-system will be able to measure the speed of objects within the sensor's field of view. • **Requirement 11:** The autonomous-system will be able to measure the trajectory of objects within the sensor's field of view. • **Requirement 12:** The autonomous-system will be able to track objects within the sensor's field of view.

Operation	Docking Requirement
Planning	• **Requirement 13:** The autonomous-system will be able to acquire a route via an over-the-air update, through a wired connection or other means, such as a USB drive, and store it onboard. • **Requirement 14:** The autonomous-system will be able to navigate stored routes.
Docking	• **Requirement 15:** The autonomous-system will be able to perform maintenance-yard maneuvers. • **Requirement 16:** The autonomous-system will be able to perform point-to-point travel. • **Requirement 17:** The autonomous-system will be able to recognize the location of the charging station. • **Requirement 18:** The autonomous-system will be able to precision park at the charging station. • **Requirement 19:** The autonomous-system will be able to communicate via a data interface with the charging station. • **Requirement 20:** The autonomous-system will be able to command the charging station to begin charging. • **Requirement 21:** The autonomous-system will be able to command the charging station to stop charging.
Vehicle	• **Requirement 22:** The autonomous-system will have an emergency stop. • **Requirement 23:** The autonomous-system will stop when the emergency stop is engaged. • **Requirement 24:** The autonomous-system will follow the velocity commands generated by the autonomy system. • **Requirement 25:** The autonomous-system will follow the steering commands generated by the autonomy system.

4.5.4 Optimization to reduce autonomous vehicle system power consumption

The objective of this research is to identify optimization techniques that the autonomous-system can exploit to reduce power consumption. Connected autonomous systems with Vehicle-to-vehicle (V2V) or Vehicle-to-infrastructure (V2I) communications and knowledge of the planned route have an advantage in reducing power consumption. Autonomous systems can intelligently exploit acceleration curves and regenerative braking.

4.5.5 Optimization techniques

Most, if not all, EVs not only employ regenerative braking to assist in decelerating the vehicle but also to recharge the vehicle's batteries and extend range. Human drivers practice techniques of either riding the brakes or coasting to increase brake regeneration time. This technique can be performed more efficiently by an autonomous-system. Inertial sensors, visual odometry sensors, and knowledge of the terrain allow the autonomous-system to optimize the amount of coasting and/or braking that can be achieved to maximize regeneration time while still maintaining a given speed for a roadway. Additionally, the autonomous-system can more accurately maintain acceleration and deceleration rates during driving tasks to optimally conserve energy.

Autonomous systems with V2V or V2I communications can employ even more techniques to improve power consumption. Path planning is a major computational component of the autonomous-system. Part of the path-

planning computation is calculating arrival time to a given location. If the autonomous-system is communicating with infrastructure, such as traffic lights, the system will know when traffic lights will turn green or red. The autonomous-system can use speed control techniques to allow it to take more time to get to a traffic light that is currently red. This technique will either allow for decreased acceleration, consuming less energy, or longer periods of deceleration, increasing regenerative braking. Similarly, an autonomous-system that is communicating with other vehicles on the road has a greater knowledge of traffic speeds and behaviors. This knowledge lets the path planner smooth the autonomous-system's speed profile to again minimize acceleration or maximize declaration times.

4.6 Conclusions and future work

A variety of topics and techniques regarding autonomy have been discussed in this report. Some of the techniques are established practice while others require additional development and testing. Areas where more research would be beneficial are:

- **Sensor Degradation**: While the tests described in this report can detect and characterize the current performance of a sensor compared to a baseline condition, the majority of this characterization is done through post processing data. More research can be done to make those comparisons in real time and report the overall sensor health to the system.
- **Terrain Identification**: More research can be performed in this area to better understand how the system interacts with not only the terrain but also differences in soil or road conditions. More modeling and simulation can be performed to better create feed-forward control algorithms allowing autonomous systems to traverse more complex terrain at higher speeds.
- **Precision Docking**: Requirements for precision docking can be derived to better constrain the platforms low-level control system. While precision docking presents challenges of localizing the autonomous-system relative to the charging station, the more significant challenge is developing an extremely precise control system at the platform level that can accurately follow velocity and steering commands with little latency. The autonomous-system can easily overshoot the goal point by a few centimeters if the platform controls are not well tuned.

- **<u>Improved Power Management</u>**: The techniques described in this section can be tested and improved as more V2I and V2V capabilities arise. A more connected area of operation will allow for more chances to test and verify these techniques.

5 Research and Develop a Plan for Testing and Demonstrating Vehicle Charging within a Tactical Microgrid Environment

The vision to ensure energy resiliency for the warfighter in a tactical environment underscores the need for a living laboratory to test candidate technologies for potential incorporation into a tactical microgrid. The Research Area 4 collaboration with CBITEC and CERL staff identified V2G charging technology that will allow electric transport technologies to serve as an alternative-energy source, lowering fossil fuel generation dependency while supporting vehicle-mission requirements. This collaboration informed the tactical microgrid model that supports the design integration effort of the selected V2G technology along with future "what-if" scenarios. Paragon SMEs developed a test plan to validate integration and evolve the overall tactical microgrid design to support integrating future enabling technologies.

The objective of Research Area 4 is to research and develop a plan for testing and demonstrating V2G charging within a tactical microgrid environment that validates EV capabilities providing energy support to critical loads, interoperating simultaneously with other generation sources, and dispatching as a load or a generation source as necessary to support the tactical microgrid's efficient operation.

In order to develop a test plan to demonstrate V2G charging within a tactical microgrid environment, the Paragon research team cataloged CBITEC microgrid assets and identified V2G operational requirements, developed a conceptual microgrid model, conducted "what-if" scenarios, and designed a test plan to verify performance of the V2G system.

Paragon SMEs cataloged CBITEC tactical microgrid assets through site visits and review of customer-provided documents, and engagement with CBITEC staff and technology providers to gather site requirements and current asset capabilities at CBITEC. System components and available V2G charging solutions were identified, and a conceptual design was prepared to reflect integration requirements necessary to establish a tactical microgrid.

Because the program's intent is to build a living laboratory to support the developing and testing technologies at CBITEC, the tactical microgrid should also include additional metering and control components to help ensure safety for personnel, and equipment, along with analytical tools for equipment evaluation and data gathering. A software model of the tactical microgrid was prepared to simulate various "what-if" scenarios and aid the final tactical microgrid design and evaluation.

5.1 Catalog CBITEC assets and identify V2G operational requirements

The objective of this research is to identify and catalog CBITEC tactical microgrid assets and to identify V2G operational requirements to integrate and use in a tactical microgrid.

To catalog the site's requirements and capabilities, Paragon SMEs collaborated with CBITEC and CERL staff, and previous equipment providers, to identify components that make up the tactical microgrid. Additionally, Paragon SMEs conducted site visits to the CBITEC facility on FLW and CERL offices in Champaign, IL to inspect existing components, location, and environment of the future living laboratory. Customer-provided documents were reviewed by SMEs, and input from vendors providing tactical microgrid technologies was documented.

During the course of this collaboration, CBITEC staff provided feedback on desired microgrid capabilities, lessons learned from previous equipment demonstrations, and practices for uniformity with current development standards as well as the Army's broader vision for tactical microgrids. Identified components were studied to ascertain capabilities and determine how to best to integrate V2G chargers with tactical microgrid components. Through engagement with CBITEC staff and equipment manufacturers, the Paragon team identified these components for:

- Specific microgrid components and equipment that must be included
- Microgrid components and equipment that must be added to meet safety and operational objectives
- Design standards that system components must adhere to.

In addition, this research effort considered the vision of creating a living laboratory at CBITEC and necessary capabilities to test and evaluate innovative energy efficiency and energy security technologies for future integration into the tactical microgrid. Adding an evaluation capability to any energy system inherently requires the following approach: developing performance requirements for the EUT, implementing a sensored and metering system to measure performance, and a test plan that will validate the EUT to meet performance requirements by conducting applicable test use cases. This approach allows Research Area 4's test plan to evaluate integrating a V2G charger and to support the program vision of a future living laboratory bringing energy resiliency to the warfighter by:

- Providing CBITEC the capability to integrate, test, and evaluate alternate energy sources that are manufacturer agnostic and based on tactical microgrid performance requirements and not specific equipment design
- Utilizing existing tactical microgrid components readily available and familiar to the warfighter for representative results
- Identifying additional components that use open standards to ease integration, monitoring, and control of microgrid assets
- Using a modeling environment to simulate "what-if" scenarios and evolve the microgrid design and associated test plans.

By supporting the tactical microgrid short- and long-term development, this approach postures CERL to efficiently evolve test plans and evaluate technologies to ultimately develop a tactical microgrid that is resilient, flexible, and secure for the warfighter.

5.1.1 CBITEC assets

Work for this research effort commenced with the preparation of, and communication to CBITEC and CERL staff, a detailed list of equipment and systems that are typically present in a tactical microgrid as well as requesting available tactical microgrid documents for the Paragon SMEs to review. Critical to preparing a suitable integration design and test plan to validate performance the existing state of the tactical microgrid and site capabilities was verified.

The following items were discussed at the project kick-off meeting held at CERL offices in Champaign, IL on April 30, 2019:

- System documentation—any available documentation to identify current and proposed design of the tactical microgrid, including equipment manuals and system drawings
- Fossil-fueled generators—power rating and quantity to be used
- ESSs—energy storage technology and power and energy ratings
- Photovoltaic (PV) systems—configuration and rating(s)
- Microgrid loads—specific load configuration, type, and size been to consume the energy produced by the microgrid's generation sources
- Distribution system—various generation sources and loads interconnection and protective devices that were included to ensure personnel and equipment safety
- Monitoring and controls system—system used to monitor and control the tactical microgrid's components and the level of control available to start and stop generation sources or loads, prioritizing available power to mission critical loads and conduct test plans
- Applicable standards—military or industry standards to incorporate
- Advanced capabilities—special capabilities and considerations that must be considered for the tactical microgrid to meet mission requirements as a living laboratory
- Site limitations—specific site limitations that could influence the tactical microgrid's design to be used as a living laboratory; how could a test plan be conducted.

5.1.2 Current capabilities and requirements for testing and operating V2G technologies at CBITEC

The CBITEC site at FLW (Figure 13) operates with great flexibility and authority to review and approve demonstrations. Operational requirements do not include site permitting, city inspections, state approvals, or an extensive design- review process from multiple site organizations before approval to install equipment is granted. Operational requirements mirror that of a deployed tactical microgrid outfitted with local staff with authority to review and approve installing equipment for testing and evaluation, as long as the equipment is compatible with the site's infrastructure and, as is the case with most host nation requirements, the equipment is not installed as a permanent structure.

Figure 13. CBITEC site at Fort Leonard Wood, MO.

Similar to an FOB, equipment installations should be designed to accommodate a dusty environment as a byproduct from an unpaved site and the associated standing water resulting from normal rain conditions. The CBITEC site designated for the tactical microgrid contains approximately 19 acres of unpaved, substantially level ground. The dusty environment can be accommodated by selecting equipment enclosures that are properly rated for the expected operating environment by the National Electrical Manufacturers Association (NEMA).

At CBITEC, equipment installations are considered permanent if the installation includes a concrete foundation. Permanently installed equipment must acquire approvals beyond local CBITEC authority and require additional time and resources to pursue. Concrete pads placed on top of the ground, but which are portable, are not considered permanent installations and can be approved by CBITEC staff directly. Consequently, integration designs that do not use permanent installations are recommended as they might have a more efficient approval process.

Extensive engagement with staff at CBITEC; CERL; and Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) ultimately revealed that a formal set of microgrid design drawings is not available. While drawings of the tactical microgrid at CBITEC were also not available, information on a subset of the equipment

to be used in the tactical microgrid was available and subsequently provided, including:

- Advanced Digital Control System (DCS) Operator's Manual; describing the parallel operation of the AMMPS generator to form a tactical microgrid
- DoD Interface Standard MIL-STD-TMS, TMS (Figure 14), version March 2018; an interface standard that is under development and has not yet been approved for release
- Army Technical Manual TM 9-6150-226-13, Operator and Field Maintenance Manual for distribution illuminations systems, electrical (DISE) and power distribution and illumination equipment (PDISE), version November 2008 (Figure 15); describing how to properly interconnect and use electrical generation sources and loads.

Figure 14. Tactical microgrid standard.
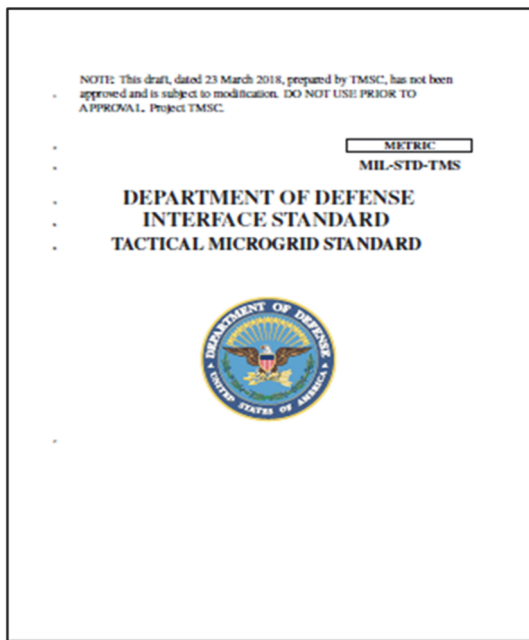
Figure 15. PDISE documentation.
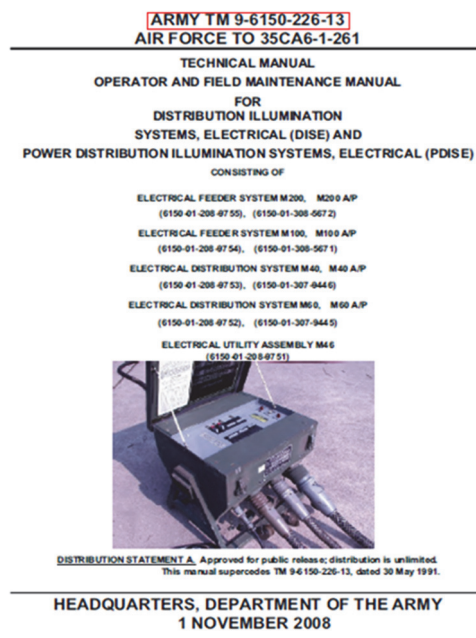
Paragon SMEs took additional steps to engage directly with vendors that have supported CERL's development and testing of legacy generators to form a tactical microgrid and acquire additional documentation and insight on the its operation, capabilities, and limitations. As a result of these engagement activities, four documents for the were developed by Humber-Garrick Consulting Engineers (HG Engineers) for the government and were provided to Paragon SMEs:

- 800A IPD Technical Manual
- IPD deployable metering and monitoring system (DMMS) User Manual
- TMS Generator Startup Procedure
- Verification of test results.

Paragon SMEs comprehensively engaged Schweitzer Engineering Laboratories (SEL) in this research given their role in the design of the controls for IPDs, test generator operation in a microgrid environment, and familiarity with the TMS and ongoing revisions. Information received from SEL included extensive discussion on existing components, the IPD design and the following documentation:

- Tactical microgrid Generator Test Procedure
- MIL-STD-TMS, TMS OMG Data Distribution Service (DDS) Implementation Guide.

On April 24, 2019, Paragon SMEs conducted a site visit to CBITEC to review available microgrid components and space to add additional equipment that would develop the living laboratory. Components of the tactical microgrid were cataloged as listed in Table 29.

Table 29. Catalog of microgrid equipment at CBITEC.

No.	Component Description	Operational Status	Notes
1	PDISE distribution center (100A)	Available	PDISE power distribution box
2	PDISE distribution center (200A)	Available	PDISE power distribution box
3	M100 distribution cables (100A)	Available	PDISE power distribution cables
4	M200 distribution cables (100A)	Available	PDISE power distribution cables

No.	Component Description	Operational Status	Notes
5	Site electrical loads	Available	ECUs, lighting, laundry on site
6	Test loads	Available	60-kW (minimum) three-phase resistive and reactive load banks to be provided as needed
7	AMMPS generation (60 W)	Available	Cummins generator
8	Lithium-ion ESS (40 kWh)	Not operational	Might be removed
9	Flow battery energy storage (300 kWh)	Not operational	Might be removed
10	Lead acid energy storage	Not operational	Will be removed
11	PV array (100 kW)	Not operational	(4) 25-kW inverters need to be upgraded
12	IPD box (200A)	Available	Test units made by HG Engineers
13	IPD box (800A)	Available	Test units made by HG Engineers
14	Metering stations	Available	Existing deployable metering and monitoring system (DMMS)
15	Microgrid controller	In development	Being developed by C5ISR
16	Dashboard	Multiple	Investigating each for applicability/capability for a living laboratory

CBITEC staff shared that the site electrical loads consisted of numerous Billeting huts that each contain indoor lighting, convenience outlets, and an Environmental Conditioning Unit (ECU). The ECU could potentially serve as a 6.2-kW load when in air-conditioning mode or a 10.2-kW load when operating in heating mode.

In total, Billeting huts could provide approximately 200 kW of load for testing purposes of the tactical microgrid. Photos of a typical Billeting hut and ECU at the CBITEC site are shown in Figures 16 and 17.

Generation sources at the CBITEC site include the AMMPS 60-kW generator (Figure 18). A total of six AMMPS (60 kW) generators are expected to be available to support up to 360 kW of electrical load as well as the testing and interoperability evaluation of multiple generation sources on the tactical microgrid. Because the AMMPS generator is rated for three-phase, 208 volts of AC (VAC) at 60 Hz, and has been selected by CERL to be the generator to serve as the backbone of the tactical microgrid, other generation sources or loads must also be rated or configured for 208 VAC, 60 Hz operation. To achieve this, appropriate power conversion devices might be required because commercially developed inverters over 10 kW or three-phase are predominantly 480 V.

Also located at CBITEC is a ground-mounted PV array (Figure 19) consisting of four, 25-kW inverters with a total output capacity of 100 kW. At the

time of the site visit, CBITEC personnel indicated the PV array inverters were expected to be upgraded. Consequently, the array is not fully functioning. Timing of the upgrade has yet to be determined.

Figure 16. Billeting huts at CBITEC.

Figure 17. ECU at CBITEC.

Figure 18. 60 kW AMMPS generator.

Figure 19. PV array at CBITEC.

Two containerized ESSs are located at the CBITEC site. One is a 300-kWh iron-flow battery system (Figure 20) provided by Energy Storage Systems, Inc. The other is a 40-kWh lithium-ion system (Figure 21) provided by EnerDel. Enerdel's Mobile Hybrid Power System (MHPS), which consists of two 20-kWh battery packs, is capable of charging or discharging at 30 kW and is rated for three-phase 208 VAC, 60 Hz. At the time of the site visit,

the flow battery system was not operational, and repairs necessary to restore operation had not been scheduled. The MHPS was operational and available to support the tactical microgrid.

Figure 20. Flow battery system at CBITEC.

Figure 21. Enerdel 40 kWh lithium-ion energy storage system.

Properly interconnected generation sources and loads require properly rated conductors, power distribution boxes, and protective devices. Program of record equipment traditionally used to meet this need is the PDISE system (Figure 22), which includes conductors and power distribution boxes with protective devices designed to connect multiple loads to a generation source. The PDISE distribution boxes are not intended to connect multiple generators or equipment with bidirectional power flow nor to monitor electricity. The PDISE protective scheme solely consists of circuit breakers and does not contain any metering or sensoring to monitor power or quality, nor is there synchronization as required to establish ring connections.

Figure 22. PDISE equipment at CBITEC.

CERL, after recognizing the need to use IPD equipment for monitoring and managing power flow, contracted HG Engineers to develop the IPD (Figure 23). The IPD design specifically addresses the intent to achieve energy resiliency by incorporating:

- Multiple ports to interconnect multiple generators
- Two ports to establish a ring distribution system
- Meters on each port to monitor, on both a system and equipment level, real-time electricity flow—including voltage, frequency, current, power, and power quality
- Synchronization on the ring-bus ports for multiple sources
- Data recording for root-cause analysis of system disturbances.

The IPD included a real-time automation controller (RTAC) and controllable devices providing both intelligence and additional control of the IPD-connected device (Figure 24). The IPD includes a communications capability to interact with an principal microgrid controller via Ethernet RJ45 connections, DDS TMS protocol per TMS as well as a Modbus Transmission Control Protocol/Internet Protocol (TCP) slave connection. With these features, the IPD quantifies system power demands, remaining generator capacity, and connects or disconnects specific devices, based on commands issued by the tactical microgrid controller to help ensure resiliency of mission critical loads.

Figure 23. 800 A IPD.

Figure 24. DMMS wireless access point.

A second type of IPD is being developed now for potential use in a tactical microgrid by C5ISR, located at Aberdeen Proving Ground in Maryland. In addtion, C5ISR is developing a microgrid controller that will provide overarching control of the tactical microgrid. Because the microgrid controller and the IPD are still in development, detailed information on these systems is not yet available to include in this report.

Currently, CBITEC's DMMS is used to wirelessly communicates with microgrid devices via a local dashboard. The DMMS only collects data is used for data collection only and does not control any of the microgrid devices. The AirGuard 3e-523 from 3e Technologies International serves provides the connection point between equipment and the CBITEC wireless local area network (WLAN)—forming a wireless mesh network at CBITEC. The DMMS allows data collection without the need for installing communications conductors.

A dashboard located in the CBITEC local office monitors equipment operations and collects data. This dashboard interface, developed by Pacific Northwest National Laboratory (PNNL), provides moderate- and high-level monitoring of system voltages and loads it collects every one to 3 seconds. A knowledgeable user can create a data collection profile on the DMMS dashboard as well as configure the operator interface to display data in different graphical forms.

By policy, distribution equipment connected to the tactical microgrid must be manually operated when conducting tests and cannot be controlled through the dashboard. C5ISR is also developing a dashboard for monitoring a microgrid; however documentation related to it was unavailable to be included in this report.

5.1.3 Cyber security requirements

At the time of this research, the government did not provide the requested list of cyber security requirements beyond standard Army Risk Management Framework (RMF) procedures. However, it has stated the DMMS wireless access points (Figure 24) have been approved from a cyber security standpoint for integrating devices into CBITEC's wireless mesh communications network, which is used to monitor and collect data. The 3e-523-3 wireless access points, manufactured by 3e TI Technology International, is the established wireless mesh network at CBITEC. This network provides sufficient cyber security and is approved for use on a Secret Internet Protocol Router Network (SIPRNet). Adding the V2G station to the tactical microgrid will not create an additional cyber security risk because it does not require specific hardware, or network architecture, to establish communications and can easily integrate within the approved DMMS network architecture.

5.1.4 V2G operational requirements in a tactical environment

Given CBITEC's vision to replicate the operating environment of an FOB, V2G operational requirements in a tactical microgrid mirror those identified at CBITEC. Many host nation agreements do not allow permanent structure installation, which prompts using concrete pads, or incorporating a structural frame suitable for direct earth contact as the equipment base, which is done with the AMMPS generators.

The AMMPS generator is used by the Army for providing electricity at FOBs. The AMMPS is availble in five sizes ranging from 5–60 kW. Each generator size is available in two models according to the frequency rating: 50/60 Hz or 400 Hz. Each generator is capable of providing multiple voltages three-phase power rated at 120/208 VAC or 240/416 VAC. CBITEC and CERL staff have identified the operaing voltage and frequency for this effort to be 120/208 VAC, 60 Hz. Legacy generators, the

desire to interconnect with host nation power, and specific load ratings, might require a different voltage and frequency rating.

Specific operating requirements will be documented in the TMS, which the Army is developing now, are not currently approved for release. A draft version on March 23, 2018 indicates this standard will establish both general and detailed requirements related to: interoperabilty, safety, cybersecurity, system architecture, communication interfaces, communication requirements, and electrical connections.

Drawings of the communications system at CBITEC were not available at the time of this report. Feedback from CBITEC and CERL staff indicates the tactical microgrid can use the developed TMS or Modbus protocols to communicate from the microgrid controller to all of the microgrid devices, including the system dashboard. This communication protocol will be used both over Ethernet and the wireless mesh network established by the 3e-523-3 wireless access points manufactured by 3e TI Technology International.

The Modbus memory map for monitoring and controlling the V2G charger is provided in **Appendix C**. A high-level roadmap to implement V2G operations in the tactical microgrid consists of:

- Hardware installation
    - Install V2G charger, step-down transformer, reference generators, loads, IPD, and interconnecting cables to form microgrid
    - Commission installed equipment
- V2G charger configuration
    - Configure voltage and frequency settings to avoid nuisance trips
- Establish charger communications
    - Install and configure wireless access points for data collection
    - Install wired communications per microgrid communications design
    - Update dashboard for data collection
- IPD configuration
    - Configure protective per connected equipment ratings and planned operation
    - Configure communications for data collection
- Microgrid controller development

- o Identify desired control capabilities
- o Develop control scheme/algorithms
- o Develop communications strategy to meet monitoring and control requirements
- o Install and commission microgrid controller
- System commissioning
  - o Verify communications
  - o Verify safety mechanisms/e-stops
  - o Develop and conduct test plans to test equipment operation/control
  - o Develop and conduct test plans to test system operation/control.

5.2 Identify V2G solutions available

The objective of this research is to identify available V2G charging solutions that can be used to apply bidirectional charging and discharging capability when integrating an EV within the tactical microgrid. Paragon SMEs researched solutions best equipped to meet the requirements outlined in **Section 2**. Additionally, Paragon researchers developed a list of pros. and cons. for diesel generators, and controller technologies that are potentially suitable to be used for military applications.

5.2.1 V2G equipment and design information

Chargers that are rated near 50 kW are referred to as "fast chargers" and are specifically designed to quickly charge an EV. To quickly charge an EV, fast chargers use DC to charge the vehicle's battery. By permanently installing power conversion equipment offboard of the EV, DC charging reduces both the weight and space burdens power conversation equipment place on an EV. DC fast chargers are designed to operate at much greater power levels–typically 30–100 kW compared to 1.4–19 kW for AC "standard" charging. In the United States, there are three fast charging-standards that specify the communications and control between an EV and a fast charger:

- Tesla
- The Combined Charging System (CCS)
- CHAdeMO.

The Tesla fast chargers, which are not bidirectional, utilize closed and proprietary protocols. Consequently, Tesla fast chargers only work with Tesla

EVs. In Europe, Tesla recently began testing Tesla EVs that can be charged with CCS stations, as these stations are Europe's most commonly used charging standard. European systems operate at different voltages and frequencies than systems in the United States, so the operating voltage and frequency of this solution needs to be modified before being deployed with equipment designed and manufactured for use in the United States.

The CCS standard, developed by the Society of Automotive Engineers (SAE), is the most commonly used fast-charging standard in the United States. This open standard is used by multiple charging station suppliers to charge CCS-compliant EVs (Figure 25). However, the CCS standard's does not incorporate communication and command structures necessary to implement are not compatible with EV on-demand discharging of EVs. Consequently, messaging between the vehicles and chargers must be customized to include unique commands enabling a V2G-capable vehicle to use the CCS standard. This customization inherently prevents the custom charger to be readily used for multiple vehicle types. Such customization also requires extensive non-recurring engineering, development, and testing to implement the V2G capability, which further limits customized CCS solutions for V2G applications. By 2025, SAE plans to update the CCS standard to include communication and controls specifications necessary to enable V2G operations between CCS-compliant vehicles and charging stations.

Figure 25. SAE CCS connector.

The CHAdeMO standard (Figure 26) is not only commonly used in Asia but also the only open standard that fully accommodates V2G applications. Using the CHAdeMO standard in the United States, however, is limited compared to the SAE CCS standard for fast-charging applications.

Figure 26. CHAdeMO connector.

Paragon SMEs identified only two vehicles in the United States available for purchase with the CHAdeMO fast-charging option: the Mitsubishi Outlander and the Nissan LEAF. Because the Outlander is a PHEV, it comes with a battery pack that has a comparatively small energy- storage capacity—, 12 kWh—, compared to the LEAF, which is a fully EV with a much larger lithium-ion battery pack in two energy storage capacity options—40 kWh and 62 kWh.

In addition to ensuring compatible communications between the EV and related bidirectional charging equipment, the V2G charging equipment must also be able to communicate with an external controller. This ability enables V2G system monitoring and control. Important V2G system information to monitor includes:

- V2G system health (equipment alarms, faults, battery pack temperature)
- Operating status (available power to charge and discharge)
- Battery pack systems on chip (SOC)
- Present rates of charge and discharge, operating mode
- Capable rates of charge and discharge
- Charge and discharge setpoints.

Through the V2G charger, EV information is accessed and does not normally require additional communications connection between the EV and external controller. External controllers, often capable of different communication protocols, are typically limited to those options available with the V2G charger. Protocol converters can also establish communications if the selected external controller and V2G charger cannot accommodate the same communications protocol.

Most V2G fast chargers operate with the electrical grid as opposed to stand-alone systems. Consequently, they are often certified to be compliant with electrical utilities' required specifications. A very common certification is the Underwriters Laboratories (UL) 1741, *Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources*. This UL Standard specifies when generation sources, including V2G systems, will disconnect from the electrical grid based on system voltage and frequency deviations beyond established limits.

The standard's intent is that generation sources will disconnect when a grid disturbance is detected so that repairs can be safely made without the potential for a V2G system to back-feed the grid, which is dangerous to repair personnel. This operating requirement might pose an operational challenge for V2G chargers that are UL1741 compliant as the voltage and frequency stability of a tactical microgrid could be inconsistent from that of the commercial electrical grid. Lightly loaded generators frequently deviate from voltage and frequency operating targets. Because of this, V2G chargers can disconnect from the tactical microgrid when constrained to UL1741 operating limits, even though a fluctuating voltage and frequency does not indicate a microgrid disturbance. Implementing a V2G charger in a tactical microgrid should provide voltage and frequency trip levels adjustment, accommodating normal operating conditions associated with tactical microgrid power generation sources.

5.2.2 Design criteria for integration of a charging station into a tactical microgrid

CBITEC and CERL staff identified integration requirements that will:

- Integrate into the 208-VAC, 60-Hz tactical microgrid electrical distribution system
- Communicate with the DMMS
- Charge, or discharge, at a minimum of 50 kW.

The microgrid controller, which C5ISR is developing, will control the charging station. Communication from the microgrid controller to the charging station is expected to use Modbus TCP/IP protocol.

5.2.3 Conceptual design of V2G charging station integration

The V2G charging station should provide three-phase power to accommodate integration design criteria. This will ensure a balanced generation and consumption of electricity for the V2G system that supports electrical distribution system stability. Fast chargers are designed to charge EVs between 200–600 volts of DC (VDC) and are typically supplied by three-phase, 480 VAC. For 208- VAC tactical microgrid integration, a properly sized transformer needs to be installed if the selected fast charger cannot be operated at 208 VAC. Because the Coritech fast charger does not use a neutral connection, the delta side of the transformer could be connected to the charger. As this configuration is an ungrounded system that can result in excessive floating voltages, the manufacturer recommends installing a grounding transformer between the charger and the step-down transformer instead of using a floating-delta connection.

Alternatively, the manufacturer advises a delta connection on the 4-wire 208 wye distribution system and grounded 3-wire wye connection on the 480-VAC connection to the charger can also be used instead, avoiding the cost associated with adding the grounding transformer. Because the charger does not use a neutral, the wye neutral is not connected to the charger and only connects to the equipment ground. Figure 27 shows the charging station integration's conceptual design.

Figure 27. Conceptual integration design.
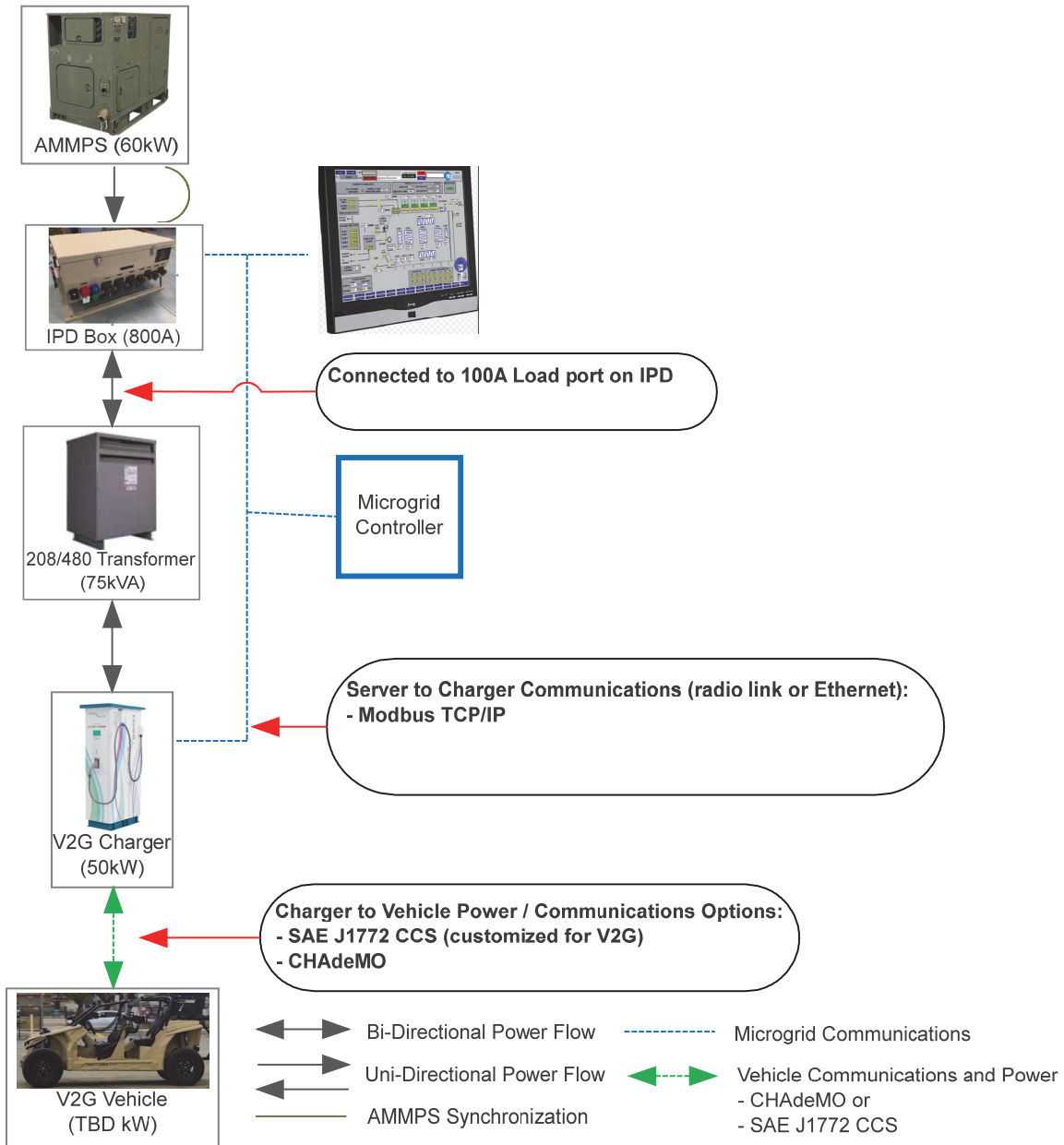
5.2.4 Available V2G charging stations that meet performance requirements

Paragon SMEs performed a market search for commercial-off-the-shelf (COTS) V2G chargers designed to operate in the United States. After an extensive search, the only supplier providing COTS V2G chargers is Coritech Services, Inc. from Royal Oak, MI. Coritech Services offers V2G chargers (Figure 28) in either a 30-kW or 60-kW power rating with the

option of either an SAE CCS or CHAdeMO communication standard. It is noteworthy that a V2G charger ordered to operate according to the SAE CCS standard still requires additional engineering services to develop and implement additional communications messaging for the selected vehicle until SAE updates the CCS standard to include V2G operations.

Figure 28. Coritech V2G fast-charging station.

During the market search for COTS suppliers of V2G fast-charging stations, Paragon SMEs identified several power conversion equipment vendors. Each could produce a V2G fast-charging system by integrating the discreet components necessary to provide monitoring and control for charging and discharging a lithium-ion battery pack. Both Go Electric and EnerDel are experienced and can create custom systems, meeting specific fast-charging needs and operational requirements.

5.2.5 Potentially suitable technologies

A list of pros. and cons. for bidirectional chargers, diesel generators, and controller technologies that are considered potentially suitable for military applications is provided in Appendix N. This list catalogs both, suitable and not suitable, bidirectional chargers, diesel generators, and controller

technologies assessed for military applicability, interoperability, cost, and plug-and-play capability.

5.3 Simulate V2G charging in the tactical microgrid environment

This research's objectives are to accommodate various "what-if" operational scenarios of the tactical microgrid and refine the V2G charging station integration's conceptual design, achieving performance requirements.

Numerous modeling packages were evaluated for being able to simulate power system components, conduct "what-if" scenarios, accommodate different configurations easily, and incorporate alternative and renewable energy sources. Initially, Paragon SMEs selected GINA™ as the appropriate modeling tool, given the technology can uniquely recognize system abnormalities in a real-time operating environment. After a material amount of model development using the GINA technology, the government expressed a desire for C5ISR to use the developed model for other supporting programs. To accommodate this preference, Paragon SMEs stopped developing the GINA modeling environment and began, again, using MATLAB/Simulink—because it a) met the above simulation criteria and b) is a tool DoD commonly uses, encouraging close collaboration with C5ISR, and other DoD stakeholders, to continually use the developed model. Table 30. provides a listing of the evaluated simulation tools.

Table 30. Simulation tools considered.

No.	Simulation Tools Considered
1	Homer
2	SimulationX
3	MATLAB/Simulink
4	COMSOL
5	ANSYS
6	Geli
7	ENERGY TOOLBASE
8	Energy Storage Valuation Tool (EVST)
9	Paladin® Microgrid Power Management System™
10	SKM
11	ETAP
12	PSCAD
13	PSPICE/OrCAD
14	VISSIM
15	PSIM

No.	Simulation Tools Considered
16	SIMetrix/SIMPLIS
17	SABER
18	GINA™
19	LTSpice

System model components are designed to enable or disable "on- the- fly" reconfiguration of the tactical microgrid simulation and "what-if" scenarios. In addition, MATLAB/Simulink can create scalable microgrid models. Each modeled component was selected to be manufacturer agnostic to evaluate a technology's energy resiliency support while avoiding the unnecessary complexity of specific manufacturer intricacies. Like the tactical microgrids it represents, the model is flexible, easy to configure, modular, and scalable.

At the time of this research, distribution boxes interconnecting multiple sources and loads have not been identified. However, given the model's simulating interoperability between sources and loads, the model does not need this detail until a full design of the tactical microgrid with specific components has commenced. At that time, specific conductors and protection schemes can be incorporated into the model.

5.3.1 Develop a computer simulation platform

After cataloging microgrid assets, SMEs prepared a conceptual design to construct a representative model and simulate performance. After several discussions with C5ISR and CERL, one conceptual design of a tactical microgrid was developed, which consisted of six 60-kW AMMPS generators, three 50-kW V2G systems, and three critical loads connected together in a bus formation using IPD-style distribution boxes. Figure 29 shows the tactical microgrid initial conceptual design.

A tactical microgrid should be dynamic, scalable, modular, adaptable and controllable to ensure energy resiliency for mission critical loads. The tactical microgrid model was constructed to be technology focused and manufacturer agnostic.

Figure 29. Tactical microgrid initial conceptual design.
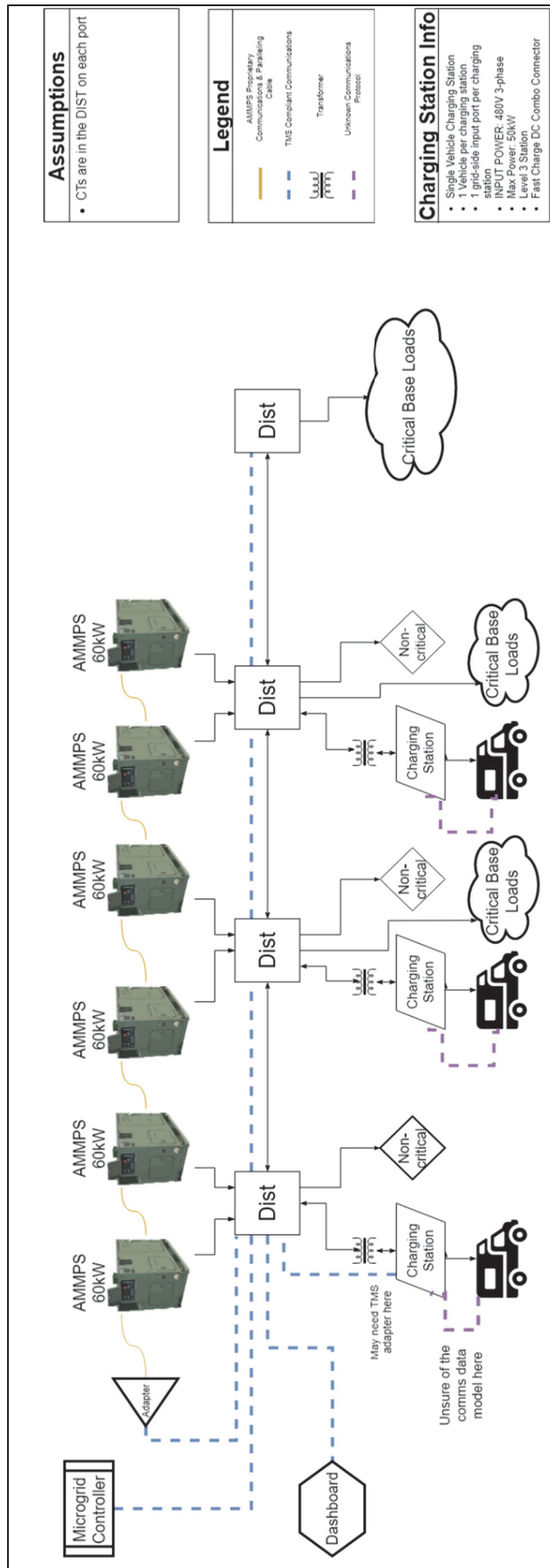
The model, which has expanded the initial conceptual design to include alternative-energy assets, is expected to be part of the living laboratory at CBITEC. The site includes a 100-kW PV array, a 40-kWh ESS, a three-phase load bank, and the above referenced Billeting loads. Incorporating an ESS and a PV system into the model, with matching power and energy capabilities, enables representative model simulations to guide tactical microgrid integration and control design at CBITEC. In addition, the model can easily incorporate a utility connection to tactical microgrid simulations, which have options to connect to host nation power or local generation stations. Model components can be enabled or disabled to accommodate numerous configurations and "what-if" scenarios tactical microgrids will inevitably encounter. A system model of the tactical microgrid is shown in Figure 30.

Solar irradiance values drive the PV model, so power production for a specific location can be simulated. Both an efficiency factor, and the size of the array, were used to determine power output, ensuring a technology-focused model that reflects real-world conditions. For this model, irradiance data for FLW's closest location will be used. The PV model is shown in Figure 31.

The energy storage model parameters reflect those of the onsite 40-kWh EnerDel MHPSs. The model has four quadrant capabilities to quantify real and reactive power. Upper- and lower-charge limits can be specified as well as recharge rates. The energy storage model can change in size easily meet different energy storage technology capacities. The ESS model is shown in Figure 32.

The system level model contains six diesel generator models simulating the six AMMPS generators to be installed at CBITEC. The generator model used the full- generator model, containing a synchronous generator, electronically fuel-injected diesel engine control unit governor, automatic voltage regulator (AVR), and excitation system to represent the dynamics of both the engine and the generator. This model (Figure 33) also allows each generator's voltage/vars and frequency/watts to be dispatched.

Figure 30. System model of the tactical microgrid.
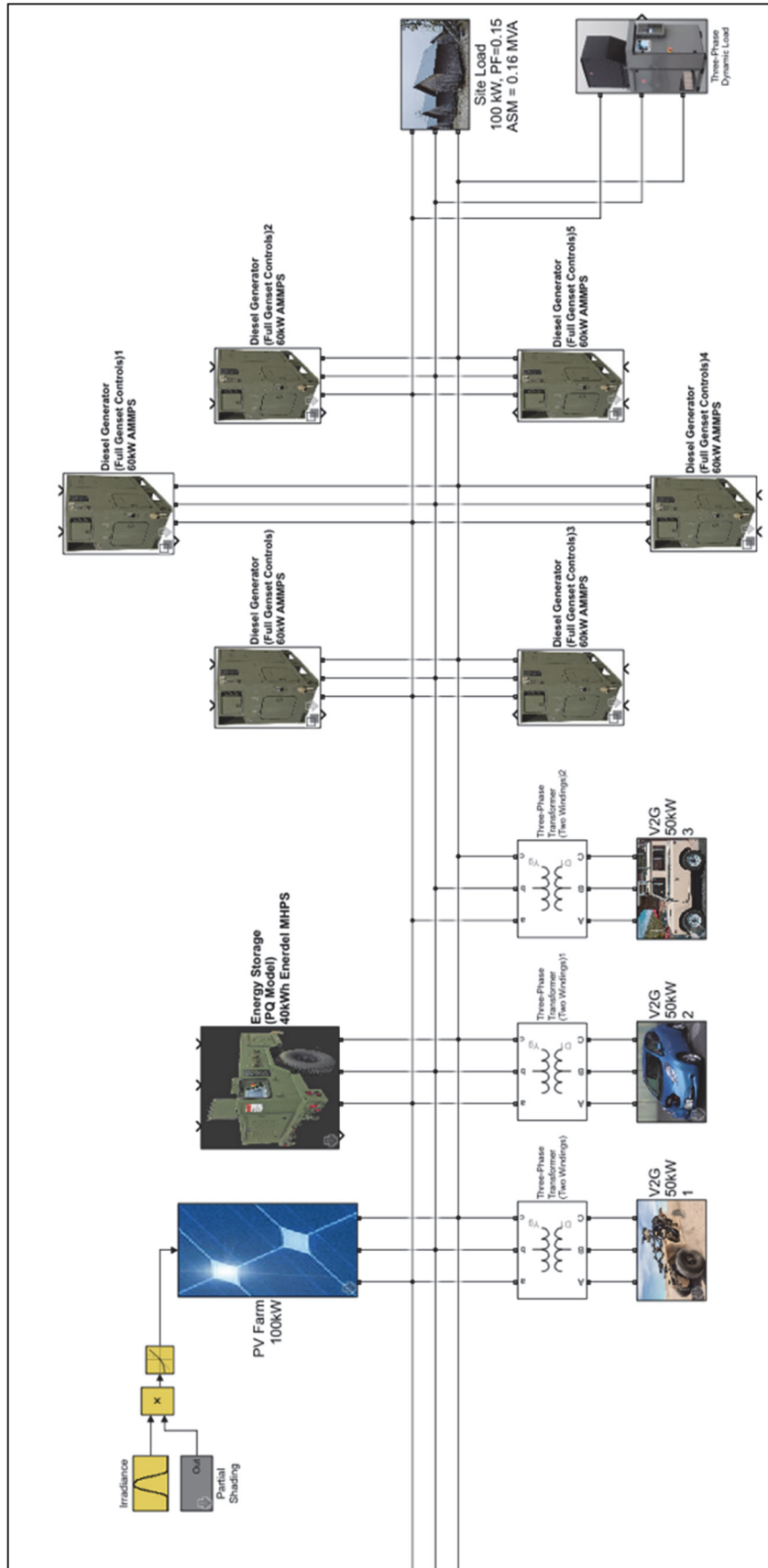
Figure 31. PV model.
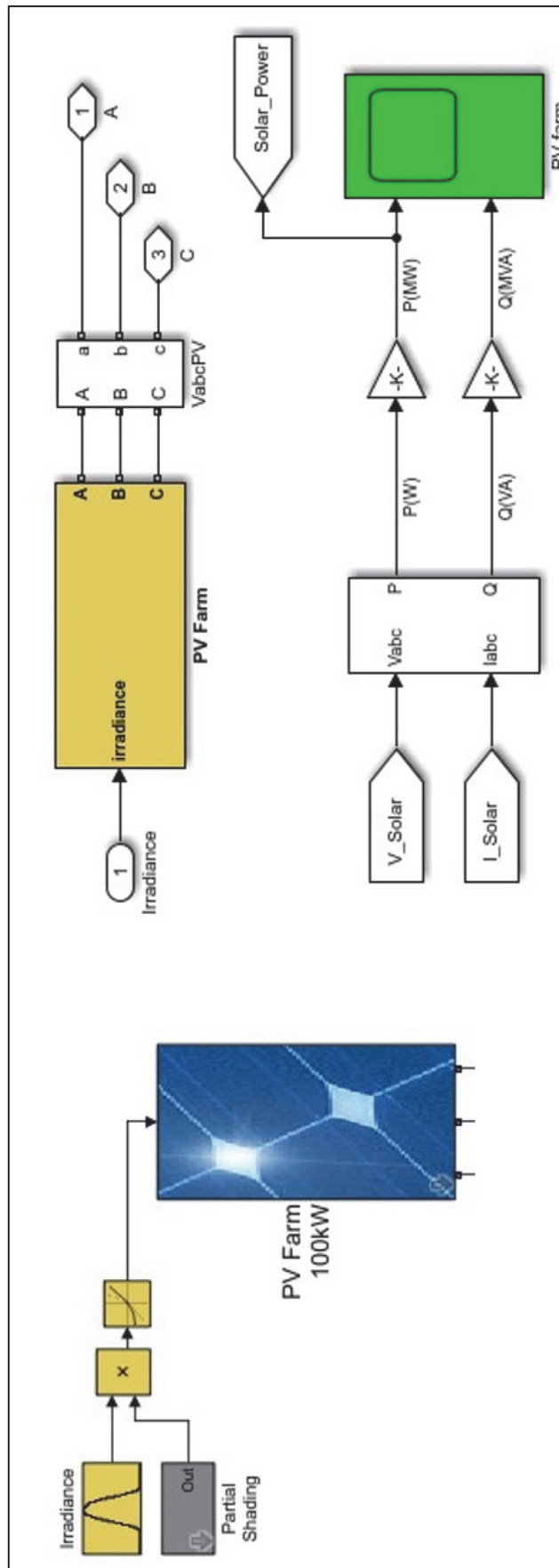
Figure 32. Energy storage model.
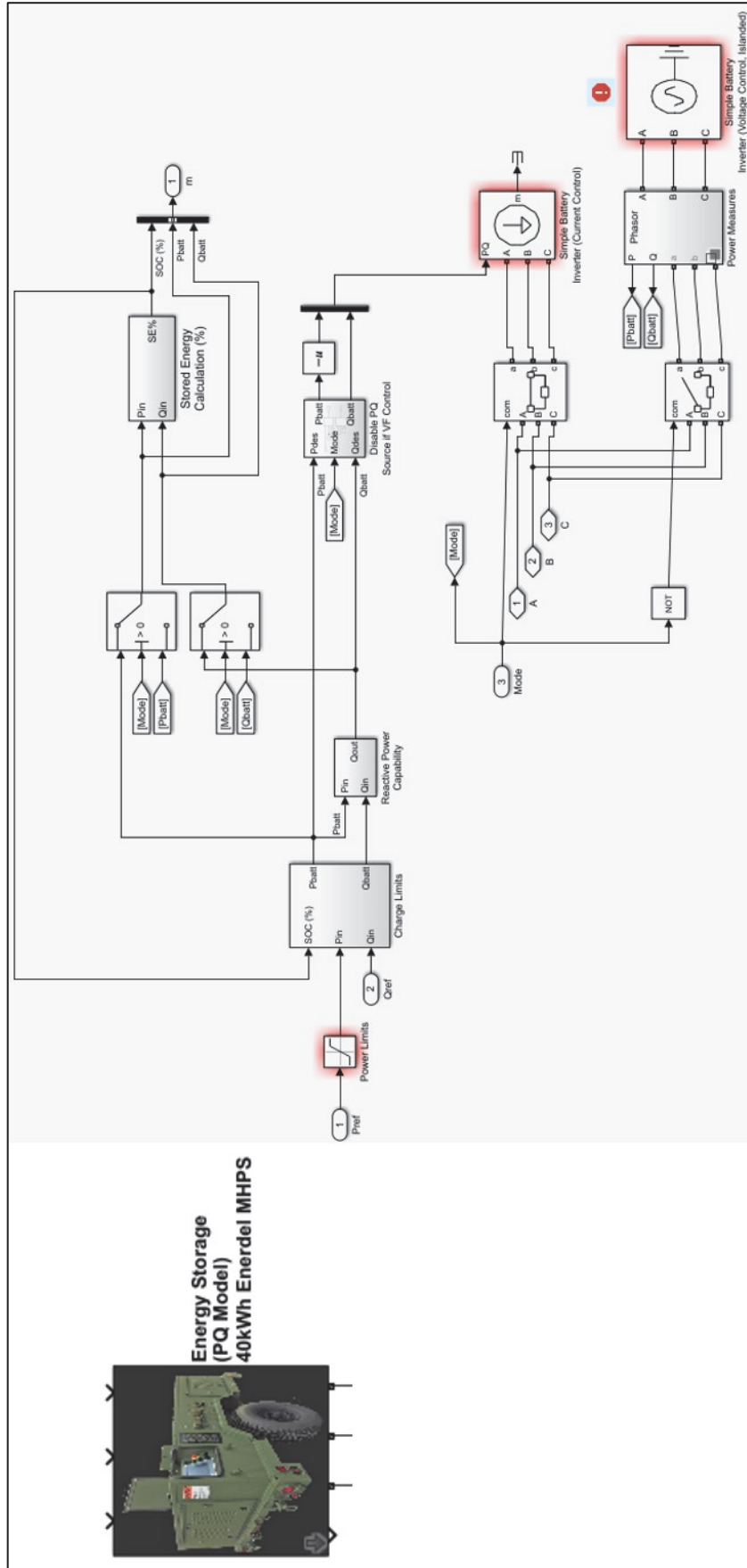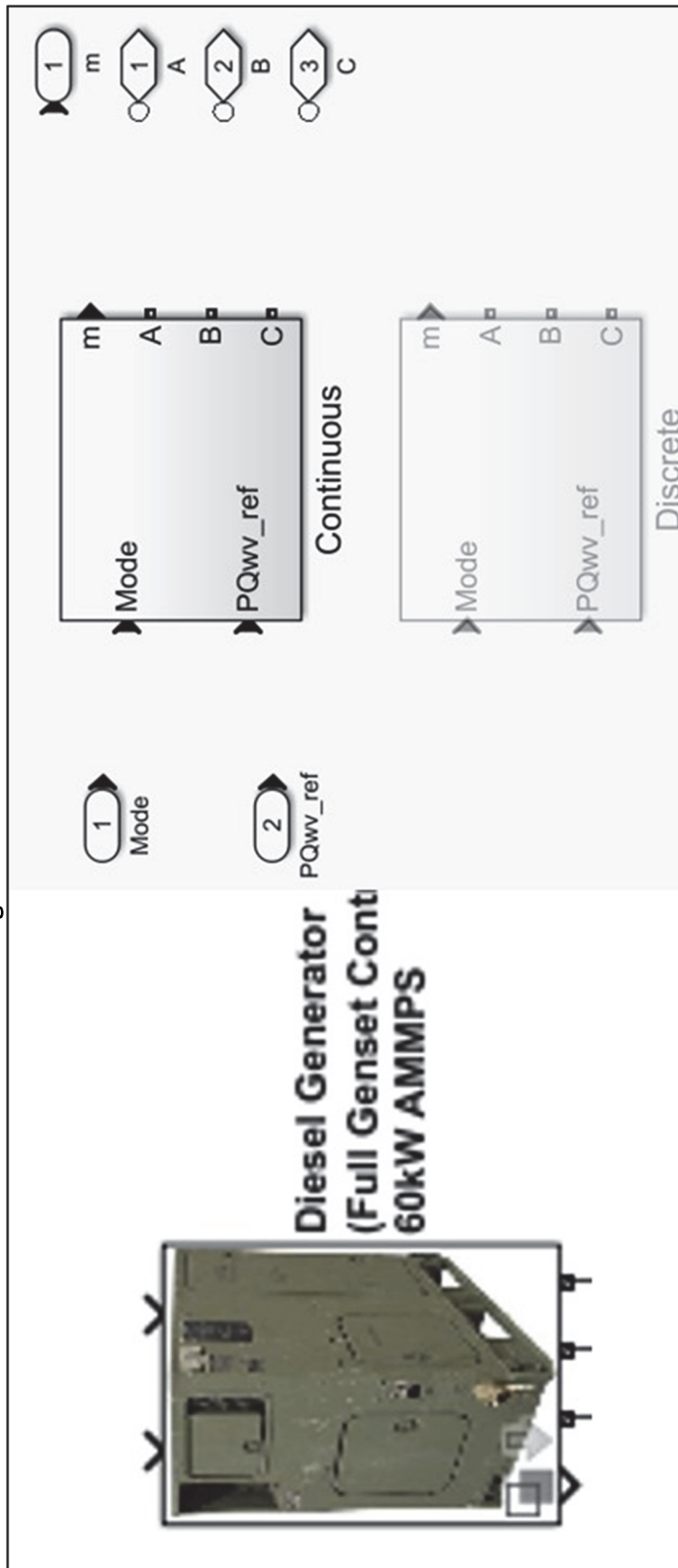
Figure 33. Generator model.

The system level model contains three V2G components that can easily be reduced to one or be expanded to represent a fleet of EVs or additional lithium-ion battery storage systems. The model has a signal for control of charge or discharge for every V2G resource while monitoring power, current, and battery pack SOC. This enables total control of the resource to support generation and load requirements. Figure 34 shows the V2G component model.

Figure 34. V2G model.
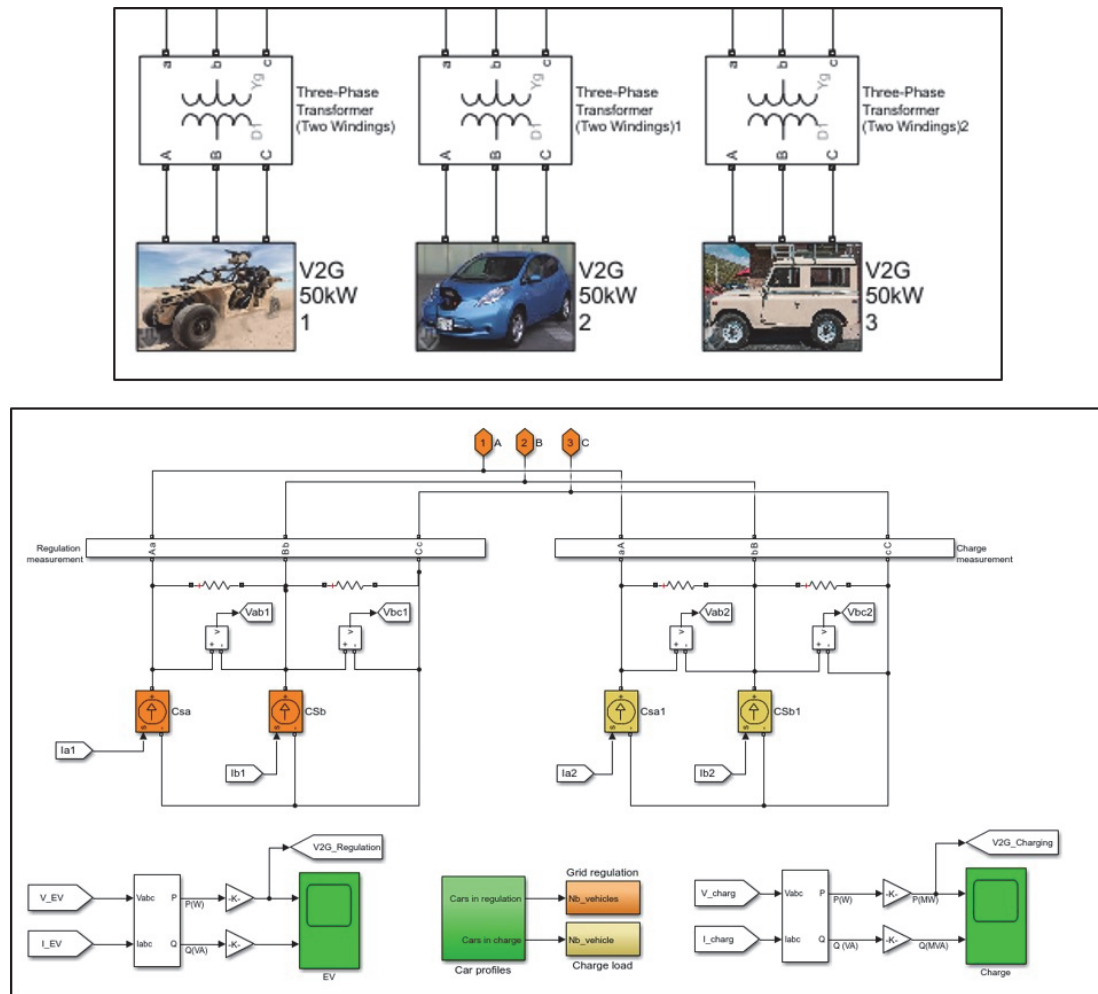
CBITEC site loads include the Billet huts and laundry facilities. The load model used contains both resistive loads as well as motor loads to represent the motors starting in-rush currents and heating operation of the ECUs feeding the Billets. The model is scalable and easily duplicated to reflect the Billet load as whole or each to disable individual huts for developing load shedding schemes. The site load model is shown in Figure 35.

Figure 35. Site load/billet model.
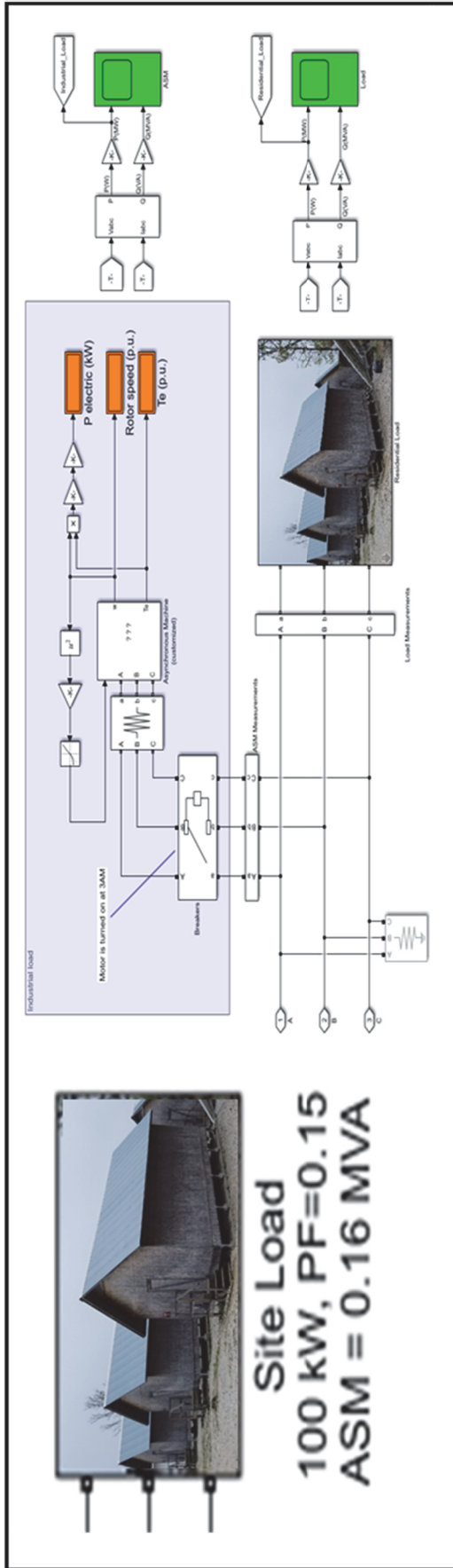
In addition to dynamic site loads, the system level model includes a three-phase load bank that simulates future loads and possible configurations without needing associated equipment. The model, which can simulate real and reactive loads, is externally controlled by a reference signal. CBITEC plans on installing a load bank serving as part of the testing and evaluation capability of the living laboratory, which can be simulated by this model to support test plan development. Figure 36 shows a model of the dynamic load bank.

Figure 36. Three-phase load bank model.
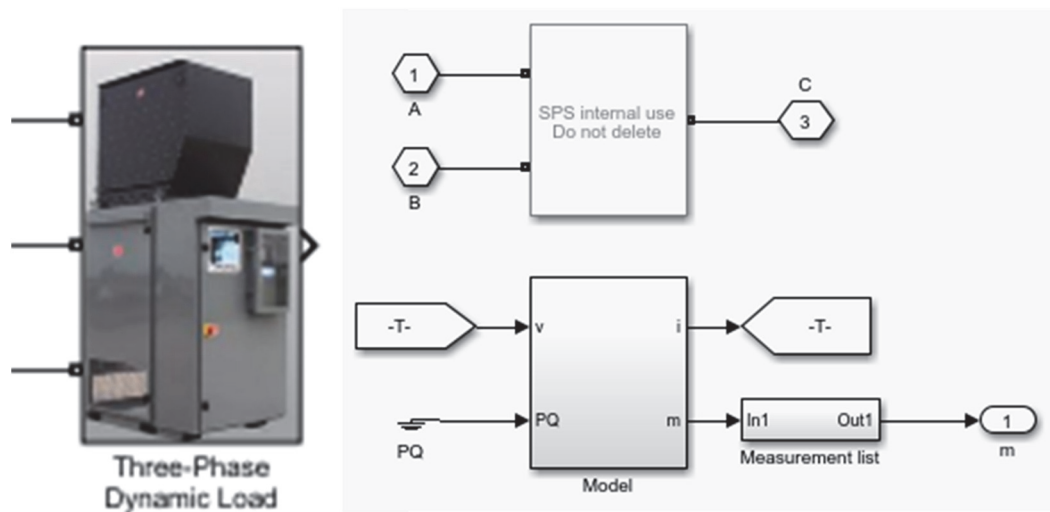
Construction of the model continues, and will be refined, through ongoing dialogue with and feedback from CERL, CBITEC, and C5ISR staff. Simulation activities will include "what-if" scenarios to establish the envisioned tactical microgrid's baseline performances and guide integration of V2G components.

5.3.2 Validation of the MATLAB microgrid computer simulation

To establish the accuracy of any model, each component must be unit validated against known performance metrics. The second step is to establish accuracy of a model is to run the entire model with all components connected simultaneously. The following figures show this validation of the model.

The following plots (Figures 37 to 39) show a single AMMPS 60-kW gener-ator increasing (at 1 second) and then decreasing (at 11 seconds) 30 kW of resistive and 10-kilovar (kVAr) inductive load. These ratios 10/30 indicate a power factor of 0.31 and worst-case scenario. This exercises both the ECU and AVR simultaneously on these electronically fuel-injected diesel engine generator sets. The response is within nominal operating behaviors for this type of generator.

The following plots (Figures 40 to 42) show six AMMPS 60-kW generators paralleled via their isochronous load-sharing lines. The load applied is the taking on (at 1 second) and then relieved (at 11 seconds) of 180 kW of re-sistive and 60-kVAr inductive load. This exercises the ECU and AVR sim-ultaneously on these electronically fuel-injected diesel- engine generator sets and the load-sharing line between the generators. The response is within nominal operating behaviors for this generator.

The following plots (Figures 43 to 46) show a single 10-kW-rated PV array located at the longitude and latitude of the CBITEC site experiencing a shading event (70% drop in irradiance) while connected to the six parallel connected generators with a load of 180 kW and 60 kVAR. The event is simulated to occur at mid-morning when the irradiance is at approxi-mately 80 kW. This shows the PV operating within nominal operating be-haviors for an inverter of this type. The **red** curve shows the generators in-creasing output to replace the loss of the PV generation. The **yellow** curve shows V2G generation, which is off for this unit test. The blue curve shows PV power production.

The following plots (Figures 47 to 50) show the PV array experiencing a more severe shading event (95% drop in irradiance) while connected to the six parallel connected generators with the same load of 180 kW and 60 kVAR. The event is simulated to occur at noon when the irradiance is at approximately 100 kW. This shows the PV operating within nominal oper-ating behaviors for an inverter of this type.

The following plots (Figures 51 to 54) show a 30-kW V2G charger being dispatched cyclically from 30-kW charge to 30-kW discharge. This is done while connected to the six AMMPS generators. The response is within nominal operating behaviors for the charger.

Figure 37. Load accept and reject for one AMMPS generator: Frequency versus seconds.
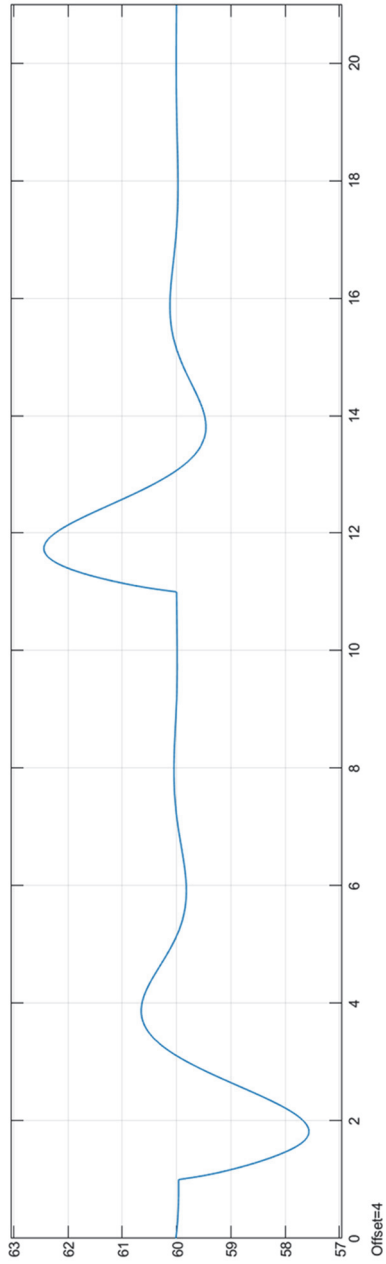
Figure 38. Load accept and reject for one AMMPS generator: Power versus seconds.
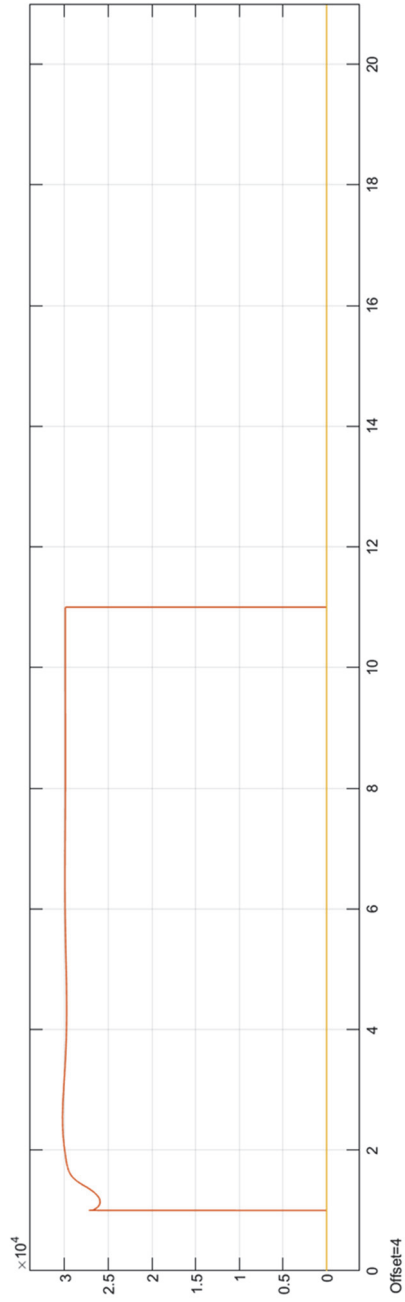
Figure 39. Load accept and reject for one AMMPS generator: Voltage versus seconds.
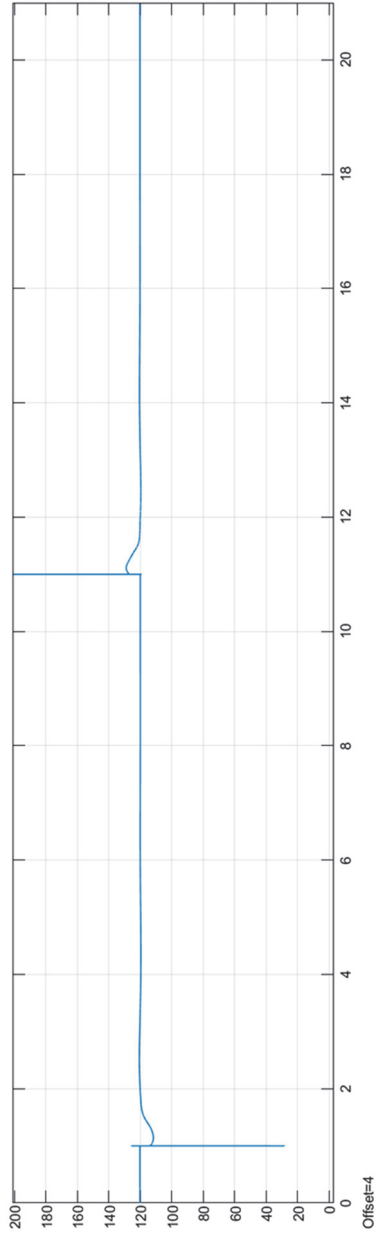
Figure 40. Load accept and reject for six AMMPS generators: Frequency versus seconds.
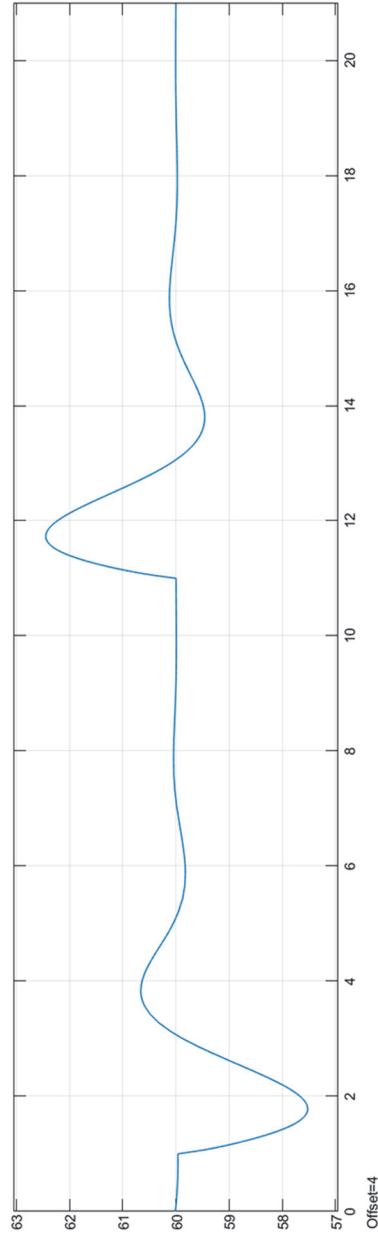
Figure 41. Load accept and reject for six AMMPS generators: Power versus seconds.
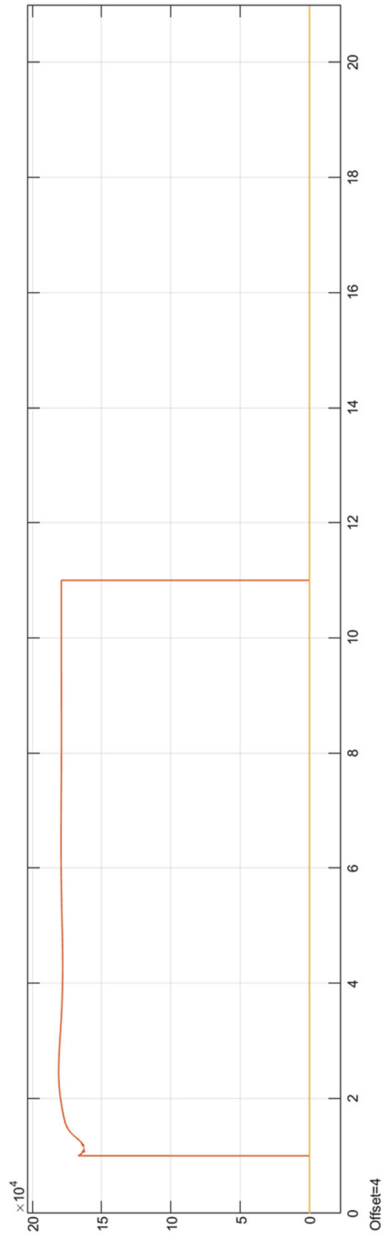
Figure 42. Load accept and reject for six AMMPS generators: Voltage versus seconds.
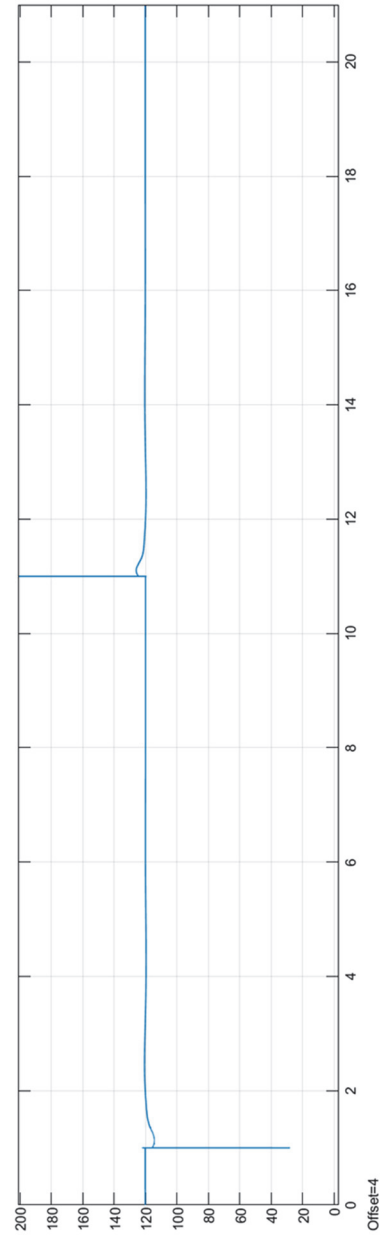
Figure 43. 70% PV shading event: Power versus seconds.
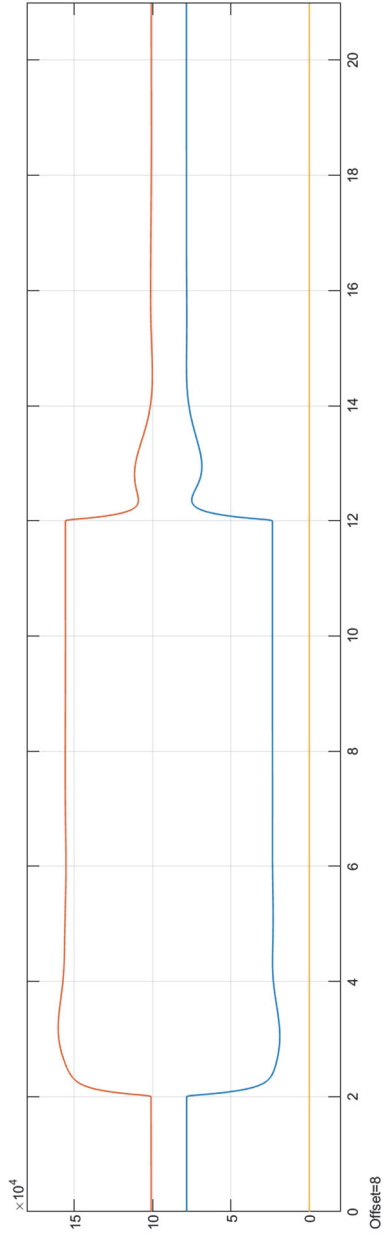
Figure 44. PV shading event: Reactive power versus seconds.
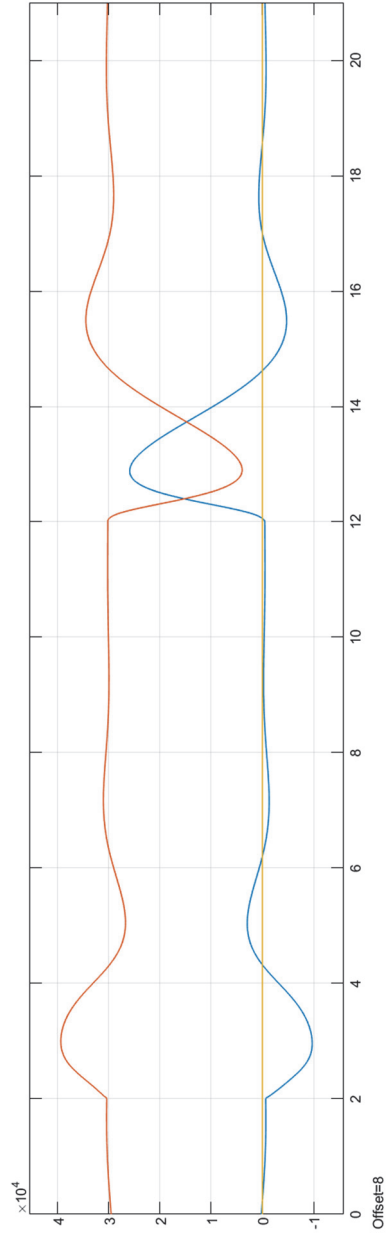
Figure 45. 70% PV shading event: Frequency versus seconds.
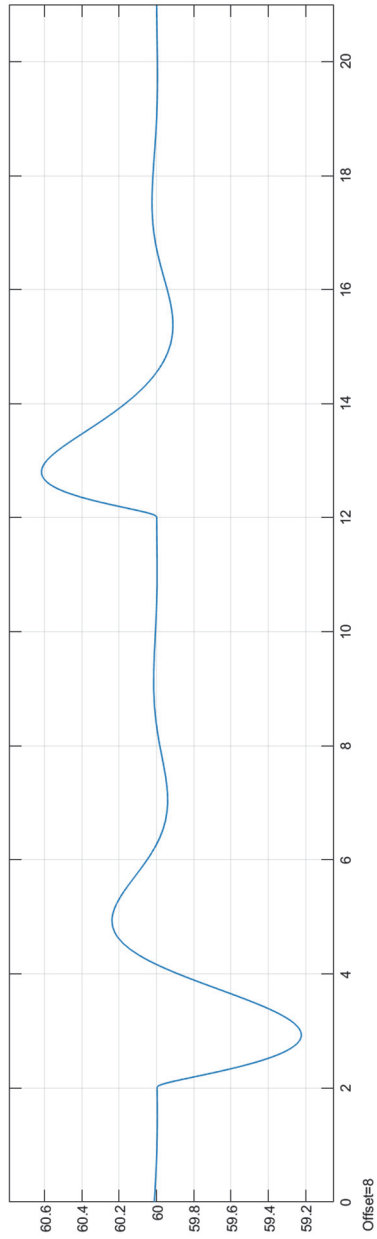
Figure 46. 70% PV shading event: Voltage versus seconds.
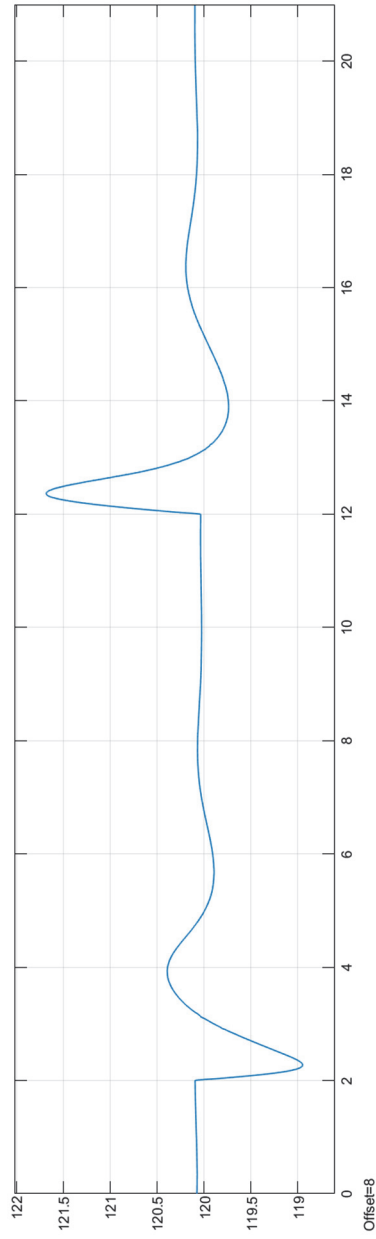
Figure 47. 95% PV shading event: Power versus seconds.
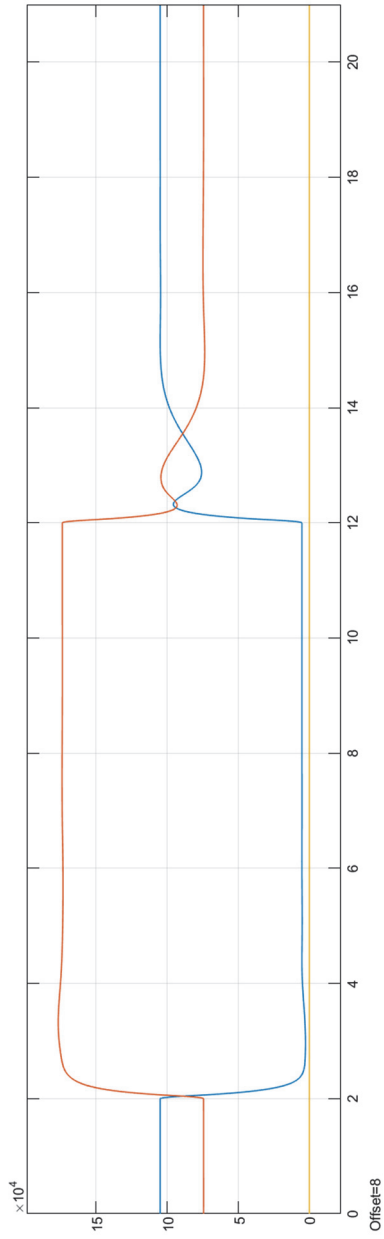
Figure 48. 95% PV shading event: Reactive power versus seconds.
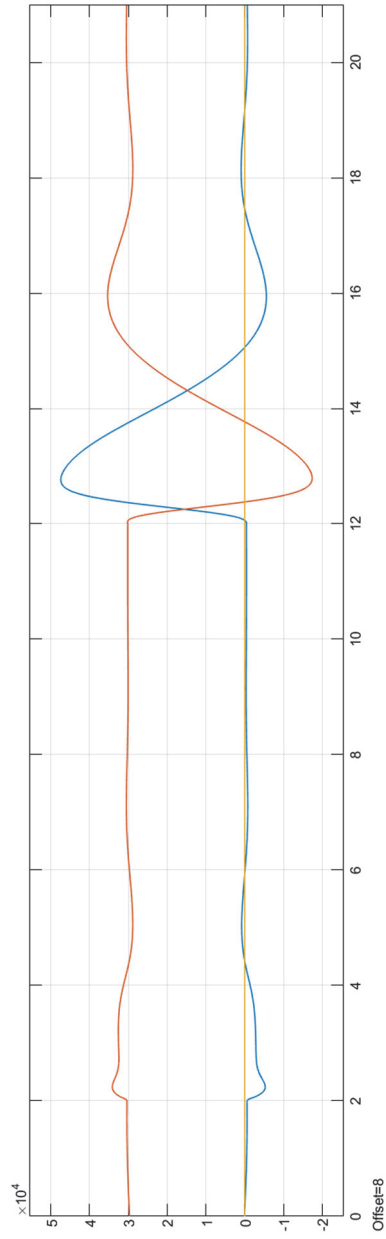
Figure 49. 95% PV shading event: Frequency versus seconds.
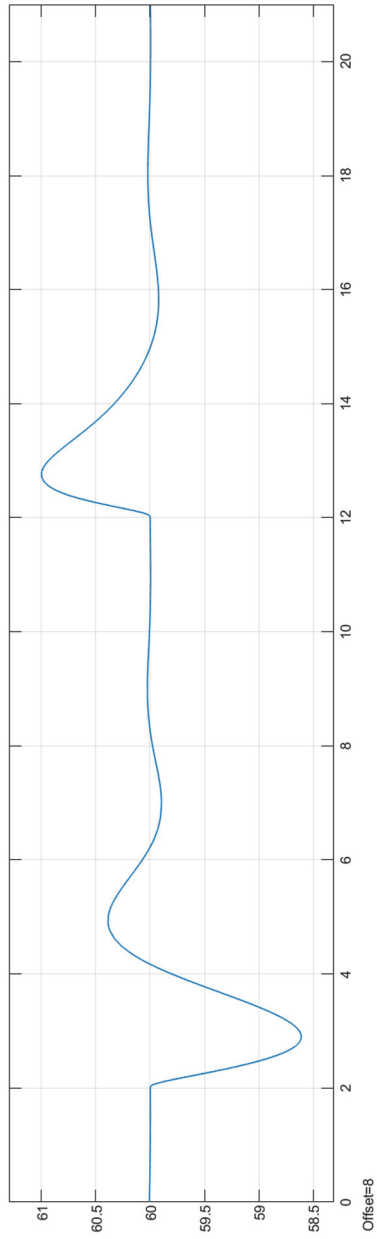
Figure 50. 95% PV shading event: Voltage versus seconds.
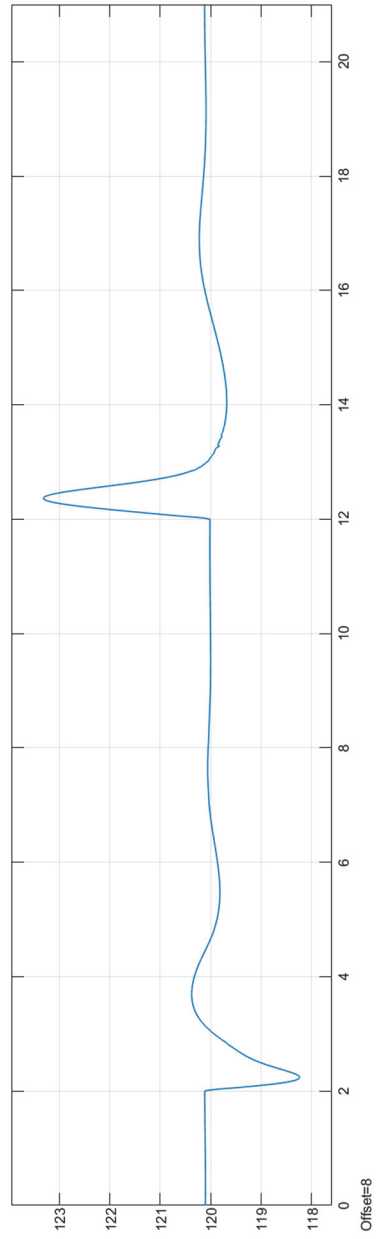
Figure 51. 30-kW V2G charger dispatched cyclically from 30-kW charge to 30-kW discharge—Real power versus seconds.

Real Power (W): Red is AMMPS, Yellow is V2G.
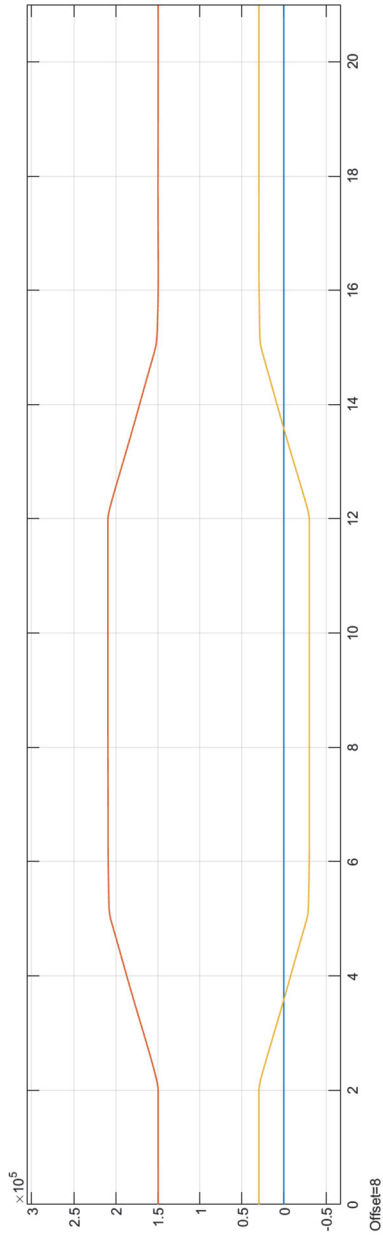
Figure 52. 30-kW V2G charger dispatched cyclically from 30-kW charge to 30-kW discharge— Reactive power versus seconds.

Reactive Power (W): Red is AMMPS, Yellow is V2G.
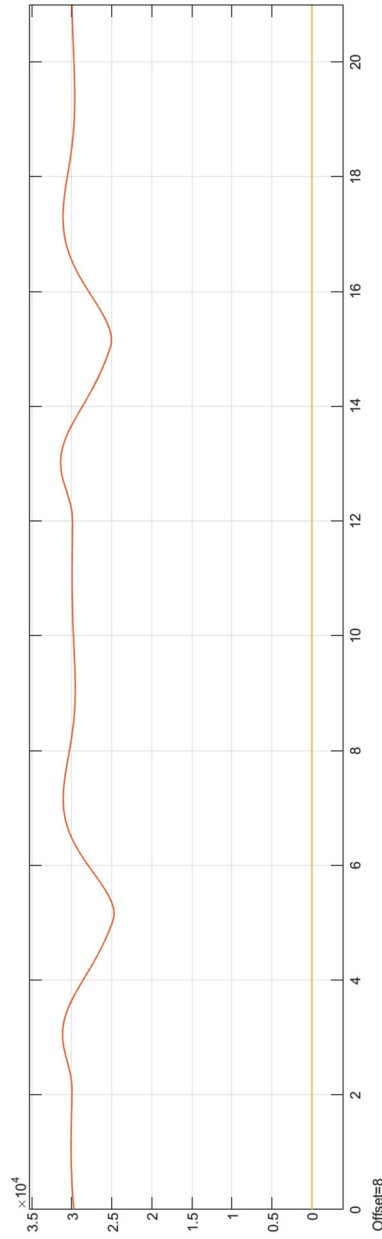
Figure 53. 30-kW V2G charger dispatched cyclically from 30-kW charge to 30-kW discharge—Frequency response versus seconds.
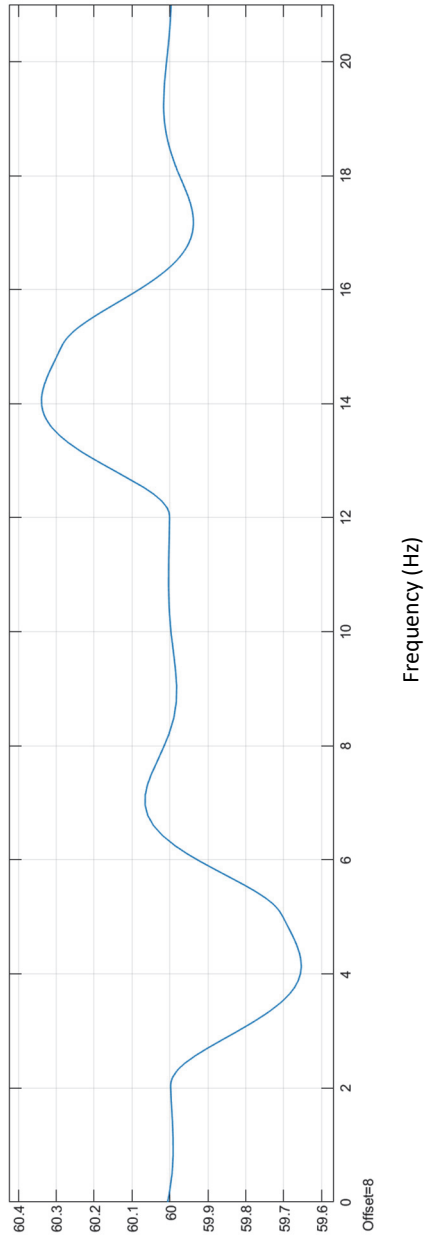
Figure 54. 30-kW V2G charger dispatched cyclically from 30-kW charge to 30-kW discharge—Voltage response versus seconds.
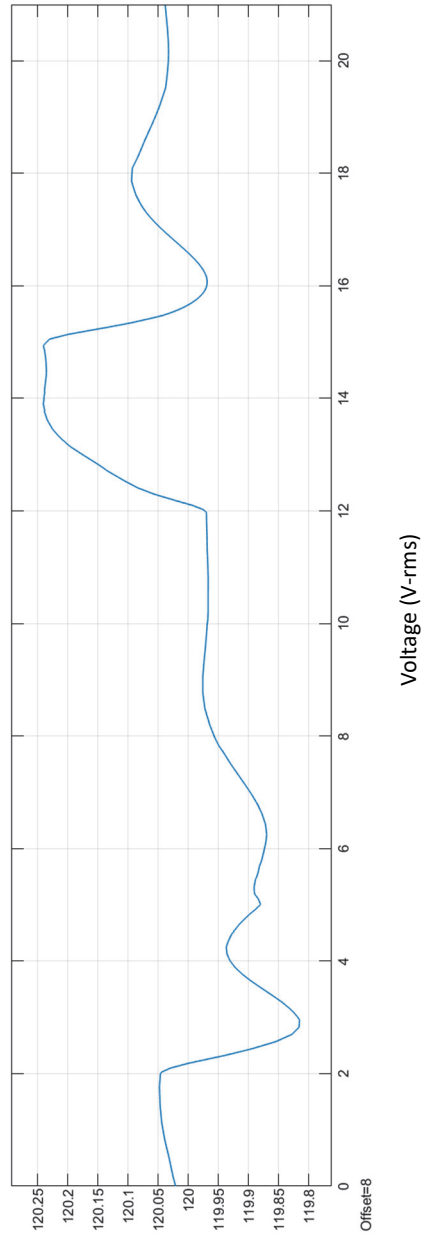
The following plots (Figures 55 to 57) show six AMMPS 60-kW generators, one 100-kW PV, and one 30-kW V2G paralleled and holding 50 kW of load. The grid then increases load (at 1 second) to 180 kW and 60 kVAr of load and (at 11 seconds) loses this same load. The V2G is dispatched again from charge to discharge following the loading and returned to charging when the total load returns to 50 kW. This proves numerical stability and a validated microgrid.

5.3.3 Recommended V2G voltage and frequency ride-through

The AMMPS generators, like all generators, can be programmed to stay online during larger voltage/frequency than inverters like on the PV or V2G inverters. The generators will ride through severe voltage and frequency events, so the voltage and frequency tripping points of these generators should be set less restrictive than the PV or charger. As the AMMPS also dominates the grid voltage and frequency behaviors, and the PV and V2G are grid following, the question that is to be answered is what ride-through voltage and frequency the PV should and V2G be set to such as to provide reliable operation.

The most common trip limits set into inverters are UL1741. The following Tables 31 and 32. show the UL1741 disconnection points programmed into most inverters over 30 kW and anticipated to be enabled in most commercial inverters. The inverters in the MATLAB model have frequency and voltage trip setpoints set at these values.

Therefore, to ensure proper coordination, all the AMMPS generators should have voltage and frequency setpoints set as listed in Tables 33 and 34.

Figure 55. V2G unit validation: Real power versus seconds.
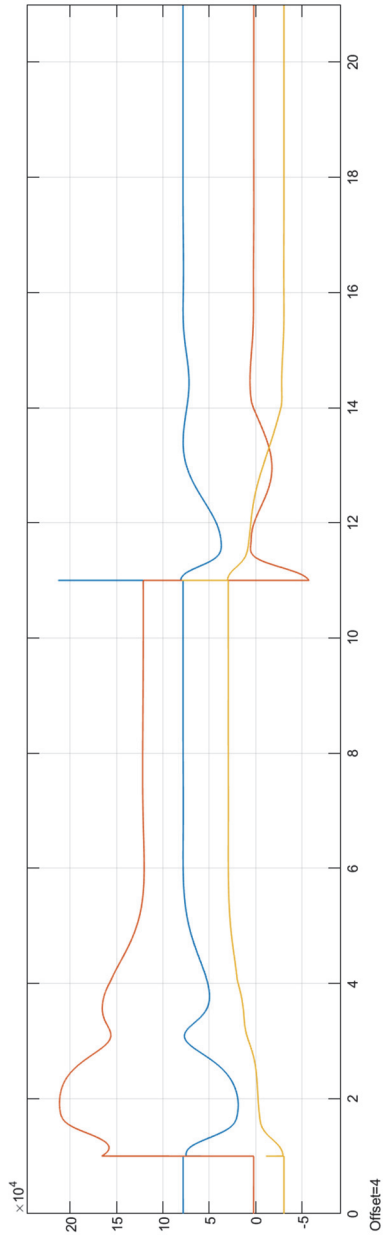
Real Power: Red AMMPS generators, Blue PV, Yellow V2G

Figure 56. V2G unit validation: Reactive power versus seconds.
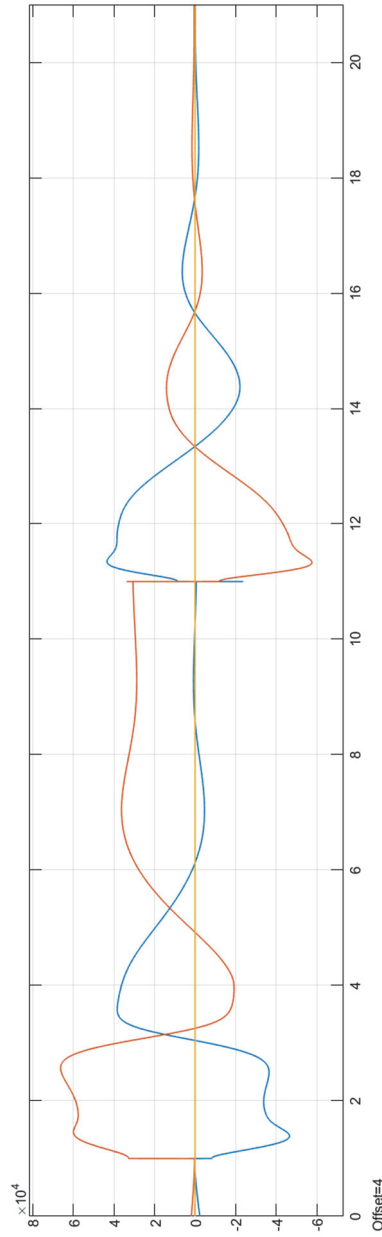
Reactive Power: Red AMMPS generators, Blue PV, Yellow V2G

Figure 57. V2G unit validation: Frequency versus seconds.
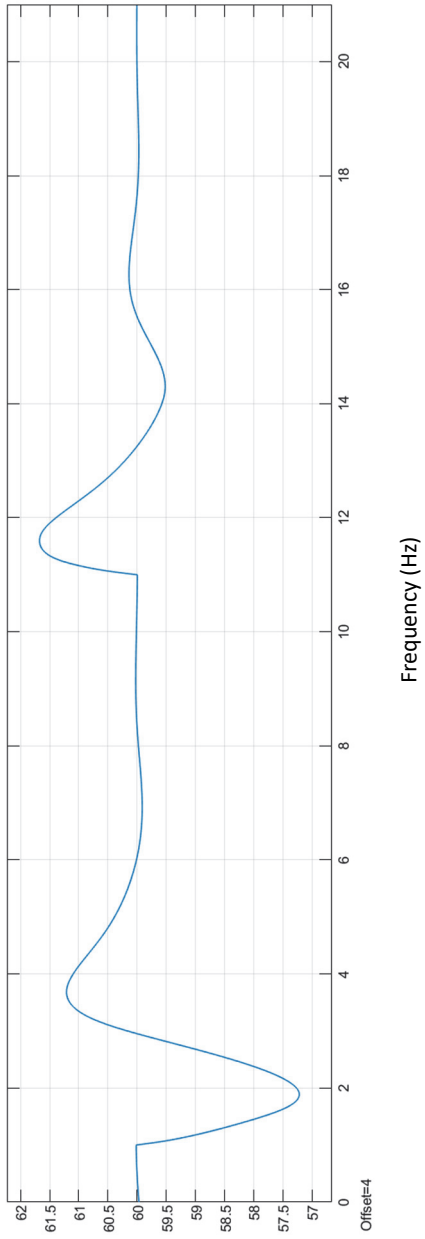
Table 31. PV and V2G ride-through % base setpoints.

Voltage range (% base)	Clearing time (sec)
V<50%	0.16
50%<V<88%	2.00
110%<V<120%	1.00
V>120%	0.16

Table 32. PV and V2G ride-through Hz setpoints.

Frequency range (Hz)	Clearing time (sec)
Freq>61.8 Hz	0.16
Freq > 61 Hz	180
Freq<59 Hz	180
Freq<57 Hz	0.16

Table 33. Generator ride-through % base setpoints.

Voltage range (% base)	Clearing time (sec)
V<50	1.16
50<V<88	3.00
110<V<120	2.00
V>120	1.16

Table 34. Generator ride-through Hz setpoints.

Frequency range (Hz)	Clearing time (sec)
freq>60.5	1.16
Freq<59.8	101
Freq<57	1.16

5.4   Test plan development

The objective of this task is to develop a test plan for demonstrating a V2G system within a tactical microgrid environment. It will validate a vehicle's providing energy support to critical loads and simultaneous interoperating with other generation sources while being dispatched as either a load or a generation source as needed to support efficient operation of the tactical microgrid.

The developed test plan reflects the tactical microgrid model's manufacture agnostic and technology focus. The test plan can gauge a technology's ability to support energy resilience for future use cases evaluated in the living laboratory. The test plan is designed to establish a baseline of the tactical microgrid consisting of AMMPS generators and site loading to quantify

how those components respond to system anomalies, followed by integrating one V2G vehicle charging system, and repeating system anomalies to analyze which systems drop offline. The test plan assumes an operator dashboard previously provided to verify generator operation in a microgrid environment is still available and can be used for testing purposes.

The test plan includes establishing a microgrid operation baseline followed by connecting a 50-kW V2G system to be operated at four power levels (25% charge, 75% charge, 25% discharge, 75% discharge), inducing the same anomalies used for the baseline test at each power level.

The anomalies will be composed of a sudden loss of generation and load as well as a sudden increase in generation and load. In addition, the test plan includes a sudden loss of the V2G system at 100-percent charge and discharge to evaluate system impact with the loss of the V2G resource. This manufacturer-agnostic approach focuses on generation source ability under test to consume or produce energy supporting the tactical microgrid. The test plan tests V2G charger response during charge and discharge modes for sudden increases and decreases for both generation and load. Table 35 lists test condition steps for reference. The current test plan is attached as **Appendix O** and is based on the configuration in Figure 58.

Table 35. Test plan conditions.

Test Condition	V2G Charging Steps	V2G Discharging Steps
Sudden generation decrease	32, 35	26, 28
Sudden generation increase	33, 36	27, 29, 37
Sudden load decrease	31	39
Sudden load increase	30, 34	38

Figure 58. Test plan configuration.
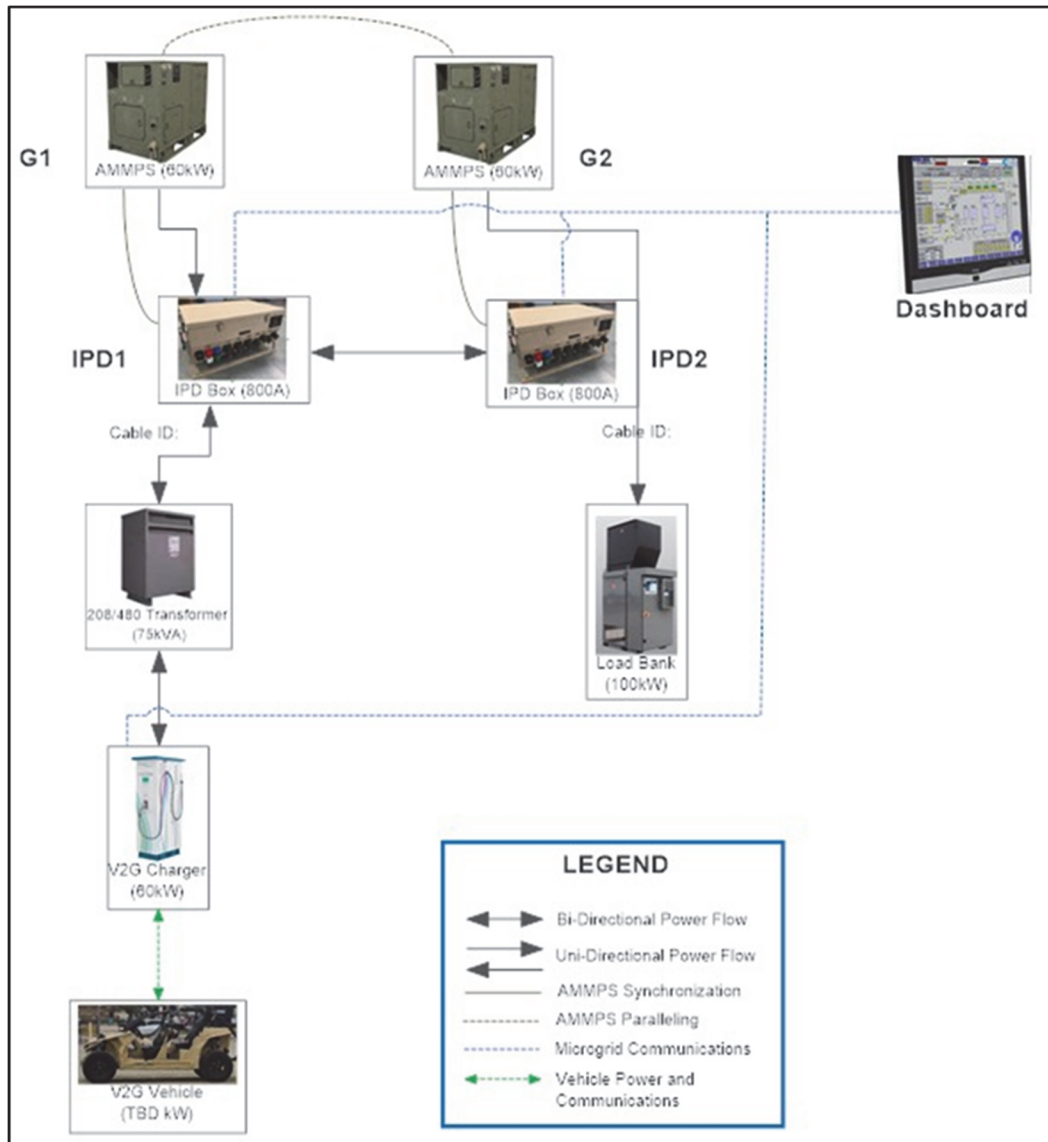
5.5 Discussion of findings

Paragon SMEs researched the existing assets and sought feedback from CBITEC, CERL, and C5ISR staff to prepare a viable model and test plan for the tactical microgrid. Through this effort, it is clear to SMEs that a technology focused, flexible approach is better aligned with the vision of a scalable, modular, and flexible tactical microgrid. A model that validates both equipment capabilities and performance when integrated into the tactical microgrid, while still flexible and user friendly, is preferred over a deeply complex and manufacturer- and product-specific model. Consequently, the resulting model and test plan were developed to test and evaluate V2G

charging integration and EV charging capabilities to provide energy support to critical loads, interoperate simultaneously with other generation sources, and dispatch as a load or a generation source as necessary to support the tactical microgrid's efficient operation.

Another important finding from this research effort is the equipment used in a tactical microgrid supporting an FOB is not identical to that used in a living laboratory. The power distribution box identified in the Program of Record PDISE equipment can easily meet the distribution requirements of a tactical microgrid located at an FOB. However, testing and evaluating new equipment in a living laboratory requires additional equipment to quantify component performance and interoperability while ensuring safety for both personnel and connected equipment. The IPD box provided by HG Engineers provides metering, oscilloscope recordings, C37.118 data streaming, and Sequence of Events (SOE) collection for each connected device and fast-acting controls for interrupting circuits to isolate fault conditions.

The 800A IPD box provides a bidirectional load port rated at 200A, which can accommodate a 57-kW load-per-design practice identified in the National Electric Code (NEC). Connecting a V2G faster charger, rated more than 50 kW to the 200A load port, requires the maximum allowed power flow with the V2G charger limited accordingly. The 800A IPD box also provides two ring-bus connection ports and two generator connection ports—all of which are rated at 400A. The generator ports, designed to be used with the AMMPS generators, utilize a control cable to determine with the IPD connects generator output power to the IPD main electrical bus. There is a mil spec connector on the back of the IPD800 that is connected to an AMMPS and tells the onboard IPD controls system that there is an isochronous source attached. The V2G inverter can be successfully connected to either the ring-bus, load port, or generator ports with no consequence. All of these ports support bidirectional power. The conceptual design shows the V2G fast charger connected to the IPD's 200A load port to keep free the generator and ring-bus ports for other usage.

The SEL automation controller inside the IPD provides communication capability to interface with a principal TMS-compliant microgrid controller. This enables control scheme development and evaluation to be implemented, ensuring available generation sources are powering mission

critical loads effectively. Incorporating the capabilities of the IPD into the living laboratory is optimal to limit risk and support developing future enabling technologies, even though those same capabilities might not be necessary to be deployed at an FOB.

5.6 Discussions and future work

The model developed for this effort included generation components that can be easily adapted as modeling needs and equipment ratings change. This enables future simulations to very quickly simulate numerous scenarios for future planning and system sizing. In particular, the V2G component has the capability to include five different EVs at any quantity to simulate the effect a fleet of V2G capable vehicles can have on the connected grid.

In addition to power distribution system sizing by scaling assets, future work should build and test control algorithms into the model to evolve the microgrid controller's control schemes. Testing control schemes in a model first is a critical step for both personnel and equipment safety.

Future could also include comparing actual field test results to the model results and refining the model for accuracy accordingly. Because the AMMPS generator will continue to be used as the standard generator, refining this model component would be very beneficial to further increase model accuracy.

5.7 Conclusions and recommendation

Based on the modeling results, the proposed V2G charger will interoperate with the tactical microgrid as planned. The anticipated voltage and frequency variations of the AMMPS generators produced by the sudden increases or decreases in load or generation are not expected to cause nuisance trips of the V2G charger.

The recommended frequency and voltage trip settings of the AMMPS generators have been provided to promote interoperability of the generation sources, even when system dynamics occur.

Paragon SMEs also recommend considering refining specific model components to increase overall simulation accuracy in cases where specific

equipment to be used is pre-determined and commonly used. Program of Record Equipment, such as the AMMPS generator, can be very accurately modeled to further increase simulation accuracy of the overall system. The repeated benefit from accurate modeling could easily offset the cost associated with additional move development time.

6 Identify Requirements for a Sensored, Living Laboratory to Assess Autonomous Transport Innovations

The objective of Research Area 5A is to research and identify appropriate sensors and methods to measure autonomous-system performance within the CBITEC site. This report will detail sensors to be used and influence developing operational tests performed within the living laboratory at the CBITEC site. The report will develop a list of high-level requirements. describing the necessary site infrastructure to conduct autonomous testing, and test plans for tests that can be performed at the site. This report will not, however, define specific test procedures as the test locations and assets have yet to be selected.

For the purpose of this document, a test plan defines the scope, objective, key personnel, and approach of the test. A test procedure is a specific set of steps or test cases with measurable outcomes that result in pass/fail criteria.

Paragon's team of SMEs identified required sensors and state-of-the-art technologies through a review of literature as well as engaged with leading industry experts.

6.1 CBITEC test environment

The objective of this research is to define the requirements and develop a test plan for testing autonomous-system performance in the living laboratory at the CBITEC site.

6.1.1 Site requirements

Robotic Research's team of engineers are SMEs in autonomous software and hardware development and integration. The following list of requirements (Table 36), developed by the Robotic Research engineering team, define the high-level infrastructure, sensors, and data necessary to measure the performance of autonomous systems within the living laboratory at the CBITEC site. These requirements are meant to evolve or be further derived as more details about the test site are defined.

Table 36. Requirements for infrastructure, sensors, and data collection operations.

Operation	Site Requirement
Infrastructure	• **Requirement 1**: The living laboratory will have provisions to charge an EV. • **Requirement 2**: The living laboratory will have electrical power connections for sensors. • **Requirement 3**: The living laboratory will have semi-permanent mounting points for sensors. (Semi-permanent mounts can be removed from the site without causing damage or disturbing the site). • **Requirement 4**: The living laboratory will have wireless communication capabilities.
Sensors	• **Requirement 5**: The living laboratory will be able to detect autonomous systems at the site. • **Requirement 6**: The living laboratory will be able to measure the relative position of autonomous systems at the site. • **Requirement 7**: The living laboratory will be able to measure absolute position of autonomous systems within 0.1 meters. • **Requirement 8**: The living laboratory will be able to communicate absolute position of the autonomous systems at the site. • **Requirement 9**: The living laboratory autonomous detection system will be able to operate in varying lighting conditions, such as full daylight, dusk, and night.
Data Collection	• **Requirement 10**: The living laboratory will be able to collect and store time data. • **Requirement 11**: The living laboratory will be able to collect and store weather data. • **Requirement 12**: The living laboratory will be able to collect and store autonomous-system position data. • **Requirement 13**: The living laboratory will be able to collect and store autonomous-system attitude data. • **Requirement 14**: The living laboratory will be able to collect and store autonomous-system velocity data. • **Requirement 15**: The living laboratory will be able to collect and store autonomous-system sensor health data.

6.1.2 Operational tests

This plan provides an overview of the test setup, measurements, and tests to be performed when testing autonomous-system performance at the CBITEC site in on- and off-road applications. The intent of this testing is to test at a system level. It is expected that software unit and integration testing will have already been conducted.

Table 37 lists the recommended personnel and equipment needed during the operational tests.

Table 37. Key personnel and test equipment during operational tests.

Item	Description
Key Personnel	• Test director • Safety officer • Safety driver/operator
Test Equipment	• Autonomous-system • Flat white painted 1-meter x 1-meter poster board • 100-meter measuring tape • Chalk • Child-sized mannequin • Barricades/barrels • Compact car, utility vehicle, or terrain appropriate vehicle • DGPS base station • Non-vehicle-mounted sensor data collection system • Temporary infrastructure (stop signs, lane markers, crosswalks)

The start of every day will begin with setting up the course (obstacle, barriers, etc.), checking sensors and systems for proper operation, and calibrating the navigation system. Every day will end with removing obstacles from the test site, pulling data collected from the day off the autonomous-system, and powering down the vehicle for the evening.

The maximum speed for the autonomous-system will be set by the test director and safety officer. Maximum speeds should be set for both manually and autonomously driven tests, but the speeds do not have to be the same.

Paragon SMEs do not anticipate that hardware changes will be necessary during testing, but, in the event of a hardware failure, the component will be changed as needed. Software changes and/or modifications will not occur during this event unless there is an error that prevents the completion of the test event.

Standard data files will be collected for every test performed during the test phase. Periodic data integrity checks will be performed throughout every day of testing to ensure data is accurately captured.

The raw data is captured in the industry standard pcap, CAN Bus, or serial format. This includes sensors, such as LiDAR, radar, cameras, and wheel encoders. Processed data is outputted in ROS bag format, which was selected because it is a common format familiar to commercial and academic institutions.

6.1.3 Baseline evaluation

The baseline evaluation is intended to include the following system capabilities:

- Vehicle physical characteristics
- Vehicle operating characteristics—includes manual and robotically operated, maximum speed, acceleration, and deceleration
- Localization—testing for navigation system
- Obstacle detection—detection distances for all sensors.

The baseline data is common across military transportation missions. It is the basic dataset needed to measure a variety of autonomous-system performances operating within the test site.

Table 38 lists the recommended data to collect during baseline tests.

Table 38. Autonomous-system baseline data.

Localization accuracy
INS accuracy
GPS satellite coverage
LiDAR minimum/maximum range
Vehicle dimensions
Vehicle acceleration/deceleration
Vehicle turning radius

Table 39 lists the recommended tests to be performed to verify the performance of the vehicle-mounted sensors.

Table 39. Sensor measurements.

Test	Test Description
Localization (GPS/INS) Sensor Accuracy	Manually drive a short loop and stop the vehicle in the same location as it started. Use a stopwatch and record the time of data collection. (This is strictly to verify that the time and position data are working correctly. The test for Absolute Accuracy will show how accurate the position estimates are.)
INS Accuracy	Disconnect the GPS antenna from the localization sensor, then drive a more than 1-km loop, and stop the vehicle at the same location as it started. Measure the error as a percentage of distance traveled.
GPS Satellite Coverage	Confirm the GPS antenna is connected to the localization sensor, then drive all areas of the planned test route. (This can be done manually or autonomously.) Process the collected data to determine the number of observed satellites along the path.
Absolute Accuracy	Drive the vehicle along the planned test route and stop at known surveyed locations. Process the collected data to compare the reported position to the surveyed location.
LiDAR Minimum Range	With a tape measure, measure the minimum distance that a flat white painted 1-meter x 1-meter poster board is not detected.
LiDAR Maximum Range	With a tape measure, measure the maximum distance that a flat white painted 1-meter x 1-meter poster board is not detected.
LiDAR Maximum Ground Distance	Collect a single frame of LiDAR data on a flat, paved road, and measure the maximum distance where the ground is returned.

Table 40 lists the recommended vehicle characteristics that should be measured before testing to confirm accuracy of the data collected and aide in post processing of the collected data.

Table 40. Vehicle characteristics.

Item	Test Description
Dimensions	The overall vehicle dimensions should be measured to analyze of data collected during testing. The following measurements should be captured: • Vehicle length, width, and height • Vehicle wheelbase • Front- and rear-track width • Distance between rear axle and rear-most point of the vehicle
Maximum Acceleration	Manually drive the vehicle at full throttle until the maximum speed (determined by the test director and safety officer) is achieved. Process the localization/inertial data to determine the maximum acceleration of the run.
Maximum Declaration	Manually drive the vehicle at full throttle until the maximum speed (determined by the test director and safety officer) is achieved, and then apply full-service brakes. Process the localization/inertial data to determine the maximum deceleration of the run.
Minimum Left-Turning Radius	Mark the front right corner of the vehicle and front right tire with chalk. Manually drive the vehicle with a full left turn until the heading has changed 180 degrees. Measure the distance between the front right corner chalk mark and the front right corner of the vehicle. Repeat this measurement for the front right tire chalk mark and the front right tire of the vehicle.
Minimum Right-Turning Radius	Mark the front left corner of the vehicle and front left tire with chalk. Manually drive the vehicle with a full right turn until the heading has changed 180 degrees. Measure the distance between the front left corner chalk mark and the front left corner of the vehicle. Repeat this measurement for the front left tire chalk mark and the front left tire of the vehicle.

6.1.4 Example test steps

The following procedure describes a sample set of steps for performing an autonomous-system test:

1. Record environmental conditions at the test site.
2. Follow procedure to power up autonomous-system.
3. Drive vehicle to calibrate localization sensor, and verify all subsystems are in ready to run.
4. For each test scenario:
   a. Place static obstacles that will be used for tests.
   b. Using the DGPS system, record the location of static obstacles.
   c. Maneuver (manually drive) the vehicle to first waypoint.
   d. Confirm the GPS/INS show correct position and heading for the vehicle.
   e. Record start time (local and GPS time), scenario, and weather conditions.
   f. Enter command for AV to follow test route.
   g. Begin autonomous-system maneuvering of the returned plan.
   h. Observe autonomous-system as it encounters obstacles on the test course and maneuvers to every waypoint. Make notes as applicable.
   i. Restart data logs if necessary.
   j. Record stop time: local and GPS time.

5. Collect all data logs and store data on test site server or hard drive at end of the day.

6.1.5 Traffic interaction test plan

The purpose of this test plan is to describe operational tests that can be used to quantify an AV's performance in an on-road environment when interacting with pedestrians and other vehicles. It is expected that the autonomous systems will be bound to a single lane of travel and not allowed to drive in the oncoming traffic lane or on the shoulder.

The following data should be collected during this test:

- Time of test (local and GPS)
- Location of test
- Autonomous-system under test
- Autonomous-system telemetry data (position, attitude, velocity, acceleration)
- Autonomous-system vision sensor data (LiDAR, radar, camera)
- Environmental and ambient conditions (temperature, humidity, pressure, light)
- Living laboratory sensor data (GPS, LiDAR, radar, camera).

Entrance criteria consist of:

- Required test personnel are present
- Autonomous-system has been baselined
- Autonomous-system sensors have been verified functional
- DGPS base station and non-vehicle-mounted sensor data collection system verified functional
- Maximum speed for autonomous under-test system defined
- Temporary infrastructure (stop signs, lane markers, crosswalks) have been placed and locations have been recorded.

The following tests should be conducted on the road surface of the TA-231 Driving Course (see Figure 59):

- Place a child-sized mannequin beyond the maximum range of the Li-DAR. Drive the AV toward the mannequin at 5 mph. Process the data to determine the range of the first detection.
- Park a car beyond the maximum range of the LiDAR. Drive the AV toward the car at 5 mph. Process the data to determine the range of the first detection.
- Position a child-sized mannequin beyond the maximum detection range of the LiDAR. Autonomously drive the vehicle toward the mannequin until the vehicle autonomously stops. Measure the distance between the vehicle and mannequin with a tape measure.
- Drive a compact car at 10 mph across the route of the autonomous-system. Autonomously drive the autonomous-system toward the compact car until the autonomous-system stops. Measure the distance between the autonomous-system and compact car with a tape measure. Conduct multiple trials increasing the compact car starting location by 10 meters until the maximum range of LiDAR is achieved.

Figure 59. Test diagram.
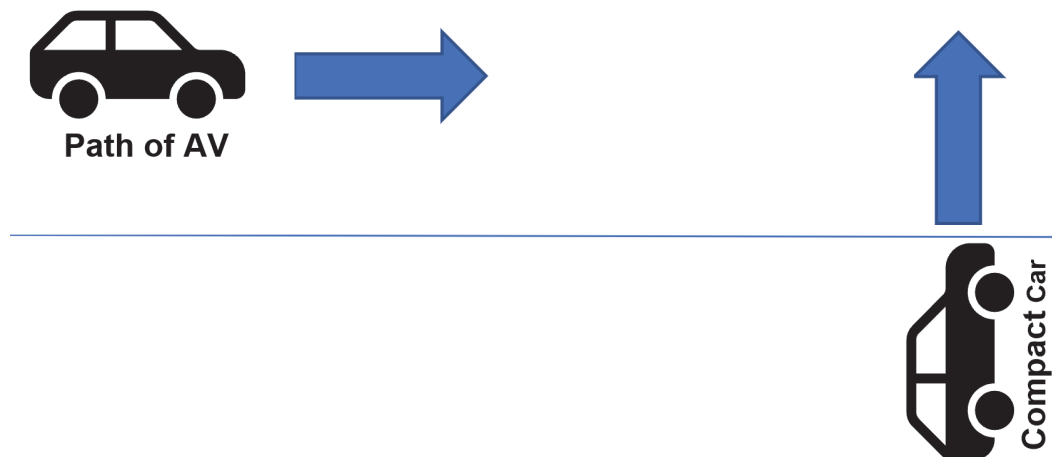
Exit criteria consist of:

- Route completed either autonomously or with safety operator's intervention
- Test data collected

- Living laboratory sensor data collected.

6.1.6 Sensor degradation test plan

The purpose of this test plan is to describe operational tests that can be used to quantify the sensor performance and degradation of an autonomous-system's sensors over time.

The following data should be collected during this test:

- Time of test (local and GPS)
- Location of test
- Autonomous-system under test
- Autonomous-system telemetry data (position, attitude, velocity, acceleration)
- Autonomous-system vision sensor data (LiDAR, radar, camera)
- Environmental and ambient conditions (temperature, humidity, pressure, light)
- Living laboratory sensor data (GPS, LiDAR, radar, camera).

Entrance criteria:

- Required test personnel are present
- Autonomous-system's baseline data is available
- Autonomous-system sensors have been verified functional
- DGPS base station and non-vehicle-mounted sensor data collection system verified functional
- Test equipment (1-meter x 1-meter poster board) and measurement instruments are present.

The following tests should be conducted at the TA-231 Driving Course:

- Drive the vehicle along the planned test route and stop at known surveyed locations. Process the collected data to compare the reported position to the surveyed location.
- Disconnect the GPS antenna from the localization sensor, then drive a more than 1-km loop, and stop the vehicle at the same location as it started. Measure the error as a percentage of distance traveled.

- With a tape measure, measure the minimum distance that a flat white painted 1-meter x 1-meter poster board is not detected.
- Collect a single frame of LiDAR data on a flat, paved road, and measure the maximum distance where the ground is seen by the LiDAR.
- Compare the results from the tests above to the initial baseline data.

Exit criteria:

- Test data collected
- Test data compared to initial baseline data and previously collected data
- Verify the sensors are still within the manufacturer specification.

6.1.7 Terrain identification test plan

The purpose of this test plan is to describe operational tests that can be used to measure an autonomous-system's ability to identify terrain.

The following data should be collected during this test:

- Time of test (local and GPS)
- Location of test
- Autonomous-system under test
- Autonomous-system telemetry data (position, attitude, velocity, acceleration)
- Autonomous-system vision sensor data (LiDAR, radar, camera)
- Environmental and ambient conditions (temperature, humidity, pressure, light)
- Living laboratory sensor data (GPS, LiDAR, radar, camera).

Entrance criteria:

- Required test personnel are present
- Autonomous-system has been baselined
- Autonomous-system sensors have been verified functional
- TA-231 Driving Course has been mapped by the autonomous-system
- DGPS base station and non-vehicle-mounted sensor data collection system verified functional
- Maximum speed for autonomous under test system defined.

The following tests should be conducted at TA-231 Driving Course:

- Start with the autonomous-system on the test loop of the driving course where the foliage is high on either side of the course.
- Command the system to navigate to a point on the other side of the course. The direct line path between the autonomous-system and the end point should go through foliage and overgrowth.
- Verify that the autonomous-system plans a route that stays on the driving course surface as it navigates to the commanded endpoint.
- Return the autonomous-system to the starting point above. Place barricades, or barrels, in front of the vehicle to block the path it took above.
- Command the system to navigate to a point on the other side of the course, and verify that the system plans a route that goes the opposite direction around the course.

Exit criteria:

- Route completed either autonomously or with intervention
- Test data collected.

6.1.8 Charging station docking test plan

The purpose of this test plan is to describe operational tests that can be used to measure an autonomous-system's ability to dock with a charging station.

The following data should be collected during this test:

- Time of test (local and GPS)
- Location of test
- Autonomous-system under test
- Autonomous-system telemetry data (position, attitude, velocity, acceleration)
- Autonomous-system vision sensor data (LiDAR, radar, camera)
- Environmental and ambient conditions (temperature, humidity, pressure, light)
- Living laboratory sensor data (GPS, LiDAR, radar, camera).

Entrance criteria:

- Required test personnel are present
- Autonomous-system has been baselined
- Autonomous-system sensors have been verified functional
- Charging station functional
- DGPS base station and non-vehicle-mounted sensor data collection system verified functional
- Maximum speed for autonomous under test system defined.

The following tests should be conducted at CBITEC:

- Start with the autonomous-system on the entrance to the autonomous test site, and command autonomous-system to navigate to charging station.
- Verify that the autonomous-system is able to navigate to the charging station test pad, and measure the position and attitude of the AV relative to the docking station.
- Verify and record if the autonomous-system was able to connect to the charging station.

Exit criteria:

- Route completed either autonomously or with intervention
- Test data collected.

6.2   Sensors

To characterize the performance of an autonomous-system, the absolute and relative position of the system must be accurately and repeatably measured. There are a variety of ways to measure the position of the systems. Some include sensors mounted on the autonomous-system, and some include sensors mounted at the test site.

The Robotic Research team of engineers are SMEs in sensor testing and integration. The following sections will describe the different types of sensors and their benefits. Additionally, data collected from a variety of sensors tested by Robotic Research will be presented.

6.2.1 Vehicle-mounted measurement sensors

DGPS (Figure 60) enhances traditional GPS solutions by supplying position corrections from a fixed location. DGPS uses two GPS receivers and a communication mechanism between the two.

Figure 60. DGPS architecture.
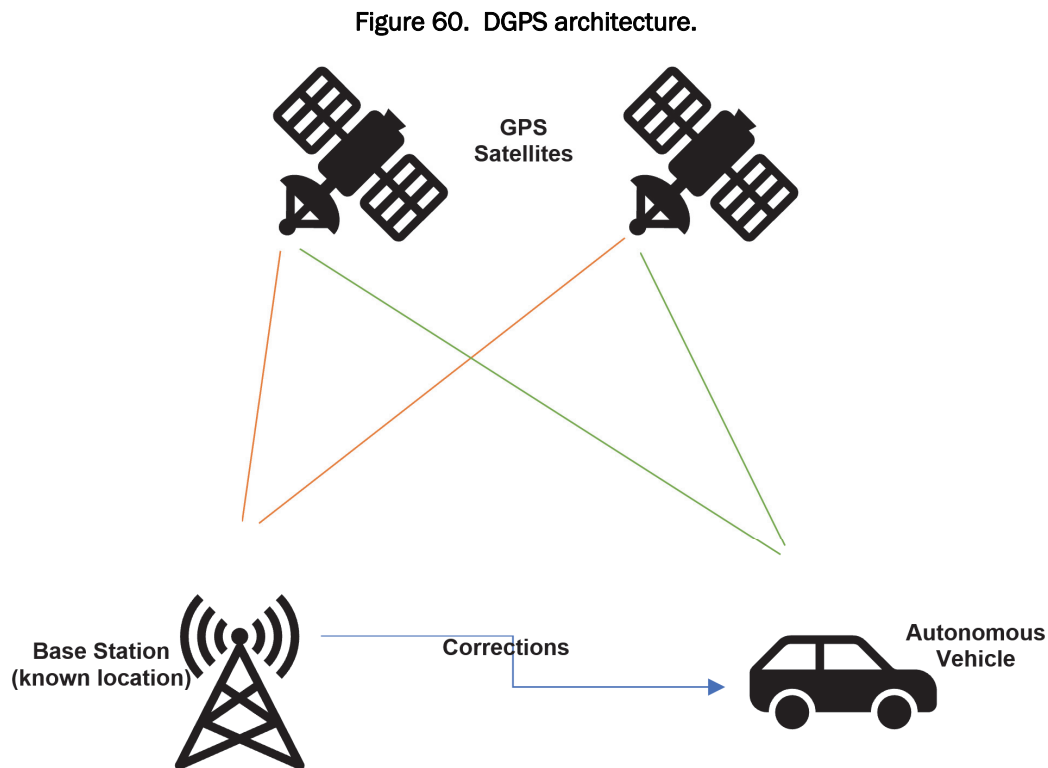
One is at a fixed location where the exact position is known, which is either by survey or measuring the GPS position for long periods of time (24–48 hours). The other receiver is mounted on the autonomous-system.

The fixed-location receiver, called a base station, computes the real-time GPS solution and compares that to its known location. The comparison is used to compute a correction factor between the real-time GPS solution and the known location. The correction factor is then sent to the GPS receiver on the autonomous-system and applied to the GPS solution of the autonomous-system.

DGPS is able to improve the position solution of the autonomous-system from over 1 meter of accuracy to less than 0.1 meter of accuracy. The typical cost of a DGPS base station is less than $20,000.

One drawback of the DGPS system is that the accuracy of the position solution degrades in areas with poor GPS satellite coverage, such as areas with dense tree coverage, or where GPS signals are being interfered with or jammed.

6.2.2 Site-mounted measurement sensors

In addition to vehicle-mounted measurement sensors, another option to track and measure autonomous-system performance is mounted sensors at fixed positions within the test site. In this scenario, vision-based sensors (LiDAR, radar, and cameras) would be mounted at locations that provide optimal viewing of the test area, and the data from every sensor would be collected in a central repository via a physical connection.

Just as the LiDARs, radars, and cameras mounted on autonomous systems classify and track different objects interacting with the vehicle, the fixed-location sensors can classify and track the different autonomous systems operating within the test site. This type of system would be more beneficial when testing in areas with poor GPS coverage or indoors.

The Safe Autonomous Unmanned Vehicles for Installations (SAUVI) surveillance tool suite was originally developed to allow autonomous systems to have greater situational awareness by providing data to the system from sensors that were mounted along the autonomous-system's route [5A4].* The SAUVI system is composed of the sensor node and distributed sensors. An example of the node and distributed sensing setup is shown in Figure 61.

The ability to classify and track autonomous systems within the test area depends largely on the type of sensors connected to the SAUVI system. For example, a system that uses narrow field-of-view radars would be able to track autonomous systems at long ranges (up to 400 meters with line of sight) but only if the autonomous-system is within the radar's field of view (Figure 62). Conversely, a LiDAR that spins 360 degrees would be more forgiving in the field-of-view context, but the overall range is much less (approximately 100 meters).

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* Lacaze, Alberto. Putney, Joseph. 1 March 2018 "SAUVI II-Safe Autonomous Unmanned Vehicles for Installations." Contractor's Final Technical Report.

Figure 61. Node and distributed sensing setup.
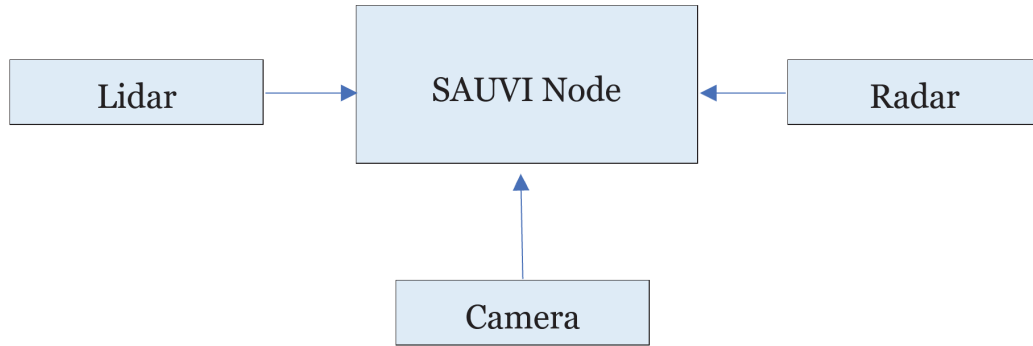
Figure 62. Node and distributed sensing setup.

|Additionally, the measurement performance of each sensor needs to be considered to achieve the desired accuracy of the collected data. The sensors listed in Table 41 can be used with the SAUVI node. A typical cost of the node is approximately $15,000.

Table 41. Radar specifications.

LiDAR	Delphi ESR	Delphi SRR2	SMS UMRR-0a Type 29	SMS UMRR-0a Type 30	SMS UMRR-0a Type 31	Continental SRR 20X	Continental ARS 300
Frequency	76.5 GHz	76.5 GHz	24 GHZ	24 GHZ	24 GHZ	24 GHZ	77 GHZ
Range	174 m (long range) 60 m (midrange)	80 m	160 m	90 m	45 m	50 m	200 m
Max Range Pedestrian	40 m		50 m	40 m	20 m		
Max Range Car/Truck	175 m		160 m	90 m	45 m		
Horizontal Field of View	+/-10° (long range) +/-45° (midrange)	+/-75°	+/-18°	+/-35°	+/-50°	+/-20° (long range) +/-75° (midrange)	+/-8.5° (long range) +/-28° (midrange)

LiDAR	Delphi ESR	Delphi SRR2	SMS UMRR-0a Type 29	SMS UMRR-0a Type 30	SMS UMRR-0a Type 31	Continental SRR 20X	Continental ARS 300
Vertical Field of View	+/-4.2-4.75°	+/-5°	+/-4°	+/-5°	+/-5°	+/-6°	+/-4.3°
Update Rate	<=50 ms	<=50 ms	<=50 ms	<=50 ms	<=50 ms	>=33 ms (typ. 38 ms)	66 ms
Tracking Targets	64	64	64	64	64	256 (126 reported)	90

6.3 Lab tests

Robotic Research has collected and analyzed data with multiple sensors. This section will describe each of the evaluated systems, discuss the pertinent specifications (and their effect on performance) for each sensor, and present some initial results.[*] Table 42 lists some key specifications for each LiDAR.[†]

Table 42. LiDAR specifications.

LiDAR	Velodyne VLP-16	Velodyne HDL-32E	Velodyne HDL-64E	GDRS XR microLADAR	IBEO LUX 8L	Optech ILRIS-HD	Optech Lynx SG1
Wavelength	903 nm	905 nm	905 nm	905 nm	905 nm	153 5 nm	15 nm
Range	100 m	100 m	120 m at ~80% reflectivity 50 m at ~10% reflectivity	120 m	200 m for "average target"[5] 50 m at ~10% reflectivity	1250 m	250 m at 10% reflectivity
Accuracy	<3 cm	<2 cm	<2 cm	Unknown	10 cm	7 cm	5 cm
Number of Lasers	16	32	64	1	8	1	2 (1 per sensor)
Scan Frequency	5-20 Hz	5-20 Hz	5-15 Hz	10 Hz	25 Hz	Unknown	Up to 500 lines per second
Field of View	HFOV: 360° VFOV: 30° (θ_{up}= 15°, θ_{down}= 15°)	HFOV: 360° VFOV: 41.3° (θ_{up}= 10.67°, θ_{down}= 30.67°)	HFOV: 360° VFOV: 26.8° (θ_{up}= 2°, θ_{down}= 24.8°)	HFOV: 120° VFOV: 20° (θ_{up}= 10°, θ_{down}= 10°)	HFOV: 110° VFOV: 6.4° (θ_{up}= -3.2°, θ_{down}= 3.2°)	H: 40° V: 40° (adjustable)	360°
Vertical Angular Resolution	2°	1.33°	0.4°	Variable (non-overlapping scan pattern)	0.8°	0.001146°	N/A

[*] Lacaze, Alberto. Murphey, Karl, Schneider, Anne. June 2014. "Perception Sensor Study for High-Speed Autonomous Operations.

[†] Lacaze, Alberto. Murphey, Karl, Schneider, Anne. Del Giorno, Mark, June 2014. "Comparison and Analysis of LADAR Sensors for Object Detection in Vegetated and Obscured Environments."

LiDAR	Velodyne VLP-16	Velodyne HDL-32E	Velodyne HDL-64E	GDRS XR microLADAR	IBEO LUX 8L	Optech ILRIS-HD	Optech Lynx SG1
Horizontal Angular Resolution	0.1-0.4°	0.16°	0.09°	Variable (non-overlapping scan pattern)	Up to 0.125°	0.001146°	Unknown
Beam Divergence	3.0 mrad	2.79 mrad	2.0 mrad	3.2 mrad	Unknown	150 μrad	Unknown

The range and accuracy of a LiDAR system are dependent on many factors, including the reflectivity of the object and ambient lighting conditions. For example, the Velodyne 64 specifies a 120-meter maximum range, but this figure is based off of objects with ~0.8 reflectivity (e.g., cars, foliage). The maximum range is reduced to 50 m for ~0.1 reflectivity (e.g., pavement).

The horizontal and vertical resolutions of a sensor are critically important when evaluating the performance of each LiDAR for the target detection application. When the desired target sizes are small (e.g., 6.5" x 6.5" x 7.75"), and the desired stand-off distances are large (e.g., 13 meters), detection is reliant on achieving enough points of the object of interest.

To illustrate this point, Figure 63 (left) shows the scan pattern of the Velodyne 64 on an object 13 meters away, which was taken from a non-moving vehicle. The red box represents the object (paint-can sized), and the blue dots represent the LiDAR scan pattern. The horizontal angular resolution is much smaller than the vertical angular resolution (0.09 vs. 0.4 degrees), producing a denser point cloud in the horizontal dimension.

In comparison, the results from the Velodyne 32 (Figure 63, right) show that the increased vertical angular resolution (1.33 degrees) produces drastically different results at the target range of 13 meters. Instead of three scan lines hitting the target of interest, only a single scan line intersects the target; at the 13 meters distance, there are close to 12 inches vertically between scan lines.

Figure 63. Velodyne 64 simulation (left); Velodyne 32 simulation (right).
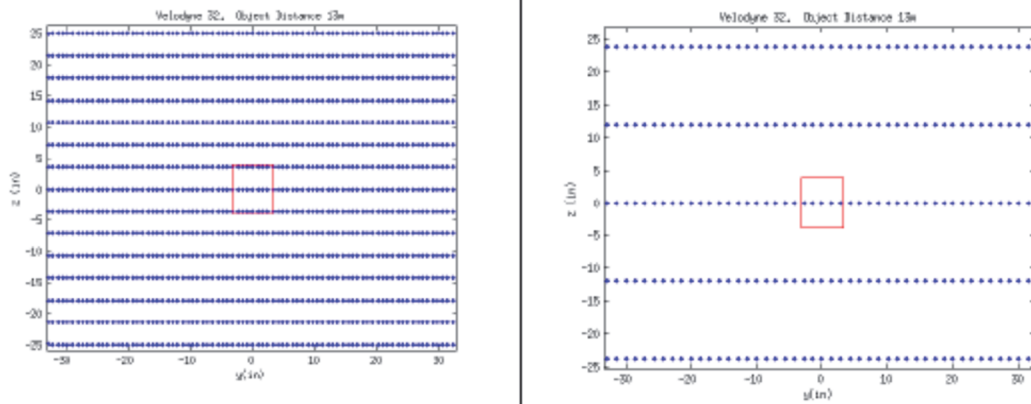
Figure 64 shows a point cloud comparison for a 30-mph collection. The top image shows the test setup, and the colored boxes represent different areas with static obstacles. The bottom images show the point clouds that are generated from driving, at speed, starting 200 meters from the first obstacles until the vehicle is approximately lined up with the first obstacles. The Velodyne HDL-64E, as expected, produces the densest point clouds; the Velodyne has 64 times as many lasers as the XR microLADAR and eight times as many lasers as the IBEO LUX 8L.

Figure 64. LiDAR point clouds from three different sensors.

Velodyne HDL-64E   GDRS XR microLADAR   IBEO LUX 8L
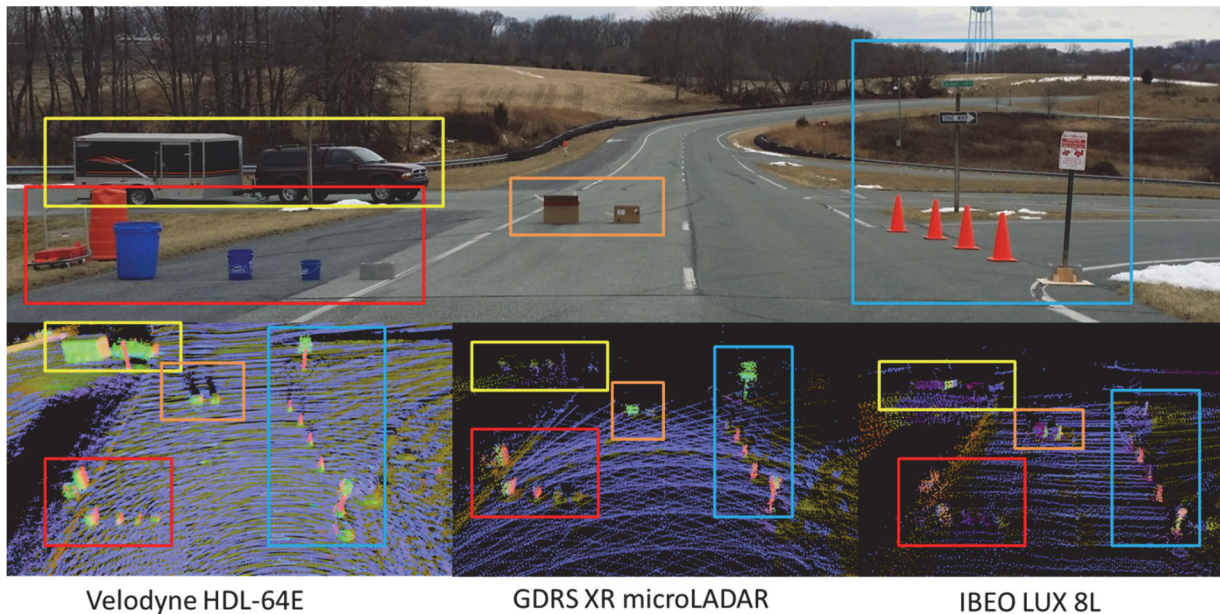
One of the objectives of the SMEs' analysis is to determine at what distances different objects can be detected. When plotting the point cloud

collected starting at 150 meters and ending at 100 meters from the obstacles, the Velodyne HDL-64E obtained points on the barrels, cardboard boxes, and one of the street signs (Figure 65). By the 50-meter range, the point cloud was filled in with a significant number of points on each of the target objects (Figure 66).

Figure 65. Velodyne HDL-64E at 150-100 m range.
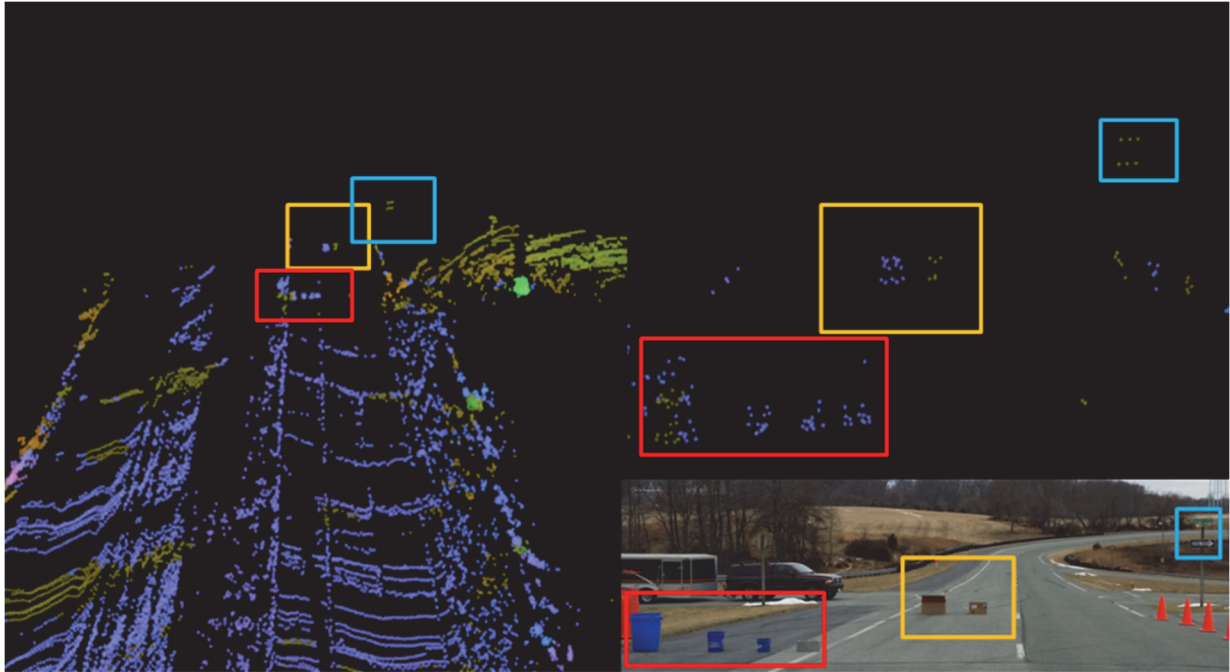
Figure 66. Velodyne HDL-64E at 100-50 m range.
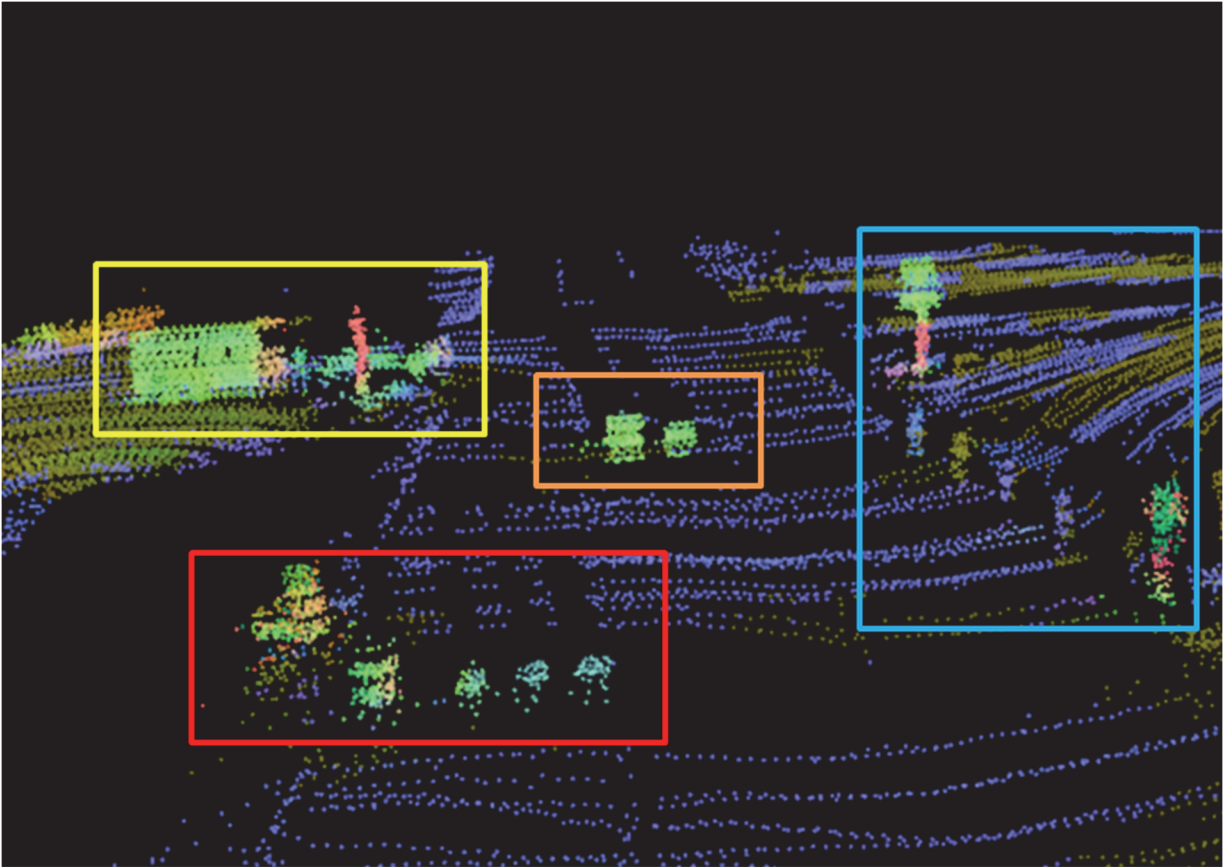
In addition to LiDARs, Electro- Optical (EO) cameras also can perceive objects from the distances required in this project.

As a starting point to determine the specifications needed for a camera system, Robotic Research is investigating the capabilities of human vision. The visual acuity of the human eye is ≈ 0.59 arcminutes per line pair. (An arcminute is equal to 1/60th of a degree.) Because you need two pixels minimum are needed to distinguish a line pair, the necessary pixel spacing to equal human vision is ≈ 0.3 arcminutes (0.005 degrees).

Robotic Research created an Excel tool to allow calculation of a variety of parameters (camera resolution, lens focal length, sensor size, object size, distance to the object of interest) and compute the resulting field of view, resolution (pix/m and angular), and number of pixels on target (Figure 67).

For example, using the specifications for one of the cameras, Robotic Research has in-house (Point Grey Grasshopper 3, 5MP [2448x2080], 2/3

inched sensor size), in combination with, a 36- mm rectilinear lens, will generate a 15.7°H x 13.8°V field of view and a 0.0065° angular resolution (close to the human acuity values). A 10-mm lens would increase the field of view (52.8°H x 47°V) but would sacrifice angular resolution (0.022 degrees). This trade-off is shown in Figure 68, which shows a plot of horizontal field of view versus focal length as well as angular resolution versus focal length for a 5-MP and 9.1-MP camera.

Figure 67. Excel-based camera analysis.
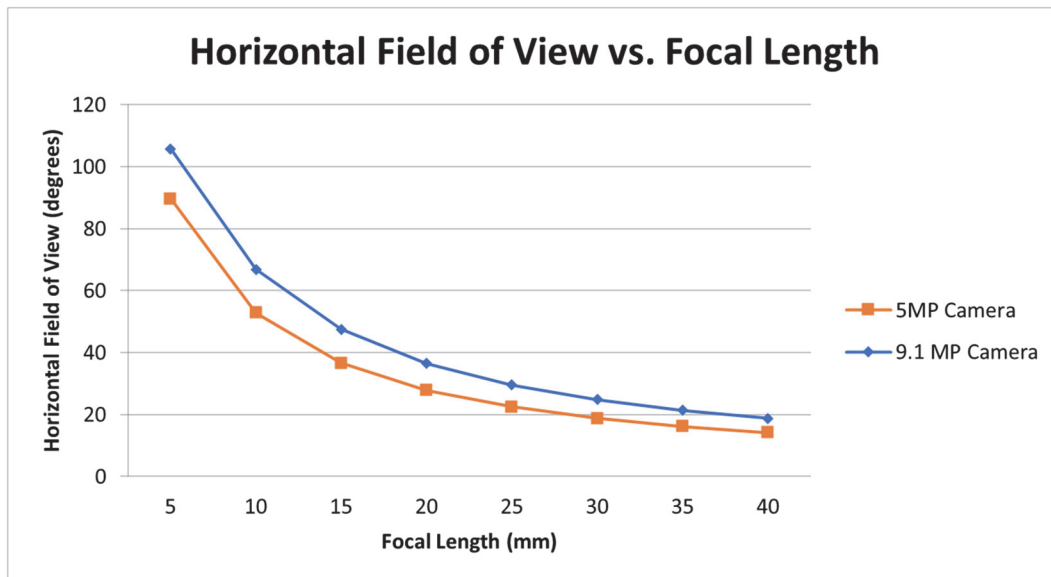
Figure 68. Excel-based camera analysis.
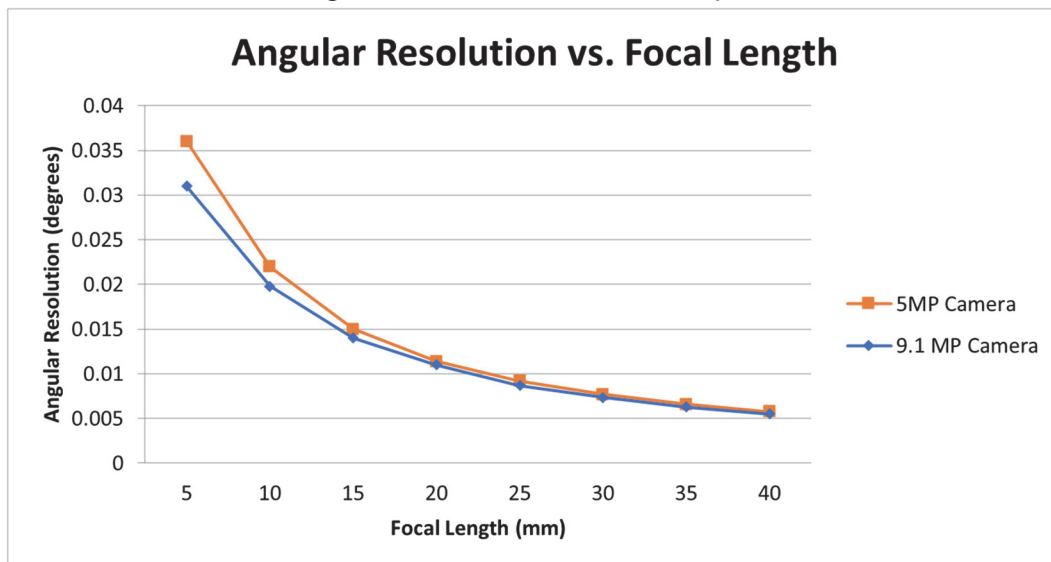
Robotic Research has also collected and analyzed data from several radar sensors. The specifications of every sensor are listed in Table 41.

6.4 Feasibility study

The objective of this research is to determine the feasibility of using the sensors described in the sections above in a variety of known test locations. The feasibility study will look at the number of sensors needed for a given test location and cost benefits versus the ability to collect autonomous-system data.

As described in **Section 3.4** under testing, LiDAR can provide centimeter accuracy of the autonomous-system and has a range of approximately 100 meters. As the test site grows in size, more LiDARs will be needed to fully cover the site.

Table 43 lists a variety of known test locations and the number of sensors needed to measure the autonomous-system performance at each site. More details of the test locations can be found in **Appendix P**.

Table 43. Autonomous-system test sites.

Site	Site Details	Number of Visual Sensors	Number of Differential GPS
CBITEC Charging Area	~100 m x 100 m relatively flat parking pad area.	2 LiDAR, 2 radar, 2 cameras on opposing corners of the parking pad area	1 base station
TA 231 Driving Course	~600 m x 150 m off-road loop with blind turns and elevation changes.	9 LiDAR, 9 radar, 9 cameras spread around the test track	1 base station *can use CBITEC base station due to proximity
The American Center for Mobility (ACM)	ACM's facility encompasses 500 acres, multiple on-road test environments, and is adjacent to the Willow Run Airport.	4 LiDAR, 4 radar, 4 cameras on opposing corners of the configurable area Visual sensor coverage is not economically feasible to cover road network area.	1 base station
Larson Transportation Institute	The facility includes the Bus Research and Testing Center, Center for Integrated Asset Management for Multi-Modal Transportation Infrastructure Systems and the Center for Dirt and Gravel Road Studies.	4 LiDAR, 4 radar, 4 cameras on opposing corners of the vehicle-handling area Visual sensor coverage is not economically feasible to cover road network area/	1 base station

Figures 69 and 70 show examples of how fixed-position sensors could be used at the CBITEC and the TA-231 Driving Course test locations. The sensor coverage map is a graphical representation of where sensors could be placed for optimal site coverage.

Figure 69. CBITEC sensor coverage map.

Figure 70. TA 231 driving course sensor coverage map.
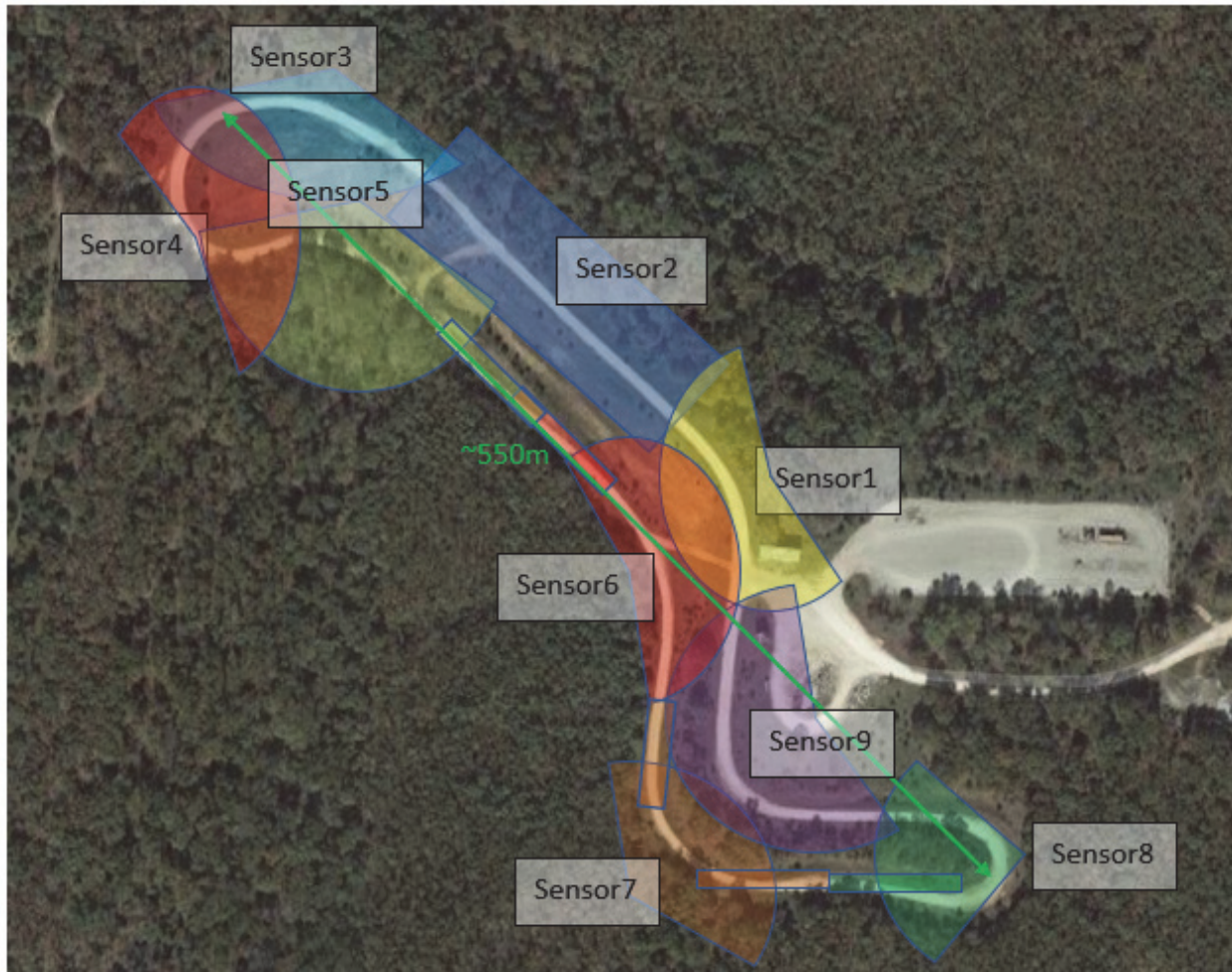
As stated in Table 43, the test areas with larger road networks become economically infeasible to outfit with vision-type sensors. The number of sensors required to cover the area and the additional infrastructure needed to power the sensors makes using a differential base station a more cost effective option. In smaller test areas, such as CBITEC, both vision-type sensors and DGPS could accurately measure the autonomous-system's position and attitude. Additionally, a hybrid approach could be used with both DGPS and a single set of vision-type sensors. The hybrid approach would allow for the vision sensors to cover areas that might have degraded GPS.

6.5   Conclusions and future work

Many of the testing methodologies discussed in this report are applicable to the test areas at FLW, specifically CBITEC, and the TA-231 Driving

Course. The next step in this research is to outfit these test areas with sensor suites discussed in the report and to begin testing autonomous systems at this site. As more details about the autonomous-system and test areas are solidified, the test plans in this report can be evolved into test procedures tailored for the FLW site.

7 Identify Requirements for a Sensored, Living Laboratory to Assess the Performance of V2G Charging in a Tactical Microgrid

The objective of Research Area 5B is to identify requirements for a sensored, living laboratory to assess the performance of V2G charging in a tactical microgrid environment and to recommend an optimal V2G solution set for use at the CBITEC site.

To achieve this research objective, Paragon SMEs established requirements for a sensored, living laboratory, to test recommended V2G solutions, and ensure adherence to current and developing standards at CBITEC. The living laboratory must have the capacity and capability to verify the V2G aspects of the system and ensure that they comply with operational requirements outlined in Research Area 4. Specific tests and measurements to determine whether measured performance meets or exceeds requirements were conducted to review procured V2G charging equipment. Paragon SMEs integrated standard test thresholds into the CBITEC tactical microgrid simulation to evaluate system performance and refine V2G solution set recommendations along with simulation results from Research Area 4.

7.1 Develop requirements for a sensored, living laboratory

The objective of this research is to develop requirements for the CBITEC sensored, living laboratory to have the capability to test recommended V2G solution and standards adherence.

To develop a set of operational requirements meeting this objective, Paragon SMEs conducted an extensive review of available literature. The SMEs collaborated with government personnel to capture and document requirements as they relate to recommended V2G technology testing and demonstration at the CBITEC site. The following items were investigated for suitability: power distribution equipment, communications equipment, EVs, EV charging equipment, and power measurement equipment. Results

of the investigation identified operational requirements to use for selection necessary to integrate the V2G solution.

7.2 Identify methods to quantify V2G system aspects

Methods to quantify V2G system aspects to ensure compliance with operational requirements outlined in Research Area 4 include confirming:

- Communication capability of the V2G solution set that enable overarching control as one system, of several systems integrated together, to provide an energy resilient tactical microgrid.
- Electrical ratings are compatible with the tactical microgrid electrical ratings of voltage and frequency.
- Operating modes of the V2G solution set can provide and receive power as part of the envisioned tactical microgrid.
- Power capabilities sufficiently support the tactical microgrid.

After quantifying V2G system aspects, Paragon researchers conducted an industry search to identify appropriate technology solutions to develop a V2G solution set recommendation.

Equipment safety tests must be available to conduct test plans. Current policy at CBITEC prevents using automated test plans and requires all testing be conducted manually. Consequently, conducting a test plan in a living laboratory at CBITEC requires a clear test plan documenting each test step. A well-defined test plan ensures tests are conducted correctly and repeatable to verify test results or to quantify system changes based on previous test results. When testing electrical equipment, a manual method for disconnecting equipment should be identified in case a protective device does not properly operate.

Prior to conducting any test plan on operating equipment, a "dry run" is recommended to ensure test personnel completely understand the test plan. Additionally, this action is an opportunity to update test plan instruction and verify test personnel understand proper test plan actions prior to energizing equipment. With appropriate equipment protective devices in place and adjusted for the EUT, a clear step-by-step test plan can be safely conducted by qualified personnel. Per the NEC, qualified personnel are individuals who possess the skills and knowledge related to

construct and operate electrical equipment and installation and have also received safety training to recognize and avoid the hazards involved.

To safely test a V2G system, the existing IPD box contains SEL 849 protective relays that communicate with a SEL 3505 RTAC (HG Engineers, 2019) that can meet the protection and metering requirements for the V2G system as well as communicate with the CBITEC data collection server. Each IPD will need to be configured to meet the data collection and protection requirements for the connected equipment that is connected to it.

To install a V2G solution at CBITEC, the charger should be bolted to a suitable concrete pad located on top of reasonably level ground. The equipment will be able to withstand potential winds without in-ground concrete foundations and the extensive approval process required for installation.

7.3 Sensored, living laboratory requirements

Testing and evaluating new equipment in a living laboratory require additional equipment to quantify component performance and interoperability while ensuring personnel and connected equipment safety. Protective devices that can be adjusted to protect and quickly disconnect EUT are critical for the safety of personnel, the EUT, and the connected test system. Protective devices, such as microprocessor relays with adjustable trips settings for current, voltage, frequency, power flow, are required. These same microprocessor relays dominate the data collection in the bulk electric power system and are likewise suggested to be employed at the laboratory.

The international* *Standard for the Testing of Microgrid Controllers,* requires collecting data collection for the testing of microgrid testing as summarized in Table 44, which below: minimum sample rates in milliseconds (mSec) for the voltage (V) and current (I) data.

Table 44.   IEEE 2030.8 required data collection.

Type of Data Collection	Minimum Time-Synchronized Accuracy	Minimum Sample Rate	Required Data to Collect
Sequence of Events (SOE)	4.16 mSec	4.16 mSec	Digital data

* Institute of Electrical and Electronics Engineers. "2030.8-2018 – IEEE Standard for the Testing of Microgrid Controllers." *IEEE Standards Association*, Institute of Electrical and Electronics Engineers, 24 Aug. 2018, standards.ieee.org/standard/2030_8-2018.html.

Type of Data Collection	Minimum Time-Synchronized Accuracy	Minimum Sample Rate	Required Data to Collect
Event Oscillography (OSC)	4.16 mSec	4.16 mSec	V and I all phases
Continuous Data Collection (CDC)	4.16 mSec	100 mSec	V and I all phases

The data listed in Table 45 is essential for root-cause analysis of events. Voltage and current are used to derive all other quantities. Frequency, root mean square (RMS) voltage, RMS current, phase angle, real and reactive power/energy, voltage sags, swells, and other characteristics, for example, are all derived from the voltage and current signals listed in Table 45.

Considering the low cost of memory storage in 2020, and the relatively slow sampling intervals of the standard, this is a low-cost requirement that is easily accomplished with COTS equipment today. Per the standard, the data collected in the prior table must occur on the AC side of every genset, inverter, and any power-wheeling breaker or load larger than 50% of the total load. Events to be tested are noted in Table 45.

Table 45. IEEE 2030.8 test events.

Event	SOE	OSC	CDC
Islanding	X	X	X
Synchronizing	X	X	X
DER trip	X	X	
Faulted circuit	X	X	
Load shed	X	X	X
Dispatch from microgrid controller			X
Black start	X	X	X

To measure the EUT's performance, sufficient measurement devices must be installed in the test system to capture the critical performance aspects. In the case of the V2G system, measurements include:

- Total three-phase real and reactive power
- Individual-phase real and reactive power for all three phases
- AC voltage, current, and frequency
- Accumulated energy exported—both real and reactive
- Accumulated energy imported—both real and reactive
- Total harmonic distortion
- Synchronized timestamp of each data point.

Minimum sampling rates, called out in the 2030.8 standard, are consistent with protective relaying equipment installed throughout the bulk electric generation, transmission, and distribution power system today.

SOE reports (SERs) are recorded in most microprocessor relays manufactured today. SERs in these relays must be configured to record breaker status, inverter status, generator controller statuses, warning events, alarms, equipment health, protection events, life/safety events, and internal logic variable state changes. SERs are fundamental to debugging new systems and time-aligning events for root-cause analysis. Power systems react in fractions of a power cycle, approximately 4 mSec, which is why microprocessor relays and SERs are so essential.

Oscillographic event reports (ERs) are recorded in most microprocessor relays manufactured today. ERs in these relays must be configured to record high-speed sampled currents and voltages for periods of time intervals up to 1 second in duration. This captures the power system' oscillatory behavior, transients, sub-transients, magnetic saturation effects, X/R time constants, fault currents, and much more. ERs are commonly used to understand the root cause of events. They are also required in 2030.8 because life-safety events, such as life-threatening arc-flash events, are captured with ERs. These events are stored in the relay and are regularly retrieved with automated software to analyze system events and performance.

CDC is most commonly accomplished with synchrophasor data collection performed inside modern microprocessor relays. Modern relays include phasor measurement units (PMU), which collect time-synchronized data samples of a power system in compliance with the Institute of Electrical and Electronics Engineers[*]. These are proven to be an excellent condition-monitoring system when pushed to synchrophasor data consolidation and historian software. In many applications, C37.118 data includes much more than just the data required by the 2030.8 standard. It also includes a single heads up display/historian with a single screen showing cyber-attack metrics, network traffic metrics, power system electrical parameters,

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[*] Institute of Electrical and Electronics Engineers. "C37.118.1-2011 – IEEE Standard for Synchrophasor Measurements for Power Systems." *IEEE Standards Association*, Institute of Electrical and Electronics Engineers, 28 Dec. 2011, standards.ieee.org/standard/C37_118_1-2011.html.

synchronization data, battery health, and engine mechanical health data. SEL implemented its standard off-the-shelf software in its TMS demonstration project as shown in Figure 71. This data was stored in an off-the-shelf computer with over 20 years of data storage for continuous microgrid operation.

Figure 71. SEL PC with 20 years of microgrid data storage.*

Visualization interface, such as the IEEE C37.118 synchrophasor data condition monitoring application shown above, is a user-configurable operator interface. This allows tests to be remotely monitored, with significantly slower refresh rates (1 Hz) to the operator display, for effective visual monitoring by zooming out to see long-term trends. When zooming, these systems scale to higher-resolution data for better precision.

Similar laboratory facilities are located at Mount Holley's in Duke Energy's† microgrid research yard. This yard contains a diverse set of generators, PV, batteries, loads, and a host of experimental equipment. This yard is instrumented with industry standard electronics primarily from SEL because of its dominance in generation, transmission, distribution, microgrid, and industrial substations throughout the United States (Figure 72).

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* Schweitzer Engineering Laboratories. "SEL-3360 Compact Industrial Computer." *Schweitzer Engineering Laboratories*, 24 Sept. 2019, selinc.com/products/3360/.

† Duke Energy. "Duke Energy Smart Grid: Designing Ways to Operate the Grid More Simply and Cost-Effectively." *Duke Energy*, Duke Energy Corporation, Jan. 2016, duke-energy.com/our-company/about-us/smart-grid/coalition.

Figure 72. SEL's TMS demonstration project with continuous data collection.
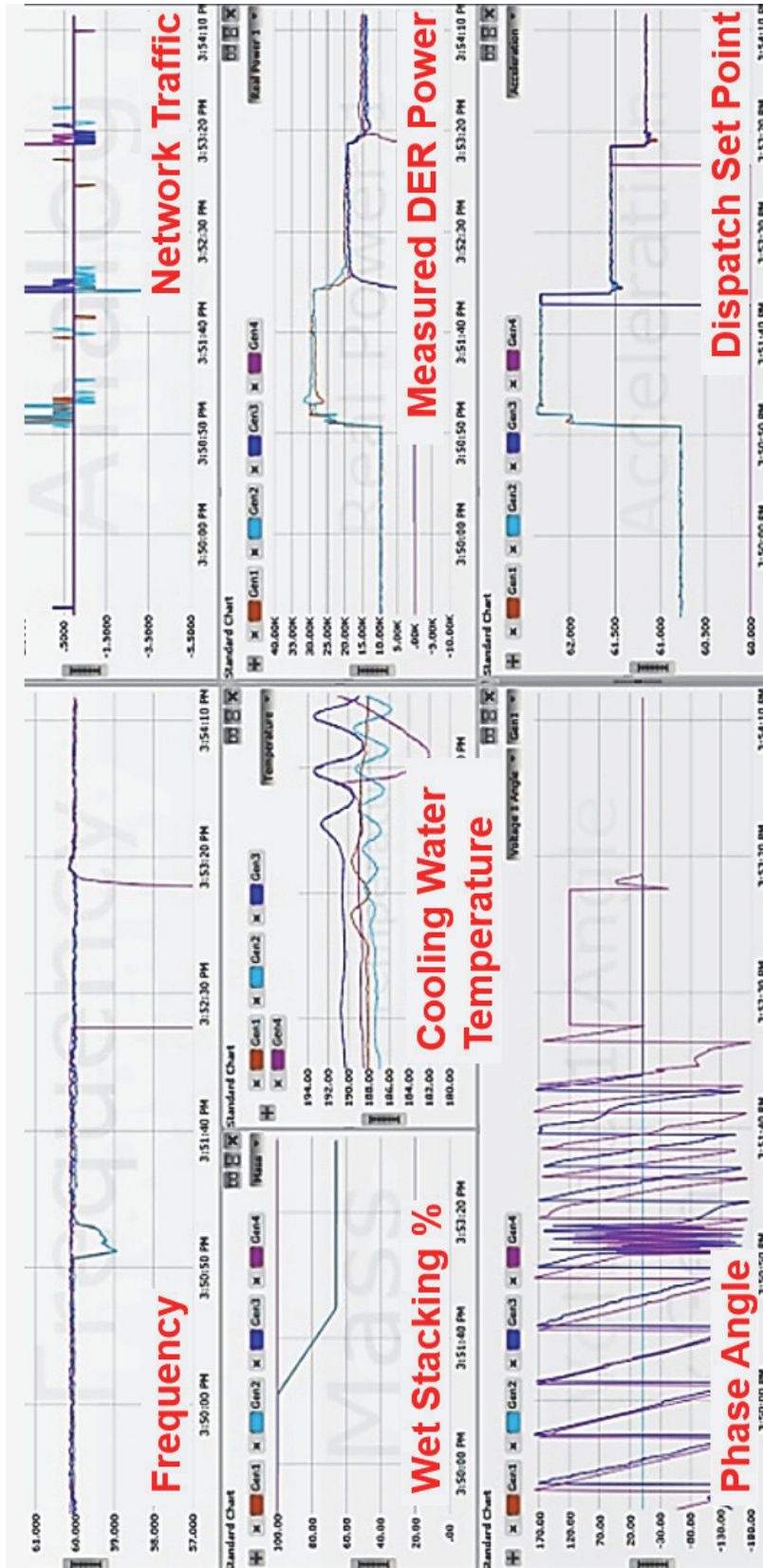
In the investigation of central versus distributed system monitoring, protective relays can provide both human safety, equipment protection, and built-in storage capabilities equal to or greater than devoted metering systems. SEL's onboard memory enables high-speed data collection that would quickly overwhelm a high-speed Ethernet network. Therefore, local storage on these relays is necessary. Off-the-shelf software is then used to download these events without undue network traffic. These data collection on the relays are first in/, last out, in that old events are eventually flushed from the relays. The protective relaying method of local (distributed) storage of data in the relay followed by a (centralized) data historian for long-term archiving appears to provide the optimal solution for power systems. This has decades of reliable operation throughout the oil and gas and utilities industries. This method avoids risks to data loss associated with noise and bandwidth limitations of communication links.

Disturbance recording systems of a non-relaying process controller-based equipment can be too slow for practical use on a microgrid. Sample rates can also be too slow, and, often, there is no remote (decentralized) storage. The systems tend to be much more expensive. One example is OSIsoft's PI System (OSISoft, n.d.), which has exorbitant license fees and complex software that requires significant coding skills to support, set up, and maintain.

Relay-based data collection methods communication requirements appear optimally designed for power systems. They are reliable with intermittent communication links; they are commonly retrieved with serial communication channels, voice channels, and other antiquated communications techniques. A restricted Ethernet system can offer sufficient bandwidth enabling connection to capture high resolution oscillography for extended tests without data loss (Figure 73).

Figure 73. SEL's relays meet SOE, OSC, and CDC data collections requirements of IEEE 2030.8.

Various components needed to outfit a living laboratory will need evaluating to maintain compatibility with existing equipment and promote interoperability with open standards. SEL components listed in Table 46 are suggested as one holistic solution.

Table 46. Living Laboratory hardware components.

Location	Suggested SEL Component	Comments
Point of utility connection	SEL-751 + SEL-3505	Acquire in a wall-mount outdoor enclosure
AMMPS genset	SEL-700G + SEL-3505	Acquire in a wall-mount outdoor enclosure
IPD input port	SEL-700G + SEL-3505	Exists in HG's IPD 800
IPD output port	SEL-849	Exists in HG's IPD 800
IPD ring-bus port	SEL-849	Exists in HG's IPD 800
Network Ethernet	SEL-2740S	Used to detect and deflect outside intrusion and cyber attacks
Data concentration	SEL-3530-4	Consolidates TMS traffic to a single C37.118 data stream
Human machine interface and engineering workstation	SEL-3360	Provides two TV monitor ports and long-term data archiving for all CDC, SOE, and OSC data
Synchrophasor historian	SEL-5078 software	Historian for 20 years of microgrid run-time
PV array	SEL-700G + SEL-3505	Acquire in a wall-mount outdoor enclosure
Battery	SEL-700G + SEL-3505	Acquire in a wall-mount outdoor enclosure
V2G	SEL-700G + SEL-3505	Acquire in a wall-mount outdoor enclosure

7.4 Procure V2G charging equipment

The objective is to procure V2G charging equipment to conduct initial testing and analyze results to confirm performance.

The approach identifying the V2G charging equipment to be procured commenced with an industry search to distinguish and evaluate V2G

charging solutions that had the potential to meet program objectives and site requirements. Program objectives included:

- Promoting interoperability of microgrid equipment through open standards
- Increasing tactical microgrid energy resiliency by using a V2G system capable of supplying, or consuming, 30 kW or more.

Site requirements that were considered included:

- Electrical ratings compatible with the tactical microgrid conceptual design
- Enclosure ratings suitable for an outdoor installation
- Ability for a driver to take control of the vehicle.

Paragon SMEs have extensive demonstration experience. Given the aforementioned program objectives and site requirements, they:

- Researched the EV and charging station industry for potential V2G solutions
- Contacted peers and potential suppliers to confirm latest offerings
- Participated in technical research and discussions with potential suppliers identified in Research Area 2
- Evaluated an alternative approach of mounting EV batteries and a power converter to a General Dynamics Multipurpose Unmanned Tactical Transport (MUTT).

Currently in the United States, the CHAdeMO standard (CHAdeMO, n.d.) (Figure 74) is the only open standard that is designed to fully support the bidirectional power flow of V2G systems. The CHAdeMO standard is commonly used in Asia and Europe; however, use in the U.S. is limited compared to the more dominant fast-charging standard that is produced by the SAE.

Figure 74. CHAdeMO connector.

SAE's CCS (Figure 75) is the most commonly used fast-charging standard in the U.S. standard for fast-charging applications. This open standard is used by multiple charging station suppliers to charge CCS-compliant EVs. However, the CCS standard does not incorporate communication and command structures necessary to implement on-demand discharging of EVs.

Figure 75. SAE CCS connector.

Consequently, messaging between the vehicles and chargers must be customized to include unique commands enabling a V2G-capable vehicle to use the CCS standard. This customization inherently prevents the custom charger to be readily used for multiple vehicle types. Such customization also requires extensive non-recurring engineering, development, and testing to implement the V2G capability, which further limits customized CCS solutions for V2G applications. By 2025, SAE plans to update the CCS standard to include communication and controls specifications necessary to enable V2G operations between CCS-compliant vehicles and charging stations.

While the SAE standards for vehicle charging might dominate the U.S., Paragon SMEs recommend using the CHAdeMO-compliant devices to validate V2G operation capabilities in the short term. This approach uses an open standard to promote interoperability, reduces non-recurring engineering costs, and schedules test compared to a custom solution that would be required by attempting to use SAE's present version of their CCS standard. Based on V2G validation results, purpose-built vehicles and charging solutions can be developed.

Currently in the United States, only two commercially available vehicles could be identified that are equipped with the CHAdeMO charging port: The Nissan LEAF (Figure 76) and the Mitsubishi Outlander (Figure 77). The 2019 Nissan LEAF is fully electric and can be ordered with either a 40-kWh lithium-ion battery pack or an extended range version rated at 62 kWh. Because the LEAF is CHAdeMO-compliant, and the CHAdeMO specification fully supports V2G operation, the LEAF can export power without additional support from Nissan Motor Corporation (Nissan) or modification. Factory configuration of the Nissan LEAF limits charge and discharge rates to 30 kW.

Figure 76. Nissan LEAF.

Source: (Vauxford 2018).

The 2019 Mitsubishi Outlander is a PHEV and consequently comes with a lithium-ion battery pack with a much lower energy storage capacity of only 13.8kWh. Because a battery's power rating is directly influenced by the energy storage rating, a lower energy storage capacity also results in a lower power rating for the same battery chemistry. Factory configuration of the Mitsubishi Outlander limits charge and discharge rates to 22 kW. Inherently, battery packs with lower energy storage ratings will typically have lower power capabilities. Further, the duration at the maximum power

level will also be less, further reducing the vehicle's capability to support connected loads.

Figure 77. Mitsubishi Outlander.

Source: (U.S. News & World Report n.d.).

At CBITEC's request, Paragon SMEs also investigated the option of adding battery packs and a bidirectional power converter onto a modifying a mobile platform. For this approach, the mobile platform recommended was the General Dynamics MUTT by General Dynamics given the wide applicability across the Army. With the MUTT selected as the mobile platform, Go Electric and EnerDel were engaged to identify their solution for this alternative approach because both companies previously supported similar vehicle configurations that were delivered to CBITEC. Go Electric offered two battery configurations—; one of which offered was a integrating numerous individual batteries manufactured by Saft (Figures 78 and 79). The second option was to integrate three battery packs from EnerDel. EnderDel's battery solution also recommended the same EnerDel pack (Figure 79) recommended by Go Electric. Neither Go Electric nor EnerDel could offer a power converter solution to consider.

Figure 78. Saft Xcelion 6T battery module.

Source: (Saft 2019)

Figure 79. EnerDel PE500-403.
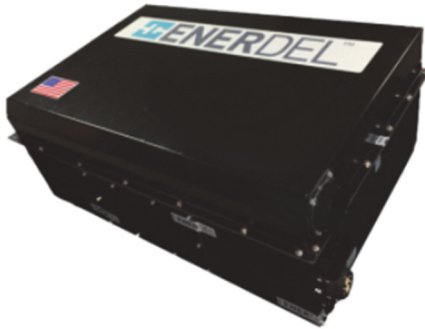
Source: EnerDel (2020).

To verify the viability of this alternate approach, Paragon SMEs compared the weight of the proposed battery solutions to the payload capacity of the MUTT (Figure 80). The weight of the battery solutions recommended by Go Electric and EnerDel ranged between 1,700 and 2,000 pounds, which exceeded the payload capacity of the largest available MUTT of 1,200 pounds by at least 40%.

Figure 80. General Dynamics MUTT.

8X8 TRACKED/WHEELED

- Payload (lbs): 1200
- GVW (lbs): 3000/3500
- Length (in): 116
- Width (in): 60/70

When considering the MUTT payload would increase hardware, protective devices, and an autonomy system integration, the weight of this alternate approach would overload the payload capacity of the MUTT. The payload

would easily exceed 80% of its rating even if the required power converter were mounted offboard the vehicle rather than onboard as originally envisioned. Reducing the battery weight to one battery module still would not leave any payload capacity necessary for integration and the autonomous-driving kit. This alternate approach was deemed unviable given that MUTT does not have the payload capacity to carry an ESS rated to sufficiently interact with the envisioned microgrid.

To support energy resiliency of a microgrid, a V2G system with a power rating to significantly offset the planned 60-kW AMMPS generator is highly recommended. While the off-road capability of the Mitsubishi Outlander might be a better fit for a tactical environment, the energy storage rating of the Outlander is only 20% that of the LEAF, which significantly limits the ability to validate impact a mobile platform might have on a microgrid. Overall, the greater power, energy, and payload capacity make the LEAF a better mobile platform for testing an EV's capability to support energy resiliency as intended by program goals.

Based on the selection of a LEAF as the mobile platform for testing purposes, Paragon SMEs searched for a V2G charger that could serve as a fast charger for the LEAF while meeting program objectives and site requirements. After searching the industry and engaging Nissan, as well as other contacts working in the V2G space, only Coritech Services, Inc. offered a suitable product, Coritech is located in Royal Oak, MI (Coritech Services, Inc.) and offers a 30-kW fast charger that is CHAdeMO-compliant. Coritech's VGI-30-DC-CHA fast charger design (Figure 81) is suitable for integrating into the tactical microgrid as it:

• Has an AC voltage configuration that easily integrates into the planned 208-VAC microgrid distribution system with the use of a COTS step-down transformer.
• Is specifically designed for fast charging and discharging of a CHAdeMO-compliant vehicle.
• Uses open protocols to interface with an overarching controller, monitoring and controlling an EV's charge and discharge rates.
• Uses open protocols commonly used to interface with EVs, including the Nissan LEAF.
• Is designed to U.S. standards applicable to V2G charging systems and distributions systems.

- Is designed to operate outdoors.
- Avoids the significant impacts to cost, schedule, and performance risks associated with developing a first-generation alternative.

Given the intent to use a Nissan LEAF, two complete Nissan LEAF battery packs were also procured to support initial field testing, if needed.

Figure 81. Coritech V2G fast-charging station.

7.5 Conduct initial testing and analysis of results

V2G charging equipment initial testing includes Factory Acceptance Testing (FAT) the V2G charger at Coritech., where the fast charger is made. The benefit of conducting a FAT is it ensures time for the manufacturer review test results and address any identified operational issues before the product leaves the factory. This approach avoids operational down time and additional costs for removal, shipping, and reinstallation that could be incurred if an issue is discovered post-installation.

Nissan tested the two Nissan LEAF battery packs and confirmed they were operational prior to shipping to suppliers. Paragon SMEs requested the test results but the manufacturer declined the request. Obtaining battery test results is not crucial for conducting future testing because baseline testing can be re-established.

7.6   Employ test results to model outcomes to refine recommended V2G solution set

The objective of this research is to apply test results, and/or design specifications of the recommended V2G solution set within the CBITEC tactical microgrid simulation, to model outcomes and develop a refined recommended solution set for review.

Paragon's research team used the MATLAB/Simulink model of the V2G solution set integrated into a conceptual microgrid developed in Research Area 4 to simulate system performance. Simulation results were used to refine the recommended V2G solution set.

In Research Area 4, the tactical microgrid assets were cataloged, and a conceptual design was prepared to construct a representative model and simulate performance. The model, based on a conceptual design of the tactical microgrid, includes the V2G solution set as well as alternative-energy assets anticipated to be part of the living laboratory at CBITEC—including a 100-kW PV array, a 40-kWh of lithium-ion batteries,, a three-phase load bank, and billeting loads. Incorporating an ESS and a PV system into the model, with matching power and energy capabilities, enables representative model simulations to guide integration and control design of a tactical microgrid at the CBITEC site.

In addition to including CBITEC assets, the Coritech V2G charger was added in the model to assess operation, especially during instances of voltage and frequency instability. The Coritech V2G charger, like many generation sources that are designed to discharge electricity into a local electrical utility grid, is compliant with UL Standard 1741, *Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With DERs* and the IEEE 1547a *Standard for Interconnecting Distributed Resources with Electric Power Systems*[*]. The Coritech V2G charger, as a result, is designed to cease generating electricity generation if the voltage or frequency of the connected distribution system exceeds operating limits as defined in the standards. Within these V2G charger

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[*] Institute of Electrical and Electronics Engineers. "1547a-2014 – IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems – Amendment 1." *IEEE Standards Association*, Institute of Electrical and Electronics Engineers, 21 May 2014, standards.ieee.org/standard/1547a-2014.html.

model's frequency and voltage trip settings of the V2G charger model, components can be enabled or disabled to accommodate numerous configurations and subsequently conduct "what-if" scenarios that tactical microgrid will inevitably encounter.

Paragon SMEs identified four "what-if" scenarios to broadly assess performance of the recommended solutions set: sudden generation decrease, sudden generation increase, sudden load decrease, and sudden load increase. In addition, the steady state operating condition of the microgrid was simulated to serve as the baseline. Voltage and frequency stability of tactical microgrid baseline operation simulations, as well as "what-if" scenarios in the Research Area 4 modeling effort, were evaluated to determine if the inverter trip settings would need to be adjusted from the default factory settings. A system model of the tactical microgrid is shown in Figure 82.

7.6.1 Protection model components

Basic protection logic was constructed to emulate protective relays and inverter embedded functions. Figures 83 to 87 show these models in detail.

The following logic (Figure 83) is for under voltage, under frequency, synchronization, and one overcurrent element for the AMMPS generators. This logic monitors the key generator operational performance aspects necessary to maintain operation in the microgrid. The elements—under voltage, under frequency, synchronization, and overcurrent—were specifically created to monitor generator performance during system changes to determine if a generator would cease operation from transient conditions like an abrupt change in system loading or generation. Thresholds and associated time limits in the logic for voltage, frequency, and current monitoring apply to all operational conditions, including the what-if scenarios used to determine system stability.

Figure 82. System model of the tactical microgrid.

Figure 83. AMMPS generator protection logic.

In addition to the phase angle synch check (25) shown in the figure above, the voltage permissive shown in Figure 84. was added.

Figure 84. AMMPS generator permissive.
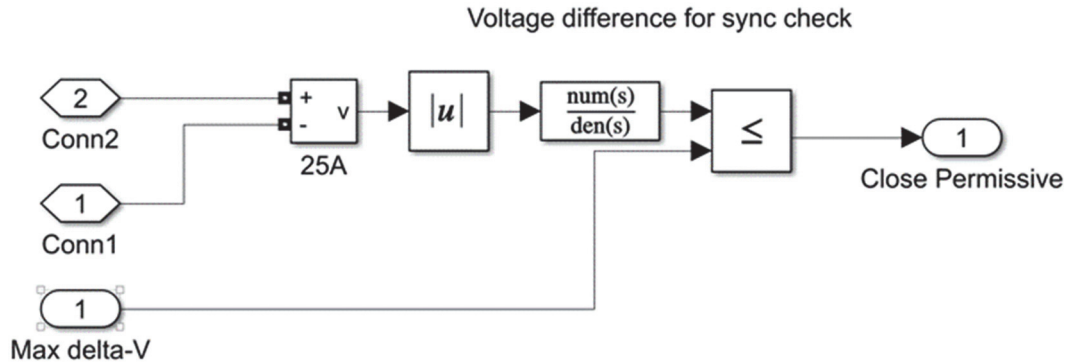
Overcurrent elements were simulated with logic shown in Figure 85.

Figure 85. AMMPS generator overcurrent elements.
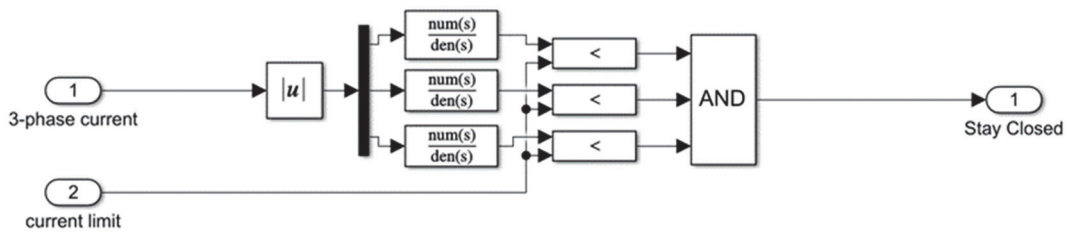
The PV and V2G inverter voltage and frequency ride-through performance was simulated with the logic as shown in both Figures 86 and 87.

7.6.2 Diesel generators model

The SimScape microgrid library has two generator models, one with basic controls (frequency reference, f_ref and voltage reference, v_ref) (Figure 88) and one with more complex controls (f_ref, v_ref, real power (P), reactive power (Q), set to classic control, PV, or PQ). The classic portion of the more complex model was used to control the generator. However, the model still includes the ability to use the "Automatic Generator Controls" for future simulations as more complex generator control schemes are developed.

Figure 86. PV and V2G inverter logic 1 of 2.
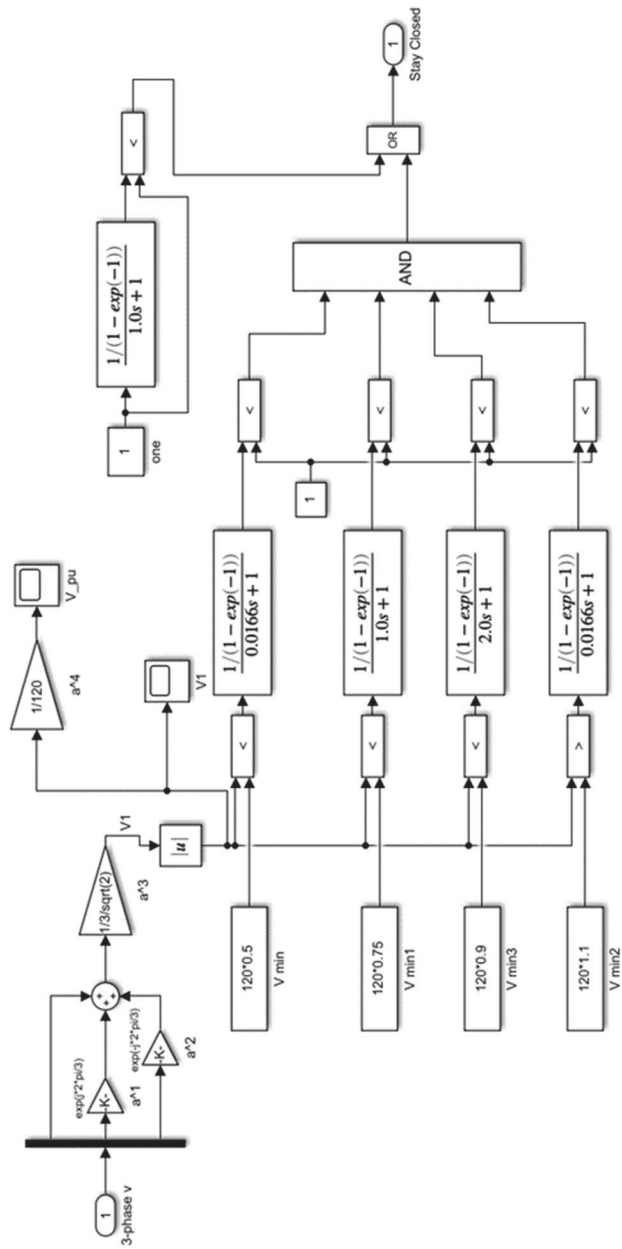
Figure 87. PV and V2G inverter logic 2 of 2.
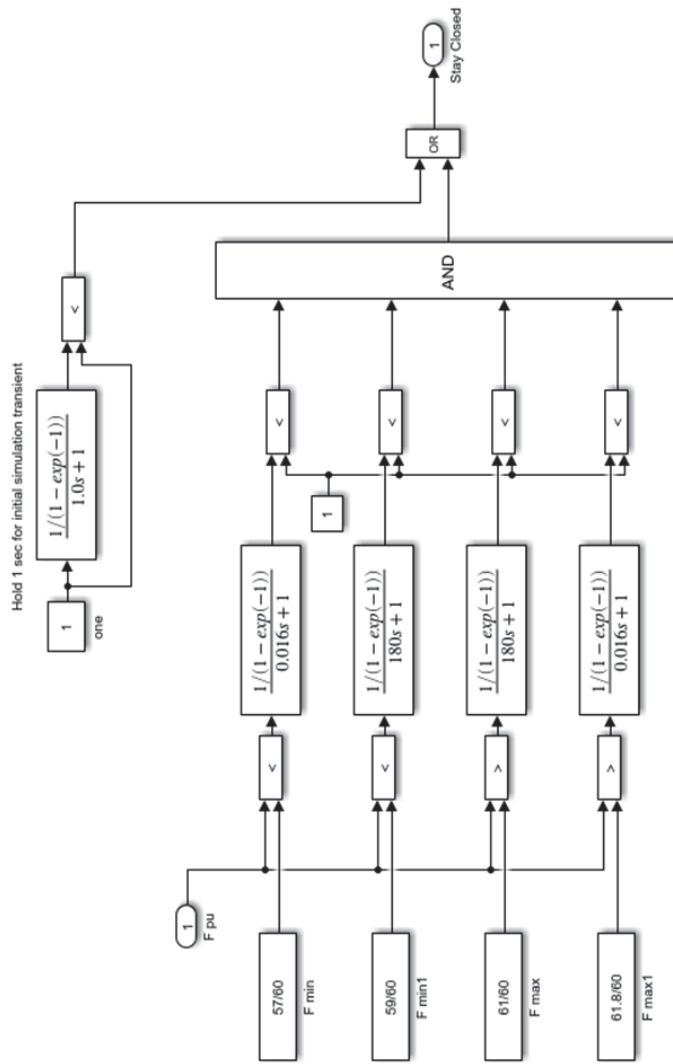
Figure 88. Generator model.
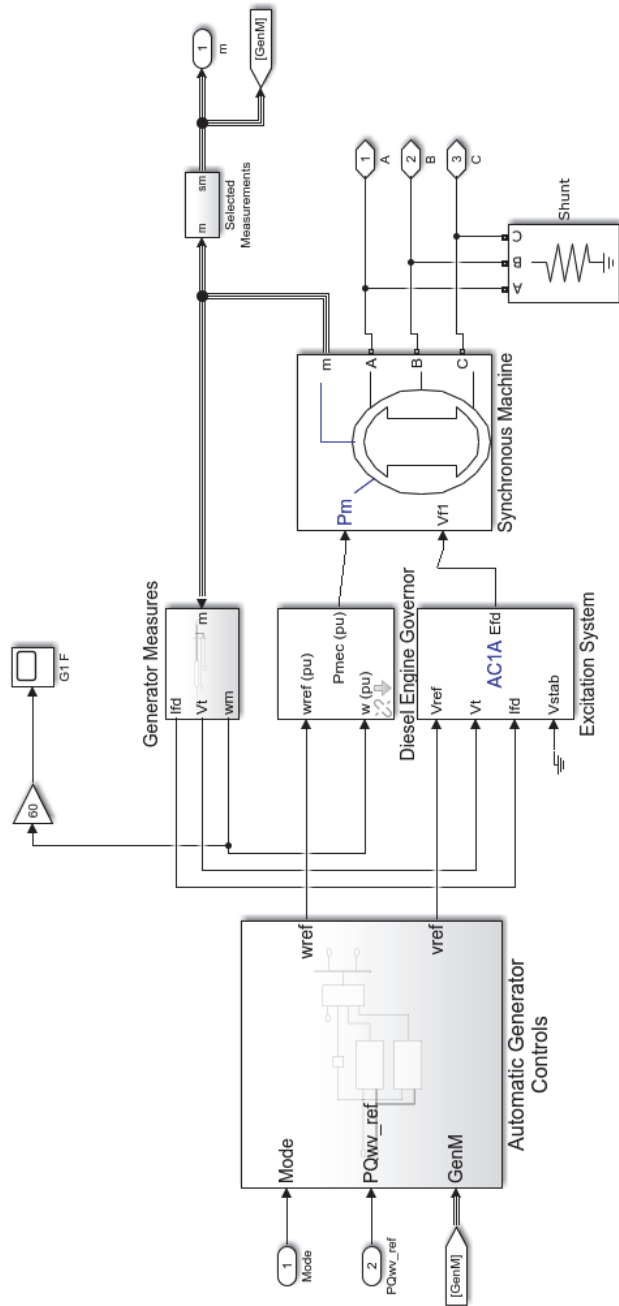
The Synchronous Machine is practically the same as the Real-time Digital Simulator (RTDS) Synchronous Machine. It allows various parameters to be set as shown in Figure 89.

Figure 89. Generator model parameters.

The governor is intended to be its own model (Figure 90) with only the following controls visible.

To increase accuracy, the modeling team instead built a standard Proportional Integral Derivative (PID) (Figure 91) to allow the engine genset to be tuned closer to real-life machine behavior.

Figure 90. Generator governor parameters.

Block Parameters: Diesel Engine Governor ✕

Diesel Engine Governor (mask)

This block implements a diesel engine and governor system. The first input is the reference speed and the second input is the measured speed. The output is the diesel engine mechanical power. The motor inertia should be combined with the generator inertia.

The model consist of a regulator represented by the following transfer function:

Hc = K.(1+T3.s)/(1+T1.s+T1.T2.s^2)

The trotte actuator is implemented as :

Ha = (1+T4.s) / [(s (1+T5.s)(1+T6.s)]

The motor engine is represented by a Time delay Td function.

Parameters

Regulator gain K:

```
1
```

Regulator time constants [T1 T2 T3] (s) :

```
[1 0.25 0.3]
```

Actuator time constants [T4 T5 T6] (s) :

```
[0.25 0.009 0.0384]
```

Torque limits [Tmin Tmax] (pu) :

```
[0 1.4]
```

Engine time delay Td (s) :

```
0.024
```

Initial value of mechanical power Pm0 (pu) :

```
0.27
```

Figure 91. Generator PID algorithm.
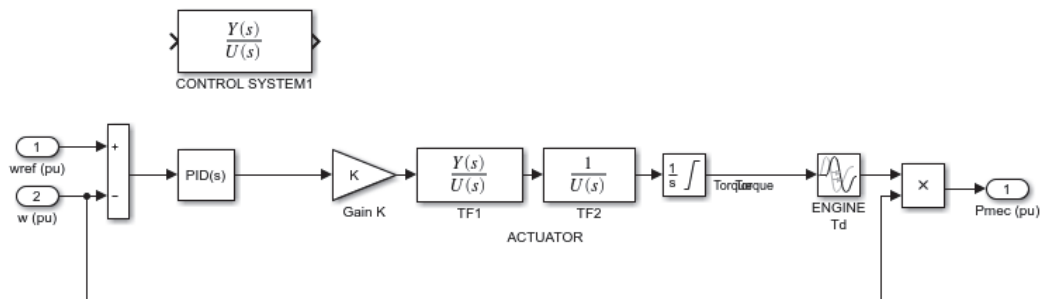
The default MATLAB generator AVR and excitation behaviors (Figures 92 and 93) were found to be reasonably accurate, so no further elaborations were made to the control other than tuning the model.

Figure 92. Excitation parameters 1 of 2.
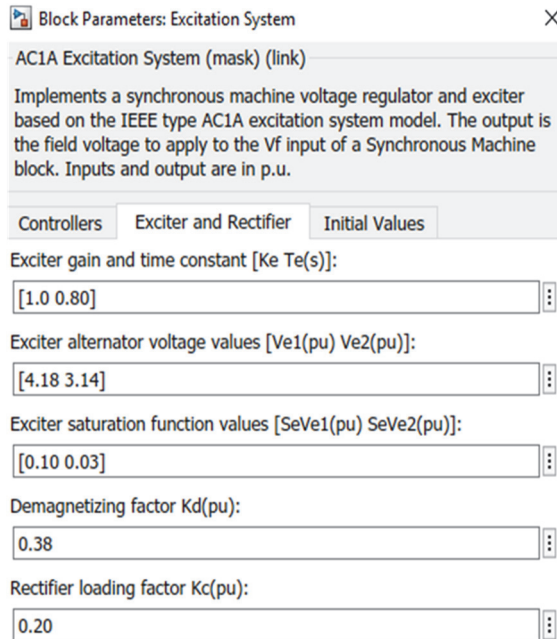
Figure 93. Excitation parameters 2 of 2.

Block Parameters: Excitation System

AC1A Excitation System (mask) (link)

Implements a synchronous machine voltage regulator and exciter based on the IEEE type AC1A excitation system model. The output is the field voltage to apply to the Vf input of a Synchronous Machine block. Inputs and output are in p.u.

Controllers Exciter and Rectifier Initial Values

Exciter gain and time constant [Ke Te(s)]:

[1.0 0.80]

Exciter alternator voltage values [Ve1(pu) Ve2(pu)]:

[4.18 3.14]

Exciter saturation function values [SeVe1(pu) SeVe2(pu)]:

[0.10 0.03]

Demagnetizing factor Kd(pu):

0.38

Rectifier loading factor Kc(pu):

0.20

Block Parameters: Excitation System

AC1A Excitation System (mask) (link)

Implements a synchronous machine voltage regulator and exciter based on the IEEE type AC1A excitation system model. The output is the field voltage to apply to the Vf input of a Synchronous Machine block. Inputs and output are in p.u.

Controllers Exciter and Rectifier Initial Values

Low-pass filter time constant Tr(s):

20e-3

Voltage regulator gain and time constant [Ka Ta(s)]:

[400 0.02]

Voltage regulator internal limits [VAmin(pu) VAmax(pu)]:

[-14.5 14.5]

Voltage regulator output limits [VRmin(pu) VRmax(pu)]:

[-5.43 6.03]

Damping filter gain and time constant [Kf Tf(s)]:

[0.03 1.0]

Transient gain reduction lead and lag time constants [Tb(s) Tc(s)]:

[0 0]

7.6.3 PV array

The inverter for the PV is essentially a DC power to AC current converter (having read voltage from the terminals) (Figure 94). Future improvement to this model would include interharmonic, islanding, out of step, current instability, or other problems based on a specific inverter to be used. At the time of this report, specific inverters to be used for the PV array had not been identified.

Figure 94. 100-kW PV array model.
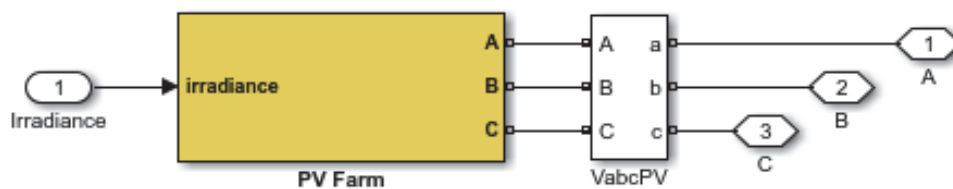
The PV array (Figure 95) is physically represented in the model solar irradiance as an input along with voltage measurements and current sources.

Figure 95. PV array model voltage elements.
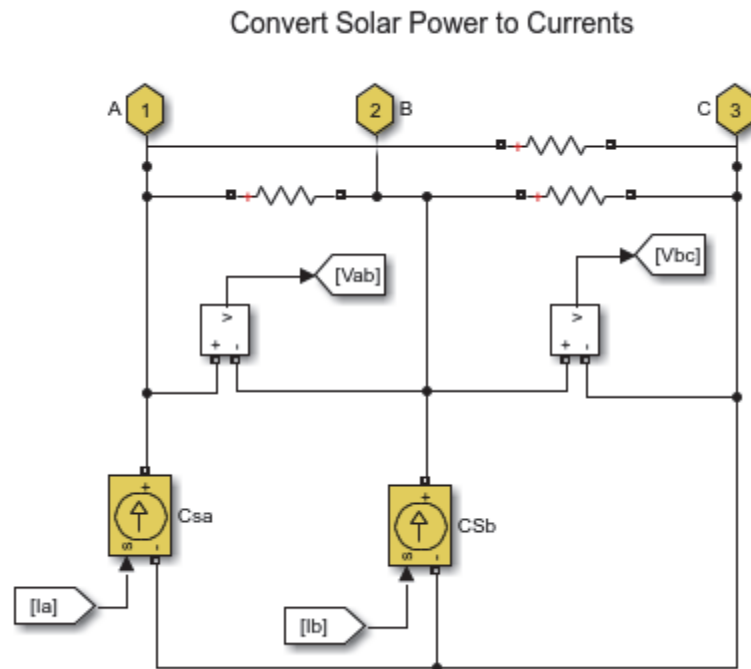
The model (Figure 96) uses voltages Vab and Vbc and power values to calculate output current.

Figure 96. PV array power calculations.
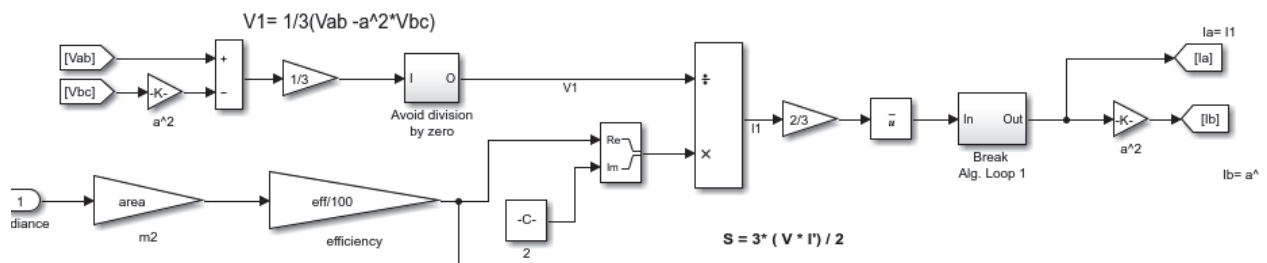
7.6.4 V2G inverter

The V2G inverter model (Figure 97) closely represents the PV inverter, except that it models multiple inverters, some of which are in the "Charge mode" (right), and some are in the "Discharge mode" (left).

Figure 97. V2G inverter model.
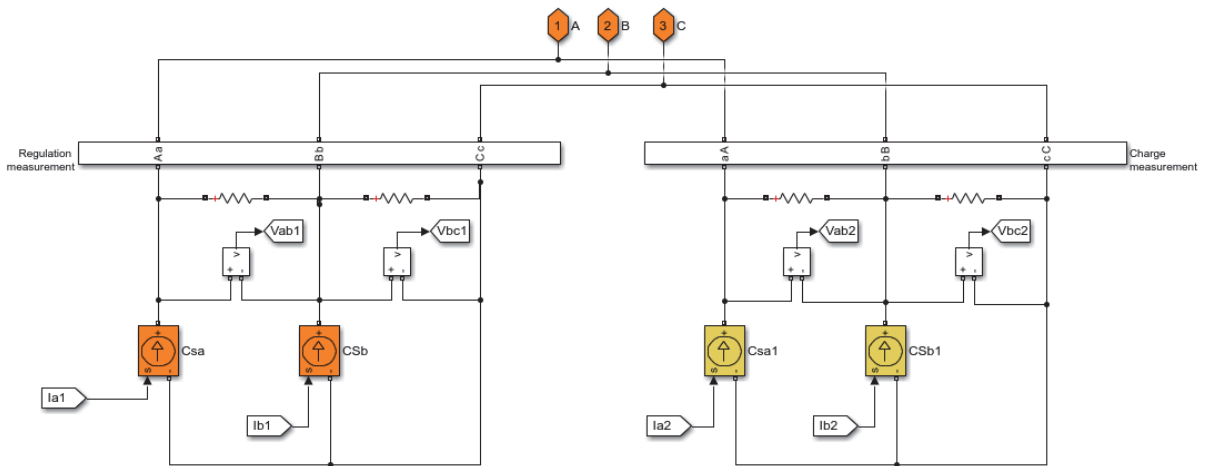
The charge/discharge fractions are determined by the blocks shown in Figures 98 and 99. The profiles specify the state of the plug (plugged in or not) and the SOC initial value to reset the internal integrator when it is newly plugged in. The block on the left contains the integrator and has the charge percentage as the output. The block on the right chooses to discharge if at above 95% charge, charge if below 85%, and hold otherwise.

Figure 98. V2G inverter charge/discharge elements 1 of 2.
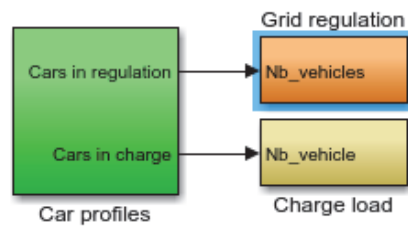
Figure 99. V2G inverter charge/discharge elements 2 of 2.
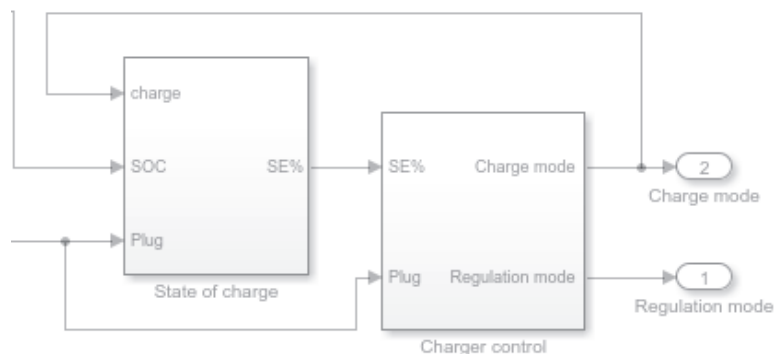
For the simulations in this report, the TechFlow team turned off (commented out) these tertiary controls (Figure 100) and directly assigned the "Charge mode" percentage and "Regulation mode" percentages as shown below in Figure 100.

Figure 100. V2G inverter charge/regulation percentage control.
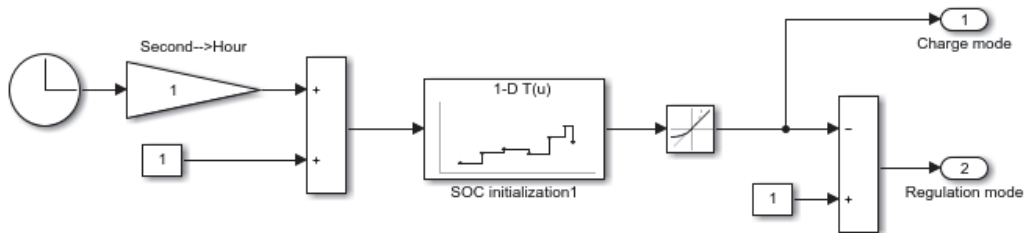
The block titled "SOC initialization1" is a look-up table that was combined with a limited-ramp rate, so the two outputs add up to 1.

7.6.5 Battery Energy Storage System (BESS)

The 40-kWh battery model (Figure 101) was the standard PQ model included in SimScape. The model is also a lithium-ion technology and could use the same model as the V2G lithium-ion model to provide additional capabilities, depending on how the site wants to use each ESS. The V2G model has the capability to include five vehicle profiles used for various energy storage technologies that need more extensive control. The block parameters for this model are shown in Figure 101.

Figure 101. Lithium-ion energy storage parameters.

Figures 102 and 103 show the control logic for the lithium-ion ESS as well as associated parameters.

Figure 102. Lithium-ion energy storage logic.
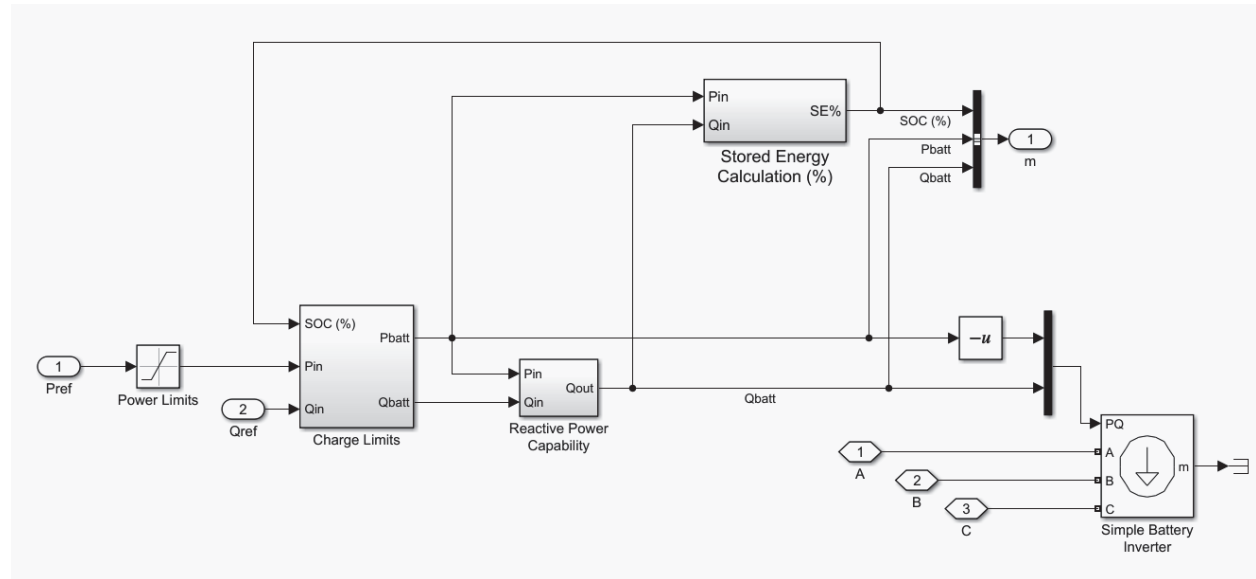
Figure 103. Lithium-ion energy storage inverter parameters.
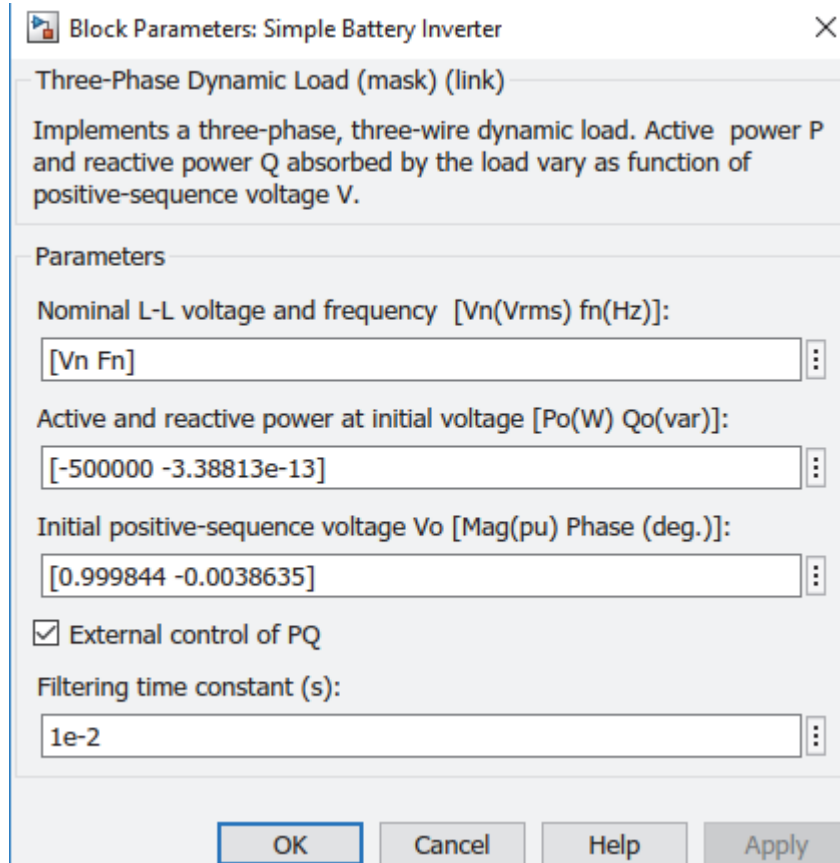
7.6.6 Model fidelity

The MATLAB modeling tools are not an Electro Magnetic Transient Program (EMTP) equipped with differential equation solvers. Instead, the MATLAB equations developed are second-order estimates of high-level machine and electrical behavior. Even simplified, the compiling and running of one test takes several minutes. Certain attributes of model outcomes, such as frequency and voltage, power, and reactive power, are estimated to be within 10% of reality and could be tuned with actual live-system data to improve accuracy to within a three to five percentage points.

Because the MATLAB simulations are not EMTP, they also cannot accurately simulate transient or sub-transient behaviors under faulted conditions. They also will neither replicate harmonics nor sub-synchronous torsional interactions between the inverters and generators sets. To gain this level of accuracy, the modeling would require a real-time EMTP Hardware in the Loop (HIL) system similar to RTDS Simulator by RTDS Technologies, HYPERSIM by OPAL-RT Technologies, or HIL Supervisory Control and Data Acquisition (SCADA) by Typhoon.

7.6.7 Discussion of work

Figures 104 to 106 plot the response of six AMMPS 60-kW generators, one 100-kW PV, and one 30-kW V2G paralleled and holding 50 kW of load. The grid then increases load (at 1 second) by 180 kW and 60-kVAr of load and (at 11 seconds) loses this same load. The V2G is re-dispatched from charge to discharge following the loading and returned to charging when the load is lost.

Figure 104. System real power response.

Time (seconds)
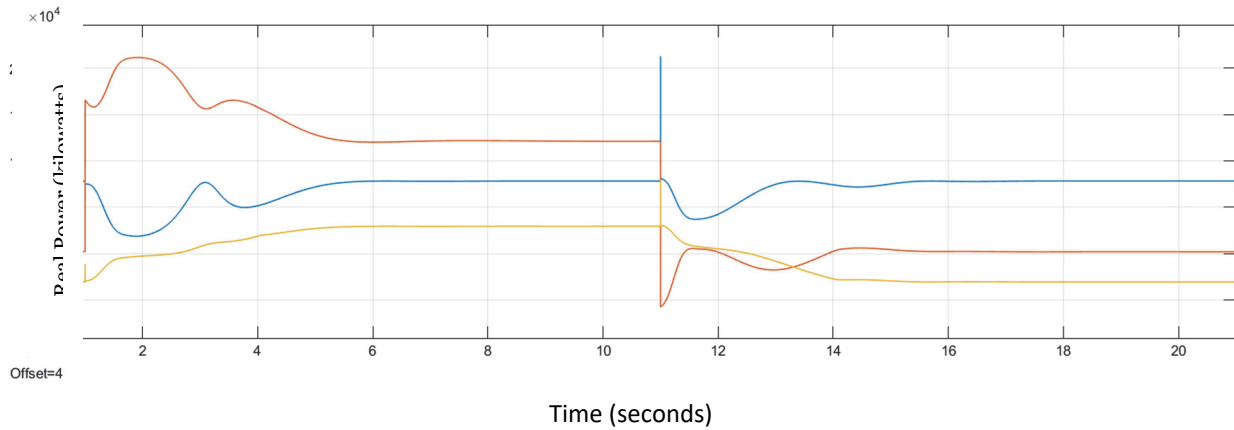
Real Power: Red AMMPS generators, Blue PV, Yellow V2G

Figure 105. System reactive power response.

Time (seconds)
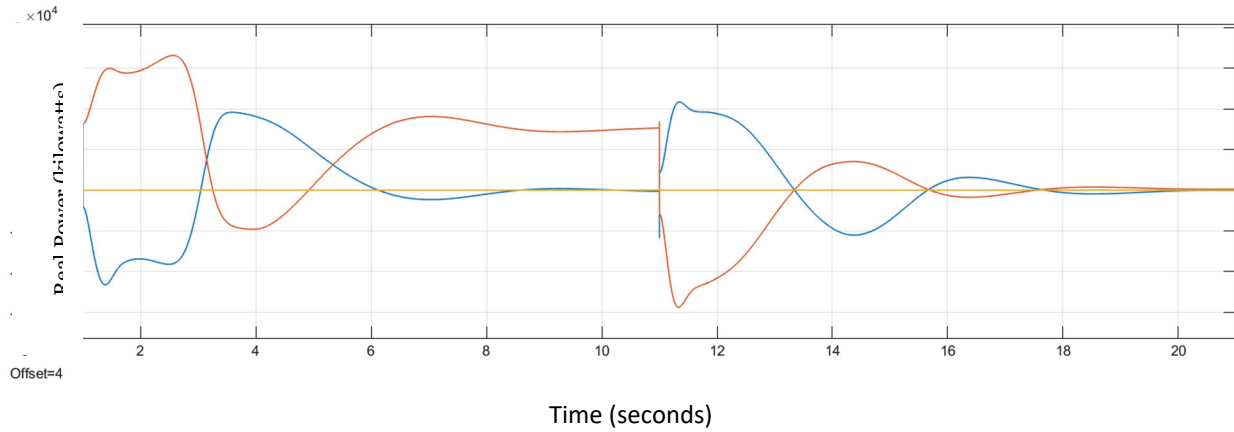
Reactive Power: Red AMMPS generators, Blue PV, Yellow V2G

Figure 106. System frequency response.

Time (seconds)

Frequency (Hz)
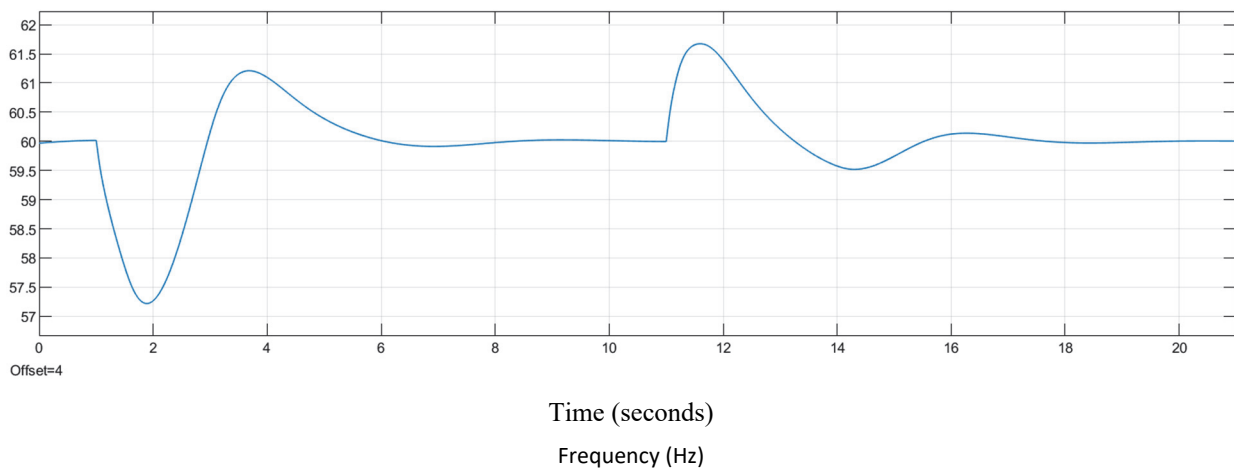
These figures represent idealized behavior, therefore the actual microgrid should be configured, tuned, and modified to inherent similar characteristics. Key behaviors that need to be replicated in the live system include:

1. Minimal oscillations among the generators, PV, and the V2G system during any form of charging or discharging. Out-of-the-box equipment will likely fight each other and require significant modification to behave in the desired manner shown.
2. PV and V2G systems do not trip offline during large load acceptances or rejections. Default PV systems will turn off from these events and settings in the PV will likely need customization to ensure this desired behavior.
3. Genset does not trip off immediately on reverse power; this is desirable for small reciprocating engines, as they work fine as compressors. This is not acceptable for turbine type engines but desired for small reciprocating engine generators.
4. Note that deviations in the Volt-Ampere Reactive (VAR) output of the PV are because of inaccuracies in the inverter's ability to track the real voltage and frequency in real time. Although these behaviors will not be identical in the field, the general behavior of PV-VAR output hunting with a genset AVR will likely happen. The only known way to eliminate this problem is to augment a PV controller with an auxiliary relay controller with energy packet controls.
5. As a result of a load increase, the V2G system will ramp up to participate in a grid-support function under a high-electrical load and ramp back to a charging position once the load was removed.
6. During a load increase, the AMMPS inertia and governor response continue to dominate the frequency response characteristic of the power system.

7.6.8 Identified issues and possible solutions

The alternative approach of using a battery solution provided by Go Electric or EnerDel was not a viable solution because the weight of the batteries and necessary integration hardware exceeds the payload rating of the MUTT. To promote interoperability and open standards usage, the best solution is a commercial vehicle. Consequently, a bidirectional vehicle and fast charger was pursued as the solution set.

The Coritech V2G fast charger is designed to be installed on a 3-wire, electrical distribution system at 480 VAC; however, the tactical microgrid is a

4-wire, wye connected distribution system that is rated at 208 VAC. To in-
tegrate the V2G charger, a step-down transformer is required to convert
the fast charger's output voltage of 480 VAC to 208 VAC. To limit the in-
troduction of harmonics from the fast charger's inverter to the tactical mi-
crogrid distribution system, a wye delta transformer is recommended.

Because the Coritech fast charger does not use a neutral connection, the
delta side of the transformer could be connected to the charger. The manu-
facturer recommends installing a grounding transformer between the
charger and the step-down transformer instead of using a floating-delta
connection because the configuration is an ungrounded system, which can
result in excessive floating voltages. The manufacturer advises a delta con-
nection on the 4-wire 208-wye distribution system and grounded 3-wire
wye connection on the 480-VAC connection to the charger can also be used
instead—avoiding the cost associated with adding the grounding trans-
former. The charger does not use a neutral therefore the wye neutral is not
connected to the charger and only connects to the equipment ground.

By design, the Coritech fast charger is compliant with industry standard
UL1741 and IEEE 1547 to cease generation if system voltage or frequency
exceeds predefined limits, especially in distribution systems with multiple
generation sources, voltage, and frequency stability to stay within these
limits can be challenging. The speed at which the charger must cease gen-
eration, also referred to as the "Clearing Time," depends on the extent of
voltage or frequency deviation as shown in the Tables 47 and 48.

Table 47. System response to abnormal voltages.

Voltage Range (% of base voltage)	Clearing Times (sec)
V<50	0.16
50≤V<88	2.00
110<V<120	1.00
V≥120	0.16

Table 48. System response to abnormal frequencies.

Distributed Resource Size	Frequency Range (Hz)	Clearing Times (sec)
≤ 30 kW	>60.5	0.16
	<59.3	0.16
> 30 kW	>60.5	0.16
	<59.8–75.0 (adjustable)	adjustable 0.16 to 300
	<57.0	0.16

Nuisance trips can be avoided so the charger remains online during normal operation by adjusting the trip settings and times in the fast charger. As loading conditions and system operating conditions, the fast charger trip settings can also be adjusted to better accommodate and normal voltage and frequency variations of the tactical microgrid.

7.7 Discussions of future work

The objective of this research area was to identify requirements for a sensored, living laboratory to assess the performance of V2G charging in a tactical microgrid and to recommend an optimal V2G solution set for use at the CBITEC site.

While MATLAB is useful for simulating high-level system behavior, future efforts could include validating the model with extensive field testing and employing some of the HIL capabilities to improve upon the MATLAB model accuracy. HIL software packages are available; however, MATLAB is more commonly used in the DoD and tends to be considerably more affordable. Including a HIL test capability into the living laboratory will increase the accuracy of modeling and controls algorithm development.

Specific modeling actions for the future include:

1. Improve MATLAB model fidelity by including field data and revising models
2. Model the system in a true EMTP environment to improve simulated rotor angle and voltage fluctuations
3. Build more robust inverter models to replicate the complex arrangements of inverter controls—including, but not limited to, anti-islanding and overload behaviors for specific inverters
4. Build the MATLAB model to accurately simulate faulted circuit events and life-safety short-circuit and arc-flash events.

In addition to building in HIL modeling and testing capability, future work can include configuring and documenting the recommended hardware settings to record system performance for future testing.

7.8   Conclusions and recommendations

Paragon SMEs determined the IPDs prepared for the site include control equipment sufficient to meet the metering and control needs for interconnecting tactical microgrid components. Additional components to complete the living laboratory and their benefits were also identified. The optimal V2G solution was recommended with parameter adjustments to avoid nuisance tripping during times of voltage and frequency instability that can be caused by sudden changes in system loading or generation.

Recommendations include:

- Completing a detailed design of the tactical microgrid
- Documenting IPD and hardware settings for interconnecting the tactical microgrid assets
- Including HIL modeling and testing to improve simulation accuracy and support control algorithm development.

8 Integrate Open Standards to Promote Interoperability

To promote interoperability, the Paragon team researched and identified current interoperability standards to support the CBITEC tactical microgrid development. They also developed an approach to bridge the gap between available microgrid technologies and standards to further promote interoperability.

The objective of Research Area 6 is to identify and integrate open standards relevant to the CBITEC tactical microgrid's operational requirements. In cases where open standards did not sufficiently meet tactical microgrid operational requirements, the team worked with technology providers to build on existing open standards, minimize customization, and provide solutions that promote future demonstrated technology integration and expansion.

The Paragon team researched and identified currently available communication and control technologies as well as applicable interoperability standards for the CBITEC tactical microgrid, which are to develop an approach to bridge the gap in these standards to promote interoperability, security, and performance reliability.

8.1 Identify and catalog currently available communication and controls technology

The objective of this research is to identify and catalog COTS communication and controls technology.

To complete this research, SMEs reviewed material provided by C5ISR, CERL, and CBITEC staff, along with previously engaged vendors, to identify communication and controls technologies with potential to provide the highest level of interoperability, security, and performance reliability. In addition, preference on design strategies and standards were also discussed for consideration.

Work related to this research effort commenced with the preparation of, and communication to CBITEC and CERL staff, a detailed list of equipment and systems that are typically present in a tactical microgrid as well

as requesting available tactical microgrid documents for Paragon SMEs to review.

Extensive engagement with staff at CBITEC, CERL, and C5ISR revealed that a formal set of microgrid design drawings is not available; however, information on a subset of the equipment to be used in the tactical microgrid is available and was subsequently provided, including:

- Advanced DCS Operator's Manual; describing the parallel operation of the AMMPS generator to form a tactical microgrid
- DoD Interface Standard MIL-STD-TMS, TMS (Figure 14), version March 2013; an interface standard that is under development and has not yet been approved for release
- Army Technical Manual TM 9-6150-226-13, Operator and Field Maintenance Manual for DISE and PDISE.

Paragon SMEs—upon CERL's recommendation—took additional steps to engage directly with vendors that have supported CERL's development of microgrid technologies to form a tactical microgrid. They acquired additional documentation and insight on the operation, capabilities, and limitations of the existing technologies. In addition, Paragon SMEs comprehensively engaged SEL given its role in the design of the controls for IPDs, test generator operation in a microgrid environment, and familiarity with the TMS and ongoing revisions. Power quality measurements, which currently reside in IPD relays, can be collected by a future server. For future testing, the Paragon team recommends using separate metering equipment specifically designed for power quality analysis. This test equipment should be portable and easy to install/remove for testing as needed.

The communication and control technologies SMEs identified in use at the CBITEC were cataloged and reviewed to confirm operation capability and integration requirements for future equipment. Given the microgrid controller is under development, the control technologies currently in use are wholly contained in the IPD provided by Humber GEs. Within the IPD, several control devices serve as protective devices, to verify and control synchronization of sources and communicate messages for IPD monitoring and control. A detailed manual of the IPD, complete with an exhaustive parts list of all control items, is included in **Appendix Q**.

For microgrid communications, CBITEC has implemented a wireless mesh network for microgrid communications. Wireless mesh networks inherently provide redundancy while minimizing the need for extending communication conductor extensions. CBITEC's DMMS is used to wirelessly communicate with microgrid devices via a local dashboard (Figure 107). The DMMS is used for data collection only and does not control any of the microgrid devices. The AirGuard 3e-523 from 3e Technologies International serves provides the connection point between equipment and the CBITEC WLAN—forming a wireless mesh network at CBITEC. A technical manual for the AirGuard 3e-523 technical manual is provided in **Appendix R**. The DMMS allows data collection without the need for communication conductors installation.

Figure 107. DMMA wireless access point.

In addition to the wireless mesh network, the IPD contains Ethernet ports to support hardwired communications. By design, the Ethernet ports were intended to be used for communicating Modbus Transmission Control Protocol/Internet Protocol (TCP/IP) and DDS messages between the IPD and an overarching controller.

By policy, equipment connected to the tactical microgrid must be manually controlled.

8.2   Identify current interoperability standards

The objective of this research is to identify current interoperability standards applicable to the CBITEC tactical microgrid.

Paragon SMEs identified technology providers that have developed open standards that minimize customization and provide solutions promoting future demonstrated technology integration and expansion. In order to identify and recommend an open standard, or set of standards, that promote interoperability applicable to the CBITEC tactical microgrid, SMEs reviewed the communications capabilities of the IPD, V2G fast chargers, and the wireless mesh network:

• Data Distribution Service
• Modbus
• CHAdeMO
• SAE J1772 CCS.

In addition, standards related to the installation of V2G charging systems were also reviewed for applicability:

• UL 1741, Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with DERs
• Institute of Electrical and Electronics Engineers (IEEE) 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems
• UL 2202, Standard for EV Charging System Equipment
• National Fire Protection Association (NFPA) 70.

8.2.1 Interoperability standards applicable to the CBITEC tactical microgrid

Many open standards exist that could be reviewed for applicability and interoperability promotion. When considering the intent and desire to use the existing wire mesh communications system and IPDs developed by Humber Garick at the CBITEC site, the list of standards to review begins with those standards associated with the existing equipment as well as any new equipment to be added.

The IPD's TMS DDS Implementation Guide identifies Modbus TCP/IP and DDS by Object Management Group (OMG) as two communications protocol standards employed by the IPD. TMS DDS Implementation Guide is provided in **Appendix S.** As a communication protocol, Modbus is the industry standard for control communications, extremely reliable, and is built for controls communications. The Modbus protocol is also the intended

communications protocol to be used by the microgrid controller, which is currently being developed. Moreover, the V2G fast charger also communicates Modbus for monitoring and control by an overarching controller.

The Tesla fast chargers are not bidirectional and utilize closed and proprietary protocols. Consequently, Tesla fast chargers only work with Tesla EVs. The SAE CCS standard, developed SAE, is the most commonly used fast-charging standard in the United States. This open standard is used by multiple charging station suppliers to charge CCS-compliant EVs (Figure 108). However, the CCS standard does not incorporate communication and command structures necessary to implement on-demand discharging of EVs. Consequently, messaging between the vehicles and chargers must be customized to include unique commands enabling a V2G-capable vehicle to use the CCS standard. This customization inherently prevents the custom charger to be readily used for multiple vehicle types. Such customization also requires extensive non-recurring engineering, development and testing to implement the V2G capability, which further limits customized CCS solutions for V2G applications. By 2025, SAE plans to update the CCS standard to include communication and controls specifications necessary to enable V2G operations between CCS-compliant vehicles and charging stations. The CHAdeMO standard (Figure 109) not only is commonly used in Asia but is also the only open standard that fully accommodates V2G applications. Using the CHAdeMO standard in the United States, however, is limited compared to the SAE CCS standard for fast-charging applications.

Figure 108. SAE CCS connector.

Figure 109. CHAdeMO connector.

Monitoring and controlling a CHAdeMO-compliant vehicle's charge and discharge is accomplished by communicating to the V2G fast charger. The microgrid controller does not need to directly communicate to the vehicle for this purpose. The V2G fast charger communicates to the EV using the CHAdeMO communication protocol and no other communication standards are required.

Several industry standards relate to the design and installation of V2G charging equipment. From an interoperability standpoint, critical is UL1741, Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with DERs.

8.3 Recommended communication and control products for the CBITEC tactical microgrid

The objective of this research is to recommend communication and control products for the CBITEC tactical microgrid. In order to recommend technologies situated to provide the highest level of interoperability, security, and performance reliability, Paragon SMEs developed a methodology to rank and stratify products.

8.3.1 Communication and controls technology ranking methodology

The ranking methodology utilized to select and recommend communication and control technologies was developed with the following criteria:

- Compatibility with existing microgrid equipment to be used
- Compatibility with planned standards under development
- Use of open standards to promote interoperability
- Ability to meet performance requirements.

8.3.2 Application of ranking methodology

Paragon SMEs applied the ranking methodology to new equipment necessary to integrate the V2G fast-charging system. Of the fast-charging technologies available, only the CHAdeMO charging system met all items of the ranking methodology.

8.3.3 Recommended technologies

Given the IPD box protecting connected equipment, communicating with the planned microgrid controller and V2G fast charger, and collecting operational data to verify connected equipment performance, Paragon SMEs recommend using the IPD to interconnect generation sources and loads for the tactical microgrid.

Considering the existing approvals to operate integration and cyber security features associated with the 3eTi's AirGuard 3e-523 gateway, SMEs recommend the gateway be incorporated to wirelessly monitor new equipment via the system dashboard. CBITEC staff's existing operations have confirmed reliable operation that provides real-time data capture rates and resolution to enable effective monitoring.

Paragon SMEs researched industry options and found Coritech's V2G fast charger the only fast charger that fully utilizes open standards and does not require customization to implement. Integrating the fast charger will require a step-down transformer to tie the 480-VAC output to the 208-VAC power distribution system of the tactical microgrid. A Coritech fast charger product brochure is provided in **Appendix T**. The operation manual for the Coritech fast charger is provided in **Appendix U**. The communications memory map to enable monitoring and control of the charger is provided in **Appendix V**.

8.4 Approach to bridge the gap between available technologies and standards

The objective of this research is to develop an approach to bridge the gap between top identified technologies and standards to promote interoperability.

For generation sources to operate in parallel with the electrical grid, electrical utilities require compliance with specific design and installation standards. With compliance to specific standards, personnel safety and grid stability can be assured. Specifically, electrical utilities require UL1741 standard compliance, which requires generation sources to disconnect from the electrical grid during a grid outage. The goal of this requirement is to mitigate the risk of personnel, tasked to work on the power distribution system, electrocution and restore grid operations. Devices that are UL1741 compliant, including V2G fast chargers, are required to disconnect based on voltage and frequency deviations as identified in the standard (Tables 49 and 50).

Table 49. Interconnection system response to abnormal voltages.

Voltage Range (% of base voltage)	Clearing Times (sec)
V<50	0.16
50≤V<88	2.00
110<V<120	1.00
V≥120	0.16

Table 50. Interconnection system response to abnormal frequencies.

Distributed Resource Size	Frequency Range (Hz)	Clearing Times (sec)
≤ 30 kW	>60.5	0.16
	<59.3	0.16
> 30 kW	>60.5	0.16
	<59.8–75.0 (adjustable)	adjustable 0.16 to 300
	<57.0	0.16

However, a tactical microgrid's voltage and frequency might not be as stable as the electrical grid. As a result, normal microgrid operation might include voltage and frequency variances in nuisance trips of the V2G fast charger—which included disconnecting during normal operation even without a "grid outage." To address this, voltage and frequency trip limits of the UL1741-compliant device might need to be adjusted. Doing this

could void the UL1741 certification associated with the installation. However, a UL1741 certification is required when connecting to an electrical grid—not when operating the tactical microgrid off the grid.

Another prevalent industry standard used to ensure grid stability is IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems. This standard includes power quality requirements for grid stability assurance. Requiring generation sources to meet standard power quality requirements will mitigate the risk of one generation device impeding other equipment connected to the microgrid by generating low quality power. While inverter technologies tend to produce more harmonics, an inverter that is IEEE1547 compliant will limit these harmonics. To further limit harmonics produced by a generation source, a delta-wye transformer, or line reactors, can be installed in between the inverter and the distribution system to limit the transmission of harmonics to other system components.

New gaps will inevitably emerge when attempting to integrate new technologies with previous technologies, in particular with communications protocols. Several potential solutions exist to help bridge gaps with communications systems, including protocol converters, media converters, and software tools. The best solution to promote interoperability completely depends on the new technology to be integrated.

8.5   Future work

Currently two documents that are under CERL development have potential to identify gaps in standards: the TMS and the TMS DDS Implementation Guide. These documents, as well as the need to implement new and novel technologies, will likely identify the need to adopt additional standards to promote interoperability.

Now, the CHAdeMO standard is the only open standard available to test the concept of V2G technologies supporting grid stability in a tactical microgrid. The Nissan LEAF is the sole CHAdeMO-compliant vehicle currently available that also meets program power requirements. Future work could install EV battery packs on a vehicle platform considered suitable for tactical environments using the CHAdeMO open standard.

SAE J1772 CCS standard for fast charging is more widely used in the United States. While this standard does not include V2G capability at this time, SAE is targeting by 2025 to incorporate this capability. Future work could include working group participation tasked to evolve the standard so that aspects related to military applications can also be incorporated.

Custom V2G solutions, an alternative to the two available open standards developed for vehicle charging in the United States, can be developed specifically for military applications by developing a purpose-built charger/inverter for battery packs to be mounted on a suitable vehicle platform. This approach can incorporate open standards to monitor and control the power converter and battery pack.

Sometimes, applications require additional vehicle information than what is provided through a charging standard. Battery temperature, operating status, or control of a specific vehicle's components might be required as part of the control algorithm used to determine appropriate charge or discharge rates. Most vehicle platforms use the open standard, CAN Bus, to monitor and control the various vehicle systems. By incorporating CAN Bus messaging into the microgrid controller, the ability to gather vehicle-related operational status can be greatly extended. The CAN Bus is often accessed via the vehicle's onboard diagnostic (OBD) Port (Figure 110).

Figure 110. Vehicle OBD port.
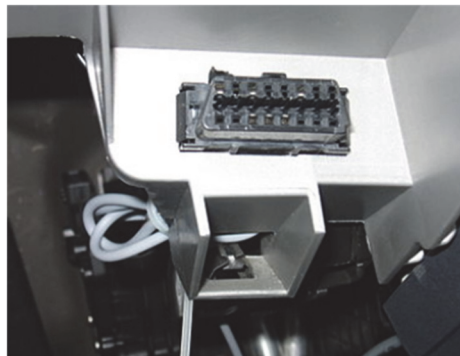
8.6 Conclusions and recommendations

While the tactical microgrid at CBITEC is not fully designed, the intent to use the IPD developed by HG Engineers, the wireless mesh network and the Modbus protocol are viable approaches that outline system communication requirements for future devices to interoperate. The 3e-523-3

wireless access points, which were manufactured by 3e TI Technology International and establish the wireless mesh network at CBITEC, are cyber secure and already approved for use on a SIPRNet. Paragon SMEs recommend using the existing hardware for wireless communications as it has proven to be reliable, secure, and interoperates easily with system assets.

As testing confirms V2G systems are a viable solution that meet mission requirements and bolster energy resilience in tactical microgrids, Paragon SMEs recommend developing a V2G system that is purpose-built for military applications operating in the tactical microgrid environment. The V2G system, primarily, must have a suitable vehicle platform that meets vehicle-mission requirements. It must also have available payload capacity that can carry the weight of the lithium-ion ESS along with the necessary interconnection hardware, controls, and power converter. One vehicle platform that might be ideal is the Nikola Reckless. This off-road vehicle is built for tactical environments and is fully electric. Product information indicates the Reckless has a battery pack with an energy storage capacity of 125 kWh—enabling the possibility of charge and discharge rates equal to the 60-kW AMMPS generator to be used at CBITEC. With an energy storage capacity nearly twice that of the proof-of-concept vehicle, the Reckless will be able to support equivalent charge/discharge rates for twice as long.

Given the program intent to serve as a living laboratory with vehicle testing capability, Paragon SMEs recommend incorporating the capability to directly communicate to vehicle CAN Bus systems for additional data gathering and the development of microgrid control algorithms. Specifically, the use of CAN Bus data loggers will provide the capability to watch the reactions of vehicle systems very closely to events in support of control algorithm development and vehicle protection. CAN Bus data loggers are directly connected to the vehicles OBD port and store time-synchronized data that is later downloaded and analyzed via software tools.

9   Summary of Findings, Recommendations, and Next Steps

The Paragon team has developed the roadmap for an innovative sensored, living laboratory that can evaluate emerging electric transport vehicles, vehicle autonomy, V2G charging, and microgrid technologies. The fundamental basis of the living laboratory is to serve as a testbed to facilitate joint research and evaluation of autonomous EVs and bidirectional-vehicle charging in a real-world, non-hostile environment. The living laboratory will leverage government and industry technical expertise to accelerate technological advancement and innovation. The collaborative environment between the Paragon and CERL teams culminated in information sharing and open innovation across technology borders that might otherwise be siloed. The living laboratory is therefore also a platform for collaborative innovation by leaders in these fields.

9.1   Research Area 1: Identify military-unique requirements for autonomous transport technologies

The Paragon team engaged with stakeholders and conducted research to identify military-unique requirements for autonomous transport technologies. The research effort resulted in a prioritized list of transport dependent Military Support Activities that could be automated to the benefit of the government.

Table 51 provides the prioritized list of activities.

Table 51. Prioritized Military Support Activities.

MSA #	MSA Type	Mission Supported	Vehicles
1	Personnel Transport: transport (1–4 people)	Installation Management Command (IMCOM)/AMC missions for logistics in support of installation operation — personnel transport supports all CONUS housing, training and deployment functions. Mass transit is more common at basic training installations. FLW provides 2.5 million round trips annually to move Soldiers to training areas, ranges, and dining facilities.	Automobile
	Personnel transport (5–20 people)		Shuttle
	Troop transport for training (platoon to company size—up to 250 Soldiers)		Buses (40–80) and tractor with personnel trailer (125)
2	**Land Management:** grounds maintenance—beautification and security cutting	IMCOM/AMC installation operation—grounds maintenance can include grass cutting, snow removal, dirt removal, wood clearing (with workers), tree removal (with workers), etc.	Tractors and mowers

MSA #	MSA Type	Mission Supported	Vehicles
	Land Management: range maintenance	Two types of ground maintenance are common: grass cutting in cantonment areas and less frequent grass cutting in range and training areas. This effort would be focused on large-scale mowers and earth movers that can be used to maintain CONUS range areas (and possibly cantonment areas).	Large/farm tractors with cutting decks, plowing
3	Logistics: materiel transport—food, water, munitions, fuel, municipal solid waste	IMCOM/AMC Installation Operations directly supporting training (TRADOC), Garrison (FORSCOM) missions, and deployment (all installations that deploy personnel). Convoys used to support all forward-operating areas.	Delivery trucks and vans, tractors with trailers, specialty trucks (tankers, refrigeration unit, waste hauler, bucket truck), secure trucks (munitions)
	Logistics: material management and warehousing—delivery, storage, and distribution		Forklifts, indoor and outdoor tugs, material handling equipment
	Logistics: airfield activities—GSVs		Various GSVs—fuelers, pallet loaders, aircraft tugs, small loaders, munitions movers and loaders (security), deicers, plows
3	Logistics: vehicle and equipment hauling	Vehicle and equipment recovery and delivery—supports IMCOM/AMC operations.	Tow trucks, vehicle lifts and haulers, tractors with trailers
4	Security monitoring	Reconnaissance in forward areas, as well as installation security monitoring.	Drones, reconnaissance vehicles
5	Land Preparation: earth moving, plowing, digging	IMCOM/AMC grounds maintenance, as well as combat engineering operations and training.	Engineering equipment—scraper, crane, dozer, plow, hauler, dump truck, grader, loader, backhoe, crawler, HYEX
6	Road Maintenance: maintenance, repair, snow removal	IMCOM/AMC installation maintenance and clearing, development, and maintenance of new and existing roads in forward areas.	Grader, sweeper, dump truck, asphalt paver, compactor, roller, snowplow

9.2 Research Area 2: Identify existing technologies that can be adapted for military applications

The focus of our research in this area was on available and emerging electric transport systems that could support the prioritized list of transport activities identified in Research Area 1. The onboard energy storage provided by electric transport vehicles introduces the potential to access an additional and distributed electric power supply to support Army energy resilience. Paragon SMEs began their research cataloging and evaluating existing and emerging electric transportation systems. This was to identify candidates for automation and to serve as a platform for future research, testing, and demonstration. The research team evaluated candidate electric transport technologies for suitability against the prioritized military transport activities and compatibility with research requirements.

Candidate technologies were prioritized by the number of criteria thresholds met. Screening criteria thresholds were TRLs, target cost, location of assembly, battery capacity, complementary research, Military Support Activity requirements, and GSA availability. Screening criteria thresholds set baseline requirements to prioritize candidate technologies and enabled the development of the list provided in Table 52.

Table 52. Prioritized candidate technologies.

Priority	Total No. of Y	TRL (7–9)	Cost ≤ $450,000	Assembled in United States	Battery Capacity ≥ 50 kWh	MSA	Related Research	Available through GSA
		MPS by: Dannar						
1	7	Y	Y	Y	Y	Y	Y	Y
		9	$200–400K	IN	125–630 kWh	2, 4, 5, 6	DHS	GSA
		Cargo Van, Chassis Cab, Cutaway Cab, Shuttle Van, Step Van by: Zenith Motors						
2	6	Y	Y	Y	Y	Y	N	Y
		9	$100K	CA	52–100 kWh	1, 3		GSA
		Medium-duty Trucks, Shuttles, and Buses by: Zero Truck						
3	6	Y	Y	Y	Y	Y	N	N
		9	$60–100K	CA	53–80 kWh	1, 3		
		Zeus Electric Shuttle bus, Utility vehicle, Flatbed truck by: Phoenix Motorcars						
4	6	Y	Y	Y	Y	Y	Y	N
		9	$240,000+	CA	105 kWh	1, 3	EPA, CA	
		T-Series Yard Hostler by: Orange Motors						
5	5	Y	Y	Y	Y	Y	N	N
		9	$200–300K	MO	80–160 kWh	1, 3		
		Reckless by: Nikola						
6	5	Y	N	Y	Y	Y	Y	N
		9	$480K/year Lease	CA	52–100 kWh	4	USMC	
		eBus by: eBus						
7	5	Y	Y	Y	Y	Y	N	N
		9	$400K	CA	130 kWh	1		
		Xcelsior Charge (multiple versions) by: New Flyer						
8	5	Y	N	Y	Y	Y	Y	N
		9	$700–1,200K	AL	160–466 kWh	1, 3	Private sector	
		R1T–EV Pick-u by: Rivian						
9	5	Y	Y	Y	Y	Y	N	N
		8	$70–100K	IL	105–180 kWh	3, 4		
		Saf-T-Liner C2 Jouley Electric School Bus by: Thomas Built						
10	5	Y	Y	Y	Y	Y	N	N
		8	$450K	NC	220 kWh	1		

Priority	Total No. of Y	TRL (7–9)	Cost ≤ $450,000	Assembled in United States	Battery Capacity ≥ 50 kWh	MSA	Related Research	Available through GSA
11	5	Edrive Tractor by: ATC						
		Y	Y	Y	Y	Y	N	N
		9	$250K	MN	250 kW	2, 5, 6		
12	4	eCargo, eTruck drayage—Class 8 Tractor by: US Hybrid						
		N	Y	Y	Y	Y	N	N
		6	$250K	CA	240 kWh	1, 3		
13	4	LFSe by: Nova Bus						
		Y	N	Y	Y	Y	N	N
		8	$700K+	NY	152 kWh	1		

To validate technology information and determine prospect for future research, Paragon SMEs engaged priority technology manufacturers. The manufacturers identified for engagement were: Dannar, Zenith Motors, Zero Truck, Phoenix Motorcars, Orange Motors, Nikola, Ebus, New Flyer, Rivian, Thomas Built, ATC, US Hybrid (USH), and Nova Bus. Based on research requirements and collaborative SME agreement, the following electric transport technologies are recommended for future autonomy testing and evaluation:

- Dannar MPS
- New Flyer Xcelsior Charge Bus
- Nikola Reckless
- Orange Motors Yard Hustler
- Phoenix Motorcars shuttle buses and trucks
- US Hybrid power conversion systems.

The Dannar is an attractive technology because of commercial maturity and versatility for a broad range of Military Support Activities. Additionally, the technology is drive-by-wire equipped and shows high probability for full autonomous capability in the next few years. The New Flyer Xcelsior is a full-size bus that could be utilized for soldier transport and is also a good candidate for automation. The Nikola Reckless provides the opportunity to explore high-speed EVs that will function in a tactical environment. The Orange EV system, which has a large hauling capacity, is appealing for logistic support activities.

## 9.3	Research Area 3: Identify research and operational tests for autonomous transport vehicles

Paragon's research team researched autonomous-system data, state-of-the-art capture and storage technologies, and recommended solutions to facilitate autonomous technology operation and performance testing. The nSight suite, developed by Robotic Research, was recommended as an end-to-end data collection and analysis solution. The nSight captures multiple streams of data with a single data-logging device, which timestamps and performs post processing operations and analytics all in one location. The nSight suite is composed of the nSight Recorder (Onboard data recorder), nSight Upload (Data disseminator to servers), nSight AAR (Server and Analysis Tool).

Paragon's research team developed test plans to verify autonomous-system safety, operation, and performance. The operational test plans are designed to assess baseline system performance, traffic safety and interaction, sensor degradation, terrain identification, and V2G station docking. These test plans are applicable to the FLW test areas, specifically CBITEC and the TA-231 Driving Course. The test plans are also scalable and can be tailored to suit technology and test cases as needed. To operationalize the test plans, the research team recommends outfitting test areas with sensor suites as detailed in Research Area 5.

## 9.4	Research Area 4: Investigate requirements for testing and demonstrating V2G vehicle charging within a tactical microgrid environment

V2G charging equipment is essential for electric power bidirectional flow between electric transport and energy systems. This connection allows electric transportation to provide ancillary energy and assurance to local energy generation resulting in improved reliability, flexibility, and resilience. Currently in the United States, the CHAdeMO standard is the only open standard that is designed to fully support V2G system bidirectional power flow. Paragon SMEs identified two electric transport technologies available for purchase in the United States with the CHAdeMO fast-charging option: the Mitsubishi Outlander and the Nissan LEAF. The Outlander is a PHEV with energy storage capacity of 12 kWh; this battery pack is comparatively small compared to the LEAF, which is solely electric and available with two energy storage capacity options—40 kWh and 62 kWh.

The Coritech V2G charger was selected for this research program, based on program objectives and site requirements. The Coritech charger is a 30-kW fast charger that is CHAdeMO-compliant. The VGI-30-DC-CHA fast charger design is suitable for integrating into a tactical microgrid because it:

- Has an AC voltage configuration that easily integrates into the planned 208-VAC microgrid distribution system with a COTS step-down transformer
- Is specifically designed for fast charging and discharging of a CHAdeMO-compliant vehicle
- Uses open protocols to interface with an overarching controller to monitor and control the charging and discharging rates of the EV
- Uses open protocols, commonly used to interface with EVs, including the Nissan LEAF
- Is designed to U.S. standards applicable to V2G charging systems and distributions systems rated for use in the United States
- Is designed to operate outdoors
- Avoids the significant impacts to cost, schedule and performance risks associated with developing a first-generation alternative.

Modeling results demonstrated that the Coritech V2G charger will interoperate with the military legacy equipment that make up the CBITEC tactical microgrid. Anticipated voltage and frequency variations of the AMMPS generators—produced by the sudden increases or decreases in load or generation—are not expected to cause nuisance trips for the V2G charger. Recommended frequency and voltage trip settings for the AMMPS generators are provided in this report. These settings will promote interoperability of the tactical microgrid generation sources, even when system dynamics occur.

Simulated tests also confirmed that the recommended V2G charging system is a viable solution to meet mission requirements and bolster energy resilience. Paragon SMEs recommend defining agnostic model components to increase simulation accuracy in cases where specific equipment is pre-determined and commonly used. Program of Record Equipment, such as the AMMPS generator, can be accurately modeled to further increase the overall system's simulation accuracy. The benefit from repeated and accurate modeling could easily offset the cost associated with additional development time.

9.5 Research Area 5: Develop requirements for a sensored living laboratory that could be used to assess the performance of autonomous innovations

9.5.1 5A – Autonomous vehicle living laboratory requirements

The Paragon research team, led by Robotic Research, researched and identified appropriate sensors and methods to measure performance of autonomous systems within the CBITEC site. The team provided high-level test plans that defined the scope, objective, key personnel, and approach for the following tests: traffic interaction, sensor degradation, terrain identification, and charging station docking.

Robotic Research's team of engineers are SMEs in autonomous software and hardware development and integration. The following list of requirements developed by the Robotic Research engineering team define the high-level infrastructure, sensors, and data necessary to measure autonomous-system performance within the living laboratory at CBITEC. These requirements are meant to evolve, or be further derived, as more details about the test site are defined in Table 53.

Table 53. Site requirements.

Operation	Site Requirement
Infrastructure	• **Requirement 1**: The living laboratory will have provisions to charge an EV. • **Requirement 2**: The living laboratory will have electrical power connections for sensors. • **Requirement 3**: The living laboratory shall have semi-permanent mounting points for sensors. (Semi-permanent mounts can be removed from the site without causing damage or disturbing the site). • **Requirement 4**: The living laboratory will have wireless communication capabilities.
Sensors	• **Requirement 5**: The living laboratory will be able to detect autonomous systems at the site. • **Requirement 6**: The living laboratory will be able to measure the relative position of autonomous systems at the site. • **Requirement 7**: The living laboratory will be able to measure absolute position of autonomous systems within 0.1 meters. • **Requirement 8**: The living laboratory will be able to communicate absolute position of the autonomous systems at the site. • **Requirement 9**: The living laboratory autonomous detection system will be able to operate in varying lighting conditions, such as full daylight, dusk, and night.
Data Collection	• **Requirement 10**: The living laboratory will be able to collect and store time data. • **Requirement 11**: The living laboratory will be able to collect and store weather data. • **Requirement 12**: The living laboratory will be able to collect and store autonomous-system position data. • **Requirement 13**: The living laboratory will be able to collect and store autonomous-system attitude data. • **Requirement 14**: The living laboratory will be able to collect and store autonomous-system velocity data. • **Requirement 15**: The living laboratory will be able to collect and store autonomous-system sensor health data.

Given the program's intent to create a living laboratory with autonomous vehicle testing capability, Paragon SMEs recommend incorporating the capability to directly communicate to vehicle CAN Bus systems for additional data gathering and the development of microgrid control algorithms. Specifically, using CAN Bus data loggers will provide the capability to closely watch vehicle system reactions to events in support of control algorithm development and vehicle protection. CAN Bus data loggers are directly connected to the vehicle's onboard diagnostic port and store time-synchronized data that is later downloaded and analyzed via software tools.

Autonomous capabilities extend the benefits that electrified transportation and V2G technologies offer. Autonomous technologies show great potential to benefit military transport-dependent activities by improving logistics, security, base operation, maintenance, transport, and, eventually, warfighting. Additionally, implementing these technologies has the potential to decrease risks to the warfighter and reduce casualties through autonomously conducted missions.

9.5.2 5B – V2G charging living laboratory requirements

Paragon's research team, led by TechFlow, identified the requirements to assess V2G charging performance in a tactical environment. SMEs determined that the IPD boxes prepared for the CBITEC site include control equipment that can meet the metering and control needs for interconnecting tactical microgrid components. Additional components, to complete the living laboratory, and their benefits were identified and provided in **Section 6** of this report. While the tactical microgrid at CBITEC is not fully designed, the IPD developed by HG Engineers, combined with the wireless mesh network and the Modbus protocol, are determined to be a viable design approach. This approach provides a baseline for system communication requirements and future device integration and interoperability. The 3e-523-3 wireless access points manufactured by 3e TI Technology International and the established wireless mesh network at CBITEC are cyber secure and already approved for use on a SIPRNet. Paragon SMEs recommend using the existing hardware for wireless communications, as it has proven to be reliable, secure, and interoperates easily with system assets.

As determined through SME research and modeling conducted in Research Area 4, the Coritech V2G charger will interoperate with the military legacy equipment that make up the CBITEC tactical microgrid. The Coritech charger was purchased by Paragon, under this research project, for future integration into the CBITEC Living Laboratory. The V2G system, primarily, must have a suitable vehicle platform that meets vehicle-mission requirement. It must also have available payload capacity that can carry the weight of the lithium-ion ESS along with the necessary interconnection hardware, controls, and power converter. Various options were considered for a proof-of-concept vehicle for evaluation at CBITEC, but the only EV that is currently available for V2G integration with open protocols is the Nissan LEAF. A vehicle platform that should be considered for future evaluation is the Nikola Reckless. This fully electric, off-road vehicle is built for tactical environments. Product information indicates that, when available, the Reckless will house a battery pack with an energy storage capacity of 125 kWh, enabling the possibility of charge and discharge rates equal to the 60-kW AMMPS generators at CBITEC. With an energy storage capacity nearly twice that of the Nissan LEAF proof-of-concept vehicle, the Reckless will be able to support equivalent charge/discharge rates for twice as long.

Future research recommendations regarding the development of the CBITEC tactical microgrid are as follows: complete a detailed design of the tactical microgrid, document IPD and hardware settings for interconnecting the microgrid assets and include hardware-in-the-loop modeling and testing to improve simulation accuracy and support control algorithm development.

9.6 Research Area 6: Integrate open standards to promote interoperability

To promote interoperability, the Paragon team identified equipment that utilizes open standards and the standards that can guide the V2G integration equipment into the tactical microgrid.

Several industry standards relate to the design and installation of V2G charging equipment. From an interoperability standpoint, UL1741, Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with DERs is critical. Paragon SMEs researched

industry options and found the V2G fast charger by Coritech as the only fast charger that fully utilizes open standards and does not require customization to implement. Integrating the fast charger will require a step-down transformer to tie the 480-VAC output to the 208-VAC power distribution system of the tactical microgrid. The CHAdeMO standard is the only open standard that fully accommodates V2G applications. Using the CHAdeMO standard in the United States, however, is limited compared to the SAE CCS standard for fast-charging applications.

For generation sources to be allowed to operate in parallel with the electrical grid, electrical utilities require specific design and installation standards compliance. With compliance to specific standards, personnel safety and grid stability can be assured. Specifically, electrical utilities require compliance with the UL1741 standard, which requires generation sources to disconnect from the electrical grid during a grid outage. The goal of this requirement is to mitigate the risk of personnel, tasked to work on the power distribution system, electrocution and restore grid operations. Devices that are UL1741 compliant, including V2G fast chargers, are required to disconnect based on voltage and frequency deviations as identified in the standard. Another common industry standard used to ensure grid stability is IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems. This standard includes power quality requirements to help ensure grid stability.

As new technologies evolve, gaps will inevitably emerge when attempting to integrate communications protocols with previous technologies. Some potential solutions exist to help bridge gaps with communications systems, include protocol converters, media converters, and software tools.

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EurekaAlert!, *Enabling autonomous vehicles to see around corners*, 28 Oct 2019, https://www.eurekalert.org/pub_releases/2019-10/miot-eav102819.php.

Lockheed Martin and U.S. Army Combat Capabilities Development Command Ground Vehicle Systems Center, *Integration of the Autonomous Mobility Applique System into the Robotic Technology Kernel*, 13 Aug 2019, http://gvsets.ndia-mich.org/publication.php?documentID=702.

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Perrone Robotics, Drop-In Autonomy Kit (DAK), accessed 19 Oct 2019, https://perronerobotics.squarespace.com/dak.

Perrone Robotics, Turn-key Solutions for Autonomous Robots, accessed 19 Oct 2019, http://perroneautorobot.com/.

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Appendix A: Military Strategic Planning Resource Documents

Resource	Author/Reference Site
U.S. Army Fort Leonard Wood Installation Strategic Sustainability Plan FY16–41	Premont, Mark, 24, Apr. 2017, Garrison Strategic Plan Annex A FY16–41 Projects, pp. 31–81, and Annex B FY11-15 Progress Summary pp. 83–93., https://eko.usace.army.mil/virtualteams/issp/index.cfm?id=273971&syspage=Documents.
USAG Vicenza Strategic Action Planning Session—Command Briefing	Barber, David, 15, Jul. 2010, slides 7–9, 12–13, 16, 19–20, and 25–26.
Central Texas Sustainable Communities Conference, Summary of Goals, and Objectives—Command Briefing	Rawlings, Jennifer, 17 Feb. 2010, slides 7–15, 17–20, 24–30, 32–40 and 42–26.
USAG Kaiserslautern Sustainability Challenges Workshop Summary—Command Briefing	Barber, David, 6 Mar. 2009, slides 6–23.
Fort Drum Goal-setting Workshop Facilitator Playbook, Internal Planning Document	LaDuc, Michael, 6 Jan. 2009, pp. 33–37.
Fort Benning 2008 Sustainability Report	Lukken, Peter J., and Col. Thomas J. MacDonald, 30 Sep. 2008, pp. 9, 15, 21–22, issuu.com/s3ops/docs/fb_2008_sustainability_performance__1c97844ec14288.
Fort Riley Sustainability Challenges	Childs, Stanley, 24 Sept. 2008, slides 3–43.
Fort Huachuca U.S. Army Installation Sustainability Workshop Summary Briefing	Sturgeon, Col. Melissa, 26-28 Aug. 2008, slides 10–13.
Transportation Team Significant Challenges to Installation Sustainability	Childs, Stanley, 4 Oct. 2007, slides 2–16.

Resource	Author/Reference Site
Fort Campbell Strategic Plan 2008-2013, Garrison Commander's Strategic Plan	Carr, Trudy, 30 Sept. 2007, pp. 5, 8, 19, A2–A9.
USAG Wiesbaden—Sustainability Goal-Setting Workshop After-Action Report	Barber, David, Commander Briefing on Logistics Line of Effort, 31 Aug. 2007, slides 2–7.
USAG Hawaii—Strategic Sustainability Goals and Objectives Development Session	Zuckerman, David, *Transportation Team*, 8 June 2007, slides 2–10.
Fort Jackson Sustainability Planning Baselining Workshop Outcomes—Command Briefing	Odom, Dr. Lynn, 14 Oct. 2005, pp. 21–34.
Sustaining Fort Bragg through Transformation: Phase 1, Fort Bragg Environmental Baseline, *Internal Garrison Planning Documentation*	Messenger, Mannette, 12 Sept. 2003, pp. 5–63.

Appendix B: Manufacturer Websites

Manufacturer	Model	Website	Contact*
ACURA	MDX	acura.com/mdx	417-883-1550*
	RLX	acura.com/rlx	N/A
ALKE	ATX Series	alke.com/products	N/A
ALTEC	GreenFleet	troposmotors.com/able_xr.html	205-991-7733
AUDI	a6	audiusa.com/models/audi-a6	N/A
AMV	EV shuttles	avmfg.com/vehicles	hello@avmfg.com
ATC	eDrive Tractor	autonomoustractor.com/	203-993-0828. kraig@atcspirit.com
BLUE BIRD	All American RE, MIcrobird G5, & Vision	blue-bird.com/electric	800-825-8273*
BMW	i3 & i3s	bmwusa.com/vehicles/bmwi/i3/sedan/overview.html	bmwgroupcorporatefleet@bmwgroup.com
	530e	bmwusa.com/vehicles/5-series/sedan.html	
BUICK	N/A	N/A	N/A
	e6	en.byd.com/auto/	
	Class 6 van	en.byd.com/truck/	
	K series	en.byd.com/bus/k7-electric-transit-bus/	
	C series	en.byd.com/bus/c9-electric-motor-coach/	
	Class 8	en.byd.com/truck/https://en.byd.com/truck/	info.na@byd.com
BYD MOTORS	Terminal Tractor		
	Class 5 & 6		
	ECB Series	byd-forklifts.com/models/	
CADILLAC	N/A	N/A	N/A
CATERPILLAR	988K XE	cat.com/en_US/products/new/equipment/wheel-loaders/large-wheel-loaders/1000033063.html	471-886-6651*

* denotes contact information for the nearest dealer.

Manufacturer	Model	Website	Contact*
	D6 XE	cat.com/en_US/products/new/equipment/dozers/medium-dozers/21453584965113362.html	
CHANJE	V8100	https://chanje.com/vehicles/	Info@chanje.com
	Bolt EV	chevrolet.com/electric/bolt-ev-electric-car	636-248-0064; government fleet sales
CHEVROLET	Malibu Hybrid	chevrolet.com/cars/malibu-mid-size-car	
	Volt	chevrolet.com/electric/volt-plug-in-hybrid	
CHRYSLER	Pacifica Hybrid	chrysler.com/pacifica/hybrid.html	N/A
COBUS INDUSTRIES	e.Cobus	cobus-industries.de/produkte/e-cobus/	info@cobus-industries.de
	3000	cobus-industries.de/produkte/cobus-3000/	
EBUS	eBus	ebus.com/	sales@ebus.com
	Axess	eldorado-ca.com/heavy-duty-bus	909-591-9557
ENC	EZ-Rider II	eldorado-ca.com/mid-size-public-bus-transportation	
FENDT / AGCO	N/A	N/A	N/A
FIAT	500e	fiatusa.com/500e.html	N/A
FORD	Fusion Hybrid	ford.com/cars/fusion/models/fusion-hybrid-se/	573-634-4444*
	Transit PHEV	ford.co.uk/future-vehicles/new-transit-custom-phev	N/A
FREIGHTLINER	eM2	freightliner.com/e-mobility/	573-886-0188*
	eCascadia		
FUSO	eCanter	mitfuso.com/en-us/models/ecanter	636-978-3670*
GLOBAL	M4 Hybrid	https://globalsweeper.com/products/global-m4-hybrid	info@globalsweeper.com
GREEN MACHINES	e210	greenmachineco.com/e210-electric-mini-excavator/	kdurham@greenmachineco.com mailto:kdurham@greenmachineco.com
	EV series		

* denotes contact information for the nearest dealer.

Manufacturer	Model	Website	Contact*
GREENPOWER BUS	Synapse EVStar	greenpowerbus.com/product-line/	info@greenpowerbus.com
HONDA	Clarity	automobiles.honda.com/clarity-electric	N/A
	Clarity Hybrid	automobiles.honda.com/clarity-plug-in-hybrid	N/A
	Accord Hybrid	automobiles.honda.com/accord-sedan	N/A
	Insight	automobiles.honda.com/insight	N/A
HYUNDAI	Ioniq Hybrid	hyundaiusa.com/ioniq-hybrid/index.aspx	
	Ioniq Plug-In	hyundaiusa.com/ioniq-plug-in-hybrid/index.aspx	hyundaifleet@hmausa.com
	Sonata Hybrid	hyundaiusa.com/sonata-hybrid/index.aspx	
IMPOSSIBLE AEROSPACE	US-1	impossible.aero/us-1/	Info@impossible.aero
JEKKO	SPX & MPK Series	jekko-cranes.com/en/eco-cranes/	800-632-7226*
JMG	MC 32	jmgusa.com/products/radio-remote-controlled-cranes/mc32.htm	mikeb@jmgusa.com
JOHN DEERE	TE 4x2	deere.com/en CAF/products/equipment/gator utility vehicles/traditional utility vehicles/te 4x2 electric/te 4x2 electric.page	417-532-2011*
JOHNSON INDUSTRIES	Various vehicles	johnsonindustries.com	606-767-2701; stevec@johnsonindustries.com
KIA	Niro Electric	kia.com/us/en/vehicle/niro-ev/2019?file=gallery_niro-ev_2019_interior_wheel	N/A
	Niro Hybrid	kia.com/us/en/vehicle/niro-plug-in-hybrid/2019/features	636-591-1775*
	Optima Hybrid	kia.com/us/en/vehicle/optima-hybrid/2019	888-504-6781*
LEXUS	ES 300h	lexus.com/models/ES-hybrid	877-230-9933*
LIGHTNING SYSTEMS	Class 6	lightningsystems.com/class6-low-cab-forward	
	Ford E-450 Cutaway	lightningsystems.com/ford-e450-cutaway	800-223-0740
	Transit Chassis Cab	lightningsystems.com/ford-transit-cab-chassis	

* denotes contact information for the nearest dealer.

Manufacturer	Model	Website	Contact*
	Ford F-59	lightningsystems.com/ford-f59-delivery-van	
	Ford Cargo	lightningsystems.com/ford-transit-cargo-van	800-223-0740
	Ford Transit Passenger	lightningsystems.com/ford-transit-passenger-wagon	
	Ford E-450 Shuttle	lightningsystems.com/ford-e450-shuttle-bus	
	LEV Repower	lightningsystems.com/buses	
MACK	LR Electric	macktrucks.com/trucks/lr-series/electric-lr/	417-869-0566
MEAN GREEN MOWERS	Nemesis	meangreenproducts.com/nxr4852/	
	CXR-52/60	meangreenproducts.com/nxr4852/	513-738-4736
	Stalker	meangreenproducts.com/sk48-stalker/	
MERCEDES-BENZ	eVito	mercedes-benz.com/en/mercedes-benz/vehicles/transporter/electrified-vito-for-commercial-vans-customers/	Fleetoperations@mbusa.com
MITSUBISHI	Outlander	mitsubishicars.com/outlander-phev/2019	N/A
	MT Series	motrec.com/vehicles/series/mt-series/	
	MC Series	motrec.com/vehicles/series/mc-series/	
MOTREC	MP Series	motrec.com/vehicles/series/mp-series/	Info@motrec.com
	MS Series	motrec.com/vehicles/series/ms-series/ms-260/	
	MX Series	motrec.com/vehicles/series/mx-series/	
NEW FLYER	Xcelsior	newflyer.com/buses/xcelsior-charge/	dj_hammingh@newflyer.com
NIKOLA	NikolaTwo	nikolamotor.com/two	N/A
NISSAN	LEAF	nissanusa.com/vehicles/electric-cars/leaf.html	damien.herd@nissan-usa.com
NOVA BUS	LFS HEV	novabus.com/bus/lfs_hev/	N/A
PETERBILT	220EV, 520EV, 579EV	peterbilt.com/about/news-events/peterbilt-unveils-model-220ev-ces	417-865-5355*
PROTERRA	Catalyst	proterra.com/products/	864-438-0000
RAYMOND CORP	8000 Series	raymondcorp.com/lift-trucks/pallet-trucks	607-656-2311

* denotes contact information for the nearest dealer.

Manufacturer	Model	Website	Contact*
SHERPA	ECO100	sherpaminiloaders.com/eng/models/sherpa-100-eco/	N/A
SKYFRONT	Perimeter Drone	skyfront.com/perimeter-drone/	products@skyfront.com
SMART	Fortwo	smartusa.com/models/eq-pure-coupe	N/A
SOLECTRAC	eUtility	solectrac.com/eutility	N/A
	eFarmer	.solectrac.com/efarmer	N/A
TAYLOR-DUNN	C, E, & T-Series	taylor-dunn.com/en-us/tow-tractor/#models	annavarro@taylor-dunn.com
TEREX UTILITIES	HyPower	.terex.com/utilities/en/products/green-solutions/hybrid-solutions/terex-hypower-hybrid-system	844-837-3948
TESLA	Model 3	tesla.com/model3	
	Model S	tesla.com/models	816-627-4836*
	Model X	tesla.com/modelx	
TORO	N/A	N/A	N/A
TOYOTA	Avalon Hybrid	toyota.com/avalonhybrid/	greg.glander@toyota.com: government fleet sales
	Prius	toyota.com/prius/	
	RAV4 Hybrid	toyota.com/rav4hybrid/	
	Camry Hybrid	toyota.com/camryhybrid/	
	Highlander Hybrid	toyota.com/highlanderhybrid/	
TROPOS	Able XR	troposmotors.com/able_xr.html	Info@tropostech.com
UTILIMASTER / SMITH ELECTRIC	Newton	utilimaster.com/ProductDetail.aspx?id=358	upfit@utilimaster.com
VERSALIFT	Electric Drive	versalift.com/electricdrive/	Darrellburnett@versalift.com
VOLVO	S models	volvocars.com/us/cars/new-models/s60/trims/polestar	N/A
	XC models	volvocars.com/us/cars/new-models/xc60	N/A

* denotes contact information for the nearest dealer.

Manufacturer	Model	Website	Contact*
	LX2	volvoce.com/united-states/en-us/about-us/news/2018/volvo-ce-unveils-electric-compact-wheel-loader-concept/	N/A
	EX2	volvoce.com/global/en/news-and-events/news-and-press-releases/2018/volvo-ce-unveils-electric-compact-wheel-loader-concept/	N/A
	FL & FE Electric	volvotrucks.com/en-en/news/press-releases/2019/feb/pressrelease-190219.html	N/A
	e-100	workhorse.com/stepvans	
WORKHORSE	NGEN 1000	workhorse.com/ngen	513-360-4704
	W-15	workhorse.com/W-15.html	
XL FLEET	F Series	xlfleet.com/content/vehicles/	sales@xlfleet.com
ZENITH	N/A	N/A	N/A
ZERO TRUCK	ZeroTruck	zerotruck.com	info@zerotruck.com

* denotes contact information for the nearest dealer.

Appendix C: Electric Transport System Information Resources

Resource	Author / Reference Site
Lewis-McChord Feasibility Study for the Application of Automated Vehicles; JBLM Feasibility Study for the Application of Automated Vehicles	Barghout, Jeff, et al. Joint Base, pp. 1–39, Joint Base Lewis-McCord.
JBLM Autonomous Vehicle Scoping Session Summary, Internal Meeting Summary with Installation Stakeholders to Identify MSAs That Could Be Performed Autonomously	Steucke, Paul, 31 Oct. 2014, pp. 1–4.
ARIBO: Fort Leonard Wood	Robotic Research, roboticresearch.com/programs/aribo-fort-leonard-wood/.
Land Ownership: Overview and Data, Congressional Research Service	Vincent, Carol Hardy, and Laurel Hanson, 3 Mar. 2017, p. 6, fas.ch/sgp/crs/misc/R42346.pdf.
Autonomous Transportation: Combat Power in the 21st Century	Henry, Capt. Matthew P. U.S. Army, 1 Nov. 2018, army.mil/article/213078/autonomous_transportation_combat_power_in_the_21st_century.
Electric Cars	Green Car Reports, greencarreports.com/news/electric-cars.
Electric Vehicles	WIRED, Conde Nast, wired.com/tag/electric-vehicles.
Electric Vehicle Guide	The Sierra Club, content.sierraclub.org/evguide/.
Clean Vehicles	Union of Concerned Scientists, ucsusa.org/clean-vehicles/electric-vehicles.
Clean Technica	Sustainable Enterprises Media, cleantechnica.com/.
Charged EVs	Isentropic Media, chargedevs.com/.
Electric Car Insider	electric-car-insider.com/.
Electric & Hybrid: Vehicle Technology International	Mark Allen Group, electrichybridvehicletechnology.com/.
Inside EV	insideevs.com/?p=3.
Clean Fleet Report	cleanfleetreport.com/.
Clean Car Congress	BioAge Group, greencarcongress.com/.
Electric Vehicle Charging News	Fleetcarma, fleetcarma.com/blog/.
Autovolt Magazine	Autovolt Limited, autovolt-magazine.com/.
Engineering and Technology	The Institution of Engineering and Technology, eandt.theiet.org/tags/electric-vehicles.
Electric and Hybrid Vehicles	The New York Times, nytimes.com/topic/subject/electric-and-hybrid-vehicles.
TC 69: Electric Road Vehicles and Electric Industrial Trucks	International Electrotechnical Commission, iec.ch/dyn/www/f?p=103:22:0::::FSP_ORG_ID:1255.
Electric/Hybrid	Renewable Energy magazine, renewableenergymagazine.com/electric_hybrid_vehicles.

Resource	Author / Reference Site
Researchers Use Blockchain to Drive Electric Vehicle Charging Infrastructure	University of Waterloo, Science News, 14 Aug 2019, sciencedaily.com/releases/2019/08/190814144501.htm.
SMERC Publications	UCLA Smart Grid Energy Research Center, smartgrid.ucla.edu/publications.htm.
Real-Time Bidirectional Electric Vehicle Charging Control with Distribution Grid Implementation	Xiong, Yingqi, et al. smartgrid.ucla.edu/publications.htm.
Hierarchical Distributed EV Charging Scheduling in Distribution Grids	Khaki, Behnam, et al. smartgrid.ucla.edu/publications.htm.
IEEE Electrification magazine	IEEE Power and Energy Society, ieee-pes.org/publications/electrification-magazine.
Classic Driver magazine	*Classic Driver*, classicdriver.com/en/magazine/tag/electric-vehicles?page=1&search_type=simple&tag=8004.
Center for Automotive Research Publications	Car Group, cargroup.org/publications/.
Center for Automotive Research	cargroup.org/?s=electric%20vehicle.
Alt Energy magazine	altenergymag.com/tag/electric-vehicles.
Green Fleet magazine	greenfleetmagazine.com/tags?tag=Battery-Electric%20Vehicles.
Government Fleet magazine	*Green Fleet* magazine, government-fleet.com/green-fleet.
Energy Digital	BizClick Media, energydigital.com/electric-vehicles.
Electrek	electrek.co/.
Greentech Media	greentechmedia.com/articles/tag/electric-vehicles.
EcoWatch	ecowatch.com/tag/electric-vehicle.
EV News	The Driven, thedriven.io/category/ev-news/.
Electric Vehicles	Phys.org, phys.org/tags/electric%20vehicles/.
Electric and Hybrid: Vehicle Technology International	Mark Allen Group Limited, electrichybridvehicletechnology.com/.
Electric Vehicles	*American Power Association*, publicpower.org/topic/electric-vehicles/public-power-magazine.
World Electric Vehicle Journal	American Public Power Association, mdpi.com/journal/wevj.
International Journal of Hydrogen Energy	International Association for Hydrogen Energy, journals.elsevier.com/international-journal-of-hydrogen-energy.
eTransportation	journals.elsevier.com/etransportation.
Journal of Power Sources	International Journal on the Science and Technology of Electrochemical Energy Systems, journals.elsevier.com/journal-of-power-sources.
International Journal of Electrical Power and Energy Systems	journals.elsevier.com/international-journal-of-electrical-power-and-energy-systems.
Research in Transportation Economics	ScienceDirect, sciencedirect.com/journal/research-in-transportation-economics.
Journal of Cleaner Production	ScienceDirect, sciencedirect.com/journal/journal-of-cleaner-production.
Synergies of Four Emerging Technologies for Accelerated Adoption of Electric Vehicles: Shared Mobility, Wireless Charging, Vehicle-to-Grid, and Vehicle Automation	Taiebat, Morteza, and Ming Xu. *Journal of Cleaner Production*, vol. 230, 1 Sept. 2019, pp. 794–797., sciencedirect.com/science/article/pii/S0959652619316683.
Transport Policy	ScienceDirect, sciencedirect.com/journal/transport-policy.

Resource	Author / Reference Site
Consumer Preferences for Public Charging Infrastructure for Electric Vehicles	Globisch, Joachim, et al. *Transport Policy*, vol. 81, Sept. 2019, pp. 54–63., sciencedirect.com/science/article/abs/pii/S0967070X1830742X.
International Journal of Electric and Hybrid Vehicles	inderscience.com/jhome.php?jcode=ijehv.
Peer-Reviewed Journal Publications	Carnegie Mellon Vehicle Electrification Group, Carnegie Mellon University, cmu.edu/cit/veg/publications.html.
Carnegie Mellon Vehicle Electrification Group	Carnegie Mellon University, cmu.edu/cit/veg/index.html.
electric://forum Blog	Electric Car Blog, electricforum.com/blog/.
electric://forum Forum	Electric Car Blog, community.electricforum.com/.
Speak EV	VerticalScope, speakev.com.
Electric Vehicles	International Council on Clean Transportation, theicct.org/electric-vehicles.
Plug-In America	Electric Auto Association, pluginamerica.org.
Maryland EV	marylandev.org/.
Drive Electric Northern Colorado	driveelectricnoco.org/.
Electrification Coalition	electrificationcoalition.org.
Midwest Evolve	midwestevolve.org/.
Electric Vehicles Initiative	International Energy Agency, iea.org/topics/transport/evi/.
World Electric Vehicle Association	Electric Drive Transportation Association, worldelectricvehicleassociation.info/.
Fuel Cell and Hydrogen Energy Association	http://www.fchea.org/transportation.
Electric Auto Association	eaa-1967.clubexpress.com/.
Electric Drive Transportation Association	electricdrive.org/.
Mid-America Electric Auto Association	maeaa.org.
Electric Vehicle Charging Association	evassociation.org/.
Hybrid and Plug-In Electric Vehicles	Alternative Fuels Data Center, DOE's Vehicle Technologies Office, afdc.energy.gov/vehicles/electric.html.
All-Electric Vehicles	DOE, fueleconomy.gov/feg/evtech.shtml.
Estimating the infrastructure needs and costs for the launch of zero-emission trucks	Hall, Dale, and Nic Lutsey, The International Council on Clean Transportation, https://theicct.org/publications/zero-emission-truck-infrastructure.
Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas	Nicholas, Michael, The International Council on Clean Energy, https://theicct.org/publications/charging-cost-US.
Early steps in the transition to electric vehicles in the Midwest	Nicholas, Mike, The International Council on Clean Energy, https://theicct.org/publications/ev-transition-US-Midwest-201907.
Update on electric vehicle costs in the United States through 2030	Nicholas, Mike, The International Council on Clean Energy, theicct.org/publications/update-US-2030-electric-vehicle-cost.
Quantifying the Electric Vehicle Charging Infrastructure Gap across U.S. Markets	Nicholas, Mike, The International Council on Clean Energy, theicct.org/publications/charging-gap-US.
Lessons Learned on Early Electric Vehicle Fast-Charging Deployments	Nicholas, Michael, and Dale Hall, The International Council on Clean Transportation, 1 Aug. 2018, theicct.org/publications/fast-charging-lessons-learned.

Resource	Author / Reference Site
Global EV Outlook 2019	IEA, iea.org/publications/reports/globalevoutlook2019/.
Electric and Plug-In Hybrid-Electric Vehicle Publications	National Renewable Energy Laboratory, DOE, nrel.gov/transportation/fleettest-publications-electric.html.
Crash statistics	NHTSA, DOT, crashstats.nhtsa.dot.gov/#/PublicationList/79.
Electric Vehicles for All: An Equity Toolkit	The Greenlining Institute, greenlining.org/publications-resources/electric-vehicles-for-all/.
DOE Vehicle Technologies Office	energy.gov/eere/vehicles/vehicle-technologies-office.
DOE Grid Modernization Initiative	energy.gov/grid-modernization-initiative.
Technology-to-Market	Office of Energy Efficiency and Renewable Energy, DOE, energy.gov/eere/technology-to-market/home.
Reports and publications	Office of Energy Efficiency and Renewable Energy: Vehicle Technologies Office, DOE, energy.gov/eere/vehicles/reports-and-publications.
Advanced Vehicle Testing Activity (AVTA) Data and Results	Office of Energy Efficiency and Renewable Energy: Vehicle Technologies Office, DOE, energy.gov/eere/vehicles/advanced-vehicle-testing-activity-avta-data-and-results.
DARPA Electric and Hybrid-Electric Vehicle Program	CTE, cte.tv/project/darpa-electric-and-hybrid-electric-vehicle-program/.
State Efforts to Promote Hybrid and Electric Vehicles	Hartman, Kristy, and Emily Dowd, National Conference of State Legislatures, 26 Sept. 2017, ncsl.org/research/energy/state-electric-vehicle-incentives-state-chart.aspx.
Procurement Preference for Electric and Hybrid-Electric Vehicles	Alternative Fuels Data Center, DOE, afdc.energy.gov/laws/431.
All Laws and Incentives Sorted by Type	Alternative Fuels Data Center, DOE, afdc.energy.gov/laws/matrix.
DoD Projects	Advanced Vehicles, Idaho National Laboratory, avt.inl.gov/project-type/united-states-department-defense.
National Transportation Research Center	Oak Ridge National Laboratory, UT-Battelle, ornl.gov/facility/ntrc.

Appendix D: Preliminary List of Existing Electric Transportation Systems

DOT Classification	Name	MSA No.	Manufacturer	Origin	TRL	Charging	GSA
Trucks & Vans							
3	Newton	3	Utilimaster/ Smith Electric	United States (assembled)	9	L1, L2	
3	e-100	3	Workhorse	United States (assembled)	6; in production	L1, L2, DC Fast	
3	NGEN 1000 van	3	Workhorse	United States (assembled)	6; in production	L1, L2, DC Fast	
3	E100 van	3	Workhorse	United States (assembled)	6; in production	L1, L2	
3	W-15 truck	1	Workhorse	United States (assembled)	7; pre-order	L1, L2, DC Fast	
3	Class 6 step van	3	BYD	China, United States	9	L2, DC Fast	
3	Super Duty F Series	1	XL Fleet/Ford	United States (assembled)	9		
3	eVito	3	Mercedes-Benz		9		
Shuttles, Transit Buses, & Vans							
4	EV22, EV27, EV3 shuttle buses	1	AVM	United States	9	DC Fast custom system	
4	e.Cobus shuttle	1	COBUS Industries	Germany	9	L2, DC Fast	
4	3000 shuttle	1	COBUS Industries	Germany	9	L2, DC Fast	
4	K7, K95, K9, K11 shuttles	1	BYD	China, United States	9	L2, DC Fast, custom systems	
4	C6, C9 & C10 buses	1	BYD	China, United States	9	L2, DC Fast, custom systems	
4	eBus	1	eBus	United States (assembled)	9	In-ground 450 kW 4C	
4	Transit EV	3	Ford		5; out in 2021		
4	Transit PHEV	3	Ford	United States (assembled)	8; delivered in 2019, UK		
4	EV250, EV300, EV350, EV400 & EV550 shuttle buses	1	GreenPower Bus	United States	9	L2, DC Fast	
4	Xcelsior	1	New Flyer	United States	9	On-route, DC Fast	
4	Catalyst	1	Proterra	United States	9	DC Fast, overhead & custom systems	
4	All American RE, Microbird G5	1	Blue Bird	United States	9	DC Fast	
	LEV Repower	1	Lightning Systems	United States	9	L2, DC Fast	

DOT Classification	Name	MSA No.	Manufacturer	Origin	TRL	Charging	GSA
3	Ford E-450 shuttle	1	Lightning Systems	United States	9	L2, DC Fast	
3	Ford Transit Passenger	1	Lightning Systems	United States	9	L2, DC Fast	
4	Synapse bus	1	GreenPower	United States	9	L2, DC Fast	
3	EVStar shuttle	1	GreenPower	United States			
	Axess	1	ENC		9	DC Fast	
	EZ-Rider II	1	ENC		9	DC Fast	
4	LFS HEV	1	Nova Bus	Canada	9	DC Fast	
Tractors, Mowers, Street Sweepers, & Refuse							
15	eDrive tractors	2	ATC	United States	9	Hybrid-electric	Y
15	Class 6 & 8 refuse	3	BYD	United States	9	L1, L2, DC Fast	
15	SESAM tractor	2	John Deere		7		
15	eUtility tractor	2	Solectrac	United States	8; available 2020	L1, L2	
15	eFarmer tractor	2	Solectrac	United States	8; available 2020	L1, L2	
15	Nemesis mower	2	Mean Green Mowers	United States	9	110V/220V charger	
15	CXR-52/60 mower	2	Mean Green Mowers	United States	9	110V/220V charger	
15	Stalker mower	2	Mean Green Mowers	United States	9	110V/220V charger	
5	FL Electric & FE Electric refuse	3	Volvo	Belgium, Brazil, China, France, Germany, India, Korea, Sweden, U.K., and United States	Delivering in Europe		
6	LR Electric refuse	3	Mack	United States	Real-world testing in 2020		
Vocational, Medium-, & Heavy-duty Trucks							
6	Class 8 Day cab	3	BYD	United States	9	L1, L2, DC Fast	
5	Terminal tractor	3	BYD	United States	9	L1, L2, DC Fast	
5	Class 5 & 6 truck	3	BYD	United States	9	L1, L2, DC Fast	
5	T-Series Terminal trucks	3	Orange	United States	9	L1, L2, DC Fast	
5	eM2 box truck	3	Freightliner	Mexico, United States	9	Custom	
8	eCascadia semi	3	Freightliner	Mexico, United States	9	Custom	
8	Class 8 semi	3	Tesla	Netherlands	8; available 2020	Megacharger	
8	ZeroTruck	3	Zero Truck	United States	9	L1, L2, DC Fast	
3	V8011 refrigerated van	3	Chanje/Thermo King	Hong Kong, United States	9	DC Fast	
3	ECantor van	3	Fuso	Egypt, the Philippines, Portugal	9	DC Fast	

DOT Classification	Name	MSA No.	Manufacturer	Origin	TRL	Charging	GSA
4	220EV, 520EV, 579EV	3	Peterbilt	Canada, United States	2020		
3	Class 6 box truck	3	Lightning Systems	United States	9	L2, DC Fast	
3	Ford E-450 Cutaway	3	Lightning Systems	United States	9	L2, DC Fast	
5	Ford Transit Chassis cab	3	Lightning Systems	United States	9	L2, DC Fast	
5	Ford F-59	3	Lightning Systems	United States	9	L2, DC Fast	
8	NikolaTwo	3	Nikola	United States	9	DC Fast	
Specialty Vehicles							
3	MPS Disaster Response Platform	5	Dannar	United States	9	L1, L2, DC Fast	Y
5	**Burden** carrier hauler	3	Johnson Industries	United States	8; custom build		
5	Airport carrier	3	Johnson Industries	United States	9		
3	**Ground** support utility truck	3	Johnson Industries	United States	9		
3	Large ground support truck	3	Johnson Industries	United States	9		
3	Airport GSVs	3	Johnson Industries	United States	9		
15	Customized hauler	3	Johnson Industries	United States	8; custom build		
15	Platform carrier	3	Johnson Industries	United States	9		
15	Indoor & outdoor towing/ lifting	3	Linde Material Handling	United States	9		
15	Warehousing	3	Taylor-Dunn (Polaris company)	United States			
	ECB Series forklift	3	BYD Motors	United States	9		
4	HyPower	3	Terex Utilities	United States	9		
5	Electric Drive bucket truck	3	Versalift	United States	9		
3	C, E, & TT Series tow tractors	3	Taylor-Dunn	United States	9		
15	**MT Series** tow tractors	3	Motrec	Canada	9		
15	**MC Series** burden carriers	3	Motrec	Canada	9		
15	**MP Series** personnel carriers	3	Motrec	Canada	9		
15	**MS Series** stock chasers	3	Motrec	Canada	9		

DOT Classification	Name	MSA No.	Manufacturer	Origin	TRL	Charging	GSA
15	MX Series (custom)	3	Motrec	Canada	9		
15	8000 Series pallet jacks	3	Raymond Corp	United States	9		
15	ATX Series (small utility, fully customizable)	3	Alke	Italy	9		
15	US-1 intelligence drone	4	Impossible Aerospace	United States	9		
15	Perimeter Drone	4	Skyfront	United States	9		
15	SPX & MPK Series mini cranes	5	Jekko	Italy	9		
15	MC 32 portable crane	5	JMG	Italy	9		
15	ECO100 mini loader	5	Sherpa	Netherlands	9		
15	e210 mini excavator	5	Green Machines	United States	9		
15	TE 4X2 gator	3	John Deere	India, United States	9		
3	Able XR (customizable small utility)	3	Tropos	United States	9		
5 & 6	GreenFleet aerial lifts	3	Altec	United States	9		
Heavy-duty Vehicles							
15	EC15 & EC27 compact excavators	5	Volvo Construction Equipment	EU, United States	mid-2020		
15	L20 & L28 wheel loaders	5	Volvo Construction Equipment	EU, U.S	mid-2020		
15	LX2 compact wheel loader	5	Volvo Construction Equipment	EU, U.S	Prototype		
15	EX2 compact excavator	5	Volvo Construction Equipment	EU, U.S	Prototype		
15	988K XE wheel loader	5	Caterpillar	Brazil, China, Russian and United States	9		
15	D6 XE dozer	5	Caterpillar	Brazil, China, Russian and United States	9		

Appendix E: Future Lines of Inquiry

MSA No.	Gap/Challenge	Description of Opportunities
Personnel Transport (1)	DoD maintains non-tactical fleets for transportation needs at most installations. The automotive industry is developing and demonstrating both EVs and AVs. As discussed in the report, each manufacturer has established proprietary autonomous features and EV systems that would make demonstrations using their vehicles more difficult.	Once EV passenger vehicles and SUVs are readily available through GSA, there might be an opportunity to modify (in partnership with the manufacturer) EV and/or AVs (if electric) to work in conjunction with microgrids if they are available with, or can be modified to provide, bidirectional charging.
	Government non-tactical fleet vehicles are necessary to operate installations/conduct the mission. Usage patterns reflect these vehicles are under-utilized. Usage patterns suggest that just-in-time arrival (central storage to point of pick-up) might provide AV demonstration opportunities.	AV delivery of vehicles for on-demand use and return to central point could reduce the No. of vehicles required to meet fleet needs. AV automobiles could act as shuttles for routine on-post destinations. Non-tactical fleet could function as a battery when linked with renewable power (solar) production capacity.
Land Management (2)	Small EV lawn maintenance mowers are too small to support microgrid requirements.	AV and EV lawnmowers are available. A demonstration could support their use in small-scale cantonment area grounds maintenance. EV tractors are available and could be made autonomous for use in larger cantonment area grounds maintenance. Demonstration could result in reduced ground maintenance costs and provide continuous cutting as needed.
	Range and training area management is a necessary and costly activity that keeps land available for training. No large-scale EV or AV systems are available for use. Smaller EV tractors are not AV and would therefore not be viable for some of the land management.	Hybrid tractor system (ATC) could be modified to run autonomously for routine grounds maintenance demonstration. The system could also be used to plow roads and conduct other land management function in ranges and training areas. ATC system could be refined with additional sensors to identify foreign materials abandoned in training areas and ranges and recover them prior to cutting (spooling device to remove abandoned concertina wire, for example). Initial project development at JBLM[7] indicated other potential demonstrations including identification and non-chemical eradication of invasive species (Scott's Broom at JBLM). An autonomous land management system that could function during off hours to prepare, restore, and maintain training areas and ranges would increase availability of these areas in support of the mission.
Logistics (3)	Small-scale, autonomous logistics systems were not considered for this research because of the limited battery capacities available in smaller warehousing EVs that are primarily used indoors.	AMC is responsible for evaluating, developing, and, eventually, deploying various automated and autonomous warehousing systems. No opportunity outside of the AMC realm is evident until sufficient capacity could be deployed to support a microgrid.

MSA No.	Gap/Challenge	Description of Opportunities
	Point-to-point logistics could be supported through development of small multi-use tugs with customized attachment to perform routine functions including: Cantonment area deliveries of material, products, mail, etc. Routine pick-ups for recyclables, refuse, etc. from specified locations on scheduled days—these pick-ups could then be used to conduct activities at night or during off hours Delivery of materiel to down-range locations and retrieval of materiel from range areas.	Initial tug project description developed after JBLM session[7]. Analysis could be updated as serve as basis for EV/AV utility tug development and demonstration. EV tugs available from at least one manufacturer who is interested in this concept—systems do not meet battery capacity to support microgrid research needs.
	Various military operations use GSVs. Operations are common for logistics for aircraft (fixed and non-fixed wing) loading, fueling, fitting, arming etc. Battery capacity of these systems does not meet microgrid research requirements.	AV/EV GSVs could be used to directly support flying missions. AV loading systems would require specialized detection and autonomous function to be developed—mishaps could impact aircraft.
Land Preparation (5)	HEV-heavy machinery is currently under development by various manufacturers. Fully EV machinery that can perform similarly to diesel-powered systems is currently not possible given battery technologies (weight too significant to provide enough power to meet transit and functional performance).	Partnership with manufacturers will explore more efficient battery technologies to be used in future systems. Partnership with manufacturers to test and validate HEV systems and their potential autonomous use could support the mission but would not support microgrid research. Research autonomous operation of diesel-powered engineering equipment.
Road Maintenance (6)	Heavy engineering equipment used in road maintenance is generally not available as EV or AV systems.	Research autonomous operation of diesel-powered engineering equipment Evaluation of available autonomous plows used in Europe for runway snow removal—not EV.
		Evaluate existing AV diesel-powered plow systems for potential medication and use for gravel and dirt trail and road development, maintenance, and repair.

Appendix F: Research Compatibility Considerations

Requirement	Metric (Quantitative)	Metric (Qualitative)	Additional Considerations
Automation	• Drive-by-wire ready • Automation Level (SAE).	• Self-docking • Self-loading • Steering • Throttle • Braking	
Battery	• Maximum charge time (hour) • Energy storage capacity (kWh) • Power capacity (kW).	• Usable depth of discharge • Battery health monitoring • Battery Monitoring System (BMS) diagnostics and reporting • SOC monitoring • Battery warranty • System bidirectional capability	Charger availability/logistics Readiness for bidirectional power flow Industry ratings Open or proprietary battery management system
Communications	• Measurement range (V) • Bandwidth (Hz) • Accuracy (SNR) • Latency • Central processor unit time (CPU Time) • Space (byte)	• Battery health monitoring • Telemetry (radio, cellular, satellite) • Interface (USB/ethernet) • Network interface • Network-attached storage • Data acquisition • Software • Versatility/universal inputs • Cybersecurity • Communications protocol • V2G readiness of protocol, commands, data mapping	Global communication capabilities (chargers, on-road vehicles) Manufacturer's willingness to collaborate/evolve for bidirectional monitoring and control Level to which cybersecurity has been addressed (or is planned to be addressed)
Cost Effective	• Total annual maintenance Cost (USD) • Efficiency (%) • Unit cost (USD) • Life cycle (years)	• Risk reduction • Ease of acquisition • GSA availability • Warranty	Need to include development cost (NRE, materials, equipment, etc.) to achieve V2G readiness Location of critical resources for development, approvals and field support/sustainment Location and access to ancillary equipment vendors (i.e., inverter mfg.)
Data Capture	• Inputs (No.) • Input measurement range • Space (byte) • Frequency (Hz) • Environmental (temp, relative humidity, PSI).	• Sensors • Calibration • Maintenance • Class	
Environmental Impacts on the Vehicle	• Temperature (F) • Humidity (relative humidity, dew point) • Pressure (PSI) • Weatherproofing (IP6*) • Industry and safety ratings.	• Battery/charger system weight, footprint •	Power quality, vibration, operating temperature range, environmental performance testing (proven; not lab level)

Requirement	Metric (Quantitative)	Metric (Qualitative)	Additional Considerations
Manufacturer Reliability	• Units manufactured (No. of units) • Total cost to manufacture (USD) • Utilization rate (actual output/optimal output) • Cycle time (hours/unit) • Yield (No. satisfactory units/total units) • Recall rate (No. recalled units/units produced) • Inventory turnover (No. units sold/units in inventory) • Production downtime (No. hours downtime/optimal hours operation) • Customer satisfaction	• Customer testimonials	Publications Website/media Past/present contracts Financial stability
Navigation	• Accuracy (cm, ft.) • Frequency (Hz) • Accuracy (degrees, radians)) • GPS Band (C, M).	• GPS • Cameras • Radar • LiDAR • Inertial measurement unit systems • Receiver • Tracker	
Programmability (Computer)	• Processor time (CPU time) • I/O [No. of inputs and outputs—digital, analog, pulse width modulation (PWM), Ethernet, CAN].	• Scheduling • Operating system • Real-time synchronization	Willingness of manufacturer to collaborate/develop V2G solution
Range	• Time (hour) • Distance (mile).	•	Regenerative capabilities
Safety	• Industry ratings/certifications • DOT • Static stability factor •	• Personnel protection • Armor • Incognito/camouflage • Redundant controls • Weaponry • Hazmat transport	
Personnel Transport	• Occupants (No.)	• Accessibility • Seating	
Vehicle Performance Metrics	• Top speed (mph) • Acceleration range (seconds) • Traction (psi) • Torque (ft-lb) • Power (hp) • Power to weight (hp/lb.) • Handling (lb./sq. ft) • Weight distribution (%) • Towing (max capacity) • Efficiency (%) • Suspension (spring rate) • Ground clearance (ft) • Turning radius (in)	• Drivetrain • Electronic stability control • Off-road durability/performance	
Versatile	• Versatility (No. of attachments) • Modularity (No. of common variants) • Variants (No. of variants).	• Supports multiple missions • Ease of maintenance/repair • Off-road mobility • Function (personnel transport, cargo transport, refrigeration, hydraulics, towing)	Supports multiple programs

Appendix G: Initial Y/N Scoring Summary

Total No. of Y:	TRL (7-9)	Cost ≤ $450,000	Assembled In U.S.	Battery Capacity ≥50 kWh	MSA	Related Research	Available through GSA
7	MPS by: Dannar						
	Y	Y	Y	Y	Y	Y	Y
	9	$200–400K	IN	125–630 kWh	2, 4, 5, 6	DHS	
6	Cargo Van, Chassis Cab, Cutaway Cab, Shuttle Van, Step Van by: Zenith Motors						
	Y	Y	Y	Y	Y	N	Y
	9	$100K	CA	52–100 kWh	1, 3		
6	Zeus Electric Shuttle bus, Utility vehicle, Flatbed truck by: Phoenix Motorcars						
	Y	Y	Y	Y	Y	Y	N
	9	$240,000+	CA	105kWh	1, 3	EPA, CA	
5	Medium-Duty Trucks, Shuttles, and Buses by: Zero Truck						
	Y	Y	Y	Y	Y	N	N
	9	$60–100K	CA	53–80 kWh	1, 3		
5	T-Series Yard Hostler by: Orange Motors						
	Y	Y	Y	Y	Y	N	N
	9	$200–300K	MO	80–160 kWh	1, 3		
5	Reckless by Nikola						
	Y	N	Y	Y	Y	Y	N
	9	$480K/year lease	CA	52–100 kWh	4	USMC	
5	eBus by: eBus						
	Y	Y	Y	Y	Y	N	Y
	9	$400K	CA	130 kWh	1		
5	Xcelsior Charge (multiple versions) by: New Flyer						
	Y	N	Y	Y	Y	Y	N
	9	$700–1,200K	AL	160–466 kWh	1, 3	Private sector	
5	R1T – EV Pick-up by: Rivian						
	Y	Y	Y	Y	Y	N	N
	8	$70–100K	IL	105–180 kWh	3, 4		
5	Saf-T-Liner C2 Jouley Electric School Bus by: Thomas Built						
	Y	Y	Y	Y	Y	N	N
	8	$450K	NC	220 kWh	1		
5	Shuttles, buses, Class 5-7 Tractor, Class 8 Day Cab by: BYD						
	Y	Y	Y	Y	Y	N	N
	9	$250–550K	CA	150–250 kWh	1, 3		
5	Edrive Tractor by: ATC						
	Y	Y	Y	Y	Y	N	N
	9	$250K	MN	250 kW	2, 5, 6		
5	EV250, EV300, EV350, EV400 & EV550 shuttle buses by: Green Power Bus						

Total No. of Y:	TRL (7-9)	Cost ≤ $450,000	Assembled In U.S.	Battery Capacity ≥50 kWh	MSA	Related Research	Available through GSA
	Y	Y	Y	Y	Y	N	N
	9	$250–600K	China/United States	210–478 kWh	1		
4	E210 and E240 (mini excavator) by: Green Machine						
	Y	Y	Y	N	Y	N	N
	9	$50K	NH, NY	48 kWh	2, 5, 6		
4	eCargo, eTruck drayage – Class 8 Tractor by: US Hybrid						
	N	Y	Y	Y	Y	N	N
	6	$250K	CA	240 kWh	1, 3		
4	LFSe by: Nova Bus						
	Y	N	Y	Y	Y	N	N
	8	$700K+	NY	152 kWh	1		
4	EV22, EV27, EV33 shuttle buses by: AVM						
	Y	Y	N	Y	Y	N	N
	9	$300K	China	250 kWh	1		
4	Catalyst by: Proterra						
	Y	N	Y	Y	Y	N	N
	9	$800K	FL	650 kWh	1		
4	eUtility, eFarmer tractors by: Soletrac						
	Y	Y	Y	N	Y	N	N
	7	$45–60K	CA	28–48 kWh	2, 5		
4	V8011 Refrigerated Truck by: Chanje Energy and Thermoking						
	Y	Y	N	Y	Y	N	N
	7	$75K	China	100 kWh	3		
4	ECantor light-duty truck by: Mitsubishi Fuso						
	Y	Y	N	Y	Y	N	N
	9	$125K	EU	42–84 kWh	3		
4	ECobus by: Cobus Industries						
	Y	Y	N	Y	Y	N	N
	8	$250K	EU	85 kWh	1		
3	Class 8 Tractor by: Tesla						
	N	Y	N	Y	Y	N	N
	6	$150–200K	EU	600–1000 kWh	1, 3		

Appendix H: Candidate System Information Packets

H.1 Green Fleet
Manufacturer: Altec

Altec Green Fleet offers a collection of products that encompass the most advanced technology and includes Jobsite Energy Management Systems (JEMS) Hybrid-Electric Technology, an integrated plug-in hybrid system that uses stored electrical energy to power aerial devices, hydraulic tools, exportable power, and engine-off cab comfort. The company manufactures aerial devices (overcenter, non-overcenter, telescopic, and telescopic articulating) and digger derricks.

The company provides products and services to the electric utility, telecommunications, tree care, lights and signs, and contractor markets and was founded in 1929.

Green Fleet **by:** Altec	
Cost	From the GSA catalog: Articulating telescopic aerial device (base): $132,106 Overcenter articulating aerial device (base): $144,266 Non-overcenter aerial device with material handling (base): $178,559 37' digger derrick: $133,368 41' digger derrick: $173,266 50' digger derrick: $221,883 65' digger derrick: $272,971
Application Maturity	Commercially available
Maintenance Requirements	Altec provides courses to technicians to enable an understanding of the fundamental operational principles on the JEMS hybrid systems, and there is an Altec service center in St. Joseph, MO.

Comments
The Green Fleet line consists of:
28 overcenter aerial devices
24 non-overcenter aerial devices
5 telescopic aerial devices
31 telescoping articulating aerial devices
28 digger derricks
Hybrid bucket trucks/aerial devices are a combination of two power units in one vehicle. An auxiliary electric motor is located under the mid-chassis section and is connected to a hydraulic pump. Powered by high-capacity battery packs, the electric motor provides power to the hydraulic system.
More information on Altec Green Fleet government sales can be found **here**.
Website altec.com/products/green fleet
Contact For federal government sales: 205-408-2341; fedgovtsales@altec.com

Green Fleet Products

Altec has several hybrid and/or alternative energy options for the utility industry. Whether you need an insulating or non-insulating aerial device, telescopic or telescopic articulating, Altec's Green Fleet lineup has what will work for you, with heights up to 66.0 ft. For more information, select the model that fits your application or specifications.

Aerial Devices

Overcenter

A50OC	A55EOC	A55OC	AM50	AM50E	AM55
AM55E	AM60	AM60E	AN46E-OC	AN50E-OC	AN50EOC-E80
AN50OC-E80	AN55E-OC	AN55EOC-E88	AN55OC-E88	L36A	L37M
L42A	L42E	L42M	L44E	L45M	LR752
LR756	LR758	LR760	LR760-E70		

Non-Overcenter

AA50	AA50-E80	AA50E	AA50E-E80	AA55	AA55-E88
AA55E	AA55E-E88	AA60	AA60E	AA67-E100	AA67E
AA67E-E100	AN32E	AN50-E80	AN50E	AN50E-E80	AN55-E88
AN55E	AN55E-E88	AN60E	AN67-E100	AN67E	AN67E-E100

Telescopic

AT200A	AT200A Cutaway Van	AT200AV	AT30G	AT40C

Telescopic Articulating

AT235P	AT237	AT237S	AT248F	AT35G	AT37G
AT37M/P	AT37ME/PE	AT37S	AT40G	AT40M – JEMS	AT40P – JEMS
AT40S	AT41M/P	AT41ME/PE	AT41S	AT48M/P	AT48ME/PE
AT48S	TA37M	TA40	TA41M	TA41M-T46	TA45M
TA45M-T50	TA50	TA50S	TA55	TA55S	TA60
TA60S					

Digger Derricks

D2045B	D2050B	D2055B	D3050E	D3050H	D3055E
D3055H	D3060E	D3060H	D4050B	D4055B	D4060B
D4065B	DC45	DC47	DH45B	DH45E	DH45H
DH48B	DH48E	DH48H	DH50B	DH50E	DH50H
DL42B	DL45B	DM45B	DM47B		

Altec A CLASS Specifications

STANDARD FEATURES

- Altec ISO-Grip® Control System
- Working Heights to 60 ft (27.4 m)
- Side Reach to 48.3 ft (14.7 m) — Non-Overcenter Position to 41.2 ft (12.6 m)
- Unique Hydraulic Leveling System, Accu-Level™ and Platform Tilt
- No Major Scheduled Maintenance Required
- Automatic Upper Boom Stow
- Material Handling Capacity – 1000 lb Minimum in any Non-Overcenter Position
- Designed for Low Life-Cycle Cost
- Designed and Manufactured in ISO 9001 Certified Facility
- Insulated, ANSI Category C, 46 kV and Below
- Lower Boom Insulator
- Boom Stow Protection
- Continuous Rotation
- Positive Hydraulic Leveling
- Positive Hydraulic Platform Tilt
- Continuous Automatic Purging of Upper Controls
- Pilot Operated or Full Pressure Hydraulic System
- Dual Hydraulic Tool Circuits at the Platform with Adjustable Pressure and Flow
- Machine/Ground Control Selector Valve
- Outrigger Motion Alarm
- Outrigger Boom Interlock System
- Back-Up Alarm

RECOMMENDED FEATURES

- Fall Protection System
- Outrigger Pads
- Platform Liner
- Wheel Chocks

REACH DIAGRAM
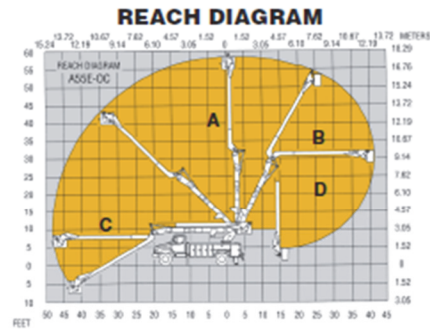
Model	A Platform Height	B Side-Reach Non-Overcenter	C Side-Reach Overcenter	D Platform to Ground
A47-OC	47.3 ft (14.2 m)	31.1 ft (9.5 m)	40.7 ft (12.4 m)	26.8 ft (8.2 m)
A50-OC	49.9 ft (15.2 m)	32.6 ft (9.9 m)	43.3 ft (13.2 m)	28.1 ft (8.6 m)
A55-OC	54.9 ft (16.7 m)	35.5 ft (10.8 m)	48.3 ft (14.7 m)	30.6 ft (9.3 m)
A55E-OC	54.9 ft (16.7 m)	41.2 ft (12.6 m)	48.3 ft (14.7 m)	28.7 ft (8.7 m)

H.2 eDrive Tractors & AutoDrive Autonomous Systems Manufacturer: Autonomous Tractor Company (ATC)

ATC, specializing in system design and third-party collaboration, develops patented retrofit electric drive technology, which claims to make today's tractors two to five times more durable and 20%–40% more fuel efficient. ATC's technology works in diverse applications that require long duty cycles, and its systems run power directly from diesel generators, fuel cells, super capacitors, etc. ATC also develops AutoDrive, an autonomous navigation system for tractors.

ATC is based in Fargo, ND and St. Michaels, MN. The company uses mostly off-the-shelf components, contract manufacturers, and dealers for sales, installation, and customer support.

	eDrive by: ATC	AutoDrive by: ATC
Cost	$500 per horsepower installed	$30,000 (in beta offering)
Application Maturity	Commercially available	Commercially available
Safety		FieldSmart artificial intelligence; associate investigator (AI) systems provide system management and tractor tracking, and systems include fail safes. Systems also use ATC's patented Laser-Radio Navigation System (LRNS), a laser and radio system used to navigate fields and remain in set boundaries.
Extras and Attachments	Includes 1–2 diesel generators, 2 or 4 electric, variable speed wheel motors, and joystick control.	
Operability in Adverse Weather or Conditions	eDrive motors are liquid cooled and totally sealed, making them ideal for use in mud, dust, and high-temperature field conditions.	
Projected Life Span	25,000 hours (50% longer than typical tractor lifespan)	20 years
Comments		
Electric motors drive wheels but power is provided by an onboard diesel generator (high efficiency, though not electric). The generator can be used to support microgrid and installation resilience. The system is implemented through existing tractor conversion or installation on an existing tractor frame.		
While not currently commercially available, ATC is developing Spirit: a prototype tractor that is truly autonomous.		
Also, of note, ATC's first sale of its drivetrain package was to FamilyFarms Group, a farm business consulting group headquartered in St Louis, MO.		
Website	autonomoustractor.com	
Contact	203-993-0828; kraig@atcspirit.com	

H.3 C Series Buses
Manufacturer: BYD

BYD, headquartered in Los Angeles, CA, is the largest EV manufacturer in the world. The company is also one of the largest battery manufacturers worldwide, and its buses are manufactured in a 450,000-square foot facility in Lancaster, CA.

BYD is the automotive subsidiary of the Chinese multinational BYD Co. LTD, which was founded in 2003 and is now based in Xi'an, Shaanxi Province and was founded in 2003.

	HEV Retro-fits		eDrive
	EATON Powering Business Worldwide	ePower	ATC
No Batteries	N	N	Y
No Transmission	N	N	Y
No Differential	N	N	Y
400+ hp	N	Y	Y
Application	Med Duty Trucks	Heavy Duty Trucks	Tractors
Cost	$100k	$100k	$75k

	C6M by: BYD	C8M by: BYD	C9M by: BYD	C10M by: BYD
Cost	Average: $297,000			
Application Maturity	Commercially available			
Charging Time and Capacity	3–4 hours; 40 kW	4.5 hours; 80 kW x 2	4–5 hours; 40 kW x 2	2-2.5 hours; 200 kW
Charging Infrastructure				

	C6M by: BYD	C8M by: BYD	C9M by: BYD	C10M by: BYD
Operation Run-Time Capabilities	Up to 124 miles	Up to 200 miles	Up to 200 miles	Up to 230 miles
Microgrid Connectivity	V2G compatible			
Operability in Adverse Weather or Conditions	Recent press details issues with BYD batteries in cold and hot temperatures: Cities using BYD buses state they underperform in, or perform poorly, in snow and excessive heat.			
Projected Life Span	10–12 years			
Maintenance Requirements	A study conducted by Stanford University on its own BYD electric bus fleet in 2015 showed that maintenance costs between September 2013 and April 2014 was 16–42 cents per mile (in 2016 dollars). A 2016 study conducted by Columbia University found that, in aggregate, maintenance cost savings was as high as 50% per bus.			
Regulations	All BYD buses are Americans with Disabilities Act (ADA) complaint.			
Comments				

Though BYD is an established manufacturer, it has experienced documented performance issues, specifically in regard to the company's stated range versus range actually realized by cities and municipalities that have purchased BYD EVs. The city of Albuquerque found that BYD buses had a range of just 177 miles on one charge (compared with BYD's contractual promise of 275), and the company is now being sued by Albuquerque. The city also claims in its suit that BYD EVs had safety issues, namely door malfunctions, that rendered them unsafe for usage.

Website: en.byd.com/bus/

Contact: info.na@byd.com

H.4 Class 5 & 6 Trucks Manufacturer: BYD

BYD, headquartered in Los Angeles, CA, is the largest EV manufacturer in the world. The company is also one of the largest battery manufacturers worldwide, and its buses are manufactured in a 450,000-square foot facility in Lancaster, CA.

BYD is the automotive subsidiary of the Chinese multinational BYD Co. LTD, which was founded in 2003 and is now based in Xi'an, Shaanxi Province and was founded in 2003.

	Class 5 by: BYD	Class 6 by: BYD
Application Maturity	Commercially available	
Charging Time and Capacity	5 hours AC (40 kW), 145 kWh battery capacity	4.5 hours AC/1.5 hours DC; 221 kWh battery capacity

	Class 5 by: BYD	Class 6 by: BYD
Operation Run-Time Capabilities	155 miles (half load)	124 miles (full load)
Microgrid Connectivity	V2G compatible	
Projected Life Span	10–12 years.	
Maintenance Requirements	BYD testing suggests average maintenance cost per mile is 23 cents per mile. While BYD provides up to 40 hours of driver and preventative maintenance training to fleets purchasing their EVs, the company is in CA, and accessing these services might prove problematic given the geographical distance and lack of local service centers.	
Hauling and Towing Capacity	16,141 GCWR	26,000 lbs. GVWR
Comments		
Though BYD is an established manufacturer, it has experienced documented performance issues, specifically in regard to the company's stated range versus range actually realized by cities and municipalities that have purchased BYD EVs. The city of Albuquerque found that BYD buses had a range of just 177 miles on one charge (compared with BYD's contractual promise of 275), and the company is now being sued by Albuquerque. The city also claims in its suit that BYD EVs had safety issues, namely door malfunctions, that rendered them unsafe for usage. Website: en.byd.com/truck/#models Contact: info.na@byd.com		

BYD Class 6 - Cab Chassis

Dimensions	Length	284.8 in
	Width	88.6 in
	Height	93.9 in
	Wheelbase	167/248 in
	Curb Weight	10,361 lbs
	GVWR	26,000 lbs
Performance	Top Speed	70 mph
	Maximum Gradeability	25%
	Range	124 miles (full-load)
	Approach/Departure Angle	24° / 15°
Chassis	Wheel Rim	20x6.5
	Tires	8.25R20
	Suspension	Front / Rear leaf spring
	Brakes	Front / Rear air disc brakes
Powertrain	Maximum Power	335 hp
	Maximum Torque	1,328 lb • ft
	Battery Capacity	221 kWh
	Charging Power	Up to 150 kW
	Charging Time	4.5 hrs AC / 1.5 hrs DC
	CO_2 Saved Annually	64 metric tons

* J1772 Level II

Note : Numbers are estimates. Precise data available upon evaluation of fleet specifications.

BYD Class 5 - Cab Chassis

Dimensions	Length	284.8 in
	Width	88.6 in
	Height	93.9 in
	Wheelbase	167/248 in
	Curb Weight	10,361 lbs
	GVWR	26,000 lbs
Performance	Top Speed	70 mph
	Maximum Gradeability	25%
	Range	124 miles (full-load)
	Approach/Departure Angle	24° / 15°
Chassis	Wheel Rim	20x6.5
	Tires	8.25R20
	Suspension	Front / Rear leaf spring
	Brakes	Front / Rear air disc brakes
Powertrain	Maximum Power	335 hp
	Maximum Torque	1,328 lb·ft
	Battery Capacity	221 kWh
	Charging Power	Up to 150 kW
	Charging Time	4.5 hrs AC / 1.5 hrs DC
	CO_2 Saved Annually	64 metric tons

* J1772 Level II

Note : Numbers are estimates. Precise data available upon evaluation of fleet specifications.

CHARGING ROADMAP – AC & DC

- Short-circuit protection
- Overheat Protection
- Lightning Protection
- Next gen AC Charger to be J3068 compliant

Charger	40 kW	80 kW	100 kW	200 kW	150 kW DC	300 kW DC
Charging Mode	AC	AC	AC	AC	DC	DC
Input Voltage	480V 3-phase	480V 3-phase	480V 3-phase	480V 3-phase	480V 3-phase	480V 3-phase
Operating Voltage Range	432V-528V 3-phase	432V-528V 3-phase	432V-528V 3-phase	432V-528V 3-phase	456V-504V 3-phase	456V-504V 3-phase
Continuous Input Current	48A	96A	120A	240A	180A	360A
Input Power	40kW	80kW	100kW	200kW	150 kW	300 kW
Frequency	60Hz	60Hz	60Hz	60Hz	60Hz	60Hz
Output Voltage	432V-528V 3-phase	432V-528V 3-phase	432V-528V 3-phase	432V-528V 3-phase	400VDC - 850 VDC	400VDC - 850 VDC
Output Current	48A	48A per coupler	120A	120A per coupler	200A	200A per coupler
Output Power	40kW	40kW per coupler	100kW	100kW per coupler	150 kW	150 kW per coupler
Charging Coupler Type	IEC62196-2	IEC62196-2	IEC62196-2	IEC62196-2	CCS Combo 1	CCS Combo 1 *2
Wires	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground	3 phase; 1 neutral; 1 ground
Width	15.8 x 7.9 x 27.2 in	15.8 x 7.9 x 27.2 in	19.7 x 15.8 x 78.8 in	19.7 x 15.8 x 78.8 in	31.5 x 39.4 x 87.8 in	27.6 x 63 x 78.7 in
Charging Cable Length	10 ft	10 ft	10 ft	10 ft	10 ft	10 ft
Reference Standard	IEC61851/IEC62196	IEC61851/IEC62196	IEC61851/IEC62196	IEC61851/IEC62196	SAE J1772	SAE J1772
Enclosure Protection	IP55	IP55	IP54	IP54	IP54	IP54
Operating Temperature	-22 to +122 F	-22 to +122 F	-22 to +122 F	-22 to +122 F	-22 to +122 F	-22 to +122 F
Operating Humidity	5-95%	5-95%	5-95%	5-95%	5-95%	5-95%

H.5 BYD Class 8 Day Cab
Manufacturer: BYD

BYD, headquartered in Los Angeles, CA, is the largest EV manufacturer in the world. The company is also one of the largest battery manufacturers worldwide, and its buses are manufactured in a 450,000-square foot facility in Lancaster, CA.

BYD is the automotive subsidiary of the Chinese multinational BYD Co. LTD, which was founded in 2003 and is now based in Xi'an, Shaanxi Province and was founded in 2003.

BYD Class 8 Day Cab by: BYD	
Cost	$300,000–$350,000
Application Maturity	Commercially available
Charging Time and Capacity	3 hours AC/1.5 hours DC.; 435 kWh battery capacity
Charging Infrastructure	Up to 300 kW
Operation Run-Time Capabilities	124 (full load), 167 (half load)
Microgrid Connectivity	Compatible
Projected Life Span	10–12 years. A 2018 study from Carnegie Mellon states that the Class 8 trucks have a typical lifetime mileage of 1 million miles.
Maintenance Requirements	BYD testing suggests average maintenance cost per mile is 23 cents per mile. While BYD provides up to 40 hours of driver and preventative maintenance training to fleets purchasing their EVs, the company is in CA, and accessing these services might prove problematic given the geographical distance and lack of local service centers.
Hauling and Towing Capacity	105,000 GCWR
Comments	
Though BYD is an established manufacturer, it has experienced documented performance issues, specifically in regard to the company's stated range versus range actually realized by cities and municipalities that have purchased BYD EVs. The city of Albuquerque found that BYD buses had a range of just 177 miles on one charge (compared with BYD's contractual promise of 275), and the company is now being sued by Albuquerque. The city also claims in its suit that BYD EVs had safety issues, namely door malfunctions, that rendered them unsafe for usage. Website: en.byd.com/truck/ Contact: info.na@byd.com	

Dimensions	Length	217.52 In
	Width	101.57 In
	Height	129.92 In
	Wheelbase	118 In
	Curb Weight	19,800 lbs
	GCWR	102,000 lbs
Performance	Top Speed	32* mph
	Maximum Gradeability	15%
	Range	10+ hours
	Approach/Departure Angle	27° / 33°
Chassis	Wheel Rim	22.5x8.25
	Tires	11R22.5
	Suspension	Front: Leaf spring, Rear: Solid mount
	Brakes	Front / Rear Air drum brakes
Powertrain	Maximum Power	241 hp
	Maximum Torque	1,106 lb • ft
	Battery Capacity	217 kWh
	Charging Power	Up to 200 kW
	Charging Time	3 hrs AC / 1.5 hrs DC
	CO_2 Saved Annually	105.9 metric tons

* Customizable

Note :   Numbers are estimates. Precise data available upon evaluation of fleet specifications.

H.6   K Series Shuttles
Manufacturer: BYD

BYD, headquartered in Los Angeles, CA, is the largest EV manufacturer in the world. The company is also one of the largest battery manufacturers worldwide, and its buses are manufactured in a 450,000-square foot facility in Lancaster, CA.
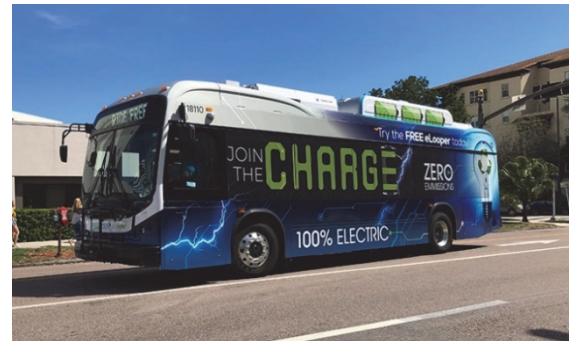
BYD is the automotive subsidiary of the Chinese multinational BYD Co. LTD, which was founded in 2003 and is now based in Xi'an, Shaanxi Province and was founded in 2003.

	K7 by: BYD	K9S by: BYD	K9 by: BYD	K11 by: BYD
Cost	Average: $750,000			
Application Maturity	Commercially available			
Charging Time and Capacity	3–4 hours; 80 kW	2–3 hours; 352 kWh	2–3 hours; 80 kWh	3–4 hours; 200 kW
Operation Run-Time Capabilities	Up to 137 miles	Up to 215 miles (high-capacity)	Up to 156 miles	Up to 220 miles
Microgrid Connectivity	Relying on its own lithium-ion, iron-phosphate battery technology, BYD offers large-scale ESSs, distributed ESSs, and microgrid systems.			
Operability in Adverse Weather or Conditions	Recent press details issues with BYD batteries in cold and hot temperatures: Cities using BYD buses state they underperform in, or perform poorly in, snow and excessive heat.			

	K7 by: BYD	K9S by: BYD	K9 by: BYD	K11 by: BYD
Projected Life Span	Typically, battery lifespan is 6–8 years while bus lifespan is 10–12 years.			
Maintenance Requirements	A study conducted by Stanford University on its own BYD electric bus fleet in 2015 showed that maintenance costs between September 2013 and April 2014 was 16–42 cents per mile (in 2016 dollars). A 2016 study conducted by Columbia University found that, in aggregate, maintenance cost savings was as high as 50% per bus.			
Regulations	All BYD buses are ADA compliant.			
Comments				

Though BYD is an established manufacturer, it has experienced documented performance issues, specifically in regard to the company's stated range versus range actually realized by cities and municipalities that have purchased BYD EVs. The city of Albuquerque found that BYD buses had a range of just 177 miles on one charge (compared with BYD's contractual promise of 275), and the company is now being sued by Albuquerque. The city also claims in its suit that BYD EVs had safety issues, namely door malfunctions, that rendered them unsafe for usage.

Website; en.byd.com/bus/

Contact: info.na@byd.com

H.7   Terminal Tractor
Manufacturer: BYD

BYD, headquartered in Los Angeles, CA, is the largest EV manufacturer in the world. The company is also one of the largest battery manufacturers worldwide, and its buses are manufactured in a 450,000-square foot facility in Lancaster, CA.
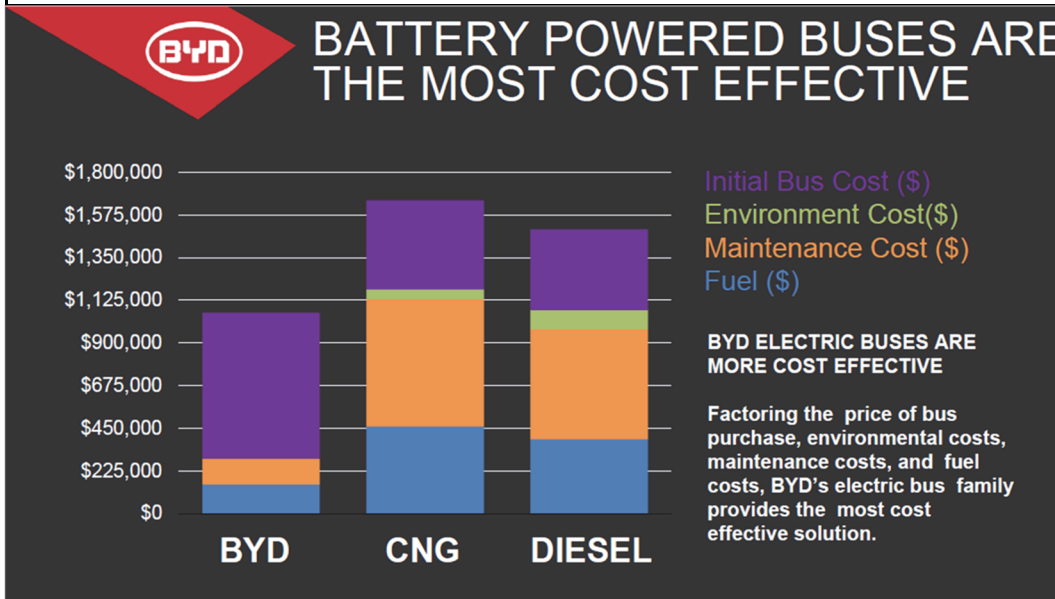

BYD is the automotive subsidiary of the Chinese multinational BYD Co. LTD, which was founded in 2003 and is now based in Xi'an, Shaanxi Province and was founded in 2003.

Terminal Tractor by: BYD	
Cost	$300,000
Application Maturity	Commercially available
Charging Time and Capacity	3 hours AC/1.5 hours DC; 217 kWh battery capacity
Charging Infrastructure	66-kW AC or 120-kW DC
Operation Run-Time Capabilities	10+ hours
Microgrid Connectivity	Compatible
Projected Life Span	10–12 years
Maintenance Requirements	BYD testing suggests average maintenance cost per mile is 23 cents per mile.
Hauling and Towing Capacity	102,000 GCWR
Comments	
Though BYD is an established manufacturer, it has experienced documented performance issues, specifically in regard to the company's stated range versus range actually realized by cities and municipalities that have purchased BYD EVs. The city of Albuquerque found that BYD buses had a range of just 177 miles on one charge (compared with BYD's contractual promise of 275), and the company is now being sued by Albuquerque. The city also claims in its suit that BYD EVs had safety issues, namely door malfunctions, that rendered them unsafe for usage. Website: en.byd.com/truck/ Contact: info.na@byd.com	

H.8 V8100 Refrigerated Van
Manufacturer: Chanje

Chanje Energy Inc., founded in 2015 and based in Los Angeles, CA, is an OEM delivering medium-duty EVs and turn-key energy infrastructure services for the last mile energy. The company is a subsidiary of FDG EVs, the international brand for FDG. In mid-2018, Chanje announced that Ryder would be the exclusive sales channel and service partner for the company and its fleet.
Ryder will offer leasing and preventative maintenance solutions as part of its ChoiceLease and SelectCare fleet maintenance portfolio.

The V8100 is manufactured in Hangzhou, China by FDG.

V8100 Refrigerated Van by: Chanje	
Cost	Ryder's ChoiceLease program offers the V8100 for $999 per month for a 3-year term or $899 per month for a 7-year lease. Pricing includes 1 EV mobile charger by eMotorWerks and four preventative maintenance services annually.
Application Maturity	Ryder serves as the exclusive sales partner for Chanje, offering lease and rental of the V8100. The company states the lease program will be available in "strategic markets" throughout 2019. That said, FedEx purchased 100 V8100's from Chanje in November 2018.
Charging Time and Capacity	10 hours or 80% at 1 hour for DC Fast; 100 kWh
Charging Infrastructure	13.2-kW onboard charger, Level 2 and DC Fast
Operation Run-Time Capabilities	150 miles
Hauling and Towing Capacity	6,000 lbs. payload/16,535 GVWR, 675 cu. ft. storage
Comments	
The V8100 is built to meet the specific needs of the last mile industry.	
Website chanje.com/vehicles/	
Contact info@chanje.com	

H.9 Mobile Power Station (MPS) Manufacturer: Dannar

Dannar is an OEM of mobile, off-road energy platforms for the U.S. govern-mental market. Dannar is located in Clemente, CA; San Jose, CA; and Muncie, IN (where it is also manufac-tured). The company currently offers the Dannar 3.00, a base configura-tion that comes with standard two 33-kWh BMW i3 lithium-ion battery packs (66 kWh total), which can be upgraded to four packs for a total of 132 kWh onboard electricity. The Dannar 4.00 base configuration comes standard with three 42-kWh BMW i3 lithium-ion battery packs (126 kWh total); the Dannar 4.00 can be up-graded with up to nine additional packs for a total of 504 kWh of onboard electricity. The Dannar 4.00 is built on a heavy-duty steel ladder frame and can be ordered with or without an operator cab or platform.

	Dannar 3.00 by: Dannar	Dannar 4.00 by: Dannar
Cost		
Application Maturity	Commercially available	Commercially available
Safety	Light bar comes standard	Light bar comes standard
Extras and Attachments	Optional open operator cab platform equipped with joystick, foot pedal, and touchscreen tool control. Base model is equipped with universal quick mounting plates that can receive CAT, Bobcat, or John Deere attachments, and an optional Cummins Tier IV generator (60 kW) is available. Submersible up to four feet and carries Type I, II, and III hydraulic tool circuits. Four-wheel, multi-mode steering. At minimum, Dannar 3.00 and 4.00 microgrids can charge two Tesla EVs or operate for 8–10 hours on site. At max, systems offer enough energy to power nearly 17 houses for 24 hours.	Export panel is configurable with multiple 110-VAC and 208-VAC outlets. The base model comes standard with dual flat beds and can accommodate scissor lifts, forklift masts, dump beds, water tanks, electric water pumps, portable light units, or mobile telescoping cell towers. Can accommodate all standard Caterpillar, Bobcat, and John Deere attachments. Its submersible up to 4 feet. Carries Type I, II, and II hydraulic tool circuits, four-wheel drive, and four-wheel multi-mode steering. At minimum, Dannar 3.00 and 4.00 microgrids can charge two Tesla EVs or operate for 8-10 hours onsite. At max, systems offer enough energy to power nearly 17 houses for 24 hours.
Operability in Adverse Weather or Conditions	eDrive motors are liquid cooled and totally sealed, making them ideal for use in mud, dust, and high-temperature field conditions.	
Projected Life Span	25,000 hours (50% longer than typical tractor lifespan)	20 years
Communication	Operator cab, operator platform, or fully remote for distance safety. TBD wireless supervision–"follow me" and autonomous operation in development.	

	Dannar 3.00 by: Dannar	Dannar 4.00 by: Dannar
Charging Time and Capacity	Up to 504 kWh of battery storage	
Charging Infrastructure	Base unit–DC Fast charge capable (CCS2 Combo), roadmap to 500 kW inbound	
Microgrid Connectivity	Up to 504 kWh of battery storage Optional 60-kW hydrogen-fuel cell Optional multi-fuel 60-W gen set V2G compatibility Mobile, off-grid power source	
Operability in Adverse Weather or Conditions	Designed for disaster relief; vehicles can function in wet conditions.	
Climate and Geographical Restrictions	Climate limitations not described in terms of temperature—can function in up to 4 feet of water.	
Environmental Risks	System is zero emission (electric) and designed for use in various disaster relief scenarios.	
Off-road Capabilities and Limitations	Rugged MPS units able to be deployed safely. Heavy-duty, water submergible to 4 feet, work tools can be attached for clearing debris.	
Current Automation Capabilities	Operate by onboard cab, X-box style remote control or TBD wireless supervision—"follow me" and autonomous operation in development.	
Future Automation Capabilities	Dannar is currently working to develop follow-the-leader autonomous function.	
Comments		

Features, specs, and industry examples in airports, agriculture, first responders, public works, universities, and warehouses here.

Website: dannar.us.com

Contact: 765-216-7191; Contact Don Gonneville for GSA sales at 949-248-7297 or sales@gonneville.com

H.10 Ebus
Manufacturer: Ebus, Inc.

Founded in 1998, Ebus is based in Downey, CA and develops electric bus technology. The company's electric propulsion system consists of a proprietary oil-cooled traction motor, a liquid-cooled traction converter, and an advanced liquid-cooled nickel-manganese-cobalt 89-kWh battery system composed of 320 cells, which are manufactured in Midland, MI, by Dow Kokam LLC. Ebus's systems allow for a diesel or CNG bus to be retrofitted as a battery-electric bus via a pre-engineered conversion kit.

Ebus utilizes a fully integrated fast-charge system for its buses called Gamma. Fast charging en route allows buses to operate all day, and the Gamma-IP is based on the Gamma self-contained fast-charge station. It was redesigned for a top down Inverted Pantograph and complies with OppCharge and the SAE J-3105 Overhead Charging Standard.

Ebus by: Ebus	
Cost	$395,000
Application Maturity	The Ebus22 is currently commercially available, and the Ebus Composite bus became available for delivery in 2019-2020.
Charging Time and Capacity	6 hours; 300kWh lithium-iron-phosphate battery
Charging Infrastructure	Ebus's utilize both fast and opportunity charging systems, known as BS&CS and Gamma-IP, respectively. The former allows for removable batteries to be swapped out via a "station" roughly every 4 hours, and the latter system, with 45- kW peak-charging power, is a self-contained fast-charge station, which is designed for a top down IP. The company maintains that installation of the Gamma-IP system is simple and inexpensive, requiring only a small concrete pad with J-bolts and a 480-V 3-phase power source located under the pad. Ebus's can also be charged via a concealed conductive charger connection (4C) for in-ground 450-kW fast charging.
Operation Run-Time Capabilities	125-mile range from nightly charge.
Projected Life Span	7 years/200,000 miles
Maintenance Requirements	A 2006 case study from the National Renewable Energy Laboratory (NREL) found that the average parts and maintenance cost over the course of a year was 88 cents per mile.

Comments
The Ebus propulsion system and charging technology can be ordered from OEM bus suppliers. Retrofitted systems include electric motor and battery and charging systems. The systems provide a repurposing alternative resulting in vehicles configured to specific uses.
The Ebus automated Battery Swap and Charging Station system allows for the bus's removable 2000-pound battery to be removed and swapped out from above in less than one minute. The company states that the BS&CS accommodates batteries for up to 24 buses, making it a more effective charging system than fast charging.
Website: ebus.com/
Contact: 562-904-3474 or 888-925-4263; sales@ebus.com

H.11 ZeroTruck Medium-duty Trucks Manufacturer: Electrorides, Inc.

Founded in 2008, ZeroTruck manufactures all-electric medium-duty trucks with advance regenerative braking systems. The company is located in Santa Ana, CA. All vehicles are delivered to the customer via dealers. ZeroTruck's parent company is Electrorides, Inc., based in Laguna Niguel, CA.

ZeroTrucks are Class 4 or 5, based on the Isuzu NPR, feature the company's Electric Drive Integration System: proprietary
battery modules using lithium-polymer cells. The battery packs are liquid cooled and single-speed, 3-speed, and 6-speed transmissions are offered.

ZeroTruck Medium-duty Trucks by: Electrorides, Inc.	
Cost	Approximately: $126,000
Charging Time and Capacity	Full charge: 20 hours Battery: 53 kWh and 80 kWh
Charging Infrastructure	Level 2 and 3
Operation Run-Time Capabilities	150 – 200 miles per charge
Projected Life Span	Battery: 10 years
Hauling and Towing Capacity	12,000 – 16,000 GVWR
Comments	
Zero Truck offers the following zero-emissions vehicles listed by division: • Airport Division: lav service, flatbed, utility, refuse, water service, and sweeper • Campus Division: stake bed, sweeper, landscaper, utility, refuse, and dump • Facilities Maintenance Division: stake bed, dump, refuse, landscaper, bucket lift, sweeper, and utility • Parks and Recreation Division: stake bed, sweeper, landscaper, utility, refuse, and dump • Sanitation Division: stake bed, sweeper, utility, container delivery, and refuse • Traffic Division: stake bed, sweeper, utility, wheel lift, and flatbed Website: zerotruck.com/our-fleet/ Contact: 714-675-7117; info@zerotruck.com	

SPECIFICATIONS

					ZT std	ZT Optional Heavy Duty Chassis
Chassis						
• Wheelbase	109"	132.5"	150"	176"		(same as standard ZT)
• Cab to Axle	86.5"	110"	127.5"	153.5"		"
• Cab to End of Frame	129.6"	153.1"	170.6"	196.6"		"
• Overall Length	200.5"	224"	241.5"	267.5"		"
Body Length (ft.)	10-12'	14'	16-18'	20'		

GVWR/GCWR	12,000/18,000 lbs.	19,500/20,500 lbs.
Body/Payload Allowance (with body)	6000 lbs.	7000 lbs.

GAWR		
• Front	4,700 lbs.	5,360 lbs.
• Rear	7,950 lbs.	9,880 lbs.
• Front Axle Capacity	6,830 lbs.	
• Rear Axle Capacity	11,020 lbs.	
• Rear Axle Ratio	4.777	5.125

Suspension, Front & Rear	
• Type Tapered/Multi-Leaf	
• Front Suspension Capacity	8,440 lbs.
• Rear Suspension Capacity	9,880 lbs.

Model Description	ZT base	ZT Optional Heavy Duty

Service Brakes
- System Vacuum/Hydraulic
- Front Disc
- Rear Drum
- Gearbox ZT VR2E (single, multi-speed)

Tires
- Goodyear® G647 RSS 245/70R 19.5" 14-ply
  225/70R-19.5F (12 Ply)

Steering
- Integral Hydraulic Power Steering Column
- Tilt & Telescopic
- Heat & Air Conditioning (std)

Motor
- Advanced liquid cooled brushless 150kW   480 ft/lbs torque

Battery Pack
- Lithium standard
- Optional Charger - 70kW - 208v on-board charger

RANGE
- 70-75 miles City driving (dependent on payload and driving style, Optional to 125 miles City)

Warranty
- 3 year

Optional V2G
- Available now

H.12 CXR-52 and CRX-60 Mowers
Manufacturer: Mean Green Mowers

Based in Ross, Ohio, Mean
Green Mowers manufactures
electric mowers that are quiet,
produce zero emissions, require
minimal maintenance, and pay
for themselves in fuel savings.
All mowers are manufactured in
the United States.

Mowers are manufactured from
aluminum alloys, high-strength steel, lightening holes, and modern bend-
ing technologies. The company's mower designs are patented, as is its lith-
ium-battery technology.

CXR-52 and CRX-60 Mowers by: Mean Green Mowers	
Cost	$19,530
Application Maturity	Commercially available
Safety	Roll over protection system, optional LED orange flashing light
Extras and Attachments	Aluminum grass catcher, rear-discharge mulching deck, debris blower, 3-kW converter, SAM system, a flexible canopy that attaches to the CRX and provides solar power; 200W charge to batteries.
Charging Time and Capacity	8–12 to full charge
Charging Infrastructure	240V
Operation Run-Time Capabilities	2–3 green-lithium-LEM48140 batteries, battery options enable from 2 hours to 7 hours of mowing time/12 acres
Performance	Built to perform on sloping hills with cutting heights of up to 5 inches
Projected Life Span	6,000–9,000 mowing hours on LEM battery
Comments	
Mean Green Mowers' smaller units are in line with smaller scale mowing requirements. Through multiple units, the company could provide sufficient coverage for large acres. Autonomous-system might yield cost savings benefit for installation management but might not be sufficient to provide substantial power for microgrid. Website: meangreenproducts.com/cxr5260/ Contact: 513-738-4736	

H.13 Nemesis NXR-48/52
Manufacturer: Mean Green Mowers

Based in Ross, Ohio, Mean Green Mowers manufactures electric mowers that are quiet, produce zero emissions, require minimal maintenance, and pay for themselves in fuel savings. All mowers are manufactured in the United States.

Mowers are manufactured from aluminum alloys, high-strength steel, lightening holes, and modern bending technologies. The company's mower designs are patented, as is its lithium-battery technology.

Nemesis NXR-48/52 by: Mean Green Mowers	
Cost	Starts at $11,925 for the 48" deck/LEM4880 battery model; $12,599 for the 52" deck/LEM48140 battery
Application Maturity	Commercially available
Safety	Roll over protection system, operator blade speed warning system, optional LED floodlight, and orange flashing light
Extras and Attachments	Optional Rite-Ride suspension, 48" or 52" heavy-gauge welded aluminum deck, optional 200W solar flex panels, optional 3-kW converter. Mean Green Mowers also offers a Solar Assisted Mower, an array of solar panels that attaches to the mower. The SAM system is eligible for a 30 percent Federal Solar Tax Credit, and energy collected by the system is immediately converted to power to assist in mowing operation.
Charging Time and Capacity	3–6 hours to complete charge
Charging Infrastructure	10A charger or optional 25A fast charger
Operation Run-Time Capabilities	LEM4880 green-lithium battery allows for 1.5 hours/3 acres mowing time and for 2.5 hours / 5 acres mowing time
Projected Life Span	green-lithium batteries last 1500–3000 mowing hours
Comments	
Mean Green Mowers' smaller units are in line with smaller scale mowing requirements. Through multiple units, the company could provide sufficient coverage for large acres. Autonomous-system might yield cost savings benefit for installation management but might not be sufficient to provide substantial power for microgrid. More information here. Website: meangreenproducts.com/nxr4852/ Contact: 513-738-4736	

Deck Size	48" or 52"	Speed	up to 8.5 mph
Voltage	48 Volts	Operational Savings/hour	$5.00/hour
Batteries (LEMs)	1 each LEM4880 1 each LEM48140	Lithium Energy Module (LEM) Life	1500-3000 mowing hours
Weight	655-710 lbs.	EMISSIONS	ZERO
Mow Time/ Charge	1 each 4880: - 48" 1.5 hrs / 52" 1.25 hrs 1 each 48140: - 48" 2.5 hrs / 52" 2.25 hrs	Sound Level	75db - NXR 48" 77db - NXR 52"
Blades/ Deck	3 each	Peak Horsepower	24 HP
Recharge Time	3-6 hrs. Complete charge	Fuel/ Oil	ZERO

*Varies with terrain, operator performance, and grass conditions

STANDARD EQUIPMENT

- Side Discharge Deck
- Custom Lumber Comfort Seat
- No Flat Front Wheel
- Drive Speed Control System
- Cup Holder
- Electronic Deck Lift System
- High/Low Blade Speed Control
- Dual Support Anti-Scalp Wheel Mounts
- Rollover Protection System

OPTIONS & ACCESSORIES

- 52" Side Discharge Deck Upgrade
- Side Aluminum Grass Catcher
- Dual LED Floodlight Kit with USB Port
- Front Suspension Yokes
- 200W Solar Package
- 3KW Inverter
- Monster Mode
- ORV-BLAST Package
- LED Orange Flashing Light
- S.A.M. Solar Canopy

Two Year Limited Mower Warranty And Three Year Limited Battery For Residential & Commercial Use

H.14 SK-48 Stalker
Manufacturer: Mean Green Mowers

Based in Ross, Ohio, Mean Green Mowers manufactures electric mowers that are quiet, produce zero emissions, require minimal maintenance, and pay for themselves in fuel savings. All mowers are manufactured in the United States.

Mowers are manufactured from aluminum alloys, high-strength steel, lightening holes, and modern bending technologies. The company's mower designs are patented, as is its lithium-battery technology.

SK-48 Stalker by: Mean Green Mowers	
Cost	Approximately: $18,000
Application Maturity	Commercially available
Safety	Optional LED orange flashing light
Extras and Attachments	LED floodlight kit with a USB port, aluminum grass catcher, rear-discharge mulching deck, debris blower, 3-kW inverter
Charging Time and Capacity	2.5 hours for full charge (240V)
Charging Infrastructure	25A (110V) or 35A (220V) 8-hour charger, optional LEMC-1548 overnight charger, or LEMC2548 fast charger
Operation Run-Time Capabilities	3.25 hours via one LEM48140 battery, 7 hours via two LEM48140; 1 LEM48112 battery, additional batteries can be added to increase run-time
Projected Life Span	Battery: 9,000 hours
Comments	
Mean Green Mowers' smaller units are in line with smaller scale mowing requirements. Through multiple units, the company could provide sufficient coverage for large acres. Autonomous-system might yield cost savings benefit for installation management but might not be sufficient to provide substantial power for microgrid.	

Website: meangreenproducts.com/sk48-stalker/

Contact: 513-738-4736

Deck Size	48"	Speed	8 mph
Voltage	48 Volts	Operational Savings/hour	$6.00/hour
Batteries (LEMs)	1-2 each LEM48140	Lithium Energy Module (LEM) Life	6000-9000 mowing hours
Weight	730-845 lbs.** **depending on the number of batteries	EMISSIONS	ZERO
Mow Time/ Charge	1 each LEM48140- 3.25hrs* 2 each LEM48140- 7hrs*	Sound Level	76db (gas engines twice as loud 90-95db)
Blades/ Deck	3 each	Peak Horsepower	24 HP (wheel drives peak torque 644 lb/ft)
Recharge Time	4-10 hrs. (240V) Complete charge	Fuel/ Oil	ZERO

*Varies with terrain, operator performance, and grass conditions

STANDARD EQUIPMENT

- Side Discharge Deck
- No Flat Front Tires
- 7 Gauge Steel Deck Chassis/Deck Design
- "Easy Adjust" Deck Height System
- Drive Speed Control System
- High/Low Blade Speed Control
- Dual Support Anti-Scalp Wheel Mounts

OPTIONS & ACCESSORIES

- Rear Discharge Mulching Deck
- Aluminum Grass Catcher
- LED Floodlight Kit with USB Port
- 3KW inverter
- LED Orange Flashing Light
- QTXN Debris Blower

Two Year Limited Mower Warranty And Three Year Limited Battery For Residential & Commercial Use

H.15 Reckless UTV
Manufacturer: Nikola

Nikola designs and manufactures EVs, vehicle components, ESSs, and EV drivetrains. The company was founded in 2014 and is based in Phoenix, AZ.

The Reckless UTV is a militarized version of Nikola's NZT off-road utility vehicle and is suited for combat, reconnaissance, and prime mover roles. The UTV is based on a 4x4 chassis and can slip into a 2x4 drive system based on mission requirement. It can accommodate four crew members and has the power capacity to support weapons systems and power command centers. The UTV, which has a low thermal signature, operates with four motors—in the event one fails, Reckless can still operate at high performance.

Reckless UTV by: Nikola	
Cost	$85,000
Application Maturity	Available in 2021
Safety	LED high/low, integrated signature light and SAE J588 turn signal, red LED tail, turn, and brake lights
Extras & Attachments	A remote weapon system with a 12.7-mm machine gun is mounted atop the Reckless. The UTV also features automatic grenade launchers and 0.3- and 0.17-m display monitors, which display mission information and enhance the driver's situational awareness. A 4-kW DC charger powered by solar energy is optional.
Charging Time and Capacity	Battery capacity: 75 kWh, 100 kWh, or 125 kWh lithium-Ion battery pack DC Fast: 2 hours 240V to J1772: 15 hours EV ARC: 19 hours
Charging Infrastructure	DC Fast, 240 V to J1772 charging, or EV ARC solar station charging
Operation Run-Time Capabilities	100–200 miles
Performance	Waterproof, instant torque, direct drive, low center of gravity
Operability in Adverse Weather or Conditions	The Reckless has an IP67 rating—all parts can be submerged, and the UTV does not need air to operate.
Stealth Capabilities	Incredibly low noise level, low heat signature
Off-Road Capabilities and Limitations	Off-road capable, on demand 2x4 and 4x4. Tires are 35-inch Kevlar reinforced.

Reckless UTV by: Nikola	
Hauling and Towing Capacity	1,4000-lb. payload capacity. Tow hitch enables the chassis to tow objects weighing up to 3,000 lbs. Front- and rear-mounted winches can be used to pull up to 10,000 lbs.
Current Automation Capabilities	Weapons system is autonomous, and the Reckless features a Planck AeroSystems system that allows drones to take off and land autonomously on moving vehicles without GPS guidance. The platform can also be used for medical evacuations. The Reckless can be remotely controlled using a 3D vision system.
Comments	

The Reckless has been off-road tested at Camp Pendleton and the USMC Air Ground Combat Center at Twentynine Palms, CA. Nikola plans to work with the DoD to add a hydrogen-fuel cell to the Reckless and is working with Envision Solar on portable battery banks.

The Reckless UTV was built via a contract between Sofwerx and Nikola to "develop a roadmap and demonstration of autonomous and mixed-autonomy capabilities."

Website: nikolamotor.com/reckless

Contact: 559-464-5652

H.16 T-Series Yard Truck/Hostler Manufacturer: Orange EV

Orange EV, based in Riverside, MO, builds, sells, and services industrial EVs. The company is the leading OEM providing industrial fleets with heavy-duty EV solutions. Orange EV's terminal trucks are purpose-built to site requirements, and the company states its technology increases energy efficiency compared to traditional diesel systems by over 400 percent.

Orange EV's trucks utilize a web-based telematics system that provides instant feedback, real-time performance statistics, and hard data, which enables fleets to understand system status, fuel efficiency, and cost savings.

T-Series Yard Truck/Hostler by: Orange EV	
Cost	$244,950–$284,950 (new, 2016); $199,950–$239,950 (re-manufactured, 2016). Subsidies are available.
Charging Time & Capacity	2- or 4-hour fast charge. Orange offers two battery packs: 80-Kw hour and 160-kW hour. The company matches charging rates to the customers' duty cycles and usage patterns.
Charging Infrastructure	Offboard, standard charging cabinet (440–480 VAC, up to 22-kW charging capacity) or offboard, fast-charging cabinet (440–480 VAC, up to 80-kW charging capacity).
Operation Run-Time Capabilities	Commercially deployed and tested Orange EV trucks are working more than 24 hours on a single charge. Trucks can run for up to 100 miles between charges.
Operability in Adverse Weather or Conditions	While cold weather is a concern with regard to charging, Orange builds in extra battery capacity for cold climates and conditions.
Maintenance Requirements	All Orange EV trucks are sold with a warranty that includes onsite warranty service. The company also offers additional preventative maintenance and non-warranty repair.
Off-Road Capabilities & Limitations	Appropriate for non-plated, in yard use.
Hauling & Towing Capacity	81,000 lbs. GCWR
Regulations	Exempt from Tier 4 emission controls.
Comments	
Orange EV, which has been collecting real-world operating data since 2015, has shown that typical distribution operations report savings up to $40,000 per truck annually in fuel, maintenance, and emission control. Orange has also demonstrated increased safety through its data collection. Further, Orange trucks reduce emissions by 1.7 tons of nitrogen oxides, 1.6 tons of carbon monoxide, 180 pounds of particulate matter, and 166 tons of carbon dioxide (per 6,000 operating hours).	
Orange EV produces two versions of a heavy hauler. While systems can be used on roads, top speed maxes out at 25 mph. Vehicles are Missouri-built, and the company can retrofit older diesel frames to electric, resulting in a potential cost savings of approximately $50,000.	
Website: orangeev.com/	
Contact: 866-688-5223 x702; mikes@orangeev.com	

Deployed Industry Segments

- **Rail Intermodal**   In use with top ramp operators and railroads
- **Seaport**   Supporting California Ports of LA, Long Beach and Oakland
- **Parcel**   The sorting operations of global brand leaders
- **Global Retail Distribution**   The big boxes
- **LTL Freight**   The largest, busiest break-bulk sites
- **3PL firms**   Global leaders and regional firms alike
- **Manufacturing**   Global and regional consumer brand leaders and commercial brands
- **Spotting**   Innovative firms electrifying and optimizing yard management
- **Waste Mgt**   Municipal waste transfer sites
- **Warehouse/DCs**   McDonald's distribution network (NALC) as well as national and regional logistics firms

ORANGE EV TRUCKS: OWNED AND OPERATED ACROSS SITES AND FLEET TYPES

BUILT TO SITE SPECIFICATIONS

Single axle (4x2) with GCWR of 81k LB up to 25 MPH. Major configurations include:

Truck:
- New
- Remanufactured

Battery:
- Standard   80 kWh
- Extended   160 kWh

Charging:
- Standard   15-22 kW per hour
- Fast   80 kW per hour

DOT:
- Off-road
- On-road (DOT compliant)

H.17 Zeus
Manufacturer: Phoenix Motors

Based in Ontario, Phoenix Motors was founded in 2003. The company develops light- and medium-duty EVs for the service and government fleet markets. Phoenix is a wholly owned subsidiary of AYL, a privately held company based in Dubai, UAE.

Phoenix's Zeus models are built out from Ford chassis' and the company maintains a scalable second-stage production line in the United States for their initial production activities, including the development and manufacturing of the Phoenix Drive System and its components. The company's R&D facility is located in Chino, CA.

	Electric Shuttle by: Phoenix Motors	Electric Flatbed by: Phoenix Motors	Utility Vehicle by: Phoenix Motors
Cost	Approximately: $290,000		
Application Maturity	Commercially available		
Safety	All vehicles have an ADA-compliant option.		
Charging Time and Capacity	J1772 Lvl II: 8–9 hours; DC fast: 3–4 hours		
Run-Time Capabilities	Up to 110 miles	Up to 100 miles	Up to 100 miles
Microgrid Connectivity	V2G capable		
Regulations	Phoenix's Zeus models are currently undergoing testing at Altoona to receive its FTA certification, which is expected to happen no later than May 31, 2020.		
Comments			
In 2005, **Phoenix delivered a Zeus flatbed** to the Naval Base Ventura County Port Hueneme, CA, and a large number of Phoenix buses was scheduled for delivery in 2019, including 29 for the EPA-funded South Coast Air Quality Management District project to electrify shuttles across key airports in Southern California. The Zeus shuttle was among **GSA's FY19 Electric Offerings.** Website: phoenixmotorcars.com/ Contact: 909-987-0815; info@phoenixmotorcars.com			

MANUFACTURING

➢ Phoenix Motorcars maintains a scalable second-stage production line in the US for our initial production activities, including the development and manufacturing of the Phoenix Drive System and its components.

Headquarters & Factory
401 S. Doubleday Av.
Ontario, CA 91761

R&D Facility
13737 Amarillo Av.
Chino, CA 91710

➢ We are also launching manufacturing operations in Dubai, UAE through our parent company, Al Yousuf, LLC.

Shuttle Bus

Flatbed Truck

Utility Truck

CUSTOMIZABLE CONFIGURATIONS
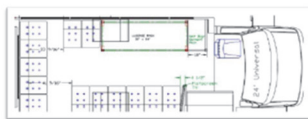
➢ 13 Passengers, Perimeter, 80" Luggage Rack
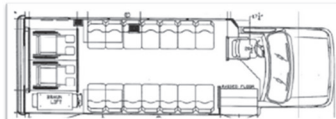
➢ 14 Passengers, Perimeter Rear Lift, 2 Wheelchair Positions
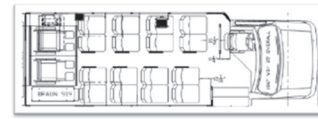
➢ 16 Passengers, Fwd Facing Rear Lift, 2 Wheelchair Positions

H.18 Sherpa 100ECO Mini Skid-Steer Loader Manufacturer: Hanenberg Materiel B.V.

Hanenberg Materiel B.V. is based in the Netherlands.

The ECO100 is a 76-cm wide mini skid-steer powered by a 2-HP front-mounted electric motor. A 360-Ampere battery powers the mini skid-steer.

Parameter	Value
Cost	$32,995
Application Maturity	Commercially available
Extras and Attachments	Optional bucket, volume bucket, 4-1 bucket, bucket with grab, hydraulic manure forks, weed brush, slab bucket, pin bucket, pallet forks, snow push/feeding scraper, hydraulic snow push, trailer coupling, lifting arm, mast with electric wench, levelling framework, broom, roller broom, hydraulic earth drill, demolition hammer, hydraulic trencher, hydraulic tile/curb clamp, hydraulic stone clamp, hydraulic tree grapple, hydraulic curbstone clamp, dumper, and hydraulic concrete mixer attachments available.
Charging Time and Capacity	Overnight charging Battery capacity: 360 Ah
Charging Infrastructure	Standard 110-volt outlet
Operation Run-Time Capabilities	Up to 8 hours
Regulations	OSHA-approved for indoor and outdoor use
Current Automation Capabilities	The Sherpa 100EHD is fully remote-control capable.
Comments	
There is only one authorized Sherpa dealer in the United States: Triple E Equipment, located in Pompano Beach, FL. Website sherpaminiloaders.com/eng/models/sherpa-100-eco/ U.S. dealer: e3equipment.com/ Contact: Dealer: 954-978-3440	

Technical data

Engine

Type: DC Motor (brushless)	
Capacity (kW/HP):	1,5/2
Revolutions per minute (rpm):	1800

Drive system

Hydraulic through 2 hydraulic wheel motors

Speed (mph):	**0-4**

Capacity data

Breakout force (lbs):	1851
Tractive force (lbs):	1230
Hydraulic drive system (psi):	2756
Hydraulic tank capacity (gal):	11

Tipping load in straight position on LCD point ( )

Pallet forks with weight low :	771
Pallet forks with weight high :	486
Bucket with weight low :	770
Bucket with weight high :	484

Tires:	**4.00x10**

Brakes

Service brake: Hydrostatic on 2 rear wheels / 2 front wheels through chain transmission

Steering

Type: Skid steering

Electrical system

Battery type: Traction battery	
Voltage (V):	24
Battery capacity (Ah):	360
Kerb weight (lbs):	1591

H.19 eUtility & eFarmer Tractors Manufacturer: Solectrac

Solectrac, based in Albion, CA., manufactures tractors that provide portable power, home power, water pumping, and other mechanical functions including hauling and transportation needs. Solectrac batteries can be charged directly by clean renewable

energy or at a low cost from the electric utility grid at off-peak rates. Quick change battery packs extend operational periods.

	eUtility	eFarmer
Cost	$45,000	$45,000
Application Maturity	Available on a first-deposit basis, commercially available 2020	Available in 2020
Extras and Attachments	Accepts all Category 1-540 rpm PTO implements on rear hitch. Front loader option available for $10,000.	Can accommodate all Category 1 implements, with the exception of those requiring hydraulics. A hydraulic pump for legacy implements can be added for an additional cost. Can also accommodate front-mounted implements, such as a reaper or low lift loader bucket.
Charging Time and Capacity	Level 2 fast for 80 percent charge in 3 hours/full charge overnight; 26-kWh battery pack	3-hour quick charge for one pack, overnight slow charge for two packs
Charging Infrastructure	240 VAC–30A	
Operation Run-Time Capabilities	5–8 hours, depending on load	4–8 hours with onboard battery pack. Additional battery packs may be added to extend run-time.
Projected Life Span	Battery: 10 years (3000 cycles at 80 percent DoD) Tractor: 80,000 hours	Battery: 10 years (3000 at 80 percent DoD) Tractor: 80,000 hours
Comments		
eUtility		eFarmer
Exchangeable 26-kWh battery packs for the eUtility are available. Can be ordered with either 12 or 18 inches of ground clearance, the former of which is suitable for steep slopes. Can accommodate snow blower attachment.		Exchangeable 26-kWh battery packs will be available. 2020 model is 2WD, but future models will be 4WD compact. Standard 18 inches of ground clearance, suitable for gentle slopes. Can accommodate snow blower attachment.
Website: eFarmer: https://www.solectrac.com/efarmer // eUtility: https://www.solectrac.com/eutility		

eUtility

Motor

Horsepower (HP)	25HP (Peak 50HP)
Type	Brushless, 3-Phase, AC Induction
Gross Power: HP (kW)	24 (32.22 kW)
RPM (Max)	2300 RPM
Max Working RPM	2000 RPM
Service Life	80,000 Hours

Battery / Run-time

On-board battery	20 kWh
Type	Fast Charging, Lithium Iron Phosphate
Run-time	3.5 to 5.5 Hours
Battery Life	10 Years (depending on operating cycles and depth of discharge, 3000 cycles @ 80% DOD)

Dimensions (Inches)

Length	115"
Width	64"
Height - Shipping	66"
Height - Max (ROPS)	92-1/2"
Track	52"
Ground Clearance (Min)	20"
Tires - Front	750 x 16 - 30-1/2"
Tires - Rear	12..4 x 28 - 49"

Weight

Gross Weight (ROPS)	4400 lbs

Power Take Off (PTO)

540 PTO	Category 1
Motor RPM	2000 RPM
Gross Power	21.6 HP (28 kW)
Accepts all Category 1 Implements	

3 Point Hitch

Electric Actuators	48 Volt, 12" Stroke (actuators replace hydraulics)
Lifting Force	1000 lbs Dynamic, 3000 lbs Static

Transmission / Drivetrain

4 Gear with High/Low
8 Speeds, Forward & Reverse
2-Wheel Drive

Battery Management System (BMS)

Charger	240 VAC, 30 Amps
Charge Rate	Up to 80% in 3 Hours
Integraged BMS protects batteries during charge and discharge.	

Traveling Speeds

Forward MPH	Low (1/4), High (20)

Pricing

Base Price	$40,000
Warranty	2 Years

Appendix I: Autonomous Vehicle OEM and Kit Manufacturers

	AV FIRM	U.S. Firm	State/ Country	OEM or Kit	Cars, Trucks, or Other	Website
1	Almotive Inc.	N	Hungary	KIT	Cars/Vans	https://aimotive.com
2	Amazon Web Services	Y	WA	AI/ML	Yes	https://amzn.to/2GtDH2a
3	Ambarella Corporation	N	China, Japan, US, EU	Computer Vision	Yes	https://www.ambarella.com
4	Apex.AI					https://www.apex.ai
5	Apple Inc.	Y	CA	TBD	TBD	https://www.drive.ai
6	Argo AI, LLC	Y	PA	KIT	Cars	https://www.argo.ai
7	Aurora Innovation	Y	PA	KIT	Yes	https://aurora.tech
8	AutoX Technologies Inc.	Y	CA	KIT	Yes	https://autox.ai
9	Baidu USA, LLC	N	China	KIT	Yes	http://usa.baidu.com/adu/
10	BMW	N	Germany	OEM	Yes	https://bit.ly/2BdM6EN
11	Bosch	N	Germany	KIT	Yes	https://bit.ly/2JslDrD
12	Boxbot Inc.	Y	CA	KIT	Vans and delivery robots	https://www.boxbot.io
13	CarOne, LLC	Y	CA	KIT	Custom	https://www.udelv.com
14	Changan Automobile	N	China	OEM	Yes	http://www.globalchangan.com/index.html
15	Continental Automotive Systems Inc.	N	Germany	KIT	TBD	https://bit.ly/2Hej4ad
16	CYNGN Inc.	Y	CA	KIT	Custom	https://www.cyngn.com
18	Deka Labs	Y	NH	KIT	Specialized	http://www.dekaresearch.com/
19	Delphi Automotive (Now Aptiv)	N	Ireland	KIT	Yes	https://bit.ly/2P0JOl3
20	DiDi Research America, LLC	N	China	KIT	TBD	www.didi-labs.com
21	EasyMile	N	France	Shuttle	Shuttle	https://easymile.com
22	Embark	Y	CA	KIT	Trucks	https://embarktrucks.com
22	Faraday & Future Inc.	N	China	OEM	Car and SUV	https://www.ff.com
23	Ford	Y	MI	OEM	All	Ford Self-Driving
24	Gatik AI. Inc.	Y	CA	KIT	Trucks and vans	http://www.gatik.ai
25	GM Cruise, LLC	Y	CA	KIT	Cars	https://getcruise.com
26	Helm.AI Inc.					
27	Honda	N	Japan	Other	Specialized	Honda Autonomous Work Vehicle
28	IKE	Y	CA	KIT	Trucks	https://www.ikerobotics.com/
29	Imagry Inc.	N	Israel	KIT	YES	https://imagry.co
30	Intel Corp	Y	CA	Chips	See Notes	https://intel.ly/2s8x6nU
31	Jingchi Corp	N	China	KIT	Yes	https://s.nikkei.com/33KCVHK

	AV FIRM	U.S. Firm	State/ Country	OEM or Kit	Cars, Trucks, or Other	Website
32	Kodiak Robotics	Y	TX	KIT	Trucks	http://kodiak.ai
33	Lyft, Inc.	Y	CA	KIT	Yes	https://self-driving.lyft.com
34	Mando America Corporation	N	Korea	KIT	Cars	https://www.mando.com/eng/
35	May Mobility	Y	MI	OEM	Shuttles	https://maymobility.com
36	Mercedes-Benz	N	Germany	Possibly	Yes	https://bit.ly/30c0yqt
37	Navya Inc.	N	France	OEM	Shuttle	https://bit.ly/2P4Xqvr
38	NIO USA, Inc.	N	China	OEM	Cars	https://www.nio.com
39	Nissan	N	Japan	OEM	Cars and trucks	https://bit.ly/2TJlvXn
40	Nullmax	N	China	Kit/Supplier	Yes	https://bit.ly/2zag8qM
41	Nuro, Inc.	Y	CA	KIT	Prius and customized vehicle	https://nuro.ai
42	NVIDIA Corporation	Y	CA	Chips, software deep learning, AI	Yes	https://bit.ly/2KJhxeB
42	Perrone Robotics	Y	VA	KIT	Yes	https://www.perronerobotics.com/
43	Phantom AI	Y	CA	KIT	Specialized yard trucks, forklifts, etc.	https://phantom.ai
44	PlusAi Inc	Y	CA	KIT	Trucks	https://plus.ai
45	Pony.AI	N	China	KIT		https://www.pony.ai
46	Qcraft.ai	Y	CA	Possibly KIT	TBD	http://qcraft.ai
47	Qualcomm Technologies, Inc.	Y	CA	Chips	TBD	https://ubm.io/2Mrcrp8
48	Renovo.auto					https://www.renovo.auto
49	Ridecell Inc.	Y	CA	KIT	TBD	https://bit.ly/2OZFVwu
50	Rivian	Y	MI	OEM	Yes	https://rivian.com
51	Roadstar.Ai					http://roadstar.ai
52	Robomart	Y	CA	Other	Mobile Mini-Marts	https://robomart.co/
53	Robotics Research	Y	MD	KIT	Yes	https://www.roboticresearch.com
54	SAIC Innovation Center, LLC	N	China			https://bit.ly/31QkKia
55	Samsung Electronics	N	Korea	KIT	TBD	https://bit.ly/31O1zp6
56	SF Motors Inc.					https://bit.ly/31NmHM7
57	Starship Technologies	Y	CA	Other	Delivery robots	https://www.starship.xyz/
58	Starsky Robotics	Y	CA	KIT	Trucks	https://www.starsky.io
59	Subaru	N	Japan			https://bit.ly/30I2HzT
60	Telenav, Inc.					https://bit.ly/30mfdiU
61	Tesla Motors	Y	CA	OEM	Cars and trucks	https://bit.ly/2eIBzhj

	AV FIRM	U.S. Firm	State/ Country	OEM or Kit	Cars, Trucks, or Other	Website
62	ThorDrive Inc.	N	Korea	KIT	TBD	https://www.thordrive.ai
63	TORC Robotics Inc.	Y	VA	KIT	Yes	https://torc.ai
64	Toyota Research Institute	Y	MA	KIT	Yes	https://bit.ly/2KKdcrr
65	TuSimple	N	China	KIT	Yes	https://www.tusimple.com
66	Udacity, Inc					https://bit.ly/2aEAnkj
67	Valeo North America, Inc.	N	France	Supplier/ KIT	Yes	https://bit.ly/2TNJqVF
68	Volkswagen Group of America	N	Germany	OEM	Cars	https://bit.ly/33JcHFn
69	Voyage					https://voyage.auto
70	Waymo LLC	Y	CA	KIT	Cars and vans	https://waymo.com
71	WeRide	N	China	KIT	Specialized	https://www.weride.ai
72	Xmotors.ai, Inc.	N	China	KIT	Yes	https://bit.ly/3OkRAap
73	Zoox, Inc.	Y	CA	KIT	Specialized	https://zoox.com

Appendix J: Interview Notes

Call with Dannar

9/27/2019 l 1 p.m.

Location: Telecon

Participants:

Birgitte Dodd, CS2
John Conger, Dannar
Scott Crepeau, Dannar
Bob Sudah, Paul Brubaker, LLC
Paul Brubaker, Paul Brubaker, LLC
Bryan Brilhart, Robotic Research
Clark Boriack, TechFlow
Michael Genseal, TechFlow

Notes:

1. ### Manufacturer and Vehicle Description
   Dannar is an OEM of mobile, off-road energy platform for the U.S. govern-mental market. Dannar is located in Clemente, CA, San Jose, CA, and Muncie, IN (manufactured). The company currently offers the Dannar 3.00, a base configuration that comes with standard two 33-kWh BMW i3 lithium-ion battery packs (66 kWh total) that can be upgraded to four packs for a to-tal of 132-kWh onboard electricity. The Dannar 4.00 base configuration comes standard with three 42-kWh BMW i3 lithium-ion battery packs (126 kWh total) and can be upgraded with up to nine additional packs for a total of 504 kWh of onboard electricity. The Dannar 4.00 is built on a heavy-duty steel ladder frame and can be ordered with or without an operator cab or platform.

2. ### Vehicle-to-Grid Charging Readiness/Effort to Implement
   Vehicle charging, battery, plugs, and range and V2G capabilities—It is easiest to envision an MPS as a DC-energy storage asset, to whose DC power bus one can connect various power converters for export of energy.

   Dannar tends to focus first on MPS power export to islanded microgrids, such as those for remote worksites where grid power is not accessible.

Implementations for these applications are simpler because onboard power converters do not need to synchronize with a/the larger utility grid.

Supply to a utility grid involves additional hardware to ensure (i) isolation of the ungrounded MPS from the grounded grid and (ii) synchronization of exported power with grid power. Dannar's power electronics partner has supplied both unidirectional and bidirectional power converters for both DC-DC applications (such as EV charging) and AC-DC applications (such as either EV charging from grid or V2G transfer), so Dannar definitely can make arrangements for this nature of export.

- Implementing V2G on an MPS amounts to installing a V2G-capable EVSE (EV charger) on the MPS, and then connecting the AC/infrastructure end of that converter to grid. The EVSE would include the isolation means. Dannar's power electronic partner has in the past implemented for DoD such electronics in more vehicle-compatible packaging.
- Higher-power V2G transfer amounts to scaling the V2G-capable EVSE on an MPS or on multiple, interconnected MPSs.
- For most EV's packaging an EVSE onboard would present a challenge. The MPS, however, was designed to provide mechanical support and mobility for such electrical/electronic attachments.

3. Vehicle Functions and Capabilities

Dannar 3.00: Optional open operator cab platform equipped with joystick, foot pedal, and touchscreen tool control. Base model is equipped with universal quick mounting plates that can receive CAT, Bobcat, or John Deere attachments and an optional Cummins Tier IV generator (60 kW) is available. Submersible up to 4 feet and carries Type I, II, and III hydraulic tool circuits. Four-wheel, multi-mode steering.

Dannar 4.00: Export panel, which is configurable with multiple 110-VAC and 208-VAC outlets, base model, which comes standard with dual flat beds and can accommodate scissor lifts, forklift masts, dump beds, water tanks, electric water pumps, portable light units, or mobile telescoping cell towers. Can accommodate all standard Caterpillar, Bobcat, and John Deere attachments, submersible up to 4 feet. Carries Type I, II, and II hydraulic tool circuits, four-wheel drive, and four-wheel multi- mode steering.

At minimum, Dannar 3.00 and 4.00 microgrids can charge two Tesla EVs or operate for 8–10 hours onsite. At max, systems offer enough energy to power nearly 17 houses for 24 hours. Designed for disaster relief, can function in wet conditions. System is zero emission (electric) and designed for use in various disaster relief scenarios. Rugged MPS units able to be

deployed safely—heavy-duty, water submergible to 4 feet, work tools can be attached for clearing debris.

4. Testing and Demonstrations

Seven vehicles have been built to date: One has been in the field for 3 years; two have been in demonstration for 1.5 years. The first two deliveries to Portes Stockten, CA are being used as fork lifts. No official testing has been done to date, but many system users can offer information/act as references regarding their experience using the system.

5. Autonomy Readiness/Effort to Implement

System has full remote capability, operating by onboard cab, x-box style remote control, or TBD wireless supervision. Dannar is currently working to develop follow-the-leader autonomous function.

6. Safety Assessments

The system uses high volume off–shelf parts, so assessments would be specific to the parts and their manufactures. As such, Dannar has not conducted technology specific safety assessments, safety standards apply to individual parts.

7. Pricing, Warranties, and Support

Axel and battery pack are under a 10-year warranty; no parts obsolescence battery guarantee for early adopters; stand by unit for 10 years; Portes Stockten, CA.

Additional Information:

Environmental Impacts

No battery disposal issues because Dannar will lease the battery, taking it back for repurposing.

Communications Systems

Onboard communication systems; sensors and data collection—data dumps every 10 seconds; augmented reality glasses (see what you see, see what I see- in field diagnostics)

Programmability and Software

Dannar has multiple CAN: ISO 11898 busses for user interface access, communication with attachments (in response to user interface communications), power management, and energy management.

1. We use multiple software platforms for various systems of the MPS, but Parker Hannifin's IQAN mobile control platform is what we use for user interface communication, and that is how we tend to let outside entities communicate with an MPS for movement and to control other functions. We favor Parker IQAN at this point for user interface communication because of industry familiarity with the platform for mobile industrial control and for the platform's reputation for ease of use. Ease of use is important to Dannar, as we expect some customers to use the MPS as a multipurpose platform, upon which the customer can develop their own end-functions.

2. If a customer wishes to integrate an external communication system to an MPS, the entry point for communication is via the user interface CAN Bus. If a customer has a special communication for offboard communication (e.g., secure wireless link), which might or might not be based on IQAN, they may access the user interface CAN Bus through an interface between their special communication system and the MPS's user interface CAN Bus physical media (twisted wire pair). The CAN format on the MPS user interface bus can be either Parker IQAN (Parker proprietary message format) or SAE J1939 (published and maintained by SAE).

3. Dannar usually does not allow direct access to low-level movement, power management, and energy management control systems. This arrangement inherently shields MPS low-level systems from external communication access. The general philosophy is to "ask the MPS at high-level; let the MPS handle functions at low-level."

Technology Information Analysis: New Flyer

Technology

New Flyer has been providing innovative transit solutions for more than 85 years, with over 50 years of experience manufacturing zero-emissions buses. New Flyer has developed the Xcelsior Charge electric bus available in 35,' 40,' and 60' lengths. The zero emissions bus contains a battery ESS ranging in size from 160 kWh to 460 kWh.

The Xcelsior Charge is commercially available and is currently being used in revenue service by several transit agencies across the United States.

ATI Research Pros

New Flyer buses are interoperable with all heavy-duty vehicle charging equipment. New Flyer has partnered with Robotic Research, LLC to develop a proof-of-concept autonomous bus. Additionally, New Flyer has committed to additional autonomous bus programs with the Xcelsior Charge.

The Xcelsior Charge electric bus and the battery system is manufactured in the United States. New Flyer has delivered several Xcelsior Charge buses to transit agencies across the United States and has a fleet of demonstration buses available for use.

New Flyer warranties the ESS for 12 years and provides support and field service upon request.

Safety standards should be acceptable for ATI research conditions. All electrical components are UL-rated and qualified. In addition to the UL-rated electrical components, the buses comply with Federal Motor Vehicle Safety Standards and have passes Altoona Testing.

ATI Research Cons

While the Xcelsior Charge contains a large ESS, the bus is designed for on-road transit application and might not be suitable for off-road use. Additionally, the entry cost of the electric bus is approximately $750k.

Technology Information Analysis: Nikola

Technology

Nikola Powersports is a division of Nikola Motor Company that is dedicated to the powersports industry, which includes UTVs for military and commercial markets as well as watercraft. Nikola Motor Company designs and manufactures EVs, vehicle components, ESSs, and EV drivetrains. The Reckless vehicle is a fully electric side-by-side UTV that can reach speeds of 100 kph in just over 3 seconds.

The Reckless is available with powertrains ranging from 266–590 horsepower and is powered by a 400-VDC battery system with 75–125 kWh of

energy storage. The Reckless is estimated to have a range of 150+ miles and a top speed of 75 mph.

The Reckless has been demonstrated for the USMC. The availability is currently limited to production prototype models.

ATI Research Pros

The Nikola Reckless is interoperable with a Remote Weapon Station (RWS) and military drones. A variant of the platform has steer and throttle-by-wire capabilities, and Nikola is working to develop more autonomous capabilities. The vehicle's onboard energy storage is large for the size of the vehicle and would be beneficial for bidirectional charging.

The Reckless boasts performance numbers that are ahead of any other side-by-side UTV currently on the market. The vehicle's capabilities make it an appealing option for high-speed off-road use.

ATI Research Cons

While the Reckless contains a large ESS, the platform does not currently support bidirectional charging. A separate effort is being made to integrate a hydrogen-fuel cell onto the vehicle. The vehicle's availability is limited. There are a few production prototypes available for lease at a cost of $40,000 per month.

Call with Orange EV

11/21/2019 | noon

Location: Conference Call

Participants:

Kurt Neutgens, Orange EV

Angie Rolufs, Paragon

Bryan Brilhart, Robotic Research

Clark Boriack, TechFlow

Michael Genseal, TechFlow

Notes:

1. Manufacturer and Vehicle Description
   - From Kansas City, MO; Orange EV's website: orangeev.com/
   - Electric Terminal Truck—called a "Yard Dog"—moves the trailers that attach to semi-trucks around a shipping yard, used by commercial warehouses and distribution centers.
   - Critical component of a distribution center—yard dog cannot go down, so no fewer than two trucks at any location; most do not have more than 20 trucks; one customer has 160 trucks.
   - Also used in railyards to load and offload shipping containers from trains.
   - Maximum speed is 25 mph.
   - Includes a hydraulic fifth wheel that allows the truck to lift the trailer—Orange uses CAN Bus to manage this communication.
   - Trucks get the job done but at a lower cost than diesel and with no diesel fumes; also quieter and smoother ride.
   - Orange EV is looking toward faster vehicles with more capabilities.
   - Orange EV is the only commercial player in this space.
   - 350,000 hours, 1.1 million miles on their fleet—can track all of the usage remotely.
   - Started company in 2012; profitable last year with substantial increase in profit this year.
   - Now in a 52,000-square-foot facility with a team of 55 people with trucks in 14 states.
   - Orange EV performs their own service on their trucks.

2. Vehicle-to-Grid Charging Readiness/Effort to Implement
   - Charging equipment: fast charge at 80-kW rate and level II
   - Battery pack sizes: 80 kWh and 160 kWh
   - Chargers: cabinet, harnesses, software, heating/cooling designed in-house.
     - The charging component, an AC/DC power converter, is purchased separately from two different suppliers. Three different AC voltage options are available depending upon site availability: 240 VAC, 208 VAC three-phase and 480 VAC three-phase.
     - Charger time depends on battery pack size (80kWh or 160kWh) and ranges from 8 hours to 2 hours (3 in parallel at 80 kW).
   - **V2G: Have you considered changes to system and how ready your system is for a bidirectional power flow?**
     - Clark—If you have the capability to customize your charger, then it is definitely viable as compared to starting from scratch.

- ▪ Kurt—Not beyond Orange EV capabilities, other than actual power conversion; not their expertise.
- ▪ Clark—Sounds like you are already to set up to communicate from vehicle to charger, so to adapt to a bidirectional power converter would not be hard to develop the communication (handshake) expertise.
- ▪ Kurt—Building to different voltage than the rest of the world is doing. Maximum voltage is 120 VDC—doing this for multiple reasons, but main reason is safety. They deliver these to small operations where there are one or two people moving groceries around, wanted to make sure that people who were not qualified to work on the trucks will not get hurt. Proud of being able to do this without having to be at the higher voltage. Positive for company that they are doing this at the lower voltage. The inverters are at a lower voltage than we may have worked with in the past. Voltage of battery pack is only 120 VDC.
- The output of the charger is 120 VDC.
- Capacity to handle the higher current resulting from charging at lower voltages has been a successful approach for them.
- Vehicle designed for specific use—can upsize cables without having a detrimental effect on the vehicle; heavy vehicle.
- **120 VDC is a safety approach?**
  - ▪ Yes, and also for reliability, per Kurt
  - Kurt familiar with how Ford did this. Large vehicle with small niche market—hard to make custom systems
- **Clark, interested in V2G? Any thoughts on how soon? 1–2 years forward, or is there a timeline?**
  - Clark—No real work yet, non-military customers not really interested in V2G. If power is down for the site, they would go home. Hard to keep a warehouse running without grid power.
- See themselves doing stationary power capability so they can do load-level cost management—charge over 8 hours and discharge over 2 or less hours. Could there be a tie-in with this to shift energy from one truck to another? Not as important for current customer but understands the value for a military customer.

3. Vehicle Functions and Capabilities

- Electric Terminal Truck—called a "Yard Dog"—moves the trailers that attach to semi-trucks around a shipping yard, used by commercial warehouses and distribution centers
- Critical component of a distribution center—yard dog cannot go down so no fewer than two trucks at any location; most do not have more than 20 trucks; one customer has 160 trucks
- Also used in railyards to load and offload shipping containers from trains
- Maximum speed is 25 mph
- Includes a hydraulic fifth wheel which allows the truck to lift the trailer—Orange uses CAN Bus to manage this communication

- Trucks get the job done but at a lower cost than diesel and with no diesel fumes, also quieter and smoother ride

4. Testing and Demonstrations
- Public Demonstration Ride and Drive on December 6 in Kansas City, but would prefer that we visit on our own after the first of the year, so Kurt can show us everything.

5. Autonomy Readiness/Effort to Implement
- **Bryan—What capabilities aiming for, who working with?**
    a. Kurt cannot share but not an exclusive agreement. Can slow truck with regenerative breaking. Driver is currently main source of braking. Acceleration and deceleration can be controlled autonomously. One of the values of vehicles is hydraulic fifth wheel that allows the truck to lift trailer; use CAN Bus to manage this communication
- All auxiliary functions will be on CAN Bus by third quarter next year—turn headlights on or windshield wipers from a CAN Bus message
- Steering is in the roadmap—working with a partner to do this—would be interested in working with a partner to do braking and other things
- Working with suppliers to develop, but they are all a little slow
- **More driver assistance functions, or automate backing into loading dock?**
    a. Kurt wants to start with crash avoidance, then go to things like backing trailer up. Current partner is working toward full autonomy.
- Kurt asked Bryan if Robotic Research has systems that are fully autonomous. Bryan identified the Army's Oshkosh tractor trailer truck and RR's work on making it a fully AV.

6. Safety Assessments
- Truck is DOT compliant for on- and off-road use.
- Self-certified: no certification required if within compliance.
- Stopping distance is half that of diesel Yard Dog, with a much lower accident rate.

7. Pricing, Warranties, and Support
- Base unit with 80-kWh battery pack is $240,000
- Cost of unit with 160-kWh battery pack is $289,950
- Level II charger (8 hours to charge) is $6,000, and DC fast charger is $60,000
- 3-year warranty

Next Steps:

- Paragon team member call lead will provide email correspondence PDF.
- Load all call information captured on CERL deliverables Research Area 2 EV Company Informational Meeting file.

Call with Phoenix Motorcars

9/17/2019, 2 p.m.

Location: Conference Call

Participants:

Sharad Agarwal, VP, Easy Mile

Angie Rolufs, Paragon

Thomas Allen, Sales, Phoenix Motorcars

Jose Paul Plackal, Business Director, Phoenix Motorcars

Bryan Brilhart, Robotics Research

Clark Boriack, TechFlow

Michael Genseal, TechFlow

Tarek Helou,

Notes:

1. ### Manufacturer and Vehicle Description (Thomas)
   - Southern California based company. Currently on the second-generation drive system. To date, 1.8 million miles driven. Current platform is Ford E450; partnered with Ford. Will be able to take all Phoenix vehicles to any Ford dealer for service soon.
   - GVWR is 14,500#; has a reasonable payload.
   - Shuttle buses are most popular. Can provide electric utility trucks with enclosed steel body or service truck body/maintenance trucks. Can provide box trucks, delivery, flatbed, stake bed, and anybody that uses the e450 chassis. Next phase extends to F550 platform with a GVWR of 19,000# in 2020.

2. Vehicle-to-Grid Charging Readiness/Effort to implement (Jose)

   - Already deployed a flatbed to the Navy that was V2G; used CPS fast charger standard.
   - V2G is not a standard offering.
   - Typical level 2 or 3 charging capability.
   - Will work with partners to enable.
   - CHAdeMO standard level 3 charging.
   - V2G should be easy to implement.
   - Can use j1772 combo connector also for V2G.
   - 4–6 months to implement V2G. 120-day manufacturing. Capabilities are in-house. Has partners for bidirectional EVSE.

3. Vehicle Functions and Capabilities

   - Most shuttle bus options are available.
   - 6500# payload for shuttles.
   - Can mount cranes, racks, inverters up to 125W for offboard power, LED lighting, worklights, toolboxes.
   - Flatbed truck has lift gates (aluminum 1300-lb. lift capacity) stake bed, animal control.
   - Refrigeration.
   - Open to customization per client needs.
   - All vehicles come with telematics for GPS tracking, emission savings; great tool for fleets monitoring.
   - Can disable GPS tracking within vehicle but keep data.
   - Telematics can help acquire incentives, up to $8,000/year per vehicle.
   - 105 kWh is standard, 25 miles in range, can drop to 87 or increase to 129 kWh. ~1 mile of range per kWh. 50-kW charge rate or discharge max;
   - Production models will have a top speed of 58 mph

4. Testing and Demonstrations

   - Had all-electric shuttle bus at LAX, first electric fleet at LAX.
   - Demonstration with U.S. Air Force (USAF) at LAAFB.
   - 4 vehicle with NASA at Caltec in Pasadena, CA, and they bought another 4.
   - Multitude of municipal contracts.
   - Port of Oakland; Austin, TX airport, 15-20 for Sacremento, CA.
   - Grant with federal transit for six at rural transit agencies in Wisconsin.
   - Grant to replace 29 ICE shuttles in SoCal area airports.

5. Autonomy Readiness/Effort to Implement (see table below for time-line)

   - Easymile is the autonomy supplier for Phoenix
   - Level IV autonomous for Phoenix vehicle platform
   - No drive-by-wire kit on e450 but has done on a car and will expand to 450

- 3 years out for autonomy package

6. Safety Assessments
   - Buy-American certified
   - CARB approved
   - NIST compliant
   - Approved for on-road and highway use throughout U.S.

7. Pricing, Warranties, and Support
   - Have baseline pricing for all vehicles.
   - All come with warranties.
   - 3-year, 36-month bumper-to-bumper with Ford; 5-year, 60 of drive system, 5-year 150,000-mile warranty on batteries with option to extend to 8 years and 300,00 miles.
   - All customers go straight to Phoenix, who handles it all. Three types of service packages, include all-inclusive maintenance.
   - Services on site, provides training.
   - Also partnered with creative bus sales where they can also be serviced for warranty or maintenance.

Phoenix Motorcars Shuttle Bus Pricing:

MSRP $234,950

Includes listed vehicle specifications and a 105-kWh battery system.

Excluding tax, title, shipping and registration

Lead time: 5–6 months

Phoenix Motorcars Cargo Truck Pricing:

MSRP $214,950

Includes listed vehicle specifications and a 105-kWh battery system.

Excluding tax, title, shipping and registration

Lead time: 5–6 months

V2G Solutions Pricing:

CHAdeMO V2G Development $99,950

SAE CCS V2G Development $249,950

V2G Option for Series Production $11,950/vehicle

Lead time: 9–12 months

Level 4 Autonomous Prototype Pricing:

Phase 1 Development: $4,448,000

Phase 2 Development: $6,230,000

Phase 3 Series Production: Level 4 Autonomous Shuttle or Cargo Truck for $399,950/vehicle

Autonomous Vehicle Development Timeline

	Y1												Y2												Y3											
T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30	T31	T32	T33	T34	T35	T36

M0 kick-off   M2 global safety analysis   M4 prototype validation   M10 safety docs pre-serie   M8 pilot site deploymt   M9 Experimentation review   M16 first series vhc

M1 Global specifications   M6 proto 1st auto run in France   M11 Pre-series vhc availa   M12 pre-series validation   M14 commercialisation start

M3 proto Architecture definition   M5 SAR for pilot site   M7 proto system release   M13 demo pre-series   M15 certification

Phase 1 - Prototype

Specification	-	-	M1									
Global Safety	-	-	-	M2								
Integration			-	-	M3	-	-	M4	-	-		
Robotics		-	-	-	-	-	-	M6	-	-	-	-	-	M7
Deployment								M5			-	-		M8	-	-	-	M9

Phase 2 - Industrialisation

Safety for pre-series	- - - - - - - M10 - - -
Integration for pre-series	- - M11 - - M12 - - -
robotics for pre-series	- - M13 - - - M14
Industrialisation	- - - - - M15 M16
TOTAL phase 2 / preserie vhc	

Call with US Hybrid Corporation

9/20/2019, 2 p.m.

Location: Telecon

Participants:

Bob Suda, Brubaker LLC (Birdsong Partners)

Paul Brubaker, Brubaker LLC

Alice Reeves, Paragon Business Solutions

Angie Rolufs, Paragon Business Solutions

Amelia Trout, Paragon Business Solutions

Bruce Brilhart, Robotics Research

Eddie Mottern, Robotics Research

Clark Boriack, Techflow

Abas Goodarzi, President and Chief Executive Officer, US Hybrid Corporation

Don Kang, Chief Engineer, US Hybrid Corporation

Daniel Orlowski, VP Business Development, US Hybrid Corporation

Notes:

1. ## Software Manufacturer and Vehicle Description

   US Hybrid Corporation (USH) specializes in the design and manufacture of power conversion systems for medium and heavy-duty electric, hybrid, and fuel cell commercial buses and trucks to enable them to become more reliable and fuel efficient, with lower emissions and better responsiveness.

   USH offers comprehensive engineering expertise in electric and hybrid vehicle systems and components, including Integrated Motor Drives DC-DC Power Conversions and High- Performance AC Motors and Controllers. USH's products utilize Integrated Digital Signal Processor power converter topologies to provide reliable and cost effective integrated system solutions for OEM applications.

2. ## Vehicle-to-Grid Readiness/Effort to Implement

   USH has built a number of prototype vehicles that can accommodate V2G applications, and they are currently providing a vehicle to the USAF that is a 230-VDC charger for sustainable power on demand. The vehicle can power most of the required AC/DC load, and the operation is monitored using a GUI-driven dashboard.

3. Implement Vehicle Functions and Capabilities

   Time to produce a prototype proof-of-concept vehicle that can vary depending on the complexity of the design, but it typically take 6 months to design, build, and field a single proof-of-concept vehicle.

4. Testing and Demonstrations

   USH EV vehicles are currently being used to support USAF flight line operations, and they have an EV step van currently being tested. USH has built an EV Special Operations Vehicle that is being tested by U.S. Special Operations Command (SOCOM), but USH could not offer specifics without more information and suggested that background information would need to be provided in a classified enviornment.

   USH has a number of other demonstration projects underway demonstrating both EV and fuel cell capabilities. They are currently testing a 480-Kw wide body tug for moving C-17s and a weapons loader. They have also electrified a 80,000-lb truck capable of moving shipping containers.

   USH typically builds anywhere from one to 15 vehicles for demonstration projects often in partnership with other OEMs or third parties (e.g., Textron or Oshkosh). The prototype vehicles have a minimum (TRL of 5 and are mostly TRL levels 6 or 7). USH is currently engaged with one such project with an R11 and R12 refuelers and is delivering jet fuel to fighter squadrons using these EVs.

5. Autonomy Readiness/Effort to Implement

   USH offer all of their modified vehicles as drive-by-wire. USH has built the EV Mine Sweeper for Textron that is driven remotely through a virtual interface. USH is also supporting a number of other military related vehicles some of which are focused on demonstrating autonomy readiness. USH does not have any autonomy capability on its own but is working on interfacing with another company's autonomous control system and is aware that that company is interfacing with the braking and steering controls through the vehicle's CAN Bus.

6. Safety Assessments

All electrical components are UL-rated and qualified. All vehicles are prototypes, do not operate on public roadways, and, consequently, do not assess against the Federal Motor Vehicle Safety Standards (FMVSS). In addition to the UL-rated electrical components, USH vehicles are built and modified in compliance with SAE standards.

7. Pricing, Warranties, and Support

The USH POC said that he needs more information about the project requirements before he could offer specifics on pricing, warranties, and support.

Additional Notes:

USH would like to offer additional detail but cannot until they know more about the requirements of a potential pilot project. The Paragon team said it would review the information gathered from all of the interviews and be in contact if additional information is needed.

Appendix K: SME Technology Recommendation

Dannar Review by: Brubaker LLC

Do you recommend this technology for ATI demonstration? Y/N: Yes

If No, please explain: N/A

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	**Demonstration concepts:** • Flexible platform that can be adopted for a variety of military applications • Rugged platform
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** • Can be outfitted with AV capabilities • Drive-by-wire capable • Unique platform that can be easily adapted for a number of uses—probably low-speed operation that will reduce complexity and risk for AV outfitting
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	**Demonstration concepts:** • Great storage • Bidirectional charging • Flexibility for microgrid
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL. **Based on our interview I believe Dannar is very interested in pursuing a RD&D opportunity with CERL.**	

Other Comments and Considerations:

John Conger former colleague and Operational Energy lead at DoD (within the Office of the Secretary of Defense) and now with the Center for Climate and Security is an advisor to Dannar. This tells me that Dannar would fully understand the importance of this RD&D project.

Dannar Review by: Robotic Research

Do you recommend this technology for ATI demonstration? Y/N: Yes

If No, please explain: N/A

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	**Demonstration concepts:** • Interchangeable components • Ruggedized
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** • EV • DBW ready • Low-speed use case
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	**Demonstration concepts:** • High energy storage system • Can be made bidirectional
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL. **Based on our interview I believe Dannar is very interested in pursuing a RD&D opportunity with CERL.**	

<table>
<tr><td colspan="2">

Other Comments and Considerations:

Danner appears to already be working with an autonomy provider. This may pro-vide a challenge for Robotic Research.
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Dannar Review by: TechFlow, Inc.

Do you recommend this technology for ATI demonstration? Y/N: Yes, if there is not a more viable option.

If No, please explain: N/A

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities? Payload capacity to move equipment fits for FOBs.	**Demonstration concepts:** •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** •
Microgrid: How can this system support microgrid research and demonstration objectives con-sistent with CERL objectives and CBITEC capabilities? Can share power be-tween charging sta-tions. Provides fast-charging capabilities. Can export power from vehicles.	**Demonstration concepts:**•

Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.

Dannar was not able to articulate their vehicles could synchronize with other power sources. This may be a feasible development for Dannar given their product already has other flexible power delivery capabilities.

Other Comments and Considerations:

New Flyer Review by: Brubaker LLC

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: The New Flyer bus platform is of limited utility from a military perspective. It does not support bidirectional charging and is very expensive. For these reasons, New Flyer is not a suitable candidate for inclusion in this RD&D project.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	**Demonstration concepts:** •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** •
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	**Demonstration concepts:** •

Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.
Other Comments and Considerations:

New Flyer Review by: Robotic Research

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: The New Flyer bus platform is of limited utility from a military/off-road perspective and is very expensive. Additionally, NF is not looking at bidirectional charging until more standards are defined.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	Demonstration concepts: •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	Demonstration concepts: •
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	Demonstration concepts: •
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	

Other Comments and Considerations:

New Flyer Review by: TechFlow, Inc.

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: Does not appear to be align with bidirectional power or tactical applications.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	Demonstration concepts: •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	Demonstration concepts: •
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	Demonstration concepts: •
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	
Other Comments and Considerations: **Initial cost-plus and development for bidirectional capability will likely not meet**	

budget or schedule constraints associated with the demonstration.

Nikola Review by: Brubaker LLC

Do you recommend this technology for ATI demonstration?
Y/N: Yes (top pick)

If No, please explain: N/A

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	**Demonstration concepts:** • Reconnaissance capabilities • Autonomous Weapons Platform • Ruggedized transport • Flexible modular capabilities
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** • Great EV platform for an autonomous demonstration • Drive-by-wire modern control system • Ready platform for outfitting
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	**Demonstration concepts:** • Great power • Bidirectional • Uses J1772 charger • DC fast-charging capable
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL. **High potential for partnership. This would be an exceptional platform to test—Nikola is willing to partner, but the cost of the vehicle is high.**	

Other Comments and Considerations:

The cost is high.

Should be able to outfit and deploy quickly.

Availability might be an issue—uncertainty about the quantity available. TOP PICK if these issues can be resolved.

Nikola Review by: Robotic Research

Do you recommend this technology for ATI demonstration? Y/N: Yes

If No, please explain: N/A

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	**Demonstration concepts:** • High power/weight capability • Long range • Quite operation
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** • Steer and throttle-by-wire ready • High energy storage system
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	**Demonstration concepts:** • Bidirectional capabilities • High-capacity energy storage system
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	

Nikola appears to want to lease vehicles, might not be ready to enter partnership.	
Other Comments and Considerations: **Very high cost (lease/month) and limited availability.**	

Nikola Review by: TechFlow, Inc.

Do you recommend this technology for ATI demonstration? Y/N: Yes, pending cost resolution.

If No, please explain: N/Q

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities? Off-road capability fits very well within a tactical environment and would support all program goals.	**Demonstration concepts:** •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** •

Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities? Bidirectional capability would make the Reckless the ideal vehicle to evaluate EVs that can support power needs in a tactical environment. This vehicle is our top pick, pending cost reduction and availability	Demonstration concepts: •
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	
Other Comments and Considerations: We believe the open chassis of the Reckless would greatly facilitate the integration of components to implement autonomy and bidirectional power flow. Since the DoD tactical space is a target market for Nokia, their products and capabilities might be a very good fit for program objectives.	

Orange EV Review by: Brubaker LLC

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: No demonstrated bidirectional charging capability. Limited platform. Not a good candidate for this RD&D project.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	Demonstration concepts: •

Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	Demonstration concepts: •
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	Demonstration concepts: •
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	
Other Comments or Considerations:	

Orange EV Review by: Robotic Research

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: Platform is limited to on-road use, does not support bidirectional charging, and does not have drive-by-wire capabilities on their roadmap.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	Demonstration concepts: •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL	Demonstration concepts: •

research objectives?	
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	**Demonstration concepts:** •
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	
Other Comments or Considerations:	

Orange Review by: TechFlow, Inc.

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: Effort to develop bidirectional power and autonomy requirements will likely not meet budget, or schedule constraints, and present more risk compared to other options.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	**Demonstration concepts:** •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** •

Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	Demonstration concepts: •
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	
Other Comments or Considerations: Initial cost-plus development for the bidirectional and autonomy capabilities will likely not meet budget or schedule constraints associated with the demonstration.US Hybrid focuses on development of prototypes that incorporate fuel cells. The all-electric, bidirectional, autonomous vehicle is not their focus.	

Phoenix Motorcars Review by: Brubaker LLC

Do you recommend this technology for ATI demonstration? Y/N: Yes

If No, please explain: N/A

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	Demonstration concepts: • Shuttle bus • Flatbeds
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	Demonstration concepts: • Good EV platform for an autonomous demonstration • Partners have experience in outfitting similar platforms • Data collection

Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	Demonstration concepts: • Storage capacity • Bidirectional charging • Potential fuel cell capabilities (only if we expanded scope)
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL. Good potential for partnership. These are fairly simple platforms to outfit and test.	
Other Comments and Considerations: Unsure about off-road capacity of the flatbed platform in an operational environment. Should be able to outfit and deploy quickly. Some risk in that they are mostly familiar with fuel cell systems.	

Phoenix Motorcars Review by: Robotic Research

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: The base platform does not seem well suited for off-road/military use. I would be more interested in a smaller truck variant as opposed to the shuttle vans.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	Demonstration concepts: •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	Demonstration concepts: •

Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	Demonstration concepts: •
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	
Other Comments or Considerations:	

Phoenix Motorcars Review by: TechFlow, Inc.

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: Effort to develop bidirectional power and autonomy requirements will likely not meet budget, or schedule constraints, and are more risk compared to other options.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	Demonstration concepts: •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	Demonstration concepts: •
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL	Demonstration concepts:

objectives and CBITEC capabil-ities?	•
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	
Other Comments or Considerations: Initial cost-plus development for the bidirectional and autonomy capabilities will likely not meet budget or schedule constraints associated with the demonstration. The relatively high cost and risk for a vehicle platform that does not readily support the tactical environment does not make the Phoenix a fit for this program.	

US Hybrid Review by: Brubaker LLC

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: Company builds one-off prototypes. Too much execution and timing risk to spec out and build a custom platform.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	**Demonstration concepts:** •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** •
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives	**Demonstration concepts:** •

and CBITEC capabilities?	
Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.	
Other Comments or Considerations:	

US Hybrid Review by: Robotic Research

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: I am concerned about the producibility of this vehicle. It seems to be second-order modified from the OEM.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	**Demonstration concepts:** •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	**Demonstration concepts:** •
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	**Demonstration concepts:** •

Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.
Other Comments or Considerations:

US Hybrid Review by: TechFlow, Inc.

Do you recommend this technology for ATI demonstration? Y/N: No

If No, please explain: Effort to develop bidirectional power and autonomy requirements will likely not meet budget, or schedule constraints, and present more risk compared to other options.

If Yes, please explain below based on the following demonstration considerations:

Military Activity: What makes this technology particularly useful to supporting one or more military transportation support activities?	Demonstration concepts: •
Autonomous Vehicle: What makes this system a good candidate for AV research, demonstration? Why is it unique and potentially useful to CERL research objectives?	Demonstration concepts: •
Microgrid: How can this system support microgrid research and demonstration objectives consistent with CERL objectives and CBITEC capabilities?	Demonstration concepts: •

Partnering in Research: Describe the potential for and interest in establishing a partnership for demonstration and research application between this manufacturer and CERL.

Other Comments and Considerations:

Initial cost-plus development for the bidirectional and autonomy capabilities will likely not meet budget or schedule constraints associated with the demonstration. US Hybrid focuses on development of prototypes that incorporate fuel cells. The all-electric, bidirectional, autonomous vehicle is not their focus.

Appendix L: Bollinger Motors

Bollinger B1 and Bollinger B2

Manufacturer: Bollinger Motors

Bollinger manufactures all-electric, all-aluminum Class 3 trucks in Detroit, MI and was founded in 2015.

	Bollinger B1	Bollinger B2
Cost	$125,000 MSRP	
Application Maturity	Production is set to start in the second half of 2020 with customer deliveries beginning in 2021. Bollinger's trucks are only available for reservation though the company states that process is "NOT a vehicle purchase." Buyers will be "required to configure vehicle and options at a later date subject to availability and production results at that time" after which buyers will finalize pricing with their independent dealers, not Bollinger. The company is targeting low-volume production.	
Safety	The B1 and B2 are to be built to exceed federal regulations for seat belt safety standards, but air bags are not available.	
Communication	Bluetooth	
Charging Time and Capacity	10 hours for 220 V and 75 minutes for DC fast	
Charging Infrastructure	Level 1 and 2: J1772 Port (110 V and 220 V), Level 3: DC fast	
Run-Time Capabilities	200-mile range	
Performance	614 HP, 668 ft-lb torque	
Operability in Adverse Weather or Conditions	Removable glass, doors, and windshields	
Projected Life Span	The company says the trucks are built to last "a lifetime," and it hopes to eventually offer updated, lighter batteries for its current trucks as they become available	
Stealth Capabilities	None	
Off-Road Capabilities and Limitations	15-inch ground clearance with 10-inch wheel travel	16-inch ground clearance and 10-inch wheel travel
Hauling and Towing Capacity	5,000-lb. payload, 14 cubic feet of "frunk" storage capacity, 7,500-lb. towing capacity	5,000-lb. payload, 72-inch bed length, 96-inch expandable bed, 14 cubic feet of "frunk," and 7,500-lb. towing capacity
Current Automation Capabilities	None	
Future Automation Capabilities	The CEO of the company has stated that Bollinger has no plans to pursue autonomy	

Comments
Bollinger bills the B2 as the "big brother of the B1," which is essentially the same vehicle with the rea seats removed, enabling a trunk bed and a wider wheelbase. Both trucks are Class 3.
Website: bollingermotors.com/
Contact: Chet Parsons, Sales Director: 313-486-0500; chet@bollingermotors.com

Appendix M: Autonomy Kits, Sensors and Technology

Table M-1. Robotic research autonomy kit for autonomous ground resupply (ARG).

Element	Summary
Description	Robotic Research was engaged by both the National Advanced Mobility Consortium (NAMC) and Army's TARDEC to develop the autonomy kit for the AGR Sustainment Operations program. Under the six-year contract, Robotic Research will develop a fault-tolerant vehicle-agnostic applique kit to enable higher-level autonomous-driving and planning functions for integration onto existing military ground vehicles.
Features	The kit implements an interoperability profile (IOP) and higher-level robotic modes, including—but not limited to—teleoperation, waypoint navigation, and leader/follower technology. The kit hardware consists of sensing and computing resources necessary for perception, world modeling, planning, and the execution of Leader/Follower and teleoperation and it contains all power conditioning, signal switching, and routing. Sensor suite includes: COTS LiDAR sensors Automotive radar Color cameras RR-N-140 Navigation System and Ultra-wideband (UWB) Ranging Nodes
References	Website: roboticresearch.com/programs/agr Robotic Research and TARDEC presentation at the 2018 NDIA Ground Vehicle Systems Engineering and Technology Symposium AUVSI Xponential: Robotic Research Paves the Way for Transportation Autonomy with Commercial and Defense Solutions, 29 Apr 2019

Table M-2. Autonomy research kit (ARK).

	Summary
Description	ARK is an all-in-one autonomy kit, enabling point-to-point autonomous navigation of mobile robots. Kit provides advanced software with a powerful processor and sensor suite. ARK is ROS ready and fully extensible with a well document API. ARK is ideal for indoor, single-level, infrastructure free-navigation.
Features	ARK provides point-to-point navigation with dynamic path planning, simultaneous mapping and localization, and obstacle avoidance. Its web-based interface, ARK Mapper, allows for manual controls of robots and the creation of 2D maps of indoor environments. Supported LiDARs include Hokuyo UST-10LX and SICK LMS1xx.
Supported Technology	Kit integrates with Clearpath mobile robotic development platforms, including the Husky UGV and Ridgeback mobile manipulation platform. ARK also integrates with the Jackal UGV.
References	Website: clearpathrobotics.com/autonomy-research-kit/ White paper: Comparing accuracy of open source vs. proprietary localization software

Table M-3. Perrone Robotics drop-in autonomy kit (DAK).

Element	Summary
Description	DAK is an autonomous kit system for outfitting existing vehicles with autonomous and remote-control driving capabilities.
Features	DAK was built using the MAX general purpose robotics and automated vehicle operating system. The DAK kit includes all necessary actuators, sensors, electronics, and software needed for operation. Key features include: Steering, brake, and throttle control 30-minute or less install Programmatic fully autonomous navigation Route and trajectory planning Maneuver planning Remote teleoperation available

Element	Summary
Supported Technology	Compatible with Locata, an alternative local position system that uses a constellation of LocataLite. Locata allows DAK to deliver tunable accuracy indoors or outdoors and in adverse weather, 24/7. Embedded software in DAK allows for defining and controlling testing and transferring and reviewing data. DAK complies with requirements from the Insurance Institute for Highway Safety and features software for performing NHTSA Crash-Imminent Braking, NHTSA Dynamic Brake Support, Euro NCAP Autonomous Emergency Braking, and others.
References	Website: perronerobotics.squarespace.com/dak Other Perrone turn-key products for autonomous robotics is found **here**.

Table M-4. Autonomous Mobility Applique System (AMAS).

Element	Summary
Description	Developed by Lockheed Martin, the AMAS autonomy kit provides a low-cost, low-risk, kit-based solution to retrofit active safety, semi-autonomy, and autonomy capability onto any vehicle in the military's logistics fleet. The AMAS Operational Demonstration and Military User Assessment (MUA) was conducted in 2014 and the system was tested more recently at the Aberdeen Proving Ground in 2015.
Features	AMAS features Driver Warning/Driver Assist functionality, Leader-Follower convoy operations, Waypoint following capabilities, and provides growth to fully autonomous operations.
References	Website: **lockheedmartin.com** **Army, Lockheed Martin, demonstrate fully autonomous convoys can operate in urban areas**, 31 Jan 2014 **Integration of the Autonomous Mobility Applique System into the Robotic Technology Kernel** presentation from U.S. Army Combat Capabilities Development Command Ground Vehicle Systems Center and Lockheed Martin at the 2019 NDIA Ground Vehicle Systems Engineering and Technology Symposium.

Table M-5. Unit-to-unit autonomous resupply vehicle (U2UARV).

Element	Summary
Description	Cybernet's U2UARV bills itself as a general purpose "Swiss Army knife" vehicle automation kit that can autonomously deliver and return ordnance, food, water, ammunition, and general logistics and resupply.
Supported Technology	Compatible with the Gladiator UGV, Polaris, and the Hyster fork truck.
References	Website: **cybernet.com** More information **here**.

Table M-6. Cybernet technologies.

Element	Summary
Features	**Automated Tactical Ammunition Classification (ATACS)** **Inertial Measurements and Magnetometer Module (I3M)** **OpenSkies** **Rapidly Generated Instrument Panels for Simulation and Training**: developed specifically for the Navy **Virtual Systems Integration Lab (VSIL)**: an integrated simulation platform for the development, modification, and prototyping of vehicle systems and components.
References	Website: cybernet.com/defense-and-security-technologies/robotics More information here.

Table M-7. Lanecruise.

Element	Summary
Description	Developed by X-Matix, LaneCruise autonomy kit is a complete system of hardware components and software elements that enables semi-autonomy, active safety, and fleet management.

Element	Summary
Features	The kit includes four major hardware components: Linx: a fully integrated vision and location sensor and computation system capable of SAE Level 3 autonomy and HD telematics data gathering. Brake actuators Gas control module: an electronic by-pass device that utilizes onboard vehicle drive-by-wire technology to sense and control throttle position. Wheel actuator
References	Website: **x-matik.com/lanecruise**

Table M-8. Luminar.

Element	Summary
Description	Luminar bills its sensor as the "first and only LiDAR sensing system to meet the stringent performance and safety requirements needed to achieve safer-than-human level perception."
Features	The sensor offers a true 250-meter range with <10% reflectively, 200 px/Deg² camera-like resolution, < 1 cm range precision with high-precision reflectance, and a 120° field of view with 30° dynamic vertical resolution. Rated IP67 for dust and water ingress. Vibration: SAE J1211 Shock: IEC 60068-2-27 to 20 g.
References	Website: **luminartech.com** **Luminar prepares for production of LiDAR at scale**, 29 Jul 2019. Luminar also offers **Iris**, a sensor for production vehicles. Iris offers the same core Luminar technology and performance in an efficient auto-grade, low-cost package for series production programs beginning SOP 2022.

Table M-9. Shadowcam.

Element	Summary
Description	On 28 Oct 2019, MIT announced the development of its Shadowcam, a system that can sense tiny changes in shadows on the ground to determine if there's a moving object coming around a corner. In a paper being presented at International Conference on Intelligent Robots and Systems, MIT researchers will describe successful experiments with an autonomous car driving around a parking garage and an autonomous wheelchair navigating hallways. When sensing and stopping for an approaching vehicle, the car-based system Shadowcam beats traditional LiDAR—which can only detect visible objects—by more than half a second.
References	**ShadowCam: Real-Time Detection of Moving Obstacles Behind a Corner for Autonomous Vehicles**, 2018 **Enabling autonomous vehicles to see around corners**, 28 Oct 2019

Table M-10. Robosense LiDAR systems.

Element	Summary
Description.	RoboSense manufactures multiple LiDAR systems (mechanical, solid-state, and static 3D laser scanner), LiDAR Perception Algorithms, and Perception solutions.

Element	Summary
Features	<u>Multi-Beam LiDAR Series</u> <u>Ruby</u> <u>BPearl</u> <u>LiDAR-32</u> <u>LiDAR-16</u> <u>LiDAR-M1</u> <u>Medium-low Speed AD LiDAR Perception Solution</u> <u>RoboTaxi LiDAR Perception Solution</u> <u>V2R LiDAR Perception Solution</u> LiDAR Software <u>RSView 3.1.5 for Windows 7/8/10</u> <u>RSView 3.1.5 for Ubuntu 16.04</u> <u>ROS Driver for RS-LiDAR-16 and RS-LiDAR-32</u>
References	Website: <u>robosense.ai</u> More information on RoboSense's available technologies is <u>here</u>.

Table M-11. Velodyne LiDAR.

Element	Summary
Description	Velodyne manufactures multiple LiDAR solutions, detailed below. Velodyne's solutions allow customers to unlock advanced capabilities for ADA features including pedestrian and bicycle avoidance, Lane Keep Assistance, Automatic Emergency Braking, Adaptive Cruise Control, Traffic Jam Assist, and more.
Features	<u>Alpha Puck</u>: for Level 4-5 autonomy, the Puck is the first 300 m capable sensor for autonomous fleets. <u>Velarray</u> <u>VelaDome</u>: specially designed for high resolution close-range sensing. <u>Ultra Puck</u> <u>Puck</u> <u>Puck 32MR</u>: built for autonomous mobile robots, shuttles, and other autonomous systems. <u>HDL-32E</u>: features 32 lasers across a 40° vertical field of view. <u>HDL-64E</u>: designed for obstacle detection and navigation of autonomous ground vehicles and marine vessels.
References	Website: <u>velodyneLiDAR.com</u> Product guides, data sheets, white papers, and more <u>here</u>. A breakdown of Velodyne models and capabilities is found <u>here</u>.

Table M-12. Mobileye.

Element	Summary
Description	Mobileye, a subsidiary of Intel, develops vision-based advanced driver assistance systems providing warnings for collision prevention and mitigation. The company is a Tier 2 automotive supplier working with all major Tier 1 suppliers and their hardware and software is developed in-house.
Features	<u>EyeQ</u>: Mobileye's system-on-chip technology family provides processing power to support ADAS functions based on a single camera sensor. <u>Road Experience Management</u> (REM): end-to-end mapping and localization engine for full autonomy. REM comprises three layers: harvesting agents, map aggregating server, and map-consuming agents. <u>Responsibility-Sensitive Safety</u> (RSS): a mathematical model for AV safety.
References	Website: <u>mobileye.com</u> Mobileye solutions specifically for fleets can be found <u>here</u>.

Table M-13. Innovusion LiDAR systems.

Element	Summary
Description	Innovusion develops image-grade LiDAR systems for Level 4 and 5 AVs and ADAS markets. Applications for Innovusion systems include vehicle safety systems, AV systems, and vehicle-to-everything (V2X) for autos, trucks, buses, trains, and off-road vehicles.
Features	Cheetah: Cheetah utilizes the industry's first proprietary dual-rotating polygon design and is billed as "compact, flexible, and easy for vehicle integration." The system draws under 40W, making it the most energy efficient system of high-performance LiDAR currently on the market. Jaguar: utilizes dual-rotating polygons to achieve detail out to 280 m and boasts a .13° resolution coupled with a frame rate of 10 fps and selectable field of vision (FOV) of 110° or 65°.
References	Website: innovusion.com *Innovusion announces high-resolution image-grade LiDAR system Cheetah*, 17 Jun 2019

Table M-14. Lumotive.

Element	Summary
Description	Lumotive develops high-performance, solid-state LiDAR powered by liquid crystal metasurface technology based on beam-steering technology. The latter leverages semiconductor chips designed using metamaterials principles and enables Lumotive's systems to perform at a high level while remaining cheaper than other systems. Initial production units will be available to select customers for beta testing in the 3rd quarter of 2019.
Features	Lumotive's system offers: Large optical aperture (25 x 25 mm) which delivers long range 120° field-of-view with high angular resolution Fast random-access beam steering
References	Website: lumotive.com *Lumotive says it's got a solid-state LiDAR that really works*, 21 Mar 2019 Lumotive Unveils High-Performance LiDAR to Enable Autonomous Vehicles, 20 Mar 2019

Table M-15. Baidu Apollo Enterprise.

Element	Summary
Description	Baidu's Apollo Enterprise is a suite of intelligent driving products and solutions for mass production vehicles that is scalable and highly customizable based on enterprise customer needs. Apollo solutions support vehicle and information safety and can be upgraded via over-the-air programming.
Features	IOV OS: a mass-produced and complete operation system solution to internet of vehicles (IoV). DuerOS: a set of AI-based IoV solutions with voice assistant, augmented reality, and motion detected capabilities. Apollo 3.5: the first open-source autonomous-driving platform able to perform in complex urban and suburban driving scenarios. The system utilizes the Apollo Cyber RT framework. Apollo V2X: an intelligent vehicle infrastructure cooperation solution.
Supported Technology	The Apollo 3.5 system is compatible with most advanced sensor suites, including those from Velodyne and LeddarTech.
References	Website: apollo.auto More information on Apollo's architecture (HD map, localization, perception, prediction, planning, and control) is found here.

Table M-16. Cepton micro-motion technology (MMT) and Sensor Development Toolkits.

Element	Summary
Description	Cepton develops and manufactures 3D sensing solutions for automotive, industrial, and mapping applications. Cepton built and uses the MMT platform, Vista, and Vista LiDAR samples are available today for Cepton's automotive partners to evaluate in their self-driving fleets.
Features	**Vista-P** LiDAR sensor: 120-line equivalent scanner delivering 200 meters of range and.2° of spatial resolution using less than 10W of power. **Vista-X**: 120° FOV enables object perception and localization in an area wider than the standard Vista sensor. **Sora-P60**: mobile object classification and volumetric measurement device that provides 1,200 scan lines per second and can send data over Ethernet, Wi-Fi, or LTE to a central processing server. **Sora-P60Lite**: lightest high-performance LiDAR for Unmanned Aerial Vehicle (UAV). Lightweight payload enables longer trips. **Vista-Edge**: LiDAR evaluation kit using Nvidia's Jetson TX2 based microcomputer, providing immediate 3D visualization of point cloud data. **Helius Smart LiDAR System**: system connects multiple LiDAR sensors enabling comprehensive, high resolution imaging, and seamless sensor-to-sensor tracking. Helius is a browser-based, PoE-powered and processes data at the edge for low-bandwidth data output.
References	Website: **cepton.com**

Table M-17. Innoviz.

Element	Summary
Description	Innoviz is a manufacturer of solid-state LiDAR sensors and perception software.
Features	**InnovizPro**: commercially available solid-state sensor. Applications include warehouse and delivery robotics, heavy machinery, smart cities, security, HD mapping, and AVs. **InnovizOne**: designed specifically for automakers and robo-taxi and delivery industries requiring an automotive-grade, mass producible solution to achieve autonomy. Offers angular resolution (HxV) of 0.1°x0.1°; a configurable frame rate of 25 FPS; detection range of 250 m; and a field of view (HxV) of 120°x25° and will be available in 2020. Systems are accompanied by the supporting perception software.
References	Website: **innoviz.tech** InnovizPro **datasheet** **Innoviz's Solid-State LiDAR Wins CES 2019 "Best of Innovation" Award**, 8 Nov 2018.

Table M-18. Leddartech.

Element	Summary
Description	LedderTech provides versatile, scalable auto and mobility LiDAR platforms based on the LeddarEngine, a suite of automotive-grade and functional safety certified SOCs that work in tandem with the LeddarSP signal processing software. LedderTech is based in Quebec City, Canada, but has offices in Silicon Valley, Detroit, and Austin.

Element	Summary
Features	**LCA2 LeddarEngine**: comprised of the LeddarCore LCA2 system-on-chip and LeddarSP signal processing library, the LCA2 LeddarEngine sets a new standard for the design of the integrated and customizable solid-state LiDAR solutions that are optimized for high volume manufacturing and production vehicles. **Leddar Pixell**: a 3D solid-state LiDAR enabling detection cocoons in autonomous shuttles, ADVs, and commercial vehicles and robotaxis. **Leddar M16**: advanced, solid-state LiDAR sensor modules combining wide-beam flash illumination with 16 independent detection segments. **LedderOne**: a single-point detection LiDAR sensor module. **Ledder d-tec System**: LiDAR-based stop-bar detection system for traffic light management. **Leddar T16**: solid-state LiDAR traffic sensor for various Intelligent Transportation System applications. **Leddar IS16**: multi-segment flash LiDAR sensor designed for the industrial market and harsh weather conditions. **Leddar Vu8**: a solid-state LiDAR sensor module that provides the ability to detect and track multiple objects simultaneously over eight distinct segments. **LCA3 LeddarEngine**: for Tier 1 suppliers and AD system integrators, enabling the design of differentiated LiDAR solutions.
References	Website: **leddartech.com** An overview of LedderTech's auto and mobility LiDAR platform is available **here**. LedderTech distributors are found **here**.

Table M-19. Nvidia Drive.

Element	Summary
Features	**Drive AGX Developer Kit**: provides hardware, software, and sample applications needed for the development of production level AVs. **Drive Hyperion**: a reference architecture for Nvidia's Level 2+ autonomy solution consisting of a complete sensor suite, an AI computing platform, and a full software stack for autonomous-driving, driver monitoring, and visualization. **Drive Constellation**: a cloud-based virtual reality simulation platform. DGX System: an integrated system of deep learning software and simplified management tools for data scientists. **Safety Force Field** (SFF): computational framework supporting frame-by-frame, physics-based SFF computations using vehicle sensor data. Information on Nvidia Drive's software is **here**, information on Drive's safety is **here**, and information on partners and innovation is **here**.
References	Website: **nvidia.com**

Table M-20. R-Car.

Element	Summary
Description	Developed by Renesas, R-Car is the company's SoC family for car information systems designed for automotive computing in AVs. R-Car is a scalable and flexible hardware platform and the company offers plug-ins for multiple open-source software tools. Renesas is based in Japan though it does have Design Centers, distributors, manufacturers, sales outlets, and value-added resellers in the United States.
Features	Links for the below listed technologies details the features, specifications, and block diagrams for each: Information on all available technologies from Renesas is **here**. **V3H**: platform supporting ADAS and Level 3+ autonomy. **SH-Navi3**: a dual-core SOC built around a pair of SH-4A CPUs for processing performance of up to 1920 MIPS. **H3**: automotive computing platform that is compliant with ISO 26262 (ASIL-B) functionality safety standard and can be applied to driving safety support systems.

Element	Summary
References	Website: **renesas.com** ADAS and Automated Driving Applications from Renesas can be found **here**.

Table M-21. LiDAR USA.

Element	Summary
Description	LiDAR USA developed and manufactures the Snoopy and ScanLook LiDAR systems
Features	**ScanLook mapping systems** **Cameras** **UAV and drones** **GNSS equipment** **Commercially available LiDAR sensors** **Snoopy Highway Mapper Z+F** **PhaseOne Industrial IXU cameras**
References	Website: **LiDARusa.com** Sample data can be found **here** and includes examples of city, power line, and railroad mapping. Case studies can be found **here**. CAGE Code: 6J1G4

Table M-22. Toposens Automotive Devkit.

Element	Summary
Description	Based in Germany and California, Toposens develops and manufactures 3D ultrasonic sensors, enabling users to implement applications like autonomous parking. The company's sensors can be integrated on the outside and inside, providing the vehicle with information about objects, obstacles, and movements in the vehicle's environment and the sensors can be adjusted, in hardware and software, to suit specific user needs.
Features	Toposens "typical work packages" includes: Joint planning of proof-of-concept Preparation and implementation of test scenarios Preparation and installation of sensor systems and auxiliary devices Setup of sensor network via UART or CAN Setup of ROS environment for evaluation and demonstration purposes Optimization of sensor parameters and installation positions Conception and presentation of a final demonstration Documentation for respective work packages
References	Website: **toposens.com/automotive-poc**

Table M-23. Racelogic.

Element	Summary
Description	RaceLogic designs and manufactures electronic systems to measure, record, display, analyze, and simulate data from moving vehicles
Features	**Data loggers** **Speed sensors** **Video data loggers** **Indoor positioning** **Telemetry systems** **Modules** **Software** **AD and ADAS systems** **Handling and dynamics** **Performance testing**

Element	Summary
References	Website: **vboxautomotive.co.uk**

Table M-24. Bosch Mobility Systems.

Element	Summary
Description.	Bosch Mobility, a division of Bosch Global, utilizes its extensive technical expertise to develop and manufacture connected and AV smart mobility solutions.
Features	Bosch Mobility solutions include: **Traffic Jam Assist** **Highway Assist** **Driver assistance system domain controllers** **Localization for automated driving** **V2X connectivity solutions** **Multi-camera driver assistance solutions**
References	Website: **bosch-mobility-solutions.us**

Table M-25. Harman Ignite Cloud Platform.

Element	Summary
Description	The Harman Ignite is an automotive digital ecosystem that enables connectivity, device management, application enablement, analytics, and managed services capabilities.
Features	**Ignite** and Harman's solutions offer multiple capabilities, including (but not limited to): Remote Vehicle Updating Service Intelligent Reasoning Assistant **Device virtualization for connected vehicles** Vehicle analytics dashboard **V2X solutions** Cloud-based driver profiles
References	Website: **car.harman.com**

Table M-26. Certus Evo.

Element	Summary
Description	Manufactured by Advanced Navigation, the Certus Evo is a miniature GPS aided inertial navigation system and AHRS that provide positioning, velocity, acceleration, and orientation under adverse conditions.
Features	Certus Evo offers: Dual frequency RTK GNSS receiver providing 8 mm accuracy positioning Multiple interfaces including Ethernet, CAN, RS232, RS422, and GPIOs. An advanced sensor fusion filter MEM intertial sensors Dual antennae moving baseline RTK IP67 standard casing
Supported Technology	All current and future satellite navigation systems, including GPS, GLONASS, GALILEO, BeiDou, and QZSS. The Certus Evo also supports all standard protocols, including NMEA 0183, NMEA 2000, TSS, PASHR, Simrad, and others.
References	Website: **advancednavigation.com** Certus Evo specifications can be found **here**. Other Advanced Navigation systems and solutions, including other MEMS GNSS/INS, speed sensors, and web-based GNSS/INS post processing software, can be found **here**.

Table M-27. Iscan modular radar demonstration and development platform.

Element	Summary
Description	Developed by Colorado Engineering, the iScan radar Series enables rapid prototyping of high-performance radar. CEI's iScan processor, expansion and antenna modules can be mixed and matched to create a customized development platform.
Features	- Capabilities include: - MIMO - Steerable beams - Digital beam forming - RCS measurements - Target tracking - Collision avoidance - Occupancy sensing
References	Website: **coloradoengineering.com** iScan Architecture **brochure**

Table M-28. APPlus+ IDapt.

Element	Summary
Description	The IDAPT, developed by Applus+, is a vehicle onboard unit that allows for flexible and multipurpose prototyping and a development tool for CAV activities. The unit can be used independently or integrated into a vehicle's electronic architecture and can be retrofit into non-connected vehicles for R&D purposes, such as V2X, 4G, and GPS.
Features	IDAPT is a development tool built for: - ADAS and CAV Field Operational Tests (FOT) - Automotive Internet of Things (IoT) prototyping - AV control - Camera imaging and object detection - Cyber security development - Machine learning algorithm development - LIDAR and radar sensor development - V2X application development
Supported Technology	The system is currently being used in **SecureIoT**, a platform that receives, validates, and stores information from AVs and **VRAIN**, a system based on cooperative communications that will enable enhanced safety and advanced management services within automated proving grounds.
References	Website: **applusidiada.com** Pricing, data sheet, and case studies can be found **here**.

Table M-29. Dataspeed ADAS Kit.

Element	Summary
Description	Dataspeed's By-Wire Kit is a complete hardware and software system, allowing for seamless electronic control of braking, throttle, steering, and shifting to enable testing for AV applications.
Features	- CAN interface module with four networks up to 1Mbps each and configurable bit rates - CAN breakout module enabling up to five additional nodes with additional available for further expansion - Inverter module - Brake, throttle, steer, and shift by-wire controller modules - Switchboard Kit or Touchscreen Display Kit 12 channel power distribution system - Demonstration pack including a laptop and joystick controller DataSpeed also manufactures and/or distributes: **Power Distribution System** **Cepton and Ouster LiDAR** **Magnetic LiDAR mounts** **CAN Breakout Board**
References	Website: **dataspeedinc.com** Other AV integrations from DataSpeed, Inc., can be found **here**.

Table M-30. Quantum R-Series.

Element	Summary
Description	Quantum's R-Series was designed for high-speed data capture in moving vehicles and allows for removable data storage and "in the field" data capture to a Quantum StorNext shared storage environment.
Features	The R-Series is an in-vehicle storage system with a small form factor well suited for military vehicles, trucks, and cars. Available in the following capacities and storage technologies: 60 TB HDD, 23 TB SSD, and 46 TB SSD.
References	Website: **quantum.com** Other Quantum products and services can be found **here**. R-Series **datasheet** Mass Storage for AV Development **datasheet** Accelerate Automotive Development with Intelligent Management of Machine-Generated Data **datasheet**

Appendix N: Bidirectional Chargers, Diesel Generators, and Controller Technologies

	Applicability	Interoperability	Cost	Plug-and-play	Resources
Bidirectional Battery Chargers					
CORITECH VGI-30	Battery Voltage Range: 200-600 Vdc Battery Charging Power: 30 kW 60A Max Reverse Power Flow V2G: 30 kW 60A Max	Aggregator Connection: Ethernet, Modbus TCP/IP, SEP 2.0	$45K	Vehicle Connection: SAE J1772-Combo CCS or CHAdeMO	https://coritech.com/ev-chargers
Diesel Generators					
CAT XQP100	Generator successfully used in the Smart and Green Energy (SAGE) for Base Camps Final Report (Jan 2014) which utilized COTS equipment within a smartgrid	Uses a proprietary control system which required changing the Tactical Quiet Gensets (TQG) control units for CAT control units to allow for system communication.	No response to multiple request for information	Literature indicates only within the Caterpillar control system architecture. However as noted in the SAGE for Base Camps Final Report these generators were successfully integrated into the Decision Support for Operations and Maintenance (DSOM) control system (see below in Controller Technologies)	https://www.cat.com/en_US/products/new/power-systems/electric-power/mobile-generator-sets/1000031338.html
Triton 1103D-E44TG1	Meets general output specifications of the 60kW AMMPS generator at 60 Hz	Connection allows for Modbus communication, Remote-control sources (10) can be accessed via SCADA, RS232 & RS485 communications, DSENet® compatible	$25K	Remote-control sources (10) can be accessed via SCADA and allows for Ethernet communications	https://www.americasgenerators.com/60 kW-Perkins-Diesel-Generator.aspx
Kohler 90REOZT4	Meets general output specifications of the 60kW AMMPS generator at 60 Hz	Communication with RS-485 and Ethernet (RJ-45), Supports Modbus RTU and Modbus TCP protocols, NFPA 110, Level 1 monitoring capable	No response to multiple request for information	Only within the Kokler control system architecture. Requires G6-148 Mobile Generator Set Paralleling Box to connect generators together (one G6-148 per two generators; maximum four G6-148 = eight generators)	https://kohlerpower.com/en/generators/industrial/product/90reozt4
Controller Technologies					
Schweitzer Engineering	Compliance to MIL-STD-TMS (DoD Tactical Microgrid	Data Distribution Service (DDS)	Varies depending on	"Plug-and-play solutions for military	https://selinc.com/solutions/microgrids/ https://selinc.com/api/download/98236/

	Applicability	Interoperability	Cost	Plug-and-play	Resources
Laboratories (SEL) PowerMax	Standard)	communications, Interoperability with Advanced-Medium Mobile Power Sources (AMMPSs), Conversion kits for TQGs, customized kits developed for various manufactures.	system size and components. Initial kit could start $10K-15K. Initial cost of customization for unique equipment is approx $40K	bases. powerMAX for Mobile Microgrids is a solution made specifically for military bases, including fixed, remote, or forward operations. It is perfect for first responders, disaster relief, or anyone requiring a mobile microgrid. Additionally, power MAX is the only microgrid control system that meets the standards for tactical microgrids."	https://selinc.com/solutions/microgrids-fob/
Spirae Wave Microgrid and energy distribution solutions	"Can be configured for three different types of operations: i) grid-connected economic-microgrid, where Wave manages generation, demand, and storage to achieve energy cost optimization, ii) resilience-microgrid, where Wave manages local assets to maximize the resiliency of the site to grid outages and switches to island mode if the grid fails, and iii) island (off-grid) microgrid mode, where Wave continuously runs in island mode to reliably serve loads using local resources."	"Wave Microgrid controls are agnostic to the types and brands of DER (distributed energy resource) in a microgrid. Choosing the Spirae solution provides the ultimate flexibility to mix and match system components including legacy equipment such as backup generators."	No response to multiple request for information	No response to multiple request for information	https://www.spirae.com/about-microgrid/
OMNETRIC Group and Siemens	No response to multiple request for information	"Verified and implemented a new interoperability reference architecture, called the Open Field Message Bus (OpenFMB) framework. This solution, integrated with Siemens Microgrid Management Software (MGMS), allows CPS Energy to overcome the lack of standardization and interoperability between the vast array of equipment in operation to better manage load behavior on the power grid."	No response to multiple request for information	No response to multiple request for information	https://www.omnetric.com/data/files/newsroom/omnetric_siemens_cps_milestone_release_final_0.pdf?cat1=demonstrating-microgrid-technology-cps-energy-and-utsa
Universal Microgrid Controller	Not aimed at very small systems. Most cost effective option in the 100 kW to	Component Communication: Protocols: Modbus	$25-50 per kw	No response to multiple request for information	http://www.sustainablepowersystems.com/products-services/universal-microgrid-controllertm/

	Applicability	Interoperability	Cost	Plug-and-play	Resources
	20 MW size range	TCP Utility Communication: Protocols: IEEE 2030.5 Modbus RTU, CAN Bus			http://www.sustainablepowersystems.com/wp-content/uploads/2019/06/UMC-Frequently-Asked-Questions-Rev-4.pdf
DSOM system	"Open, flexible configuration and capability that could be easily adapted for energy management at base camps. With documented use in the SAGE for Base Camps"	"Talks to most monitoring and control systems, mitigating the need for expensive upgrades of instrumentation for compatibility"	Only prototyped for the SAGE experiment	"Provides a flexible plug-and-play system to communicate with almost all commercial data acquisition systems and facility control systems"	https://www.pnnl.gov/dsom/
Bidirectional Battery Chargers					
KI platform VCharge by OVO	not available on open market (Great Britain only), 50 Hz only	Currently only works within the Kaluza network architecture.	NA	CHAdeMO protocol	https://www.ovoenergy.com/electric-cars/vehicle-to-grid-charger https://www.indra.co.uk/v2g
Fermata Energy					https://www.fermataenergy.com/
NICHICON CORPORATION	Single phase voltage only	NA	Not available in the United States	CHAdeMO protocol	https://www.nichicon.co.jp/english/product_news/new124.html
Nuvve PowerPort	Vehicle must have bidirectional inverter to be V2G capable delivers up to 100kW in three-phase configuration and 19kW in single phase configuration	Proprietary communication system	$4500 (does not include cost of compatible OEM DC charger for fast DC charging)	J1772 Type 1, J3068 Type 2 and compatible with several charger manufacturers both in DC (such as CHAdeMO) and AC mode (vehicle must have bidirectional inverter)	https://nuvve.com/v2g-chargers/
Diesel Generators					
Generac MDG75DF4	This system is designed to work with generators connected on the mobile switching center (MSC) network only. All other power sources must be isolated from the MSC network	Supports Modbus RTU and Modbus TCP protocols	No response to multiple request for information	Only within the Generac control system architecture. This system is designed to work with generators connected on the MSC network only	https://www.generacmobileproducts.com/products/generators/products/mdg75df4-diesel generator
Controller Technologies					

	Applicability	Interoperability	Cost	Plug-and-play	Resources
Spirae Wave Microgrid and energy distribution solutions	Can be configured for three different types of operations: i) grid-connected economic-microgrid, where Wave manages generation, demand, and storage to achieve energy cost optimization, ii) resilience-microgrid, where Wave manages local assets to maximize the resiliency of the site to grid outages and switches to island mode if the grid fails, and iii) island (off-grid) microgrid mode, where Wave continuously runs in island mode to reliably serve loads using local resources.	"Wave Microgrid controls are agnostic to the types and brands of DER in a microgrid. Choosing the Spirae solution provides the ultimate flexibility to mix and match system components including legacy equipment such as backup generators."	No response to multiple request for information	No response to multiple request for information	https://www.spirae.com/about-microgrid/
GE microgrid controller					https://www.gegridsolutions.com/app/DownloadFile.aspx?prod=microgrid&type=1&file=1
					https://www.gegridsolutions.com/multilin/catalog/mcs.htm
OMNETRIC Group and Siemens	No response to multiple request for information	"Verified and implemented a new interoperability reference architecture, called the OpenFMB framework. This solution, integrated with Siemens Microgrid Management Software (MGMS), allows CPS Energy to overcome the lack of standardization and interoperability between the vast array of equipment in operation to better manage load behavior on the power grid."	No response to multiple request for information	No response to multiple request for information	https://www.omnetric.com/data/files/newsroom/omnetric_siemens_cps_milestone_release_final_0.pdf?cat1=demonstrating-microgrid-technology-cps-energy-and-utsa
Ovation™ Microgrid Control	Designed specifically for the power industry	Ovation communicates with intelligent electronic devices (IEDs) using various protocols including: Modbus over RS485 serial link, Modbus over TCP/IP, DNP, Profibus, IEC 61850, IEC, 60870-5-104	No response to multiple request for information	No response to multiple request for information	https://www.emerson.com/documents/automation/microgrid-control-system-en-1263362.pdf
Eaton Power Xpert Energy Optimizer	"Configured instead of custom programmed, allowing for maximum	Based on open standards, including IEC 61850	No response to multiple request for	No response to multiple request for information	https://www.eaton.com/us/en-us/catalog/services/microgrid-and-distributed-energy-resources.html

	Applicability	Interoperability	Cost	Plug-and-play	Resources
	flexibility and scalability for both microgrid and stand-alone energy storage applications."	communications.	information		https://www.eaton.com/content/dam/eaton/services/eess/eess-documents/power-xpert-energy-optimizer-controller-pa027032en.pdf

Appendix O: V2G Test Plan (longitudinal)

Step No.	Step Description	Use Case	V2G Setting	Load Bank Setting	Check	Notes
PRE	Visual Inspection to confirm: fluids, warm engines	Baseline	N/A	N/A		
PRE	Verify all generators are off and ESTOPPED	Baseline	N/A	N/A		
PRE	Confirm IPD load bank, generator and bus ports are all open	Baseline	N/A	N/A		
PRE	Confirm site loads and IPD load ports are open	Baseline	N/A	N/A		
PRE	Confirm all breakers on IPDs are open	Baseline	N/A	N/A		
PRE	Confirm all generators are ESTOPPED and stopped	Baseline	N/A	N/A		
PRE	Confirm all IPD bus and generator breakers/contactors are open	Baseline	N/A	N/A		
PRE	Confirm all generators are connected to IPDs generator ports per the configuration to be tested	Baseline	N/A	N/A		
PRE	Confirm V2G is connected to an IPD No. 1 load port	Baseline	N/A	N/A		
PRE	Confirm the load bank is connected to an IPD No. 2 load port	Baseline	N/A	N/A		
1	Hearing and eye protection on all participants	Baseline	N/A	N/A		
2	Start and close CB on generator No. 1 (G1)	Baseline	N/A	N/A		
3	Confirm G1 MCCB closed on IPD No. 1	Baseline	N/A	N/A		
4	Close 200A bus breaker for IPD No. 1	Baseline	N/A	N/A		
5	Energize all bus ring and generator ports	Baseline	N/A	N/A		
6	Start and synchronize G1	Baseline	N/A	N/A		
7	Start and close CB on generator No. 2 (G2)	Baseline	N/A	N/A		
8	Confirm G2 MCCB closed on IPD No. 2	Baseline	N/A	N/A		
9	Close 200A bus breaker for IPD No. 2	Baseline	N/A	N/A		
10	Energize all bus ring and generator ports	Baseline	N/A	N/A		
11	Start and synchronize G2	Baseline	N/A	N/A		
12	Set load bank to 0 kW	Baseline	N/A	0 kW		
13	Close load port on IPD No. 2	Baseline	N/A	0 kW		
14	Set load bank to 60 kW	Baseline	N/A	60 kW		Observe frequency depression

Step No.	Step Description	Use Case	V2G Setting	Load Bank Setting	Check	Notes
15	Simultaneously adjust sourcing machines to achieve 60 Hz and equal load balance (achieve both control objectives simultaneously)	Baseline	N/A	60 kW		Note inter-dependencies between generator speed setpoints, power outputs, and system frequency
16	Open G1 port on IPD No. 1	Baseline	N/A	60 kW		Islanding G1. Observe no instabilities and load sharing continues
17	Close G1 port on IPD No. 1	Baseline	N/A	60 kW		Reconnecting G1, G2 via IPD No. 1 and 2
18	Open G2 port on IPD No. 2	Baseline	N/A	60 kW		Islanding G2. Observe no instabilities and load sharing continues
19	Close G2 port on IPD No. 2	Baseline	N/A	60 kW		Reconnecting G1, G2 via IPD No. 1 and 2
20	Close V2G port on IPD No. 1	Baseline	N/A	60 kW		Observe system voltage and frequency stability
21	Set V2G charging at 12.5 kW (25-percent load)	Baseline	Charging 12.5 kW	60 kW		Observe system voltage and frequency stability
22	Set V2G charging at 37.5 kW (75-percent load)	Baseline	Charging 37.5 kW	60 kW		Observe system voltage and frequency stability
23	Set V2G charging at 0 kW	Baseline	Charging 0 kW	60 kW		Observe system voltage and frequency stability
24	Set V2G discharging at 12.5 kW (25-percent load)	Baseline	Discharging 12.5 kW	60 kW		Observe system voltage and frequency stability
25	Set V2G discharging at 37.5 kW (75-percent load)	Baseline	Discharging 37.5 kW	60 kW		Observe system voltage and frequency stability
26	Open G1 port on IPD No. 1	Sudden generation decrease	Discharging 37.5 kW	60 kW		Observe system voltage and frequency stability
27	Close G1 port on IPD No. 1	Sudden generation increase	Discharging 37.5 kW	60kW		Observe system voltage and frequency stability and V2G operational status
28	Open G2 port on IPD No. 2	Sudden generation decrease	Discharging 37.5 kW	60 kW		Observe system voltage and frequency stability and V2G operational status
29	Close G2 port on IPD No. 2	Sudden generation increase	Discharging 37.5 kW	60 kW		Observe system voltage and frequency stability and V2G operational status
30	Set V2G charging to 50 kW (100 percent)	Sudden load increase	Charging 50 kW	60 kW		Observe system voltage and frequency stability and V2G operational status
31	Decrease load bank from 50 kW to 0 kW	Sudden load decrease	Charging 50 kW	0 kW		Observe system voltage and frequency stability and V2G operational status
32	Decrease G1 to 0 kW	Sudden generation decrease	Charging 50 kW	0 kW		Observe system voltage and frequency stability and V2G operational status

Step No.	Step Description	Use Case	V2G Setting	Load Bank Setting	Check	Notes
33	Increase G1 to 50 kW	Sudden generation increase	Charging 50 kW	0 kW		Observe system voltage and frequency stability and V2G operational status
34	Increase load bank from 0 kW to 50 kW	Sudden load increase	Charging 50 kW	50 kW		Observe system voltage and frequency stability and V2G operational status
35	Decrease G1 to 0 kW	Sudden generation decrease	Charging 50 kW	50 kW		Observe system voltage and frequency stability and V2G operational status
36	Increase G1 to 50 kW	Sudden generation increase	Charging 50 kW	50 kW		Observe system voltage and frequency stability and V2G operational status
37	Set V2G for discharging at 40 kW	Sudden generation increase	Discharging 40 kW	50 kW		Observe system voltage and frequency stability and V2G operational status
38	Increase load bank from 50 kW to 100 kW	Sudden load increase	Discharging 40 kW	100 kW		Observe system voltage and frequency stability and V2G operational status
39	Decrease load bank from 100 kW to 50 kW	Sudden load decrease	Discharging 40 kW	50 kW		Observe system voltage and frequency stability and V2G operational status
40	Set V2G to charge at 0 kW	Test end	0 kW	50 kW		
41	Set load bank to 0 kW	Test end	0 kW	0 kW		
42	Open both bus ports A&B on IPD No. 1	Test end	0 kW	0 kW		
43	Open both bus ports A&B on IPD No. 2	Test end	0 kW	0 kW		
44	Reset (open) all IPD breakers; all load banks offline; estop all generators	Test end	0 kW	0 kW		

Appendix P: Autonomous Vehicle Testing Facilities

The American Center for Mobility

The ACM at Willow Run was originally built in 1940—it was one of the first assembly line production facilities for planes, designed on a napkin by Ford's chief engineer, despite both the U.S. government and established aircraft manufacturers of the time believing assembly line plane production was impossible. At its peak, ACM produced one B-52 Liberator bomber every 55 minutes.

ACM's facility (Figure P-1) encompasses 500 acres, multiple test environments, and is adjacent to the Willow Run Airport. The test area contains highways, exit ramps, single, and multi-lane roads, intersections, and a configurable area. The configurable area is flat, approximately 400 m x 400 m asphalt pad that can be made into complex intersections, round abouts, or other user desired functions.

ACM is open to private industry, government, standard bodies, and academia and is a global center for testing and validation, education, and product and standards development related to connected and autonomous systems.

ACM is currently 13 months into a study, involving the center, defense, academia, and the public sector, to further research and test automated convoy platooning featuring both military and commercial grade trucks. The study is the first of its kind in the United States.

Figure P-1. American Center for Mobility site map.
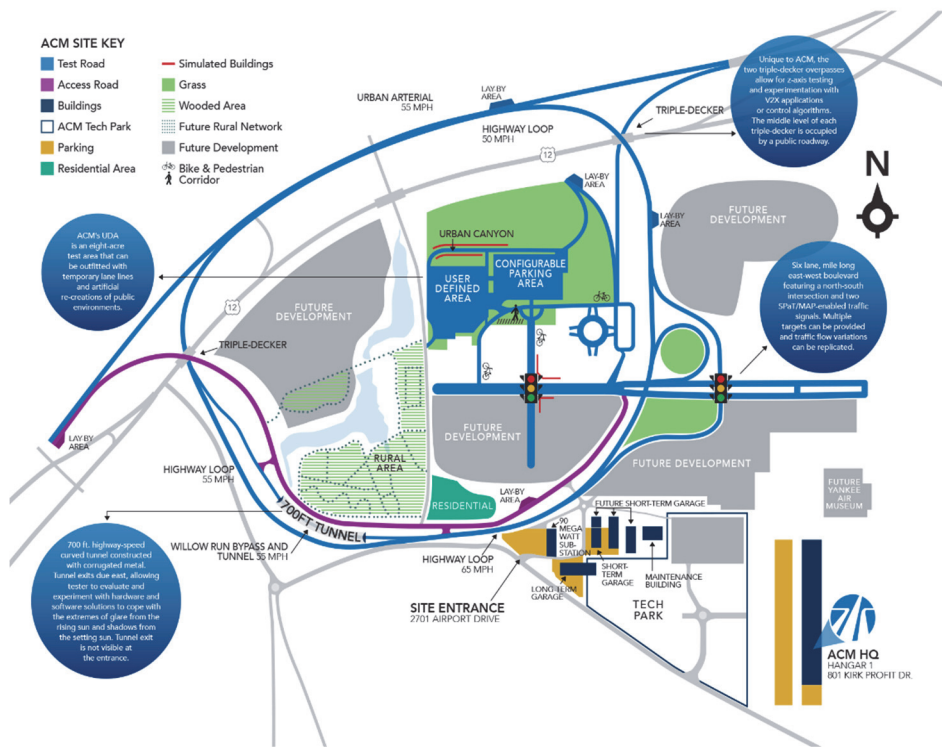
Larson Transportation Institute

The Thomas D. Larson Pennsylvania Transportation Institute at Pennsylvania State University is a transportation research center and a group of public and private stakeholders formed to address critical transportation-related problems.

The Institute "maintains a broad range of activities that support corporate and governmental needs and goals for research and collaboration."

The facility (Figure P-2) includes the Bus Research and Testing Center, Center for Integrated Asset Management for Multi-Modal Transportation Infrastructure Systems and Center for Dirt and Gravel Road Studies. Other facilities include the Battery Application Technology and Energy Research Laboratory, a hydrogen fueling station, Hybrid and Hydrogen Vehicle Research Lab, test track, and a vehicle-handling area test pad

Figure P-2. Larson Transportation Institute facility map

Appendix Q: 800A Intelligent Power Distribution Box Technical Manual

SCHWEITZER ENGINEERING LABORATORIES

SEL Engineering Services, Inc.

User Manual

Humber Garick

20190320

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Table of Revisions

Revision Number	Date	Description	Author	Reviewer	Approved
0		Initial issue	BM	SM	SM

Table of Contents

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Figures

SECTION 1   INTRODUCTION

This document is produced to describe the Modbus communication functionality of the 800A Intelligent Power Distribution (IPD800) box. Figure 1 below shows the IPD800 control panel.

Figure 1: IPD800

Figure 2 below shows the ethernet ports that can be used for Modbus communication. They are the bottom two ports on the Bus A (left) side of the IPD. The top right port will not communicate via Modbus and is for internal programming and diagnostics only.

Figure 2: Ethernet Ports with Modbus Comms

Figure 3 below shows the Data Flow Diagram of the IPD and the testing PC. Both the Real-Time Automation Controller (RTAC) and relays are installed inside the IPD800. The relays talk IEC-61850 GOOSE to the RTAC, which acts as a protocol translator (gateway) and converts the GOOSE messages to Modbus and DDS messages. DDS and Modbus are both available simultaneously on the same ethernet ports.

In order to translate the Modbus data coming from the IPD800, you will need to have a PC that acts as the Modbus master. SEL used Kepware ServerEX software to act as the Modbus master, as well as Kepware OPC Quick Client to interpret the Modbus data.

DISTRIBUTION A. Approved for public release: distribution unlimited
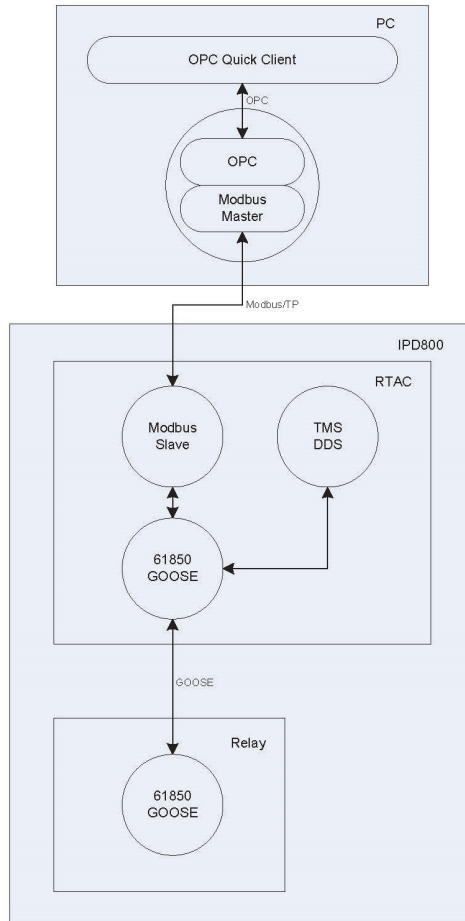
Figure 3: Data Flow Diagram of the Test

SECTION 2   DATA MAP

Table 1 below shows the data map of the Modbus registers used by the IPD800.

Tag Name	Address	Data Type	Tag Name	Address	Data Type	Tag Name	Address	Data Type
Breakers	400001	Word	P05_VA	400034	Word	P09_VA	400066	Word
P01_VA	400002	Word	P05_VB	400035	Word	P09_VB	400067	Word
P01_VB	400003	Word	P05_VC	400036	Word	P09_VC	400068	Word
P01_VC	400004	Word	P05_IA	400037	Word	P09_IA	400069	Word
P01_IA	400005	Word	P05_IB	400038	Word	P09_IB	400070	Word
P01_IB	400006	Word	P05_IC	400039	Word	P09_IC	400071	Word
P01_IC	400007	Word	P05_P	400040	Short	P09_P	400072	Short
P01_P	400008	Short	P05_Q	400041	Short	P09_Q	400073	Short
P01_Q	400009	Short	P06_VA	400042	Word	P10_VA	400074	Word
P02_VA	400010	Word	P06_VB	400043	Word	P10_VB	400075	Word
P02_VB	400011	Word	P06_VC	400044	Word	P10_VC	400076	Word
P02_VC	400012	Word	P06_IA	400045	Word	P10_IA	400077	Word
P02_IA	400013	Word	P06_IB	400046	Word	P10_IB	400078	Word
P02_IB	400014	Word	P06_IC	400047	Word	P10_IC	400079	Word
P02_IC	400015	Word	P06_P	400048	Short	P10_P	400080	Short
P02_P	400016	Short	P06_Q	400049	Short	P10_Q	400081	Short
P02_Q	400017	Short	P07_VA	400050	Word	P11_VA	400082	Word
P03_VA	400018	Word	P07_VB	400051	Word	P11_VB	400083	Word
P03_VB	400019	Word	P07_VC	400052	Word	P11_VC	400084	Word
P03_VC	400020	Word	P07_IA	400053	Word	P11_IA	400085	Word
P03_IA	400021	Word	P07_IB	400054	Word	P11_IB	400086	Word
P03_IB	400022	Word	P07_IC	400055	Word	P11_IC	400087	Word
P03_IC	400023	Word	P07_P	400056	Short	P11_P	400088	Short
P03_P	400024	Short	P07_Q	400057	Short	P11_Q	400089	Short
P03_Q	400025	Short	P08_VA	400058	Word	P12_VA	400090	Word
P04_VA	400026	Word	P08_VB	400059	Word	P12_VB	400091	Word
P04_VB	400027	Word	P08_VC	400060	Word	P12_VC	400092	Word
P04_VC	400028	Word	P08_IA	400061	Word	P12_IA	400093	Word
P04_IA	400029	Word	P08_IB	400062	Word	P12_IB	400094	Word
P04_IB	400030	Word	P08_IC	400063	Word	P12_IC	400095	Word
P04_IC	400031	Word	P08_P	400064	Short	P12_P	400096	Short
P04_P	400032	Short	P08_Q	400065	Short	P12_Q	400097	Short
P04_Q	400033	Short				FREQ	400098	Word

Table 1: Modbus Data Map

Figure 4 below maps out the port numbers assigned to the Modbus registers with the physical switches on the control panel. P01-P05 are all rated at 200A, P06-P08 are 100A rated, and P09-P12 are 60A rated. The IPD800 is rated at 400A total input per generator port, and 800A total output on each bus port.

Figure 4: Modbus Port IDs
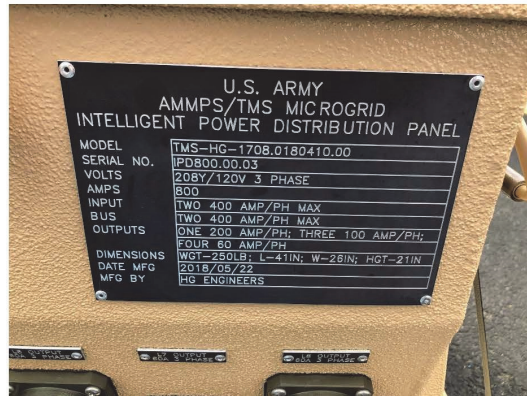
Figure 5: IPD800_3 ID Plate

SECTION 3   TESTING RESULTS

For test results and proof of functionality, we refer you to the attached video files.

01_TestSetup.mp4 explains the communication data flow as explained in section 1.

02_DigitalTest.mp4 explains and demonstrates the bit-packing of the Breakers register 40001.

03_VoltTest.mp4 shows the change in AC voltage on each port as each port is opened in sequence, beginning with P12 and ending with P04.

04_AnalogTests.mp4 explains the analog tests we perform in videos 05_AnalogTest1.mp4 through 08_AnalogTest4.mp4.

Note that port P06 should not be used because the breaker status does not report properly. The wire termination at the MCCB is faulty.

SECTION 4   ATTACHMENTS

01_TestSetup.mp4

02_DigitalTest.mp4

03_VoltTest.mp4

04_AnalogTests.mp4

05_AnalogTest1.mp4

06_AnalogTest2.mp4

07_AnalogTest3.mp4

08_AnalogTest4.mp4

Appendix R: Technical Manual for the AirGuard 3e-523

3eTI Technology International

Airguard 3e-525/523 Series Wireless Access Points (NDcPP20E/WLANAScEP10) Security Target

Version 0.5
05/08/18

3e Technologies International

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5th Floor
Rockville, MD   20850   USA

www.ultra-3eti.com

1. Security Target Introduction

This section identifies the Security Target (ST) and Target of Evaluation (TOE) identification, ST conventions, ST conformance claims, and the ST organization. The TOE is 3eTI AirGuard 3e-525/523 Wireless Access Points provided by 3e Technologies International. The TOE is being evaluated as a Network Device and Wireless Access Point.

The Security Target contains the following additional sections:

- Conformance Claims (Section 2)
- Security Objectives (Section 3)
- Extended Components Definition (Section 4)
- Security Requirements (Section 5)
- TOE Summary Specification (Section 6)

Conventions
The following conventions have been applied in this document:

- Security Functional Requirements – Part 2 of the CC defines the approved set of operations that may be applied to functional requirements: iteration, assignment, selection, and refinement.

  o Iteration: allows a component to be used more than once with varying operations. In the ST, iteration is indicated by a parenthetical number placed at the end of the component. For example FDP_ACC.1(1) and FDP_ACC.1(2) indicate that the ST includes two iterations of the FDP_ACC.1 requirement.

  o Assignment: allows the specification of an identified parameter. Assignments are indicated using bold and are surrounded by brackets (e.g., [**assignment**]). Note that an assignment within a selection would be identified in italics and with embedded bold brackets (e.g., [*[selected-assignment]*]).

  o Selection: allows the specification of one or more elements from a list. Selections are indicated using bold italics and are surrounded by brackets (e.g., [*selection*]).

  o Refinement: allows the addition of details. Refinements are indicated using bold, for additions, and strike-through, for deletions (e.g., "… **all** objects …" or "… ~~some~~ **big** things …").

- Other sections of the ST – Other sections of the ST use bolding to highlight text of special interest, such as captions.

1.1 Security Target Reference

ST Title – 3eTI AirGuard 3e-525/523 Wireless Access Points (NDcPP20E/WLANAScEP10) Security Target

ST Version – Version 0.5

ST Date – 05/08/18

1.2 TOE Reference

TOE Identification – 3e Technologies International AirGuard 3e-525/523 Wireless Access Points

TOE Developer – 3e Technologies International

TOE Models – 3e-525N, 3e-525N-MP, 3e-525NV, 3e-523N, 3e-523NF and 3e-523NR Wireless Access Points, firmware version 5.1.0

Evaluation Sponsor – 3e Technologies International

Keywords – Encryption, Wireless Access Points, IPsec, access control, traffic filter

1.3 TOE Overview

The Target of Evaluation (TOE) includes the following 3eTI AirGuard™ Wireless Access Points models: 3e-525N, 3e-525N MP, 3e-525NV, 3e-523N, 3e-523NF and 3e-523NR. The models share the identical hardware platform and firmware. Differences between models are limited to enclosure, power options, the number of Wi-Fi radio interfaces and extra video component.

The table below shows the differences among the 3eTI Wireless Access Points (APs)

Table 1-1 Access Point Products Comparison

Model	Number of Radio	Radio Mode	Mechanical	Comments
3e-525N	2	Access Point	Ruggedized for industrial and outdoor	
3e-525N MP	2	Access Point	Ruggedized for industrial and outdoor	Same as 3e-525N except mobile power input
3e-525NV	2	Access Point	Ruggedized for industrial and outdoor	Same as 3e-525N with extra video capture card
3e-523N	1	Access Point	Indoor Enclosure	Operate in Industrial temperature range -40C to 75C
3e-523NF	1	Access Point	Indoor Enclosure	Same as 3e-523N Operate in -10-60C
3e-523NR	1	Access Point	Ruggedized for industrial and outdoor	Same as 3e-523N except enclosure for outdoor deployment

1.3.1 Hardware, Firmware, and Software Required by the TOE

The TOE consists of hardware and firmware residing on the Access Point appliances as listed in Section 1.2 above. The evaluated configuration of the TOE requires the following Operational Environment support which is not included in the TOE's physical boundary.

- **RADIUS Server:** The TOE requires a RADIUS Server in the Operational Environment for wireless client authentication.
- **Wireless Clients:** All wireless client hosts connecting to the wired network from the wireless network.
- **Administrator Workstations:** Trusted administrators access the TOE through the HTTPS protocol.

- **Audit Servers:** The TOE relies upon the audit server for storage of audit records.
- **NTP Servers:** The TOE relies upon an NTP server to provide reliable time.

1.4 TOE Description

The TOE is classified as a Wireless Local Area Network (WLAN) Access Device. The TOE employs mesh networking, which allows multiple TOEs to network within the operational environment (802.11s is not validated).

The TOE sits between wired and wireless portions of an enterprise network and provides integrity and confidentiality of wireless traffic and restricts access of wireless endpoints to wired network systems. The TOE provides a secure, yet flexible, WLAN environment as an Access Point that mediates authenticated wireless client's data through encryption/decryption and integrity protection between the wireless link and the wired LAN.

1.4.1 TOE Architecture

The 3eTI 3e-525N, 3e-525N MP, 3e-525NV, 3e-523N, 3e-523NF and 3e-523NR Access Points (hereafter referred to as Access Points or APs) provide the connection point between wireless client hosts and the wired network. Once installed as trusted nodes on the wired infrastructure, the APs provide the encryption service on the wireless network between themselves and the wireless clients. The APs can also communicate among themselves through the secured channel via 3eTI mesh forming or 802.11s mesh network. However, this AP to AP secured communication service is not evaluated here.

The Access Points are appliances consisting of hardware and firmware. Wireless communications between clients and APs are carried out using the IEEE 802.11 protocol standard. The 802.11 standard governs communication transmission for wireless devices. For this evaluation, the APs use 802.11a, 802.11g and 802.11n for wireless communication. The wireless security protocol that is to be used with the APs is WPA2, which is the Wi-Fi Alliance interoperable specification based on IEEE 802.11i security standard.

The APs have one or more RF interfaces and one or more Ethernet interfaces. All these interfaces are controlled by the software executing on the APs. The Access Points included in the TOE vary by the number of RF and Ethernet interfaces and antenna support; however, the differences do not affect the security functionality claimed by the TOE. The APs maintain a security domain containing all hardware and software of the appliance for its own execution. The APs maintain this security domain by controlling the actions that can occur at the interfaces described above and providing the hardware resources that carry out the execution of tasks on the APs. The APs provide for isolation of different wireless clients that have sessions with the WLAN, which includes maintaining the keys necessary to support encrypted sessions with wireless devices.

The APs control the actions and the manner in which external users may interact with its external interfaces. Thus, the APs ensure that the TOE's enforcement functions are invoked and succeed before allowing the external user to carry out any other security function with or through the APs. The figure below shows the TOE and its operational environment. The trusted path between the TOE and Administration Station is TLS/HTTPS and the trusted path between the TOE and NTP, Log Server and RADIUS server is IPsec.

The figure below illustrates the typical deployment use case and operational environment setup for TOE devices.
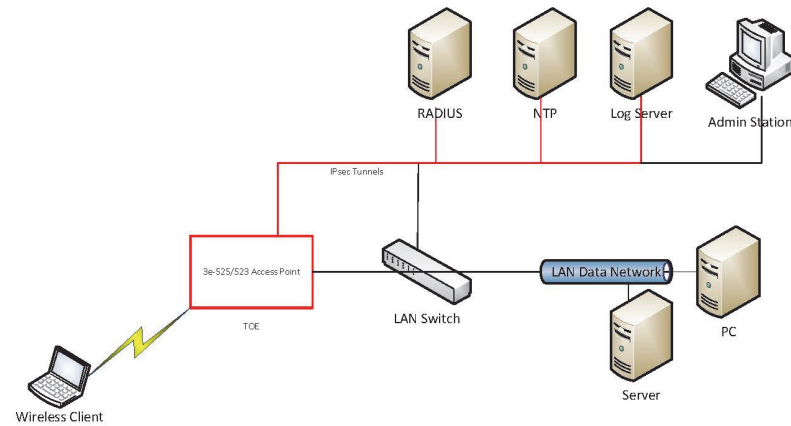
1.4.1.1 Physical Boundaries

The TOE physical boundary defines all hardware and firmware that is required to support the TOE's logical boundary and the TOE's security functions. The TOE hardware platform uses Freescale MPC8378E CPU and the TOE's firmware contains an embedded Linux Kernel customized by 3eTI based on kernel version 3.6. In short, the TOE's physical boundary is the physical device/appliance for all models. The APs have the following physical interfaces.

- **AP antenna ports** – The AP antenna ports are connected to one 802.11a/b/g/n radio for wireless connectivity to secure WLAN clients.

- **LAN local port** – The LAN local port is used exclusively for management of the access point. It supports Ethernet 10/100/1000 Mbps wired traffic, full duplex for fast configuration and management. The LAN port is locally terminated – no data entering here goes out to the WLAN, only management data is accepted.

- **WAN uplink port** – The WAN uplink port is intended to connect the 3eTI access points to the wired LAN. It also supports Ethernet 10/100/1000 Mbps wired traffic in a full duplex configuration. The WAN port bridges all data between the wireless domain and the wired network.

1.4.1.2 Logical Boundaries

This section summarizes the security functions provided by the TOE:
- Security audit
- Cryptographic support
- Identification and authentication
- Security management
- Protection of the TSF
- TOE access
- Trusted path/channels

1.4.1.2.1 Security audit

The TOE generates auditable events for actions on the TOE with the capability of selective audit record generation. The records of these events can be viewed within the Web User Interface (UI) or they can be exported to audit log servers in the Operational Environment. The TOE generates records for its own actions, containing information about the user/process associated with the event, the success or failure of the event, and the time that the event occurred. Additionally, all administrator actions relating to the management of TSF data and configuration data are logged by the TOE's audit generation functionality.

1.4.1.2.2 Cryptographic support

The TOE uses NIST SP 800-90 DRBG random bits generator and the following cryptographic algorithms: AES, RSA, ECDSA, SHA, HMAC to secure the wireless client data to the LAN, trusted channel and trusted path communication. The TOE zeroizes Critical Security Parameters (CSPs) to mitigate the possibility of disclosure or modification.

1.4.1.2.3 Identification and authentication

The TOE provides Identification and Authentication security functionality to ensure that all users are properly identified and authenticated before accessing TOE functionality. The TOE displays a configurable access banner and enforces a local password-based authentication mechanism to perform administrative user authentication. Passwords are obscured when being displayed during any attempted login.

The wireless users are authenticated by the RADIUS server in the Operational Environment. EAP-TLS is used for WPA2 wireless authentication via x.509 certificates. The TOE sets up an IPsec tunnel with a RADIUS server and supports IKEv2 with x.509 certificates for IPsec endpoints mutual authentication with its IPsec peer.

1.4.1.2.4 Security management

The Web User Interface (UI) of the TOE provides the capabilities for configuration and administration. The Web UI can be accessed via the dedicated local Ethernet port configured for "out-of-band" management. There is no local access such as a serial console port. Therefore, the local and remote management is considered the same for this evaluation.

An authorized administrator has the ability to modify, edit, and delete security parameters such as audit data, configuration data, and user authentication data. The Web UI also offers an authorized administrator the capability to manage how security functions behave. For example, an administrator can enable/disable certain audit functions query and set encryption/decryption algorithms used for network packets.

1.4.1.2.5 Protection of the TSF

Internal testing of the TOE hardware, software, and software updates against tampering ensures that all security functions are running and available before the TOE accepts any communications. The TSF prevents reading of pre-shared keys, symmetric keys, private keys, and passwords. The TOE uses electronic signature verification before any firmware/software updates are installed.

1.4.1.2.6 TOE access

The TOE provides the following TOE Access functionality:

- Configurable MAC address and/or IP address filtering with remote management session establishment
- TSF-initiated session termination when a connection is idle for a configurable time period
- Administrative termination of own session

- Configurable MAC address filtering for wireless client session establishment (either allow or deny the client access)
- TOE Access Banners

1.4.1.2.7 Trusted path/channels

The TOE protects interactive communication with administrators using TLS/HTTPS, both integrity and disclosure protection is ensured.

The TOE protects communication with wireless clients using WPA2 with 802.1x EAP-TLS. IPsec tunnels are used by the TOE to setup trusted channels with an NTP, RADIUS and Audit Log server.

1.4.2 TOE Documentation

- Ultra Electronics 3eTI AirGuard User's Guide 3e-523N, 3e-523NR, 3e-523NF, 3e-525N, 3e-525N-MP, 3e-525NV, May 08, 2018, 29010012-001, Revision G (**Admin Guide**)

2. Conformance Claims

This TOE is conformant to the following CC specifications:

- Common Criteria for Information Technology Security Evaluation Part 2: Security functional components, Version 3.1, Revision 4, September 2012.

    - Part 2 Extended

- Common Criteria for Information Technology Security Evaluation Part 3: Security assurance components, Version 3.1 Revision 4, September 2012.

    - Part 3 Conformant

- Package Claims:

    - collaborative Protection Profile for Network Devices Version 2.0 + Errata 20180314, Version 2.0, 14 March 2018 (NDcPP20E) with technical decisions TD0290 and TD0228.

    - Extended Package Wireless Local Area Network (WLAN) Access Systems, Version 1.0, 29 May 2015 (NDcPP20E/WLANAScEP10) with technical decisions TD0282, TD0271, TD0277 and TD0315

2.1 Conformance Rationale

The ST conforms to the NDcPP20E/WLANAScEP10. As explained previously, the security problem definition, security objectives, and security requirements have been drawn from the PPs.

3. Security Objectives

The Security Problem Definition may be found in the NDcPP20E/WLANAScEP10 and this section reproduces only the corresponding Security Objectives for operational environment for reader convenience. The NDcPP20E/WLANAScEP10 offers additional information about the identified security objectives, but that has not been reproduced here and the NDcPP20E/WLANAScEP10 should be consulted if there is interest in that material.

In general, the NDcPP20E/WLANAScEP10 has defined Security Objectives appropriate for Network Device and Wireless Access Point and as such are applicable to the 3e-525/523 TOE.

3.1 Security Objectives for the Operational Environment

OE.ADMIN_CREDENTIALS_SECURE The administrator's credentials (private key) used to access the TOE must be protected on any other platform on which they reside.

OE.COMPONENTS_RUNNING (applies to distributed TOEs only)

OE.CONNECTIONS TOE administrators will ensure that the TOE is installed in a manner that will allow the TOE to effectively enforce its policies on network traffic flowing among attached networks.

OE.NO_GENERAL_PURPOSE There are no general-purpose computing capabilities (e.g., compilers or user applications) available on the TOE, other than those services necessary for the operation, administration and support of the TOE.

OE.NO_THRU_TRAFFIC_PROTECTION The TOE does not provide any protection of traffic that traverses it. It is assumed that protection of this traffic will be covered by other security and assurance measures in the operational environment.

OE.PHYSICAL Physical security, commensurate with the value of the TOE and the data it contains, is provided by the environment.

OE.RESIDUAL_INFORMATION The Security Administrator ensures that there is no unauthorized access possible for sensitive residual information (e.g. cryptographic keys, keying material, PINs, passwords etc.) on networking equipment when the equipment is discarded or removed from its operational environment.

OE.TRUSTED_ADMIN TOE Administrators are trusted to follow and apply all guidance documentation in a trusted manner.

OE.UPDATES The TOE firmware and software is updated by an administrator on a regular basis in response to the release of product updates due to known vulnerabilities.

T.SECURITY_FUNCTIONALITY_FAILURE An external, unauthorized entity could make use of failed or compromised security functionality and might therefore subsequently use or abuse security functions without prior authentication to access, change or modify device data, critical network traffic or security functionality of the device.

4. Extended Components Definition

All of the extended requirements in this ST have been drawn from the NDcPP20E/WLANAScEP10. The NDcPP20E/WLANAScEP10 defines the following extended requirements and since they are not redefined in this ST the NDcPP20E/WLANAScEP10 should be consulted for more information in regard to those CC extensions.

Extended SFRs:

- NDcPP20E:FAU_STG_EXT.1: Protected Audit Event Storage
- NDcPP20E:FCS_HTTPS_EXT.1: HTTPS Protocol
- NDcPP20E:FCS_IPSEC_EXT.1: IPsec Protocol
- NDcPP20E:FCS_RBG_EXT.1: Random Bit Generation
- NDcPP20E:FCS_TLSS_EXT.1: TLS Server Protocol
- WLANAScEP10:FIA_8021X_EXT.1: Extended: 802.1X Port Access Entity (Authenticator) Authentication
- NDcPP20E:FIA_PMG_EXT.1: Password Management
- WLANAScEP10:FIA_PSK_EXT.1: Extended: Pre-Shared Key Composition
- NDcPP20E:FIA_UAU_EXT.2: Password-based Authentication Mechanism
- NDcPP20E:FIA_UIA_EXT.1: User Identification and Authentication
- NDcPP20E:FIA_X509_EXT.1(2): X.509 Certificate Validation (Rev)
- NDcPP20E:FIA_X509_EXT.2: X.509 Certificate Authentication
- NDcPP20E:FIA_X509_EXT.3: X.509 Certificate Requests
- NDcPP20E:FPT_APW_EXT.1: Protection of Administrator Passwords
- NDcPP20E:FPT_SKP_EXT.1: Protection of TSF Data (for reading of all pre-shared, symmetric and private keys)
- NDcPP20E:FPT_STM_EXT.1: Reliable Time Stamps
- NDcPP20E:FPT_TST_EXT.1: TSF testing
- WLANAScEP10:FPT_TST_EXT.1: Extended: TSF Testing
- NDcPP20E:FPT_TUD_EXT.1: Trusted update
- NDcPP20E:FTA_SSL_EXT.1: TSF-initiated Session Locking

5. Security Requirements

This section defines the Security Functional Requirements (SFRs) and Security Assurance Requirements (SARs) that serve to represent the security functional claims for the Target of Evaluation (TOE) and to scope the evaluation effort.

The SFRs have all been drawn from the NDcPP20E/WLANAScEP10. The refinements and operations already performed in the NDcPP20E/WLANAScEP10 are not identified (e.g., highlighted) here, rather the requirements have been copied from the NDcPP20E/WLANAScEP10 and any residual operations have been completed herein. Of particular note, the NDcPP20E/WLANAScEP10 made a number of refinements and completed some of the SFR operations defined in the Common Criteria (CC) and that PP should be consulted to identify those changes if necessary.

The SARs are also drawn from the NDcPP20E/WLANAScEP10 which includes all the SARs for EAL 1. However, the SARs are effectively refined since requirement-specific 'Assurance Activities' are defined in the NDcPP20E/WLANAScEP10 that serve to ensure corresponding evaluations will yield more practical and consistent assurance than the EAL 1 assurance requirements alone. The NDcPP20E/WLANAScEP10 should be consulted for the assurance activity definitions.

5.1 TOE Security Functional Requirements

The following table identifies the SFRs that are satisfied by 3e-525/523 TOE.

Requirement Class	Requirement Component
FAU: Security audit	NDcPP20E:FAU_GEN.1: Audit Data Generation
	NDcPP20E:FAU_GEN.2: User identity association
	NDcPP20E:FAU_STG_EXT.1: Protected Audit Event Storage
FCS: Cryptographic support	NDcPP20E:FCS_CKM.1: Cryptographic Key Generation
	WLANAScEP10:FCS_CKM.1(2): Cryptographic Key Generation (Symmetric Keys for WPA2 Connections)
	NDcPP20E:FCS_CKM.2: Cryptographic Key Establishment
	WLANAScEP10:FCS_CKM.2(2): Cryptographic Key Distribution (PMK)
	WLANAScEP10:FCS_CKM.2(3): Cryptographic Key Distribution (GTK)
	NDcPP20E:FCS_CKM.4: Cryptographic Key Destruction
	NDcPP20E:FCS_COP.1/DataEncryption: Cryptographic Operation (AES Data Encryption/Decryption)
	WLANAScEP10:FCS_COP.1(1): Cryptographic Operation (AES Data Encryption/Decryption)
	NDcPP20E:FCS_COP.1/SigGen: Cryptographic Operation (Signature Generation and Verification)
	NDcPP20E:FCS_COP.1/Hash: Cryptographic Operation (Hash Algorithm)
	NDcPP20E:FCS_COP.1/KeyedHash: Cryptographic Operation (Keyed Hash Algorithm)
	NDcPP20E:FCS_HTTPS_EXT.1: HTTPS Protocol
	NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1: IPsec Protocol
	NDcPP20E:FCS_RBG_EXT.1: Random Bit Generation
	NDcPP20E:FCS_TLSS_EXT.1: TLS Server Protocol
FIA: Identification and authentication	WLANAScEP10:FIA_8021X_EXT.1: Extended: 802.1X Port Access Entity (Authenticator) Authentication
	NDcPP20E:FIA_AFL.1: Authentication Failure Management
	WLANAScEP10:FIA_AFL.1: Authentication Failure Handling
	NDcPP20E:FIA_PMG_EXT.1: Password Management

	WLANAScEP10:FIA_PSK_EXT.1: Extended: Pre-Shared Key Composition
	WLANAScEP10:FIA_UAU.6: Re-authenticating
	NDcPP20E:FIA_UAU.7: Protected Authentication Feedback
	NDcPP20E:FIA_UAU_EXT.2: Password-based Authentication Mechanism
	NDcPP20E:FIA_UIA_EXT.1: User Identification and Authentication
	NDcPP20E:FIA_X509_EXT.1/Rev: X.509 Certificate Validation (Rev)
	NDcPP20E:FIA_X509_EXT.2: X.509 Certificate Authentication
	NDcPP20E:FIA_X509_EXT.3: X.509 Certificate Requests
FMT: Security management	NDcPP20E:FMT_MOF.1/ManualUpdate: Management of security functions behaviour (Manual Update)
	NDcPP20E:FMT_MTD.1/CoreData: Management of TSF Data (CoreData)
	NDcPP20E:FMT_SMF.1: Specification of Management Functions
	WLANAScEP10:FMT_SMR.1: Security Management Roles
	NDcPP20E:FMT_SMR.2: Restrictions on Security Roles
FPT: Protection of the TSF	NDcPP20E:FPT_APW_EXT.1: Protection of Administrator Passwords
	WLANAScEP10:FPT_FLS.1: Failure with preservation of secure state
	NDcPP20E:FPT_SKP_EXT.1: Protection of TSF Data (for reading of all pre-shared, symmetric and private keys)
	NDcPP20E:FPT_STM_EXT.1: Reliable Time Stamps
	NDcPP20E:FPT_TST_EXT.1: TSF testing
	WLANAScEP10:FPT_TST_EXT.1: Extended: TSF Testing
	NDcPP20E:FPT_TUD_EXT.1: Trusted update
FTA: TOE access	NDcPP20E:FTA_SSL.3: TSF-initiated Termination
	NDcPP20E:FTA_SSL.4: User-initiated Termination
	NDcPP20E:FTA_SSL_EXT.1: TSF-initiated Session Locking
	NDcPP20E:FTA_TAB.1: Default TOE Access Banners
	WLANAScEP10:FTA_TSE.1: TOE Session Establishment
FTP: Trusted path/channels	NDcPP20E:FTP_ITC.1: Inter-TSF trusted channel
	WLANAScEP10:FTP_ITC.1: Inter-TSF Trusted Channel
	NDcPP20E:FTP_TRP.1/Admin Trusted Path: Trusted Path (Admin)

Table 1 TOE Security Functional Components

5.1.1   Security audit (FAU)

5.1.1.1   Audit Data Generation (NDcPP20E:FAU_GEN.1)

NDcPP20E:FAU_GEN.1.1

The TSF shall be able to generate an audit record of the following auditable events:
a) Start-up and shut-down of the audit functions;
b) All auditable events for the not specified level of audit; and
c) All administrative actions comprising:
- Administrative login and logout (name of user account shall be logged if individual user accounts are required for administrators).
- Changes to TSF data related to configuration changes (in addition to the information that a change occurred it shall be logged what has been changed).

- Generating/import of, changing, or deleting of cryptographic keys (in addition to the action itself a unique key name or key reference shall be logged).
- Resetting passwords (name of related user account shall be logged).
- [*no other actions*];
d) Specifically defined auditable events listed in Table 2.

Requirement	Auditable Events	Additional Content
NDcPP20E:FAU_GEN.1	None	None
NDcPP20E:FAU_GEN.2	None	None
NDcPP20E:FAU_STG_EXT.1	None	None
NDcPP20E:FCS_CKM.1	None	None
WLANAScEP10:FCS_CKM.1(2)	Failure of the key generation activity.	None
NDcPP20E:FCS_CKM.2	None	None
WLANAScEP10:FCS_CKM.2(2)	Failure of the key distribution activity.	None
WLANAScEP10:FCS_CKM.2(3)	Failure of the key distribution activity, including failures relate to wrapping the GTK.	Identifier(s) for intended recipients of wrapped key.
NDcPP20E:FCS_CKM.4	None	None
NDcPP20E:FCS_COP.1/DataEncryption	None	None
WLANAScEP10:FCS_COP.1(1)	Failure of the WPA2 encryption or decryption.	Cryptographic mode of operation, name/identifier of object being encrypted/decrypted, non-TOE endpoint of connection (IP address).
NDcPP20E:FCS_COP.1/SigGen	None	None
NDcPP20E:FCS_COP.1/Hash	None	None
NDcPP20E:FCS_COP.1/KeyedHash	None	None
NDcPP20E:FCS_HTTPS_EXT.1	Failure to establish a HTTPS Session.	Reason for failure.
NDcPP20E:FCS_IPSEC_EXT.1	Failure to establish an IPsec SA.	Reason for failure.
WLANAScEP10:FCS_IPSEC_EXT.1	Protocol failures. Establishment/Termination of an IPsec SA. Negotiation "down from an IKEv2 to IKEv1 exchange.	Reason for failure. Non-TOE endpoint of connection (IP address) for both successes and failures.
NDcPP20E:FCS_RBG_EXT.1	None	None
NDcPP20E:FCS_TLSS_EXT.1	Failure to establish a TLS Session.	Reason for failure.
WLANAScEP10:FIA_8021X_EXT.1	Attempts to access the 802.1X controlled port prior to successful completion of the authentication exchange.	Provided client identity (MAC address).
NDcPP20E:FIA_AFL.1	Unsuccessful login attempt limit is met or exceeded.	Origin of the attempt (e.g., IP address).
WLANAScEP10:FIA_AFL.1	The reaching of the threshold for the unsuccessful authentication attempts and the actions taken (e.g., disabling of an account) and the subsequent, if appropriate, restoration to the	None

	normal state (e.g., re-enabling of a terminal).	
NDcPP20E:FIA_PMG_EXT.1	None	None
WLANAScEP10:FIA_PSK_EXT.1	None	None
WLANAScEP10:FIA_UAU.6	Attempts to re-authenticate.	Origin of the attempt (e.g., IP address).
NDcPP20E:FIA_UAU.7	None	None
NDcPP20E:FIA_UAU_EXT.2	All use of identification and authentication mechanism.	Origin of the attempt (e.g., IP address).
NDcPP20E:FIA_UIA_EXT.1	All use of identification and authentication mechanism.	Origin of the attempt (e.g., IP address).
NDcPP20E:FIA_X509_EXT.1/Rev	Unsuccessful attempt to validate a certificate.	Reason for failure.
NDcPP20E:FIA_X509_EXT.2	None	None
NDcPP20E:FIA_X509_EXT.3	None	None
NDcPP20E:FMT_MOF.1/ManualUpdate	Any attempt to initiate a manual update.	
NDcPP20E:FMT_MTD.1/CoreData	All management activities of TSF data.	
NDcPP20E:FMT_SMF.1	None	None
WLANAScEP10:FMT_SMR.1	None	None
NDcPP20E:FMT_SMR.2	None	None
NDcPP20E:FPT_APW_EXT.1	None	None
WLANAScEP10:FPT_FLS.1	Failure of the TSF.	Indication that the TSF has failed with the type of failure that occurred.
NDcPP20E:FPT_SKP_EXT.1	None	None
NDcPP20E:FPT_STM_EXT.1	Discontinuous changes to time - either Administrator actuated or changed via an automated process. (Note that no continuous changes to time need to be logged. See also application note on FPT_STM_EXT.1)	For discontinuous changes to time: The old and new values for the time. Origin of the attempt to change time for success and failure (e.g., IP address).
NDcPP20E:FPT_TST_EXT.1	None	None
WLANAScEP10:FPT_TST_EXT.1	Execution of this set of TSF self-tests. Detected integrity violations.	For integrity violations, the TSF code file that caused the integrity violation.
NDcPP20E:FPT_TUD_EXT.1	Initiation of update; result of the update attempt (success or failure).	None
NDcPP20E:FTA_SSL.3	The termination of a remote session by the session locking mechanism.	None
NDcPP20E:FTA_SSL.4	The termination of an interactive session.	None
NDcPP20E:FTA_SSL_EXT.1	(if 'lock the session' is selected) Any attempts at unlocking of an interactive session. (if 'terminate the session' is selected) The termination of a local session by the session locking mechanism.	None
NDcPP20E:FTA_TAB.1	None	None

WLANAScEP10:FTA_TSE.1	Denial of a session establishment due to the session establishment mechanism.	Reason for denial, origin of establishment attempt.
NDcPP20E:FTP_ITC.1	Initiation of the trusted channel. Termination of the trusted channel. Failure of the trusted channel functions.	Identification of the initiator and target of failed trusted channels establishment attempt.
WLANAScEP10:FTP_ITC.1	Failed attempts to establish a trusted channel (including IEEE 802.11). Detection of modification of channel data.	Identification of the initiator and target of channel.
NDcPP20E:FTP_TRP.1/Admin	Initiation of the trusted path. Termination of the trusted path. Failure of the trusted path functions.	

Table 2 Auditable Events

NDcPP20E:FAU_GEN.1.2

The TSF shall record within each audit record at least the following information:
a) Date and time of the event, type of event, subject identity, and the outcome (success or failure) of the event; and
b) For each audit event type, based on the auditable event definitions of the functional components included in the cPP/ST, information specified in column three of Table 2.

5.1.1.2   User identity association (NDcPP20E:FAU_GEN.2)

NDcPP20E:FAU_GEN.2.1

For audit events resulting from actions of identified users, the TSF shall be able to associate each auditable event with the identity of the user that caused the event.

5.1.1.3   Protected Audit Event Storage (NDcPP20E:FAU_STG_EXT.1)

NDcPP20E:FAU_STG_EXT.1.1

The TSF shall be able to transmit the generated audit data to an external IT entity using a trusted channel according to FTP_ITC.1.

NDcPP20E:FAU_STG_EXT.1.2

The TSF shall be able to store generated audit data on the TOE itself.

NDcPP20E:FAU_STG_EXT.1.3

The TSF shall [*overwrite previous audit records according to the following rule: [when allotted space has reached its threshold]*] when the local storage space for audit data is full.

5.1.2   Cryptographic support (FCS)

5.1.2.1   Cryptographic Key Generation (NDcPP20E:FCS_CKM.1)

NDcPP20E:FCS_CKM.1.1

The TSF shall generate asymmetric cryptographic keys in accordance with a specified cryptographic key generation algorithm: [
- RSA schemes using cryptographic key sizes of 2048-bit or greater that meet the following: FIPS PUB 186-4, 'Digital Signature Standard (DSS)', Appendix B.3,

- ECC schemes using 'NIST curves' [P-256, P-384, P-521] that meet the following: FIPS PUB 186-4, 'Digital Signature Standard (DSS)', Appendix B.4,

- FFC Schemes using Diffie-Hellman group 14 that meet the following: RFC 3526, Section 3
].

5.1.2.2 Cryptographic   Key   Generation   (Symmetric   Keys   for   WPA2   Connections) (WLANAScEP10:FCS_CKM.1(2))

WLANAScEP10:FCS_CKM.1(2).1

Refinement: The TSF shall generate symmetric cryptographic keys in accordance with a specified cryptographic key generation algorithm PRF-384 and [*no other*] and specified cryptographic key sizes 128 bits and [*no other key sizes*] using a Random Bit Generator as specified in FCS_RBG_EXT.1 that meet the following: IEEE 802.11-2012 and [*no other standards*].

5.1.2.3   Cryptographic Key Establishment (Refinement) (NDcPP20E:FCS_CKM.2)

NDcPP20E:FCS_CKM.2.1

The TSF shall perform cryptographic key establishment in accordance with a specified cryptographic key establishment method: [

- RSA-based key establishment schemes that meet the following: NIST Special Publication 800-56B Revision 1, 'Recommendation for Pair-Wise Key Establishment Schemes Using Integer Factorization Cryptography',

- Elliptic curve-based key establishment schemes that meet the following: NIST Special Publication 800-56A Revision 2, 'Recommendation for Pair-Wise Key Establishment Schemes Using Discrete Logarithm Cryptography',

- Key establishment scheme using Diffie -Hellman group 14 that meets the following: RFC 3526, Section 3
].

5.1.2.4   Cryptographic Key Distribution (PMK) (WLANAScEP10:FCS_CKM.2(2))

WLANAScEP10:FCS_CKM.2(2).1

Refinement: The TSF shall receive the 802.11 Pairwise Master Key (PMK) in accordance with a specified cryptographic key distribution method: from 802.1X Authorization Server that meets the following: IEEE 802.11-2012 and does not expose the cryptographic keys.

5.1.2.5   Cryptographic Key Distribution (GTK) (WLANAScEP10:FCS_CKM.2(3))

WLANAScEP10:FCS_CKM.2(3).1

Refinement: The TSF shall distribute Group Temporal Key (GTK) in accordance with a specified cryptographic key distribution method: AES Key Wrap in an EAPOL-Key frame that meets the following: NIST SP 800-38F, IEEE 802.11-2012 for the packet format and timing considerations and does not expose the cryptographic keys.

5.1.2.6   Cryptographic Key Destruction (NDcPP20E:FCS_CKM.4)

NDcPP20E:FCS_CKM.4.1

The TSF shall destroy cryptographic keys in accordance with a specified cryptographic key destruction method:

- For plaintext keys in volatile storage, the destruction shall be executed by a [single overwrite consisting of [zeroes];

- For plaintext keys in non-volatile storage, the destruction shall be executed by the invocation of an interface provided by a part of the TSF that [
> *o logically addresses the storage location of the key and performs a [single-pass] overwrite consisting of [a new value of the key]]*

that meets the following: No Standard.

5.1.2.7 Cryptographic Operation (AES Data Encryption/Decryption) (NDcPP20E:FCS_COP.1/DataEncryption))

NDcPP20E:FCS_COP.1.1/DataEncryption
> The TSF shall perform encryption/decryption in accordance with a specified cryptographic algorithm AES used in [*CBC, GCM*] mode and cryptographic key sizes [*128 bits, 256 bits*] that meet the following: AES as specified in ISO 18033-3, [*CBC as specified in ISO 10116, GCM as specified in ISO 19772*].

5.1.2.8 Cryptographic Operation (AES Data Encryption/Decryption) (WLANAScEP10:FCS_COP.1(1))

WLANAScEP10:FCS_COP.1(1).1
> Refinement: The TSF shall perform encryption/decryption in accordance with a specified cryptographic algorithm AES used in CBC, CCMP [*GCM*] mode and cryptographic key sizes 128 bits [*256 bits*] that meet the following: AES as specified in ISO 18033-3, CCMP as defined in NIST SP 800-38C and IEEE 802.11-2012, [*CBC as specified in ISO 10116, GCM as specified in ISO 19772, CCMP as specified in NIST SP800-38D*].

5.1.2.9 Cryptographic Operation (Signature Generation and Verification) (NDcPP20E:FCS_COP.1/SigGen))

NDcPP20E:FCS_COP.1.1/SigGen
> The TSF shall perform cryptographic signature services (generation and verification) in accordance with a specified cryptographic algorithm [*- RSA Digital Signature Algorithm and cryptographic key sizes (modulus) [2048]*,
> *- Elliptic Curve Digital Signature Algorithm and cryptographic key sizes [256, 384, 512]*]
> that meet the following:
> [*- For RSA schemes: FIPS PUB 186-4, 'Digital Signature Standard (DSS)', Section 5.5, using PKCS #1 v2.1 Signature Schemes RSASSA-PSS and/or RSASSA-PKCS1v1_5; ISO/IEC 9796-2, Digital signature scheme 2 or Digital Signature scheme 3,*
> *- For ECDSA schemes: FIPS PUB 186-4, 'Digital Signature Standard (DSS)', Section 6 and Appendix D, Implementing 'NIST curves' [P-256, P-384, P-521]; ISO/IEC 14888-3, Section 6.4*].

5.1.2.10 Cryptographic Operation (Hash Algorithm) (NDcPP20E:FCS_COP.1/Hash)

NDcPP20E:FCS_COP.1.1/Hash
> The TSF shall perform cryptographic hashing services in accordance with a specified cryptographic algorithm [*SHA-1, SHA-256, SHA-384, SHA-512*] and message digest sizes [*160, 256, 384, 512*] that meet the following: ISO/IEC 10118-3:2004.

5.1.2.11 Cryptographic Operation (Keyed Hash Algorithm) (NDcPP20E:FCS_COP.1/KeyedHash)

NDcPP20E:FCS_COP.1.1/KeyedHash
> The TSF shall perform keyed-hash message authentication in accordance with a specified cryptographic algorithm [*HMAC-SHA-1, HMAC-SHA-256, HMAC-SHA-384, HMAC-SHA-512*] and cryptographic key sizes [*160, 256, 384, 512*] and message digest sizes [*160, 256, 384, 512*] bits that meet the following: ISO/IEC 9797-2:2011, Section 7 'MAC Algorithm 2'.

5.1.2.12 HTTPS Protocol (NDcPP20E:FCS_HTTPS_EXT.1)

NDcPP20E:FCS_HTTPS_EXT.1.1
The TSF shall implement the HTTPS protocol that complies with RFC 2818.

NDcPP20E:FCS_HTTPS_EXT.1.2
The TSF shall implement HTTPS using TLS.

NDcPP20E:FCS_HTTPS_EXT.1.3
If a peer certificate is presented, the TSF shall [*not establish the connection*] if the peer certificate is deemed invalid.

5.1.2.13 IPsec Protocol (NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1)

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.1
The TSF shall implement the IPsec architecture as specified in RFC 4301.

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.2
The TSF shall have a nominal, final entry in the SPD that matches anything that is otherwise unmatched, and discards it.

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.3
The TSF shall implement [*transport mode, tunnel mode*].

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.4
The TSF shall implement the IPsec protocol ESP as defined by RFC 4303 using the cryptographic algorithms [*AES-CBC-128, AES-CBC-256 (specified by RFC 3602)*] together with a Secure Hash Algorithm (SHA)-based HMAC [*HMAC-SHA-1, HMAC-SHA-256, HMAC-SHA-384, HMAC-SHA-512*] and [*AES-GCM-128, AES-GCM-256 (specified in RFC 4106)*].

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.5
The TSF shall implement the protocol: [*- IKEv2 as defined in RFC 5996 and [with mandatory support for NAT traversal as specified in RFC 5996, section 2.23], and [no other RFCs for hash functions]*].

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.6
The TSF shall ensure the encrypted payload in the [*IKEv2*] protocol uses the cryptographic algorithms [*AES-CBC-128, AES-CBC-256 (specified in RFC 3602)*].

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.7
The TSF shall ensure that [*- IKEv2 SA lifetimes can be configured by a Security Administrator based on [length of time, where the time values can be configured within [1-24] hours]*].

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.8
The TSF shall ensure that [*- IKEv2 Child SA lifetimes can be configured by a Security Administrator based on [number of bytes, length of time, where the time values can be configured within [1-8] hours]*].

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.9
The TSF shall generate the secret value x used in the IKE Diffie-Hellman key exchange ('x' in g^x mod p) using the random bit generator specified in FCS_RBG_EXT.1, and having a length of at least [*112 , 128 , 192*] bits.

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.10
The TSF shall generate nonces used in [*IKEv2*] exchanges of length [*according to the security strength associated with the negotiated Diffie-Hellman group*].

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.11
The TSF shall ensure that all IKE protocols implement DH Group(s) [*14 (2048-bit MODP), 19 (256-bit Random ECP), 20 (384-bit Random ECP)*].

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.12
The TSF shall be able to ensure by default that the strength of the symmetric algorithm (in terms of the number of bits in the key) negotiated to protect the [*IKEv2 IKE_SA*] connection is greater than or equal to the strength of the symmetric algorithm (in terms of the number of bits in the key) negotiated to protect the [*IKEv2 CHILD_SA*] connection.

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.13
The TSF shall ensure that all IKE protocols perform peer authentication using [*RSA, ECDSA*] that use X.509v3 certificates that conform to RFC 4945 and [*Pre-shared Keys*].

NDcPP20E/ WLANAScEP10:FCS_IPSEC_EXT.1.14
The TSF shall only establish a trusted channel if the presented identifier in the received certificate matches the configured reference identifier, where the presented and reference identifiers are of the following types: [*Distinguished Name (DN), IP Address, Fully Qualified Domain Name (FQDN)*] and [*no other reference identifier type*].

5.1.2.14 Random Bit Generation (NDcPP20E:FCS_RBG_EXT.1)

NDcPP20E:FCS_RBG_EXT.1.1
The TSF shall perform all deterministic random bit generation services in accordance with ISO/IEC 18031:2011 using [*CTR_DRBG (AES)*].

NDcPP20E:FCS_RBG_EXT.1.2
The deterministic RBG shall be seeded by at least one entropy source that accumulates entropy from [*[a single] hardware-based noise source*] with a minimum of [*256 bits*] of entropy at least equal to the greatest security strength, according to ISO/IEC 18031:2011, of the keys and CSPs that it will generate.

5.1.2.15 TLS Server Protocol (NDcPP20E:FCS_TLSS_EXT.1)

NDcPP20E:FCS_TLSS_EXT.1.1
The TSF shall implement [*TLS 1.2 (RFC 5246), TLS 1.1 (RFC 4346)*] and reject all other TLS and SSL versions. The TLS implementation will support the following ciphersuites:
[*TLS_RSA_WITH_AES_128_CBC_SHA as defined in RFC 3268,*
TLS_RSA_WITH_AES_256_CBC_SHA as defined in RFC 3268,
TLS_DHE_RSA_WITH_AES_128_CBC_SHA as defined in RFC 3268,
TLS_DHE_RSA_WITH_AES_256_CBC_SHA as defined in RFC 3268,
TLS_RSA_WITH_AES_128_CBC_SHA256 as defined in RFC 5246,
TLS_RSA_WITH_AES_256_CBC_SHA256 as defined in RFC 5246,
TLS_DHE_RSA_WITH_AES_128_CBC_ SHA256 as defined in RFC 5246,
TLS_DHE_RSA_WITH_AES_256_CBC_ SHA256 as defined in RFC 5246].

NDcPP20E:FCS_TLSS_EXT.1.2
The TSF shall deny connections from clients requesting SSL 2.0, SSL 3.0, TLS 1.0, and [*none*].

NDcPP20E:FCS_TLSS_EXT.1.3
The TSF shall [*perform RSA key establishment with key size [2048 bits], generate Diffie-Hellman parameters of size [2048 bits]*].

5.1.3 Identification and authentication (FIA)

5.1.3.1 Extended: 802.1X Port Access Entity (Authenticator) Authentication (WLANAScEP10:FIA_8021X_EXT.1)

WLANAScEP10:FIA_8021X_EXT.1.1
The TSF shall conform to IEEE Standard 802.1X for a Port Access Entity (PAE) in the 'Authenticator' role.

WLANAScEP10:FIA_8021X_EXT.1.2
The TSF shall support communications to a RADIUS authentication server conforming to RFCs 2865 and 3579.

WLANAScEP10:FIA_8021X_EXT.1.3
The TSF shall ensure that no access to its 802.1X controlled port is given to the wireless client prior to successful completion of this authentication exchange.

5.1.3.2 Authentication Failure Management (NDcPP20E:FIA_AFL.1)

NDcPP20E:FIA_AFL.1.1
The TSF shall detect when an Administrator configurable positive integer within [1-**8**]

unsuccessful authentication attempts occur related to Administrators attempting to authenticate remotely.

NDcPP20E:FIA_AFL.1.2

When the defined number of unsuccessful authentication attempts has been met, the TSF shall [*prevent the offending remote Administrator from successfully authenticating until an Administrator defined time period has elapsed*].

5.1.3.3　Authentication Failure Handling　(WLANAScEP10:FIA_AFL.1)

WLANAScEP10:FIA_AFL.1.1

Refinement: The TSF shall detect when an Administrator configurable positive integer of successive unsuccessful authentication attempts occur related to administrators attempting to authenticate remotely.

WLANAScEP10:FIA_AFL.1.2

When the defined number of unsuccessful authentication attempts has been met, the TSF shall [*prevent the offending remote administrator from successfully authenticating until an Administrator defined time period has elapsed*].

5.1.3.4　Password Management　(NDcPP20E:FIA_PMG_EXT.1)

NDcPP20E:FIA_PMG_EXT.1.1

The TSF shall provide the following password management capabilities for administrative passwords:

a) Passwords shall be able to be composed of any combination of upper and lower case letters, numbers, and the following special characters: [*'!', '@', '#', '$', '%', '^', '&', '*', '(', ')'*];

b) Minimum password length shall be configurable to [**8**] and [**30**].

5.1.3.5　Extended: Pre-Shared Key Composition　(WLANAScEP10:FIA_PSK_EXT.1)

WLANAScEP10:FIA_PSK_EXT.1.1

The TSF shall be able to use pre-shared keys for IPsec and [IEEE 802.11 WPA2-PSK] (TD0277 applied)

WLANAScEP10:FIA_PSK_EXT.1.2

The TSF shall be able to accept text-based pre-shared keys that:

- are 22 characters and [**lengths from 8 to 63 characters for WPA2; and lengths from 16 to 32 characters for IPsec**];

- are composed of any combination of upper and lower case letters, numbers, and special characters (that include: '!', '@', '#', '$', '%', '^', '&', '*', '(', and ')').

WLANAScEP10:FIA_PSK_EXT.1.3

The TSF shall be able to [*accept*] bit-based pre-shared keys.

5.1.3.6　Re-authenticating　(WLANAScEP10:FIA_UAU.6)

WLANAScEP10:FIA_UAU.6.1

The TSF shall re-authenticate the administrative user under the conditions: when the user changes their password, [**following a TSF-initiated session locking**].

5.1.3.7　Protected Authentication Feedback　(NDcPP20E:FIA_UAU.7)

NDcPP20E:FIA_UAU.7.1

The TSF shall provide only obscured feedback to the administrative user while the authentication is in progress at the local console.

5.1.3.8 Password-based Authentication Mechanism (NDcPP20E:FIA_UAU_EXT.2)

NDcPP20E:FIA_UAU_EXT.2.1

The TSF shall provide a local password-based authentication mechanism, and [*no other authentication mechanism*] to perform local administrative user authentication.

5.1.3.9 User Identification and Authentication (NDcPP20E:FIA_UIA_EXT.1)

NDcPP20E:FIA_UIA_EXT.1.1

The TSF shall allow the following actions prior to requiring the non-TOE entity to initiate the identification and authentication process:
- Display the warning banner in accordance with FTA_TAB.1;
- [**network packets configured by an authorized administrator may flow through the TOE**].

NDcPP20E:FIA_UIA_EXT.1.2

The TSF shall require each administrative user to be successfully identified and authenticated before allowing any other TSF-mediated actions on behalf of that administrative user.

5.1.3.10 X.509 Certificate Validation (Rev) (NDcPP20E:FIA_X509_EXT.1/Rev)

NDcPP20E:FIA_X509_EXT.1.1/Rev

The TSF shall validate certificates in accordance with the following rules:
- RFC 5280 certificate validation and certificate path validation supporting a minimum path length of three certificates.
- The certificate path must terminate with a trusted CA certificate.
- The TSF shall validate a certificate path by ensuring the presence of the basicConstraints extension and that the CA flag is set to TRUE for all CA certificates.
- The TSF shall validate the revocation status of the certificate using [*a Certificate Revocation List (CRL) as specified in RFC 5280 Section 6.3*]
- The TSF shall validate the extendedKeyUsage field according to the following rules:
> o Certificates used for trusted updates and executable code integrity verification shall have the Code Signing purpose (id-kp 3 with OID 1.3.6.1.5.5.7.3.3) in the extendedKeyUsage field.
> o Server certificates presented for TLS shall have the Server Authentication purpose (id-kp 1 with OID 1.3.6.1.5.5.7.3.1) in the extendedKeyUsage field.
> o Client certificates presented for TLS shall have the Client Authentication purpose (id-kp 2 with OID 1.3.6.1.5.5.7.3.2) in the extendedKeyUsage field.
> o OCSP certificates presented for OCSP responses shall have the OCSP Signing purpose (id-kp 9 with OID 1.3.6.1.5.5.7.3.9) in the extendedKeyUsage field.

NDcPP20E:FIA_X509_EXT.1.2/REV

The TSF shall only treat a certificate as a CA certificate if the basicConstraints extension is present and the CA flag is set to TRUE.

5.1.3.11 X.509 Certificate Authentication (NDcPP20E:FIA_X509_EXT.2)

NDcPP20E:FIA_X509_EXT.2.1

The TSF shall use X.509v3 certificates as defined by RFC 5280 to support authentication for [*HTTPS, IPsec, TLS*], and [*no additional uses*].

NDcPP20E:FIA_X509_EXT.2.2

When the TSF cannot establish a connection to determine the validity of a certificate, the TSF shall [*accept the certificate*].

5.1.3.12 X.509 Certificate Requests (NDcPP20E:FIA_X509_EXT.3)

NDcPP20E:FIA_X509_EXT.3.1

The TSF shall generate a Certificate Request Message as specified by RFC 2986 and be able to

provide the following information in the request: public key and [*Common Name, Organization, Country*].

NDcPP20E:FIA_X509_EXT.3.2
The TSF shall validate the chain of certificates from the Root CA upon receiving the CA Certificate Response.

5.1.4   Security management (FMT)

5.1.4.1   Management of security functions behaviour (Manual Update)   (NDcPP20E:FMT_MOF.1/Manual Update)

NDcPP20E:FMT_MOF.1.1/ManualUpdate
The TSF shall restrict the ability to enable the functions to perform manual update to Security Administrators.

5.1.4.2   Management of TSF Data (CoreData) (NDcPP20E:FMT_MTD.1/CoreData))

NDcPP20E:FMT_MTD.1.1/CoreData
The TSF shall restrict the ability to manage the TSF data to Security Administrators.

5.1.4.3   Specification of Management Functions (NDcPP20E:FMT_SMF.1)

NDcPP20E:FMT_SMF.1.1
The TSF shall be capable of performing the following management functions:
- Ability to administer the TOE locally and remotely;
- Ability to configure the access banner;
- Ability to configure the session inactivity time before session termination or locking;
- Ability to update the TOE, and to verify the updates using [*digital signature*] capability prior to installing those updates;
- Ability to configure the authentication failure parameters for FIA_AFL.1;
- [*Ability to configure audit behavior,*
 Ability to configure lifetime for IPsec SAs
 Ability to configure the cryptographic functionality,
 Ability to set the time which is used for time-stamps;
 Ability to configure the reference identifier for the peer;].

5.1.4.4   Security Management Roles (WLANAScEP10:FMT_SMR.1)

WLANAScEP10:FMT_SMR.1.1
The TSF shall ensure that the ability to remotely administer the TOE from a wireless client shall be disabled by default.

5.1.4.5   Restrictions on Security Roles (NDcPP20E:FMT_SMR.2)

NDcPP20E:FMT_SMR.2.1
The TSF shall maintain the roles: - Security Administrator.
NDcPP20E:FMT_SMR.2.2
The TSF shall be able to associate users with roles.
NDcPP20E:FMT_SMR.2.3
The TSF shall ensure that the conditions
- The Security Administrator role shall be able to administer the TOE locally;
- The Security Administrator role shall be able to administer the TOE remotely
are satisfied.

5.1.5 Protection of the TSF (FPT)

5.1.5.1 Protection of Administrator Passwords (NDcPP20E:FPT_APW_EXT.1)

NDcPP20E:FPT_APW_EXT.1.1
> The TSF shall store passwords in non-plaintext form.

NDcPP20E:FPT_APW_EXT.1.2
> The TSF shall prevent the reading of plaintext passwords.

5.1.5.2 Failure with preservation of secure state (WLANAScEP10:FPT_FLS.1)

WLANAScEP10:FPT_FLS.1.1
> The TSF shall preserve a secure state when the following types of failures occur: failure of the power-on self-tests.

5.1.5.3 Protection of TSF Data (for reading of all pre-shared, symmetric and private keys) (NDcPP20E:FPT_SKP_EXT.1)

NDcPP20E:FPT_SKP_EXT.1.1
> The TSF shall prevent reading of all pre-shared keys, symmetric keys, and private keys.

5.1.5.4 Reliable Time Stamps (NDcPP20E:FPT_STM_EXT.1)

NDcPP20E:FPT_STM_EXT.1.1
> The TSF shall be able to provide reliable time stamps for its own use.

NDcPP20E:FPT_STM_EXT.1.2
> The TSF shall [*allow the Security Administrator to set the time, synchronise time with external time sources*].

5.1.5.5 TSF testing (NDcPP20E:FPT_TST_EXT.1)

NDcPP20E:FPT_TST_EXT.1.1
> The TSF shall run a suite of the following self-tests [*during initial start-up (on power on), at the request of the authorized user*] to demonstrate the correct operation of the TSF: [*Software integrity test and AES, SHA, HMAC, DRBG, RSA, and ECDSA Known Answer Tests*].

5.1.5.6 Extended: TSF Testing (WLANAScEP10:FPT_TST_EXT.1)

WLANAScEP10:FPT_TST_EXT.1.1
> The TSF shall run a suite of the following self-tests during initial start-up (on power on) and [*at the request of the authorized user*] to demonstrate the correct operation of the TSF: [*Software integrity test and AES, SHA, HMAC, DRBG, RSA, and ECDSA Known Answer Tests*].

WLANAScEP10:FPT_TST_EXT.1.2
> The TSF shall provide the capability to verify the integrity of stored TSF executable code when it is loaded for execution through the use of the TSF-provided cryptographic service specified in FCS_COP.1(2).

5.1.5.7 Trusted update (NDcPP20E:FPT_TUD_EXT.1)

NDcPP20E:FPT_TUD_EXT.1.1
> The TSF shall provide Security Administrators the ability to query the currently executing version of the TOE firmware/software and [*no other TOE firmware/software version*].

NDcPP20E:FPT_TUD_EXT.1.2
> The TSF shall provide Security Administrators the ability to manually initiate updates to TOE firmware/software and [*no other update mechanism*].

NDcPP20E:FPT_TUD_EXT.1.3

> The TSF shall provide means to authenticate firmware/software updates to the TOE using a [*digital signature mechanism*] prior to installing those updates.

5.1.6   TOE access (FTA)

5.1.6.1   TSF-initiated Termination (NDcPP20E:FTA_SSL.3)

NDcPP20E:FTA_SSL.3.1

> The TSF shall terminate a remote interactive session after a Security Administrator-configurable time interval of session inactivity.

5.1.6.2   User-initiated Termination (NDcPP20E:FTA_SSL.4)

NDcPP20E:FTA_SSL.4.1

> The TSF shall allow Administrator-initiated termination of the Administrator's own interactive session.

5.1.6.3   TSF-initiated Session Locking (NDcPP20E:FTA_SSL_EXT.1)

NDcPP20E:FTA_SSL_EXT.1.1

> The TSF shall, for local interactive sessions, [*- terminate the session*] after a Security Administrator-specified time period of inactivity.

5.1.6.4   Default TOE Access Banners (NDcPP20E:FTA_TAB.1)

NDcPP20E:FTA_TAB.1.1

> Before establishing an administrative user session the TSF shall display a Security Administrator-specified advisory notice and consent warning message regarding use of the TOE.

5.1.6.5   TOE Session Establishment (WLANAScEP10:FTA_TSE.1)

WLANAScEP10:FTA_TSE.1.1

> Refinement: The TSF shall be able to deny establishment of a wireless client session based on TOE interface, time, day, [*wireless client's MAC address*].

5.1.7   Trusted path/channels (FTP)

5.1.7.1   Inter-TSF trusted channel (NDcPP20E:FTP_ITC.1)

NDcPP20E:FTP_ITC.1.1

> The TSF shall be capable of using [*IPsec*] to provide a trusted communication channel between itself and authorized IT entities supporting the following capabilities: audit server, [*[NTP server]*] that is logically distinct from other communication channels and provides assured identification of its end points and protection of the channel data from disclosure and detection of modification of the channel data.

NDcPP20E:FTP_ITC.1.2

> The TSF shall permit the TSF or the authorized IT entities to initiate communication via the trusted channel.

NDcPP20E:FTP_ITC.1.3

> The TSF shall initiate communication via the trusted channel for [*audit logging, accessing an NTP server*].

5.1.7.2 Inter-TSF Trusted Channel (WLANAScEP10:FTP_ITC.1)

WLANAScEP10:FTP_ITC.1.1

Refinement: The TSF shall be capable of using IEEE 802.11-2012 (WPA2), IEEE 802.1X, [*IPsec*] and [*no other protocol*] to provide a trusted communication channel between itself and authorized IT entities supporting the following capabilities: WLAN clients, audit servers, 802.1X authentication servers, and [*NTP server*] that is logically distinct from other communication channels and provides assured identification of its end points and protection of the channel data from disclosure and detection of modification of the channel data. (TD0271 applied)

5.1.7.3 Trusted Path (Admin) (NDcPP20E:FTP_TRP.1/Admin Trusted Path (Refinement))

NDcPP20E:FTP_TRP.1.1/Admin

The TSF shall be capable of using [*TLS, HTTPS*] to provide a communication path between itself and authorized remote Administrators that is logically distinct from other communication paths and provides assured identification of its end points and protection of the communicated data from disclosure and provides detection of modification of the channel data.

NDcPP20E:FTP_TRP.1.2/Admin

The TSF shall permit remote Administrators to initiate communication via the trusted path.

NDcPP20E:FTP_TRP.1.3/Admin

The TSF shall require the use of the trusted path for initial Administrator authentication and all remote administration actions.

5.2 TOE Security Assurance Requirements

The SARs for the TOE are the components as specified in Part 3 of the Common Criteria. Note that the SARs have effectively been refined with the assurance activities explicitly defined in association with both the SFRs and SARs.

Requirement Class	Requirement Component
ADV: Development	ADV_FSP.1: Basic Functional Specification
AGD: Guidance documents	AGD_OPE.1: Operational User Guidance
	AGD_PRE.1: Preparative Procedures
ALC: Life-cycle support	ALC_CMC.1: Labelling of the TOE
	ALC_CMS.1: TOE CM Coverage
ASE: Security Target	ASE_TSS.1: Security Target
ATE: Tests	ATE_IND.1: Independent Testing - Conformance
AVA: Vulnerability assessment	AVA_VAN.1: Vulnerability Survey

Table 3 Assurance Components

5.2.1 Development (ADV)

5.2.1.1 Basic Functional Specification (ADV_FSP.1)

ADV_FSP.1.1d

The developer shall provide a functional specification.

ADV_FSP.1.2d

The developer shall provide a tracing from the functional specification to the SFRs.

ADV_FSP.1.1c

The functional specification shall describe the purpose and method of use for each SFR-enforcing and SFR-supporting TSFI.

ADV_FSP.1.2c

The functional specification shall identify all parameters associated with each SFR-enforcing and SFR-supporting TSFI.

ADV_FSP.1.3c

The functional specification shall provide rationale for the implicit categorization of interfaces as SFR-non-interfering.

ADV_FSP.1.4c

The tracing shall demonstrate that the SFRs trace to TSFIs in the functional specification.

ADV_FSP.1.1e

The evaluator shall confirm that the information provided meets all requirements for content and presentation of evidence.

ADV_FSP.1.2e

The evaluator shall determine that the functional specification is an accurate and complete instantiation of the SFRs.

5.2.2   Guidance documents (AGD)

5.2.2.1   Operational User Guidance (AGD_OPE.1)

AGD_OPE.1.1d

The developer shall provide operational user guidance.

AGD_OPE.1.1c

The operational user guidance shall describe, for each user role, the user accessible functions and privileges that should be controlled in a secure processing environment, including appropriate warnings.

AGD_OPE.1.2c

The operational user guidance shall describe, for each user role, how to use the available interfaces provided by the TOE in a secure manner.

AGD_OPE.1.3c

The operational user guidance shall describe, for each user role, the available functions and interfaces, in particular all security parameters under the control of the user, indicating secure values as appropriate.

AGD_OPE.1.4c

The operational user guidance shall, for each user role, clearly present each type of security-relevant event relative to the user-accessible functions that need to be performed, including changing the security characteristics of entities under the control of the TSF.

AGD_OPE.1.5c

The operational user guidance shall identify all possible modes of operation of the TOE (including operation following failure or operational error), their consequences, and implications for maintaining secure operation.

AGD_OPE.1.6c

The operational user guidance shall, for each user role, describe the security measures to be followed in order to fulfill the security objectives for the operational environment as described in the ST.

AGD_OPE.1.7c

The operational user guidance shall be clear and reasonable.

AGD_OPE.1.1e

The evaluator shall confirm that the information provided meets all requirements for content and presentation of evidence.

5.2.2.2   Preparative Procedures (AGD_PRE.1)

AGD_PRE.1.1d

The developer shall provide the TOE, including its preparative procedures.

AGD_PRE.1.1c

The preparative procedures shall describe all the steps necessary for secure acceptance of the delivered TOE in accordance with the developer's delivery procedures.

AGD_PRE.1.2c

The preparative procedures shall describe all the steps necessary for secure installation of the TOE and for the secure preparation of the operational environment in accordance with the security objectives for the operational environment as described in the ST.

AGD_PRE.1.1e

The evaluator shall confirm that the information provided meets all requirements for content and presentation of evidence.

AGD_PRE.1.2e

The evaluator shall apply the preparative procedures to confirm that the TOE can be prepared securely for operation.

5.2.3 Life-cycle support (ALC)

5.2.3.1 Labelling of the TOE (ALC_CMC.1)

ALC_CMC.1.1d

The developer shall provide the TOE and a reference for the TOE.

ALC_CMC.1.1c

The TOE shall be labelled with its unique reference.

ALC_CMC.1.1e

The evaluator shall confirm that the information provided meets all requirements for content and presentation of evidence.

5.2.3.2 TOE CM Coverage (ALC_CMS.1)

ALC_CMS.1.1d

The developer shall provide a configuration list for the TOE.

ALC_CMS.1.1c

The configuration list shall include the following: the TOE itself; and the evaluation evidence required by the SARs.

ALC_CMS.1.2c

The configuration list shall uniquely identify the configuration items.

ALC_CMS.1.1e

The evaluator shall confirm that the information provided meets all requirements for content and presentation of evidence.

5.2.4 Security Target (ASE)

5.2.4.1 Security Target (ASE_TSS.1)

ASE_TSS.1.1c

For distributed TOEs only the SFRs classified as 'all' have to be fulfilled by all TOE parts. The SFRs classified as 'One' or 'Feature Dependent' only have to be fulfilled by either one or some TOE parts, respectively. To make sure that the distributed TOE as a whole fulfills all the SFRs the following actions for ASE_TSS.1 have to be performed as part of ASE_TSS.1.1E.
The evaluator shall examine the TSS to determine that it is clear which TOE components contribute to each SFR or how the components combine to meet each SFR.
The evaluator shall verify the sufficiency to fulfil the related SFRs. This includes checking that the TOE as a whole fully covers all SFRs and that all functionality that is required to be audited is in fact audited regardless of the component that carries it out.

5.2.5 Tests (ATE)

5.2.5.1 Independent Testing Conformance (ATE_IND.1)

ATE_IND.1.1d

The developer shall provide the TOE for testing.

ATE_IND.1.1c

The TOE shall be suitable for testing.

ATE_IND.1.1e

The evaluator shall confirm that the information provided meets all requirements for content and presentation of evidence.

ATE_IND.1.2e

The evaluator shall test a subset of the TSF to confirm that the TSF operates as specified.

5.2.6 Vulnerability assessment (AVA)

5.2.6.1 Vulnerability Survey (AVA_VAN.1)

AVA_VAN.1.1d

The developer shall provide the TOE for testing.

AVA_VAN.1.1c

The TOE shall be suitable for testing.

AVA_VAN.1.1e

The evaluator shall confirm that the information provided meets all requirements for content and presentation of evidence.

AVA_VAN.1.2e

The evaluator shall perform a search of public domain sources to identify potential vulnerabilities in the TOE.

AVA_VAN.1.3e

The evaluator shall conduct penetration testing, based on the identified potential vulnerabilities, to determine that the TOE is resistant to attacks performed by an attacker possessing Basic attack potential.

6. TOE Summary Specification

This chapter describes the security functions:

- Security audit
- Cryptographic support
- Identification and authentication
- Security management
- Protection of the TSF
- TOE access
- Trusted path/channels

6.1   Security audit

The Security audit function satisfies the following security functional requirements:

NDcPP20E:FAU_GEN.1:

The TOE is capable of generating log records for a wide range of security relevant and other events as they occur. The events that can cause an audit record to be logged include starting and stopping the audit function, Security Administrator's configuration of CSPs and security functions as well as all of the events identified in **Error! Reference source not found.**. The TOE generates records for several separate classes of events: authentication/access to the system, actions taken directly on the system by network clients, and management of security functions by authorized administrators.

All audit records include the date/time of the event, the identity associated with the event (such as the service, computer or user), the success/failure of the event and a definition of the event (by code or explanation). For example, when the administrator creates, modifies or deletes the cryptographic keys, the key name will be logged in the event to identify the relevant key.

NDcPP20E:FAU_GEN.2-Notes:

All actions performed by the TOE are associated with a unique identifier such as administrator's user name, wireless client's MAC/IP address and NTP/RADIUS/Log server's IP address. This information is maintained in the audit record, allowing the events stored there to be traced directly to the user or system for which they were performed.

NDcPP20E:FAU_STG_EXT.1:

The TOE stores audit logs locally with up to a fixed size of 256K bytes. Local password based authentication and authorization limits the access to the local audit log records. Only the Security Administrator can gain access to the local audit log records.

When the TOE is configured to export audit logs to an external SYSLOG server, it simultaneously sends the message to the server and local store. The TOE requires the external audit server and itself to be connected via an IPsec session. The Admin Guide provides details about the "Export Audit Logs" configuration. The TOE exports audit data over IPsec using AES128/256 bit encryption. Disconnection to external entities such as syslog server will result in log of communication error and attempt to re-establish secure channel. At no point, will plaintext be transmitted. The TOE does not implement an automatic synchronization mechanism between the local and remote audit storage.

When the audit log storage space is full, the TOE also provides the Authorized Administrator the option of overwriting "old" audit records rather than preventing auditable events.

6.2 Cryptographic support

There are two cryptographic engines within the TOE models as shown in the figure below. All models share the same hardware MPC8378E cryptographic core and OpenSSL library.

Figure 6-1: TOE Cryptographic Cores
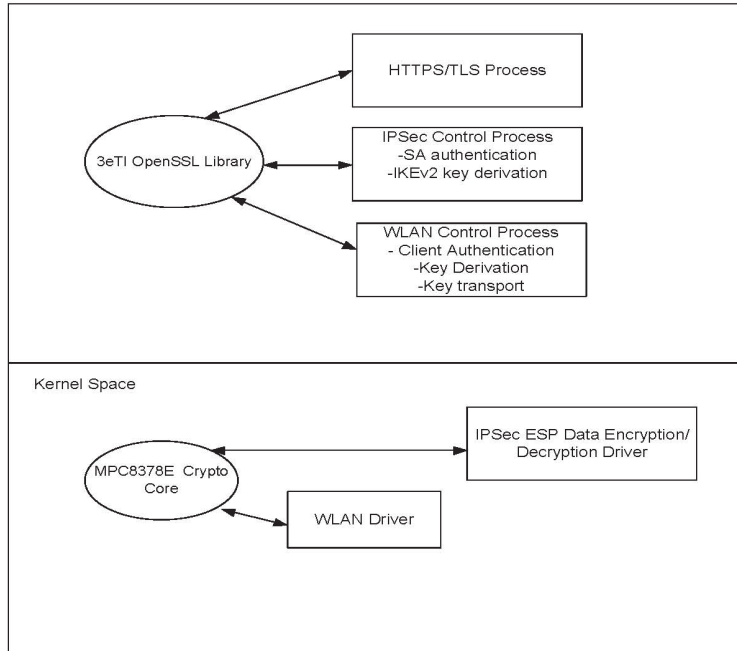
First is the 3eTI's own OpenSSL library. 3eTI's OpenSSL Library serves as the sole user application level cryptographic library. It provides the FCS_COP functions listed below. All user level applications, such as HTTPS/TLS Web UI, Wireless LAN Control Application and IPsec SA authentication module use this library. 3eTI's OpenSSL provides the following cryptographic algorithms: AES, RSA, HMAC, SHS, ECDSA and DRBG.

The 3eTI OpenSSL Library represents not the entire OpenSSL Library, but the FIPS Object Module that is compiled into the larger OpenSSL Library. Because 3eTI has already compiled the FIPS Object Module and then links that same, identical Object Module into different versions of the larger OpenSSL library, the version of the larger OpenSSL Library is not relevant.

There is a FreeScale MPC8378E cryptographic core within the TOE as well. It provides cryptographic functions for the Linux kernel drivers. Wireless client data encryption/decryption functions using AES-CCMP is provided by this engine. IPsec ESP data encryption/decryption using AES-CBC with SHS or AES-GCM is provided by this engine. The MPC8378E cryptographic core provides the following cryptographic algorithms in FIPS mode: AES (CBC, GCM, CCM), HMAC, SHS.

The TOE utilizes version 2.0 of its OpenSSL Algorithm Implementation and version 1.0 of the MPC8378E cryptographic core in firmware version 5.1.0 of the TOE.

Table 6-1: TOE CAVP Tested Algorithms

Algorithm	Cert No.	SFR Mapping
3eTI OpenSSL		
AES (CBC, 128, 256 bits key)	2060	FCS_COP.1/DataEncryption
AES-KW	2060	FCS_CKM.2(3)
CVL KAS ECC	1357	FCS_CKM.2
ECDSA, KeyPairGen, sign/verify with P256, P384 and P521	415 303	FCS_COP.1/SigGen FCS_CKM.1
SHS (SHA-1, SHA-256, SHA-384, SHA-512)	1801	FCS_COP.1/Hash
HMAC (HMAC-SHA-1, HMAC-SHA-256, HMAC-SHA-384, HMAC-SHA-512)	1253	FCS_COP.1/KeyedHash
RSA key generation (2048 bits)	2568	FCS_CKM.1
RSA sign/verify (2048 bits)	1491	FCS_COP.1/SigGen
DRBG NIST SP800-90 with one independent hardware based noise source of 256 bits of non-deterministic (CTR_DRBG (AES))	822	FCS_RBG_EXT.1
MPC8378E Cryptographic Core		
AES (CBC 128, 256 bits; CCM 128, 256 bits)	2078	FCS_COP.1(1)
AES (GCM 128, 256 bits)	2105	FCS_COP.1(1)
HMAC (HMAC-SHA-1, HMAC-SHA-256, HMAC-SHA-384, HMAC-SHA-512)	1259	FCS_COP.1/KeyedHash
SHS (SHA-1, SHA-256, SHA-384, SHA-512)	1807	FCS_COP.1/Hash

As shown in Figure 6.1, the 3eTI OpenSSL library provides cryptographic services to the TOE's application modules. The IPsec module uses the OpenSSL library during the IKEv2 SA authentication and key establishment. The Wireless Access Point module uses the library's cryptographic service during the client's authentication and the IEEE 802.11i 4-way handshake key establishment. The MPC 8378E cryptographic core provides services for fast path data encryption. For IPsec, this module provides the IPsec ESP encryption with AES-GCM or AES-CBC-HMAC-SHS. For WLAN data communication between the TOE and the wireless client, this core provides AES-CCM encryption/decryption service.

NDcPP20E:FCS_CKM.1:

The TOE support both RSA and ECDSA key generation. The key generation is used by the TOE when it creates a Certificate Signing Request (CSR) to apply for a certificate from the Certificate Authority (CA). The TOE enforces the key size of 2048 or greater for RSA key pairs and supports NIST curves P256, P384 and P521 for ECDSA key pairs. The TOE implements FFC schemes using Diffie-Hellman group 14. The TOE implementation of Diffie-Hellman group 14 (2048 MODP) meets RFC 3526, Section 3. The scheme is used by both IPsec IKEv2 and TLS module.

WLANAScEP10:FCS_CKM.1(2):

The symmetric key of size 128 bits for communications between the TOE and the wireless client is generated during the 802.11i defined 4-way handshake process using random numbers generated by ISO/IEC 18031:2011DRBG random bits generator. 802.11-2012 specified cryptographic key derivation algorithm [PRF-384] is strictly followed by the TOE. The TOE is Wi-Fi Alliance certified (Certification ID: WFA56890) to prove the correctness of key derivation and interoperability between the TOE and other commercial Wi-Fi products.

End-to-end wireless encryption between the TOE and the wireless client is implemented using WPA2. The PMK is generated by the RADIUS Server in coordination with the wireless client, encrypted by the IPsec tunnel, and passed to the AP in the RADIUS ACCESS_ACCEPT message. The AP uses the PMK and the 802.11i four-way handshake to generate the Pairwise Transient Key (PTK) and the GTK (Group Temporal Key).
The PTK is generated by concatenating the following attributes: PMK, AP nonce (ANonce), the client (station) nonce (SNonce), AP MAC address, and client MAC address. The product is then put through a cryptographic hash function. The four steps are as follows:

1. The AP sends a nonce-value to the client (ANonce). The client now has all the attributes to construct the PTK.

2. The client sends its own nonce-value (SNonce) to the AP together with a MIC, including authentication, which is really a Message Authentication and Integrity Code: (MAIC).

3. The AP sends the GTK and a sequence number together with another MIC. This sequence number will be used in the next multicast or broadcast frame, so that the receiving STA can perform basic replay detection.

4. The client sends an acknowledgement to the AP.

The messages exchanged during the handshake are depicted in Figure 6-2 below.

Figure 6-2: 802.11i Four Way Handshake
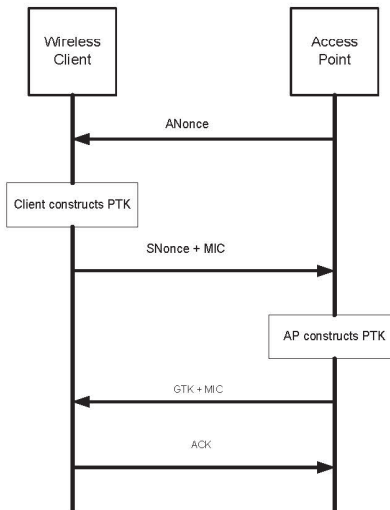
The PTK is divided into the individual session keys including the Key Encryption Key (KEK), the Key Confirmation Key (KCK) and the temporal key (TK)) for encrypting the wireless traffic with each wireless client that has been authenticated. The KEK is used by the EAPOL-Key frames to provide confidentiality. The KCK is

used by IEEE 802.11i to provide data origin authenticity. The TK, also known as the CCMP key, is the 802.11i session key for unicast communications.

The TSF distributes the Group Temporal Key (GTK) by using AES Key Wrap in an EAPOL-Key frame that meets RFC 3394 for AES Key Wrap and 802.11-2012 standard for the packet format and timing considerations.

The TOE allows for the detection of modification of user data while carrying out network communications on the wireless network through the use of AES operating in CCM (CCMP). This is done through the integrity protection capabilities of the algorithm. The Cipher Block Chaining Message Authentication Code (CBC-MAC) component of CCMP provides data integrity. The CBC-MAC allows for the detection of a modified packet. If a CBC-MAC indicates a packet has been modified the packet is dropped.

NDcPP20E:FCS_CKM.2:

The TOE acts as both receiver and sender for RSA-based key establishment and ECDSA based key establishment in cryptographic operations. The TOE implementation of Diffie-Hellman-group-14 meets RFC 3526, Section 3 by virtue of using a 2048-bit MODP group for key establishment.

WLANAScEP10:FCS_CKM.2(2):

The TSF's key material, such as the Pair-wise Master Key (PMK) for Wireless Protected Access (WPA2) is distributed by the RADIUS server to the TOE's 802.1X authenticator components via the ACCESS_ACCEPT message after the wireless client's successful authentication with the RADIUS server. The MSK/PMK is included in the message with attribute: MS_MPPE_SEND_KEY (16) Vendor Specific Attribute (VSA) as defined by RFC 2548. The IPsec tunnel between the TOE and RADIUS server protects the PMK from exposure.

The TSF distribute Group Temporal Key (GTK) by using AES Key Wrap in an EAPOL-Key frame that meets NIST SP 800-38F and IEEE 802.11-2012 standard for the packet format and timing considerations. The GTK is first distributed to the client after the client's successful authentication with the RADIUS server, followed by the process of 802.11i 4-way handshakes which is detailed in Figure 6-2 illustrates the GTK distribution.
The TOE has a configurable GTK timeout value. At the configured time expiration, the TOE will update each client with the GTK using the AES key wrap mechanism just described.

NDcPP20E:FCS_CKM.4:

Table 6- below lists all the keys and CSPs used and managed by the TOE.

Table 6-2: TOE CSPs Use and Management

Non-Protocol Keys/CSPs						
Key/CSP	**Type**	**Generation/ Input**	**Output**	**Storage**	**Zeroization**	**Use**
Operator passwords	ASCII string	Input encrypted (using TLS session key)	Not output	PKCS5 hash in flash	Zeroized when reset to factory settings.	Used to authenticate Security Admin and Admin role operators
Firmware verification key	ECDSA public key	Embedded in firmware at compile time. Firmware upgrade is through encrypted (using TLS session key)	Not output	Plaintext in flash	Zeroized when firmware is upgraded.	Used for firmware digital signature verification

802.1X RADIUS Server Password	ASCII string	Input encrypted (using TLS session key)	Not output	Plaintext in flash	Zeroized when password is upgraded.	Used to create authentication hash value with RADIUS server
RBG Keys/CSPs						
Key/CSP	**Type**	**Generation/ Input**	**Output**	**Storage**	**Zeroization**	**Use**
DRBG CTR V	32-byte value	32 bytes from /dev/random file, /dev/random is populated by hardware noise generator	Not output	Plaintext in RAM	Zeroized every time a new random number is generated using the FIPS DRBG after it is used.	Used as CTR V value for FIPS DRBG.
DRBG CTR Key	32-byte value	32 bytes from /dev/random file, /dev/random is populated by hardware noise generator	Not output	Plaintext in RAM	Zeroized every time a new random number is generated using the FIPS DRBG after it is used.	Used as CTR key for FIPS DRBG.
RFC 2818 HTTPS Keys/CSPs						
Key/CSP	**Type**	**Generation/ Input**	**Output**	**Storage**	**Zeroization**	**Use**
RSA private key	RSA (2048) (key wrapping; key establishment methodology provides 112-bits of encryption strength)	Not input (installed at factory)	Not output	Plaintext in flash	Zeroized when new private key is uploaded	Used to support Security Admin and Admin TLS/HTTPS interfaces.
TLS session key for encryption	AES (128/256)	Not input, derived using TLS protocol	Not output	Plaintext in RAM	Zeroized when a page of the web UI is served after it is used.	Used to protect TLS/HTTPS session.
Public Security Parameter						
HTTPS Public certificate	RSA (2048)	Input encrypted (using TLS session key)	During TLS session setup			Used to setup TLS session for TLS/HTTPS
HTTPS root certificate	RSA (2048)	Input encrypted (using TLS session key)	Not output			Used to setup TLS session for TLS/HTTPS
IPsec Keys						
DH Private Key	2048 bits private key	Generated	Not output	Plaintext in RAM	Zeroized when no longer used	IKE v2 SA setup

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ECCDH Private Key	256,384,521 bits	Generated	Not output	Plaintext in RAM and encrypted in FLASH	RAM copy zeroized when no longer used	IKE v2 SA setup
IPSec SA Authenticatio n certificate private key	RSA (2048), ECDSA (256,384,512)	Input encrypted using TLS session key	Not output	Plaintext in RAM and encrypted in FLASH	RAM copy zeroized when no longer used	IKE v2 SA authentication
IPSec SA private key password	Text string	Input encrypted using TLS session key	Not output	Plaintext in RAM and encrypted in FLASH	Zeroized when no longer used	Encrypt the IPSec SA certificate private key
IPSec SA session key	Derived from DH/ECCDH key exchange	Not input	Not output	Plaintext in RAM	Zeroized when no longer used	Encrypt and Authenticate SA_Auth messages of IKE v2
IPSec ESP symmetric Data encryption key	AES, AES_GCM (128, 256)	Not input (derived from SA setup)	Not output	Plaintext in RAM	Zeroized when child SA lifetime expired	Encrypt IPSec ESP data
Wireless Access Point Keys						
PMK	802.11i pairwise master key	If 802.11i PSK, it's input directly as a Hex string. Input encrypted using the TLS session key. If 802.11i EAP-TLS, then not input, instead derived (TLS master secret resulting from successful User EAP-TLS authentication)	Not output	If 802.11i PSK, then plaintext in flash For both 802.11i PSK and EAP-TLS, plaintext in RAM	Zeroized when wireless user disconnect or at PMK expiration If 802.11i PSK, zeroized when reset to factory settings.	802.11i PMK
KCK	HMAC key (128 bits from PTK)	Not input (derived from PTK)	Not output	Plaintext in RAM	When 802.11i session ends.	802.11i KCK
KEK	AES ECB(e/d; 128)	Not input (derived from PTK)	Not output	Plaintext in RAM	When 802.11i session ends.	802.11i KEK
PTK	AES CCM (e/d; 128)	Not input (derived from PTK)	Not output	Plaintext in RAM	When 802.11i session ends.	802.11i TK
PTK (copy in driver)	AES CCM (e/d; 128)	Not input (derived from PTK)	Not output	Plaintext in RAM	When 802.11i session ends.	802.11i TK
GTK	AES CCM (e/d; 128)	Not input (derived from GMK)	Output encrypted (using KEK)	Plaintext in RAM	Zeroized when local antennae	802.11i GTK

				Approved encrypting mode either reconfigured or changed from IEEE 802.11i mode to any other local antennae Approved encrypting mode (including from 802.11i PSK to 802.11i EAP-TLS, and 802.11i EAP-TLS to 802.11i PSK). When re-key period expires	

The zeroization technique is to write all 0xa5, then 0x5a, 0xff and finally all zeros to the memory location where the key is stored in non-volatile storage. A read-verify is performed after the zeroization. The technique is implemented in the firmware that uses Linux file system APIs. The TOE does not store keys in EEPROM. For keys stored in RAM, a single overwrite of all zeroes is performed. IPsec authentication certificate's private keys are encrypted with the corresponding private key passwords. The passwords are stored as plain text in flash and they are zeroized the same way as described above.

NDcPP20E:FCS_COP.1/DataEncryption:

WLANAScEP10:FCS_COP.1(1):

AES is implemented with key sizes of 128, and 256 bits in Cipher Block Chaining (CBC) mode and Galois Counter Mode (GCM) and 128 bits in CCMP mode. The 3eTI's OpenSSL Library provides AES services for application level data encryption and decryption. The management interface uses this library to provide Transport Layer Security (TLS/HTTPS). For the TOE's TLS interface, AES_CBC with 128 or 256 bits key is used. 3eTI's MPC8378E Cryptographic Core provides AES_GCM and AES_CBC services for IPsec data encryption. 128 and 256 bits keys are supported. AES_CCM with 128 bits is provided by the MPC8378E core for WLAN data packets encryption/decryption.

Table 6-1 lists the AES mode and key sizes; all AES algorithm implementations are NIST CAVP validated.

NDcPP20E:FCS_COP.1/SigGen:

The 3eTI OpenSSL Library provides the RSA Digital Signature Algorithm (rDSA) to the TLS/HTTPS Daemon for the TLS session. The TLS/HTTPS Daemon enforces a 2048 or larger bits RSA key length for use with the RSA. TOE Firmware's digital signature is using ECDSA with P256. The 3eTI OpenSSL library provides ECDSA sign/verify operation support. IPsec tunnels can be configured to use RSA (2048 bits) or ECDSA with key size 256, 384, and 521 bits using NIST curve P256, P384 and P521 certificate for IPsec SA authentication. Table 6-1 lists RSA and ECDSA CAVP validation certificate numbers.

NDcPP20E:FCS_COP.1/Hash:

The TSF supports SHA-1, SHA-256, SHA-384, and SHA-512 for secure hashing. See Table 6-1 for details. The security hashing functions are used in IPsec IKEv2 and ESP to provide data packet integrity.

NDcPP20E:FCS_COP.1/KeyedHash:

The TOE's OpenSSL Library and the MPC8378E cryptographic core both implement HMAC-SHA-1, HMAC-SHA-256, HMAC-SHA-384, and HMAC-SHA-512, keyed-hash message authentication supporting digest sizes: 160, 256, 384, and 512 bits and key size of 160 bits, 256 bits, 384 and 512 bits implemented to meet ISO/IEC 9797-2:2011, Section 7 "MAC Algorithm 2. The block size is 512 bits for HMAC-SHA-1, HMAC-SHA-256 and 1024 bits for HMAC-SHA-384, and HMAC-SHA-512 and the output size is the same as the underlying hash function.

NDcPP20E:FCS_IITTPS_EXT.1.1:

The Web UI with remote administration station is always TLS/HTTPS. The HTTPS implementation is fully compliant with RFC 2818. The TOE acts as an HTTPS server and waits for client connections on TCP port 443. The TOE's HTTPS server permits an HTTP client to close the connection at any time, and the HTTPS server will recover gracefully. In particular, the HTTPS server is prepared to receive an incomplete close from the client, and is willing to resume TLS sessions closed in this fashion.

NDcPP20E/WLANAScEP10:FCS_IPSEC_EXT.1:

The TOE implements IPsec protocol in full compliance with IETF RFCs as specified by NDcPP20E. Within the TOE, the NTP client uses an IPsec tunnel for communications with an NTP server. The TOE uses IPsec to protect communications with the remote log server as well.

The TOE supports IKEv2 only as defined by RFCs 5996 and always attempts NAT traversal, hence an administrator need not configure either. During the Security Association (SA) setup phase, the TOE supports the following DH groups:

- ecp384

- ecp256

- modp2048

If the administrator selects "auto negotiation" from IPsec "Cipher Suites" configuration Web UI, then the groups listed above will be send to the IPsec peer during the IKEv2 negotiation. If "Suite B GCM128" is selected, then the TOE will use ecp256 group. If "Suite B GCM256" is selected, then the TOE will use ecp384 group.

The TOE chooses and enforces the group and AES cipher to make sure that the SA confidentiality strength is equivalent or greater than the configured ESP confidentiality strength. For example, the TOE (when configured for "Auto Negotiation") will reject any ESP proposal with an AES key length greater than the negotiated IKE AES key length. Similarly, administrator selection of "Suite B GCM128" or similar ciphers ensure the TOE will enforce a single, prescribed set of modes to make sure that the parents IPsec SA confidentiality strength is equal or greater than the child SA's strength.

Mode	IKE (openssl library)				ESP (Hardware encryption)	
	Encryption	Integrity	Pseudo Random Function	DH Group	Encryption	Integrity (where applicable)
Suite B GCM 128	aes128cbc	sha256	sha256	ecp256	aes128gcm128	-

The TOE uses ISO/IEC 18031:2011 DRBG to generate the nonce and "x" in each DH group with lengths of 112 (for DH group 14), 128 (for DH group 19 and 192 (for DH group 20). After the Diffie Hellman exchanges that setup the session keys, the IKEv2 payload is protected by the following encryption algorithms:

- AES-CBC-256

- AES-CBC-128

SHA-512, SHA-384, SHA-256 and SHA1 are used to provide payload data integrity. X.509 certificates with rDSA 2048 bits or larger key or ECDSA 256, 384, and 521 bits key with NIST P256, P384 and P521 are used for IPsec tunnel authentication with its peer.

The TOE supports IPsec tunnel mode and transport mode which allows the payload of packets to be encrypted. The TOE requires no administrative configuration and negotiates either depending on the peer. The TOE uses IPsec standard encapsulating Security Payload (ESP) protocol to provide authentication, encryption and anti-replay services. It uses the following ciphers to encrypt the IPsec data payload:

1. GCM mode with Nonce length of 128, 96 and 64 bits

    - AES-GCM-128
    - AES-GCM-256

2. CBC mode with HMAC-SHA-512, HMAC-SHA-384, HMAC-SHA-256 and HMAC-SHA1 as integrity

    - AES-CBC-128
    - AES-CBC-256

When the administrator chooses AES-GCM-128 for ESP encryption, the TOE will automatically choose SHA-256 for the IKE's integrity and pseudo random function. If the choice is AES-GCM-256, then SHA-256 will be used in IKE integrity and SHA-384 will be used for the pseudo random function. If the administrator chooses "Auto Negotiation" for IPsec, the TOE will send cipher list ranked with the highest security first to its peer. For example, the IKE integrity list will be sent as: SHA-512, SHA-384, SHA-256 and SHA1. It's expected that the peer will pick the strongest one it could support. There is no need to explicitly configure security hashing functions in the IPsec configuration.

The IPsec daemon module implements implicit policies such that only expected data packages are allowed. Any data packages that violate the policy will be discarded.

The TOE allows the Security Administrator to configure the IKEv2 SA and child SA lifetime by minutes (20-1440, default 180) and the TOE additionally allows the Administrator to configure child SA lifetime by number of bytes (90 to 2047Kb, 0 for unlimited) or by number of data packets (192 to 2097151K, 0 for unlimited).

The TOE supports X.509 certificate for IPsec mutual authentication. RSA certificate with 2048 bits, ECDSA certificates with 256, 384, and 521 bits key is supported implementing NIST curves P256, P384 and P521. When certificates are used for authentication, the Distinguished Name (DN), IP Address and Fully Qualified Domain Name (FQDN) are verified to ensure the certificate is valid and is from a valid entity. These reference identifiers in the certificate are compared with the expected reference identifiers (as specified by an administrator) and deemed valid if the attribute types are the same and the values are the same and as expected.

The TOE can be configured to use pre-shared key for IPsec authentication as well. The security administrator first selects "Pre-Shared Key" under "Authentication" when configuring the IPsec tunnel via the Web UI, then enters the pre-shared key manually.

The TOE's IPsec Security Policy Database (SPD) is dynamically configured based upon the trusted paths IPsec is used to protect. For example, the TOE uses IPsec to protect a remote syslog trusted path. In this instance, records are written into the SPD to protect packets passing between the TOE and the remote syslog server based on source address, destination address, protocol and port number. When protecting remote syslog trusted path, the SPD will have record matching ingress UDP traffic with source address and port corresponding to the remote syslog server. Additionally, the SPD will have record matching egress traffic with destination address and port corresponding to the remote syslog server. Traffic passing through the security boundary and matching either of these two records will be classified as "PROTECTED" using IPsec transport mode. Traffic that does not match any records in the SPD but does match the local firewall access list will be allows to "BYPASS" the security boundary unperturbed. Traffic that does not match any records in the SPD will be "DISCARDED". Additional records are written into the SPD when additional trusted paths are configured for IPsec protection (i.e. remote audit log, NTP and RADIUS server).

NDcPP20E:FCS_RBG_EXT.1:

The TOE implements RBG as defined ISO/IEC 18031:2011 using CTR_DRBG (AES). The entropy source is a hardware based noise generator. Entropy is obtained from a zener diode operated in avalanche mode. The noise from the diode is passed through a cascaded pair of operational amplifiers, then applied to the input of a Microchip MCP3221. MCP3221 is a successive approximation analog to digital converter (ADC) with a 12 bit resolution. The TOE communicates with the MCP3221 hardware over the 2-wire I2C and reads in the raw entropy. The raw entropy is further conditioned by the Linux kernel to produce 8 bits of entropy per byte. Then the random bytes are read by the DRBG implementation of 256 bits of DRBG key and DRBG seed.

NDcPP20E: FCS_TLSS_EXT.1:

The TOE's HTTPS server supports TLS version 1.1/1.2 only and will deny connection requests from TLS clients with a lower version. It supports the following ciphers:

- TLS_RSA_WITH_AES_128_CBC_SHA
- TLS_RSA_WITH_AES_256_CBC_SHA
- TLS_DHE_RSA_WITH_AES_128_CBC_SHA
- TLS_DHE_RSA_WITH_AES_256_CBC_SHA
- TLS_RSA_WITH_AES_128_CBC_SHA256
- TLS_RSA_WITH_AES_256_CBC_SHA256
- TLS_DHE_RSA_WITH_AES_128_CBC_SHA256
- TLS_DHE_RSA_WITH_AES_256_CBC_SHA256

The TOE's TLS/HTTPS server uses RSA 2048 bits certificate for TLS authentication. After the TLS session's successful setup, the security administrator logs into the TOE via user name and passwords. If the failure count reaches the configured threshold, the TLS/HTTPS session will be terminated by the TLS/HTTPS server. The Diffie-Hellman group 14 with parameters of size 2048 bits is used for the key agreement.

6.3 Identification and authentication

The Identification and authentication function satisfies the following security functional requirements:

WLANAScEP10:FIA_8021X_EXT.1:

When a wireless user attempts to associate to a given network, they must first associate with an Access Point (AP). The TOE maintains the userID and MAC address for the user (and their client) throughout the user's session. During the security policy discovery phase of 802.11i, the wireless client determines the security methods enforced by the TOE that are advertised by the AP.   The Extensible Authentication Protocol (EAP) over LAN (EAPOL) protocol is used for communication between the wireless client and the TOE. The TOE functions as Authenticator as defined by 802.1X-2010. The TOE strictly follows the port-based network control model as defined in section 7.1 of 802.1X-2010.

Once the wireless client and the TOE have negotiated the required security methods, the authentication phase of the process is initiated. The TOE acts as 802.1X authenticator and provides remote EAP-TLS authentication pass through to the RADIUS server. The TOE implements the Authenticator's state machine and counters as defined in section 8.9 & 8.10 of 802.1X-2010. The TOE's authenticator module strictly enforces EAPOL PDU format as defined in section 11 of 802.1X-2010. The TOE's authenticator implementation uses all 8021.X-2010 mandatory definitions. No optional or non-conformance definitions of 802.1X are implemented. The TOE is Wi-Fi Alliance certified for WPA2 interoperability. The interoperability tests include many EAP methods, among which EAP-TLS is included.

The TOE establishes IPsec tunnel with the RADIUS server to protect the EAPOL data packets between itself and the RADIUS server. The IPsec tunnel is also used to protect the PMK sent by the RADIUS server as part of RADIUS Access-Accept message. During this 802.1x authentication state, the TOE denies all packets sent by the client that are not 802.1x EAP packets.

After successful authentication of a wireless client, an IP address is also associated with the client. The IP address may be obtained from a DHCP server on the wired network, or if the client is not using DHCP, then the IP address already configured into the client will be used as an additional identifier for the client along with the MAC address.

NDcPP20E:FIA_AFL.1:

WLANAScEP10:FIA_AFL.1:

If the administrator's authentication fails with the TOE, the failure counter will be incremented. Once the failure counter reaches the configured threshold, the TOE's HTTPS server will refuse connection from this end point for an administrator. The authentication failure threshold is configurable by an authorized security administrator with a maximum value of 8, the default value is 3. Once a connection is refused, the administrator would have to re-login after the configurable lockout time period has elapsed, the login failure counter would be reset to 0 by then. The default lockout period is 10 minutes and is configurable between ranges of 0-90 minutes. In order to ensure that remote administrator authentication failures do not lead to a situation where no administrator access is available, an administrator account with local access can be configured with a lockout period of "0" minutes. When the value is set at 0, the administrator won't be locked out even after the login threshold is reached.

NDcPP20E:FIA_PMG_EXT.1:

The TOE supports the local definition of users with corresponding passwords. The passwords can be composed of any combination of upper and lower case letters, numbers, and the following special characters: '!', '@', '#', '$', '%', '^', '&', '*', '(', ')'. Minimum password length is settable by the Authorized Administrator and can be configured for minimum password lengths of 8 to 30 characters. Additionally, the TOE supports password lengths up to 32 characters long. NOTE: The TOE will truncate passwords that are longer than 32 characters when creating a user or changing passwords for an existing user.

WLANAScEP10:FIA_PSK_EXT.1:

The TOE uses pre-shared keys for IPsec. The TOE accepts IPsec PSK keys between 16 and 32 characters in length. The TOE also supports PSK for wireless client authentication. The pre-shared key for wireless client is between 8 and 63 characters. The pre-shared keys must be composed of any combination of upper and lower case letters, numbers, and special characters (that include: "!", "@", "#", "$", "%", "^", "&", "*", "(", and ")"). Note that the '&' character is not supported for WPA2 pre-shared keys, but it is supported for IPsec pre-shared keys.

For IPsec, the TOE conditions the text-based pre-shared keys using the SHA-1, SHA-256, and SHA-384 hash algorithm and can accept bit based pre-shared keys. For WPA2, the TOE only accepts text based PSKs that are transformed into bit-based PSKs. Text-based keys are conditioned using PBKDF2, as specified in 802.11i.

WLANAScEP10:FIA_UAU.6:

An administrative user is required to re-authenticate when he/she changes password, and following a TSF-initiated locking as described in any of the FTA_SSL requirements in this ST.

NDcPP20E:FIA_UAU.7:

When a user is entering their password information, the password is obscured such that no observer could read the password off the screen.

NDcPP20E:FIA_UAU_EXT.2:

NDcPP20E:FIA_UIA_EXT.1:

The TOE requires all users to be successfully identified and authenticated before allowing any TSF mediated actions to be performed except for the login banner that is displayed prior to user authentication and any network packets as configured by the authorized administrator may flow through the TOE.

The administrator logs on the TOE through either dedicated local Ethernet port or over WAN Ethernet port to access the Web UI. The Web UI is accessible over HTTPS only and the TOE supports TLS 1.1/1.2. There is no local access such as a serial console port. Therefore, the local and remote management is considered the same for this evaluation.

A successful authentication is determined by a successful username and password combination after the HTTPS connection. An incorrect password will result in a failed authentication attempt. The TOE does not provide a reason for failure in the cases of a login failure. The TOE supports local authentication using a local user database.

NDcPP20E:FIA_X509_EXT.1/Rev:

NDcPP20E:FIA_X509_EXT.2:

NDcPP20E:FIA_X509_EXT.3:

The TOE uses X.509 certificates for IPsec authentications. The TOE can be configured with the certificates and their corresponding private key by security administrator or by creating CSRs and importing the CA signed CSRs to the TOE. The security administrator can load and delete certificates for usage of IPsec authentication, load and delete CAs, intermediated CAs and CRLs. The TOE checks that the basicConstraints extension and CA flag are set to TRUE for all CA certificates before their acceptance. During the IPsec authentication using X509 certificate, the TOE develops a certificate path from a trust anchor configured by security administrator which is fully compliant with RFC 5280. When a certificate chain is received from a peer, the TOE processes the certificate chain path until the first trusted certificate, or trust point, is reached. The TOE uses CRL that have been preloaded by the administrator to validate the peer certificates, and the TOE will accept as valid, a certificate for which the administrator has not loaded a CRL. Failure by the TOE to establish the certification path to a trust anchor will lead to the failure of establishment of this IPsec trusted channel.

The TOE allows the security administrator to view the certificates and CAs. The TOE's Web UI will display the certificates' name, subject name, issuer name, valid-start date, expiration date.

6.4 Security management

The Security management function satisfies the following security functional requirements:

WLANAScEP10:FMT_SMR.1:

By default, the TOE disallows wireless client devices to access the TOE's Web UI interface. For each wireless client that successfully authenticates with the TOE and obtains an IP address, the TOE will use its MAC address and IP address to build an entry in the TOE's access table to disallow the client's access to the TOE's Web UI.

NDcPP20E:FMT_MOF.1/ManualUpdate:

NDcPP20E:FMT_MTD.1/CoreData:

NDcPP20E:FMT_SMF.1:

NDcPP20E:FMT_SMR.2:

The Web UI over HTTP/TLS provides capabilities for the authorized administrator to manage the TOE security functions and data. The TOE provides the role of Security Administrator (encompassing both the Crypto Officer and Administrator role as described in the guidance). The Security Administrator accesses the TOE through the Web UI over TLS/HTTPS. Upon successful authentication with the TOE, the Security Administrator role can perform the following operations:

- Configure cryptographic functionality – generate/import a key, change a key, delete/zeroize a key, set a key lifetime, set the cryptographic algorithms, set the TOE to encrypt or not to encrypt wireless transmissions, execute self tests of the cryptographic functions.

- Configure lifetime for IPsec SAs

- Configure authentication failure parameters by setting the number of authentication failures that may occur before the TOE takes action to prevent future logins for an administrator defined time period.

- Configure session inactivity by setting the length of time a session may remain inactive before it is terminated.

- Configure the TOE Access Banner

- Configure the time used for timestamps on the TOE – set the time locally on the TOE, set the time using an NTP server

- Configure the reference identifier for the peer

- Configure the audit behavior – remote audit logging, audit storage exhaustion settings

- Perform TOE updates and verification of those updates using digital signatures.

- Configure Users – create and manage user accounts

- Reset Passwords – administrators can modify their own passwords

No Web UI interfaces are accessible to the user prior to authentication. The TOE enforces authentication then enables the TSF data configuration interfaces. The Non-security administrators have no access to those TSF data configuration interfaces.

6.5 Protection of the TSF

The Protection of the TSF function satisfies the following security functional requirements:

NDcPP20E:FPT_APW_EXT.1:

NDcPP20E:FPT_SKP_EXT.1:

The authentication passwords are stored in PKCS5 format in the TOE. All other CSPs are stored in encrypted format in the TOE on non-volatile memory. The file system that holds the hashed password and encrypted CSPs are made read-only during runtime to avoid data corruption. None of the files or CSPs is available through any external interfaces to users/administrators. The Web UI allows the security administrator to input keys/passwords to the TOE with no output capabilities.

NDcPP20E:FPT_STM_EXT.1:

The TOE has a running NTP daemon to synchronize the local time with an external NTP server. IPsec tunnel is setup between the TOE and NTP server to protect the integrity and privacy of the time source. In the absence of an NTP server in the Operational Environment, the authorized administrator has the capability to set the time locally. The local time is used for the following security functions identified in this ST:

- Time stamping each audit record.
- Verifying the validity of the Web Server X509v3 Certificate.
- Verifying the validity of the IPsec tunnel peer's Certificate.
- Verifying the validity of the Firmware X509v3 Certificate during the firmware upload process.
- Enforcing user lockout periods for "Bad Password" login attempts.
- Timing out login sessions due to inactivity.

NDcPP20E:FPT_TST_EXT.1:

WLANAScEP10:FPT_TST_EXT.1:

WLANAScEP10:FPT_FLS.1:

The TSF performs a firmware integrity check and a configuration file integrity check on system start up. Algorithm Known Answer Tests are run at startup time or at security administrator's request as shown below:

Power-on self-tests:
Software Integrity Test
- Bootloader Integrity Test
- Firmware Integrity Test

FreeScale PowerQUICC Crypto Engine Power-on self-tests:
- AES_GCM   encrypt/decrypt KAT
- AES_CCM   encrypt/decrypt KAT
- SHA-1, SHA256, SHA384, SHA512   KAT
- HMAC SHA-1, SHA256, SHA384, SHA512   KAT

3eTI OpenSSL library Power-on self-tests:

- HMAC SHA-1, SHA256, SHA384, SHA512   KAT
- SHA-1, SHA256, SHA384, SHA512   KAT
- FIPS SP800-90 DRBG   KAT
- RSA sign/verify   KAT
- ECDSA sign/verify   KAT

Vectors for each known answer test (KAT) are compiled into the Firmware. The known inputs are provided to the cryptographic function and the output of that function is compared to the known output. The firmware is halted if any of the known answer tests fail.

After the device is powered on, the first thing done by the bootloader is to check its own integrity. If the integrity is broken, the firmware won't boot. Firmware integrity is performed at firmware boot up. Both firmware and bootloader are digitally signed with ECDSA.

NDcPP20E:FPT_TUD_EXT.1:

Security Administrators can query the currently active TOE version via the Web UI by going to the System Administration -> Help screen and clicking on the 'About' button. When a new version of firmware is released, the customers are notified by 3eTI's customer service department, normally via e-mail. If a customer desires to get a copy of the new firmware, the customer will be provided with an URL link to the secured download site together with a onetime valid user name and password.

The Security Administrator can update the TOE's firmware. The firmware is digitally signed with ECDSA. The TOE uses the public key to verify the digital signature. Upon successful verification, the TOE will load the new update upon reboot. The update will be rejected if the verification fails.

6.6 TOE access

The TOE access function satisfies the following security functional requirements:

NDcPP20E:FTA_SSL.3:

NDcPP20E:FTA_SSL.4:

NDcPP20E:FTA_SSL_EXT.1:

The Web UI terminates the remote or local session if it detects inactivity longer than the configured time period. The default time period is 10 minutes. The remote session will be closed by the Web UI together with the HTTPS session. The Security Administrator is required to re-authenticate with the TOE and setup a new session. The time intervals are configurable by the security administrator.

NDcPP20E:FTA_TAB.1:

The Web UI displays a customizable TOE access banner to the remote administrative user before the user can log into the system.

WLANAScEP10:FTA_TSE.1:

The TOE implements wireless client MAC address filtering functions. The security administrator can specify white list (allow) or black list (deny) or both. The list's attributes are IP address, client WiFi MAC address, time (hour and minute) and day.

An authorized security administrator can configure the TSF to deny establishment of a wireless client based on that client's location, time or day. The location is based on client MAC address as the client will usually move within one wireless Basic Service Set (BSS).

6.7 Trusted path/channels

The Trusted path/channels function satisfies the following security functional requirements:

NDcPP20E:FTP_ITC.1:

WLANAScEP10:FTP_ITC.1:

The TOE provide a trusted communication channel between itself and all authorized IT entities that is logically distinct from other communication channels. IPsec is setup between the TOE and the audit log server, RADIUS and NTP server. The trusted channel can be initiated either by the TOE or by the remote IT entities. The TOE establishes WPA2 with 802.1x EAP-TLS connections with wireless clients and uses IPsec for communications with authentication servers.

NDcPP20E:FTP_TRP.1(1):

All remote administrative communications take place over a secure encrypted TLS session. The HTTPS/TLS implementation allows web browser clients to connect to the TOE's HTTPS server. The remote users are able to initiate TLS communications with the TOE.

Appendix S: Tactical Microgrid Standard Data Distribution Service Implementation Guide

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TMS OMG DDS Implementation Guide

Release 1.5
For TMSC Draft Dated 1 February 2017

This draft, dated 29 March 2017, prepared by TMSC, has not been approved for use and is subject to modification. Questions, suggestions, or comments about the document or its maturity should be addressed to Tom Bozada, the TMSC Project Manager, Thomas.a.bozada@usace.army.mil.

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Change Summary

Release	Changes
1.2	Added "`GetConfig<Device Command>Response`" topics for the response to the `GetConfigContentsRequest` topic. Clarified USER_DATA QoS settings. Simplified the tables defining the IDL data types and rates.
1.3	Added new `SecondaryControlCapabilities` topic name.
1.4	Added section on determining Device liveliness.
1.5	• Clarified Liveliness kind and lease duration for "Publish Last" QOS Profile. Only the DeviceAnnoucement topic has a lease duration. • Added Resource Limits to QOS Profiles • Change "Continuous" QOS Profile deadline from 1 to 2 seconds. • Added "Response" to QOS Profile to indicate which topics or published in response to a command. The new "Response" profile has the same QOS settings as the "Command" profile. • Corrected topic "ReserveConfigReply" as a command "Response" QOS profile. • Updated the tms.idl to reflect changes during the TMSC DDS IO Loop Check.

1   TMS OMG DDS Implementation Guide

This document provides additional details needed to implement the DEPARTMENT OF DEFENSE INTERFACE STANDARD TACTICAL MICROGRID STANDARD (TMS).

The following list are important references to sections in the TMS standards.

- Appendix B - Data Model Object Definitions
  - Defines the data types named in this document.

1.1   Assumptions

- The reader is familiar with "Publish / Subscribe" based architectures such as OMG DDS.
- The reader is familiar with UML.
- Data Model Provisional Sections are subject to change which may result in changes to this implementation guide.
- Assignment of TMS devices to a Microgrid not covered. Assume all devices are part of a single microgrid.
- Vendor specific OMG DDS implementation steps are not provided.   An example is compilation of the tms.idl file. Refer to the selected OMG DDS Vendor Documentation for details.

2   High Level Implementation Steps

The following sections outline the high level steps required to implement a TMS compliant device.

2.1   OMG DDS Vendor Selection

The OMG DDS Standard is designed to be vendor-neutral. TMS IDL is tested to compile with products from the following vendors.

- RTI
- Twin Oaks Computing INC.
- PrismTech

The following OMG DDS Specifications are required for TMS.

- http://www.omg.org/spec/DDS/1.2
- http://www.omg.org/spec/DDSI-RTPS/2.1

Future releases of TMS may require support for the following OMG DDS Extensions

- DDS-XTypes v1.1
- DDS-Security v1.0 Beta 1
- DDS-RPC v1.0 Beta 1

2.2   Platform and Programming Language Selection

As part of the OMG DDS vendor selection, ensure the vendor supports the target platform (hardware / operating system) and programming language.

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2.3 Compile TMS IDL

After acquiring the selected OMG DDS vendor software and setting up a target development environment, the next step is to compile the TMS IDL and generate code in the target programming language.

3 TMS Device Role Implementation

Implement the required TMS device roles based on the following sections.

3.1 TMS Component Roles

Figure 1- TMS Device Roles below illustrates the TMS device roles that are software-only or that include power ports. TMS currently plans to deploy the Microgrid Controller (MC) software as part of the Distribution (DIST) device but the 'TMS Software Only' device roles can be deployed on any computer networked with the other TMS devices.
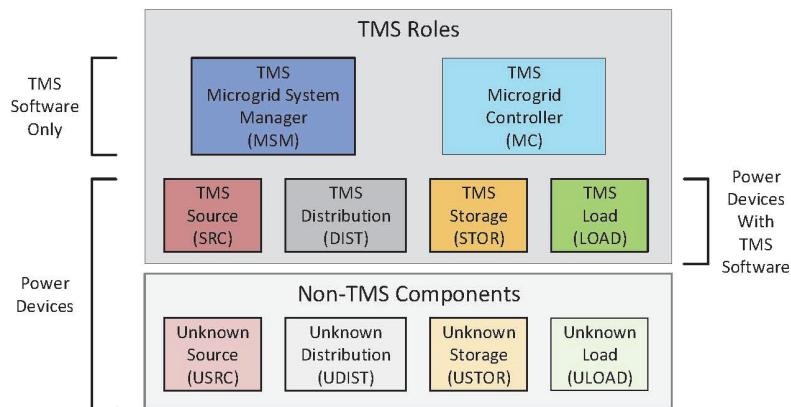
Figure 1- TMS Device Roles

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Figure 2- TMS Power Cable View below provides an example of the power connections between various TMS device roles.
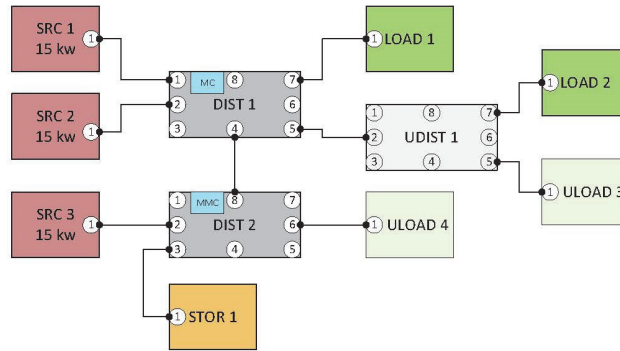
Figure 2- TMS Power Cable View

3.2 TMS OMG DDS Basics

A TMS compliant device uses OMG DDS standard for communications with other TMS compliant devices.   Refer to an OMG DDS compliant vendor software product for additional details.

Figure 3 below provides the OMG DDS view of TMS devices roles all participating in the DDS global data exchange.   Each link between the TMS device and the DDS cloud represent data being published or subscribed to by each device. This section focuses on the steps required to implement a TMS compliant device that interfaces/communicates with other TMS compliant devices using the DDS Global Data.
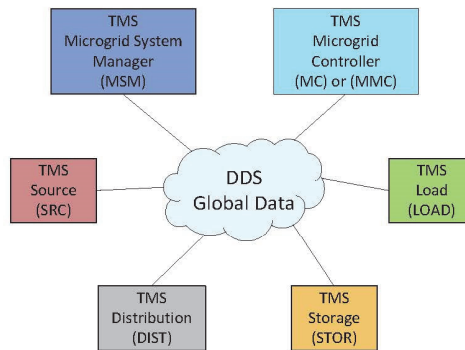
Figure 3 - TMS OMG DDS View

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3.3   Device Role List

The following table summarizes the TMS device roles used defined in the Data Model.

Role	Description	TMS Compliant	Required Instances
MSM	**Microgrid System Manager** Software component that serves as the operator's primary Human Machine Interface (HMI) used to monitor and configure the Microgrid operations.	Yes	0 - many (typically 1)
MC	**Microgrid Controller** Software component authorized to send configuration settings and commands to other TMS compliant devices in the Microgrid.	Yes	0 - many (typically many)
MGR	**Manager** An alias for the MSM and MC. MGR is used later in this document to simplify the sequence diagrams when either the MSM or MC can be included.	Yes	0 - many (typically many)
MMC	**Master Microgrid Controller** The elected master MC. Only the MMC will send configuration settings and commands to the other TMS compliant Microgrid devices.	Yes	0 - 1. Exactly 1 if MC included
SRC	**Source** Power Device Hardware component that provides energy to the Microgrid. Note: A microgrid will typically include at least one SRC or STOR device.	Yes	0 - many (typically many)
USRC	**Unknown Source**	No	0 - many
STOR	**Storage** Power Device Hardware component that consumes energy with the intent to provide it later.	Yes	0 - many
DIST	**Distribution** Power Device Hardware component with cabling and switching that transports energy	Yes	0 - many (typically many)
LOAD	**Load** Power Device Hardware component that consumes energy from the Microgrid.	Yes	0 - many
ULOAD	**Unknown Load** Hardware component that consumes energy from the Microgrid. It is classified as "unknown" because it is a non-TMS compliant device or communications is currently unavailable.	Yes or No	0 - many
DEV	**Device** Denotes a generic device that is participating in the microgrid communications. Includes MSM, MC, SRC, STOR, DIST, and LOAD	Yes	-

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PDEV	Power Device Denotes a generic device that provides, consumes, or transports energy. Includes SRC, STOR, DIST, and LOAD. PDEV is used later in this document to simplify the sequence diagrams when any of the power device roles are allowed.	Yes	0 - many

Table 1 - Device Role List

3.4 Device Role Class Diagram

The following class diagram illustrates the TMS Device hierarchy.
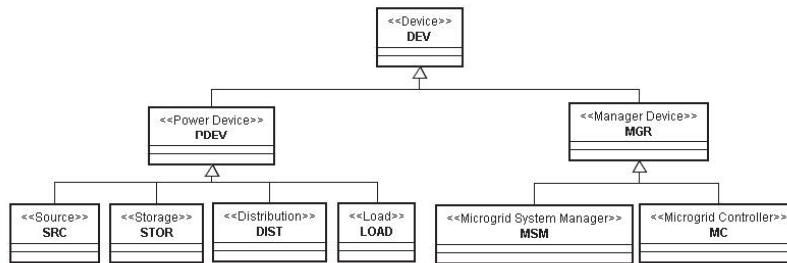
Figure 4 - Device Class Diagram

4 TMS DDS Topic Summary

This section summarizes the individual topics that are required to implement the TMS Device Roles. A topic is defined by a unique "Topic Name". Each topic has an associated data type defined in the tms.idl. The topic names give additional meaning to the data type as multiple topics can share the same IDL data type. Every topic has one or more publishers and one or more subscribers. The publishers and subscribers are allocated to the different TMS device roles. See the Topics Spreadsheet for the publisher subscriber allocations by TMS device role.

The topics are summarized from the publisher's perspective. See the Topic Spreadsheet for the corresponding subscribers.

4.1 Common Published Topics

This section describes the topics that are published by all TMS device roles.

- Device Announcement: Used to discover TMS compliance devices.
- Device Clock Status: Reports changes to a device clock(s). A device must support relative time and can optional support absolute time.
- Active Diagnostics: Reports a devices diagnostics state including information and alarm states.
- Request Response: Used to implement a generic request (command) and response (reply) pattern.

4.2   Power Device Published Topics (SRC, STOR, DIST, and LOAD)

This section describes the topics that all TMS Power Devices publish.   A power device is any device that provides, consumes, or transports energy.

- Device Power Port List: Reports static data for a devices power ports.
- Device Power Status List: Reports dynamic state changes for a devices power ports.
- Discovered Connection List: Reports device discovered power connections to a devices power ports.
- Device Power Measurement List: Reports dynamic power measurements for a devices power ports.

4.3   Source (SRC) and Storage (STOR) Published Topics

This sections describes the topics all TMS SRC and STOR device roles publish.

- Engine State: Reports dynamic state changes of a SRC/STOR device if an engine is present.
- Source Transition State: Reports the operational state (off, on, running, sourcing) of the SRC/STOR device

4.4   Distribution (DIST) Published Topics

The DIST devices publish the topics already described in section 4.1 Common Published Topics and section 4.2 Power Device Published Topics (SRC, STOR, DIST, and LOAD)

4.5   Load (LOAD) Published Topics (FUTURE)

This section describes the topics that only the LOAD device role publishes.

- Energy Ration: Reports the LOAD devices energy consumption limits (power budget).

4.6   Microgrid System Manager (MSM) Published Topics

This section describes the topics that are only published by the MSM device role.

- Operator Connection List: Part of topology discovery to report operator device power connections when a device does not support connection discovery.
- Operator Intent Request: Used to set a microgrid control directives that influence how the microgrid behaves.

4.7   Microgrid Controller (MC) Published Topics

This section describes the topics that are only published by the MC device role.

- Microgrid Connection List: Part of topology discovery used to report the effective microgrid topology.
- Load Sharing: Used to configure and select microgrid load sharing algorithms.
- Consensus Protocol (FUTURE): Used to implement distributed control across the microgrid.
- Source Transition Request: User to request a change in a SRC/STOR device state.
- Device Configurations: Used to define a set of commands for execution by a power device.

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5   TMS DDS Topic Publishers and Subscribers

This section describes key concepts required to implement the publishers and subscribers.   The concepts discussed include the publishing rates, topic categories, DDS implementation, and DDS QoS profiles.

5.1   Topic Publishing Rates

The rate a topic is published is specified by the "QoS Profile", "Publisher Rate" columns in the Topics Spreadsheet.   The following table summarizes the supported rates of a TMS device.

Publisher Rate Names	Data Model Rate	Publisher Rate Summary
`Once`	Rate-0	Only published once after device joins a DDS domain.
`On Change`	Rate-0	Published after device joins a DDS domain and again when a previously published value has changed.
`Command`	Command	Published when a device state change is being requested. See section 5.2.2.
Fixed Maximum Rates		
`Rare`	Rate-1ks	Published every 1000 seconds.
`Slow`	Rate-10s	Published every 10 seconds.
`Continuous`	Rate-01s	Published every 100 milliseconds.
`Burst`	Rate-10s-bur	Published in bursts ~10 seconds.

Table 2 - Publisher Rates

5.1.1   Publish `Once` (Static Data)

The publisher must publish the topic once.   The data is static and is not expected to change for the time the device is part of the current microgrid.   An example of a `Once` topic is the rated power of a generator.

5.1.2   Publish `On Change` (Dynamic Data)

The publisher is expected to publish the topics when the device data defined for the topic changes from the previously published value.   These topics are expected to change over time but at no pre-determined rate. An example of an `On Change` topic is the position of a power switch / contactor on a distribution box.

5.1.3   Publish Commands

The topic represents a command/request from the publisher to the subscribing device to perform a state change. See Command Topics below.

5.1.4   Publish At Fixed Rates

The publisher must publish the topic at the specified rate, even if the values have not changed from the previous published data.   Topics assigned to fixed rate published are expected to change frequently and the liveliness of the published data determines the overall state of the microgrid. An example of a fixed rate topic is the active power measured at a power port of a device.

5.2   Topic Categories

Topics are divided into two categories, Data Topics or Command Topics.

5.2.1   Data Topics

Data Topics are published asynchronously by a TMS device to share static configuration data and dynamic state changes.   An example Data Topic is `EngineStatus` or `DeviceAnnouncement`.

5.2.2   Command Topics

Command Topics are published by a TMS device when some action or device state change is required on another TMS device.   A TMS device receives a Command Topic by subscribing to specific topic names. Then, the receiving TMS device publishes a generic `CommandResponse` topic to report on the results of the specific Command Topic.   In addition to the generic `CommandResponse` the device will publish one or more additional Data Topics that report dependent device state changes.   Example Command topics are included in later sections.

6   DDS Publisher and Subscriber Implementation

This section outlines the basic steps a device role must follow to implement to publish or subscribe to a DDS topic.

6.1   Common Implementation Notes

IMPORTANT: Since DDS is inherently asynchronous, no assumptions can be made about the order different topics are received by a subscriber.

6.2   Domain Participant Implementation

A single DDS Domain Participant is required per TMS device.

Create a DDS Domain Participant with a configurable domain ID.   Recommendation is to make the domain ID runtime configurable to allow for flexibility during testing and deployment.

6.3   Publisher Implementation

A DDS publisher publishes to a topic with the following steps. In general the first four steps occur during device startup.   Only the last step is required to publish additional data for a specific topic.   These are the logical steps to publish a message, the actual required steps depend on the selected OMG DDS vendor.

a) Creates a DDS Publisher
b) Registers the IDL Data Type specified for the topic.
c) Creates a DDS Topic with the specified Topic Name and registered IDL Data Type.
d) Creates a DDS DataWriter for the specified IDL Data Type and QoS profile.   See Table 3 - QoS Settings Part 1 for details.
e) Invokes the write method on the DDS DataWriter with an instance of the IDL Data Type specified for the topic.

6.4 Subscriber Implementation

A DDS subscriber subscribes to a topic with the following steps. These steps are repeated for each subscriber topic a device role implements. These are the logical steps to subscribe to a topic, the actual required steps depend on the selected OMG DDS vendor.

a) Creates a DDS Subscriber
b) Registers the IDL Data Type specified for the topic.
c) Creates a DDS Topic with the specified Topic Name and registered IDL Data Type.
d) Creates a DDS DataReader for the specified IDL Data Type and QoS profile.
e) Either
    a. Invoke the read method on the DDS DataReader to poll for the subscribed data or
    b. Registers a DataReader listener to receive the subscribed data asynchronously.

6.5 DDS QoS Profiles

OMG DDS publishers and subscribers use Quality of Service (QoS) settings to control the behavior of individual topics. This section describes the QoS profiles used by TMS. Refer to the Topics Spreadsheet "QoS Profiles" tab for detailed settings.

6.5.1 Publish Last Profile

The `Publish Last` QoS profile is used by publisher rates "`Once`" and "`On Change`". This profile ensures that the order publishers and subscribes join the DDS domain does not impact the availability of the topic data. The last published data is cached inside the DDS middleware for re-publishing as needed. There are two possible cases;

1) Subscriber is running before the Publisher. In this case, when the publisher writes topic data, the subscriber is already running and receives the published data.
2) Publisher is running before the Subscriber. In this case, the subscriber starts after a publisher has written topic data. Using the `Publish Last` profile, the DDS middleware recognizes the new subscriber matches the published data and re-sends the cached last published topic data to the new subscriber. This behavior is transparent to the publishers reducing the complexity of application.

6.5.2 Rate Based Profiles

The next set of QoS profiles is used by all fixed rate publishers. That includes `Rare`, `Slow`, `Continuous`, and `Burst`. Since fixed rate publishers are expected to publish at a predetermined interval, the rate based profiles is used to trigger "liveliness" changes in the subscriber when the publishers fails to meet the predetermined interval. This liveliness trigger allows the subscriber to detect the missing time sensitive topic data and take appropriate actions.

6.5.3 Command Profile

The final QoS profile is the `Command` profile. This profile is used for all `Command Topics` described in section 5.2.2 Command Topics.

6.5.4 QoS Settings

The following two tables define the QoS settings by QoS Profile and Publisher Rate. These QoS settings must be specified for each DDS DataWriter and DataReader using the vendor specific technique. The QoS settings are specified using two tables for formatting purposes only.

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QoS Profile (Topic Name)	Publisher Rate	User Data value	History kind	depth	Liveliness kind	lease duration (seconds)
Publish Last (DeviceAnnoucement)	On change	Fingerprint[1]	KEEP_LAST	1	MANUAL BY TOPIC	3
Publish Last (All Other Topics)	On change	Fingerprint	KEEP_LAST	1	AUTOMATIC	INFINITE[2]
Rare	rate-1ks	Fingerprint	KEEP_LAST	1	AUTOMATIC	INFINITE
Slow	rate-10s	Fingerprint	KEEP_LAST	1	AUTOMATIC	INFINITE
Continuous	rate-01s	Fingerprint	KEEP_LAST	1	AUTOMATIC	INFINITE
Burst	rate-10s- burst	Fingerprint	KEEP_LAST	1	AUTOMATIC	INFINITE
Command	Command	Fingerprint	KEEP_LAST	1	AUTOMATIC	INFINITE
Response	Response	Fingerprint	KEEP_LAST	1	AUTOMATIC	INFINITE

Table 3 - QoS Settings Part 1

QoS Profile	Publisher Rate	Reliability kind	Durability kind	Deadline period (seconds)	Ownership kind	Resource Limits
Publish Last	On change	RELIABLE	TRANSIENT_LOCAL	INFINITE	EXCLUSIVE	None[3]
Rare	rate-1ks	BEST_EFFORT	VOLATILE	2000	EXCLUSIVE	None
Slow	rate-10s	BEST_EFFORT	VOLATILE	20	EXCLUSIVE	None
Continuous	rate-01s	BEST_EFFORT	VOLATILE	2	EXCLUSIVE	None
Burst	rate-10s- burst	BEST_EFFORT	VOLATILE	INFINITE	EXCLUSIVE	None
Command	Command	RELIABLE	VOLATILE	INFINITE	EXCLUSIVE	None
Response	Response	RELIABLE	VOLATILE	INFINITE	EXCLUSIVE	None

Table 4 - QoS Settings Part 2

6.5.5 Device Liveliness

6.6 Topic to Device Role Mapping

The following table provides a mapping from a TMS topic name to the device roles that publish or subscribe to each role.

NOTE: The topic names are included in the TMS IDL as constant strings named TOPIC_<topic name>.

Topic Name	MSM	MC	SRC	STOR	DIST	LOAD
ActiveDiagnostics	sub	pub/sub	pub	pub	pub	pub
ConfigReservationState	-	sub	pub	pub	pub	pub

---

[1] The 32 byte unique device ID.
[2] OMG DDS Vendor specific value for infinite number of seconds.
[3] Based on future performance testing, this is likely to change.

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CopyConfigRequest	-	pub	sub	sub	sub	sub
DeviceAnnouncement	pub/sub	pub/sub	pub/sub	pub/sub	pub/sub	pub/sub
DeviceClockStatus	pub/sub	pub/sub	pub	pub	pub	pub
DevicePowerMeasurementList	sub	sub	pub	pub	pub	pub
DevicePowerPortList	sub	sub	pub	pub	pub	pub
DevicePowerStatusList	sub	sub	pub	pub	pub	pub
DiscoveredConnectionList	-	sub	pub	pub	pub	pub
EngineState	sub	sub	pub	-	-	-
GetConfigContentsRequest	-	pub	sub	sub	sub	sub
GetConfigPowerSwitchResponse	-	sub	pub	pub	pub	pub
GetConfigPrimaryControlResponse	-	sub	pub	pub	-	-
GetConfigSecondaryControlResponse	-	sub	pub	pub	-	-
GetConfigSourceTransitionResponse	-	sub	pub	pub	-	-
MicrogridConnectionList	sub	pub	-	-	-	-
OperatorConnectionList	pub	sub	-	-	-	-
OperatorIntentRequest	pub	sub	-	-	-	-
OperatorIntentState	sub	pub	-	-	-	-
PowerSwitchRequest	-	pub	-	-	sub	-
PrimaryControlRequest	-	pub	sub	sub	-	-
ReleaseConfigRequest	-	pub	sub	sub	sub	sub
RequestResponse	sub	pub/sub	pub	pub	pub	pub
ReserveConfigReply	-	sub	pub	pub	pub	pub
ReserveConfigRequest	-	pub	sub	sub	sub	sub
SecondaryControlCapabilities	-	sub	pub	pub	-	-
SecondaryControlRequest	-	pub	sub	sub	-	-
SourceTransitionRequest	-	pub	sub	sub	-	-
SourceTransitionState	sub	sub	pub	pub	-	-
StandardConfigMaster	sub	sub	pub	pub	pub	pub

Table 5 - Topic Name to Device Roles

6.7   Topic to IDL Data Type

The following table defined the IDL data type and publisher rate for each of the TMS topic names.

Topic Name	IDL Data Type	Publisher Rate
ActiveDiagnostics	tms.ActiveDiagnosticMessages	On Change
ConfigReservationState	tms.ConfigReservationList	On Change
CopyConfigRequest	tms.CopyConfigRequest	Command
DeviceAnnouncement	tms.ProductInfo	Once
DeviceClockStatus	tms.ClockStatus	On Change
DevicePowerMeasurementList	tms.DevicePowerMeasurements	Continuous
DevicePowerPortList	tms.DevicePowerPortTypes	Once
DevicePowerStatusList	tms.DevicePowerPortStatuses	On Change
DiscoveredConnectionList	tms.PowerConnectionList	On Change

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EngineState	tms.EngineState	Slow
GetConfigContentsRequest	tms.GetConfigContentsRequest	Command
GetConfigPowerSwitchResponse	tms.PowerSwitchCommand	Response
GetConfigPrimaryControlResponse	tms.PrimaryControlRequest	Response
GetConfigSecondaryControlResponse	tms.SecondaryControlRequest	Response
GetConfigSourceTransitionResponse	tms.SourceTransitionRequest	Response
MicrogridConnectionList	tms.PowerConnectionList	On Change
OperatorConnectionList	tms.PowerConnectionList	On Change
OperatorIntentRequest	tms.OperatorIntentRequest	Command
OperatorIntentState	tms.OperatorIntentState	On Change
PowerSwitchRequest	tms.PowerSwitchCommand	Command
PrimaryControlRequest	tms.PrimaryControlRequest	Command
ReleaseConfigRequest	tms.ReleaseConfigRequest	Command
RequestResponse	tms.RequestResponse	Response
ReserveConfigReply	tms.ReserveConfigReply	Response
ReserveConfigRequest	tms.ReserveConfigRequest	Command
SecondaryControlCapabilities	tms.SecondaryControlCapabilities	Once
SecondaryControlRequest	tms.SecondaryControlRequest	Command
SourceTransitionRequest	tms.SourceTransitionRequest	Command
SourceTransitionState	tms.SourceTransitionState	On Change
StandardConfigMaster	tms.StandardConfigMaster	Slow

Table 6 Topic IDL Data Types

6.8   Device Role to Topic Mapping

The following table provides a mapping from the TMS Device Roles to the topics publish or subscribed to.   The table contains similar information to

ActiveDiagnostics	sub	pub/sub	pub	pub	pub	pub
ConfigReservationState	-	sub	pub	pub	pub	pub
CopyConfigRequest	-	pub	sub	sub	sub	sub
DeviceAnnouncement	pub/sub	pub/sub	pub/sub	pub/sub	pub/sub	pub/sub
DeviceClockStatus	pub/sub	pub/sub	pub	pub	pub	pub
DevicePowerMeasurementList	sub	sub	pub	pub	pub	pub
DevicePowerPortList	sub	sub	pub	pub	pub	pub
DevicePowerStatusList	sub	sub	pub	pub	pub	pub
DiscoveredConnectionList	-	sub	pub	pub	pub	pub
EngineState	sub	sub	pub	-	-	-
GetConfigContentsRequest	-	pub	sub	sub	sub	sub
GetConfigPowerSwitchResponse	-	sub	pub	pub	pub	pub
GetConfigPrimaryControlResponse	-	sub	pub	pub	-	-
GetConfigSecondaryControlResponse	-	sub	pub	pub	-	-
GetConfigSourceTransitionResponse	-	sub	pub	pub	-	-
MicrogridConnectionList	sub	pub	-	-	-	-
OperatorConnectionList	pub	sub	-	-	-	-

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OperatorIntentRequest	pub	sub	-	-	-	-
OperatorIntentState	sub	pub	-	-	-	-
PowerSwitchRequest	-	pub	-	-	sub	-
PrimaryControlRequest	-	pub	sub	sub	-	-
ReleaseConfigRequest	-	pub	sub	sub	sub	sub
RequestResponse	sub	pub/sub	pub	pub	pub	pub
ReserveConfigReply	-	sub	pub	pub	pub	pub
ReserveConfigRequest	-	pub	sub	sub	sub	sub
SecondaryControlCapabilities	-	sub	pub	pub	-	-
SecondaryControlRequest	-	pub	sub	sub	-	-
SourceTransitionRequest	-	pub	sub	sub	-	-
SourceTransitionState	sub	sub	pub	pub	-	-
StandardConfigMaster	sub	sub	pub	pub	pub	pub

Table 5 - Topic Name to Device Roles but is organized by device role.

Device Role	Pub/Sub	Topic Name
Distribution / DIST	pub	ActiveDiagnostics
	pub	ConfigReservationState
	pub	DeviceAnnouncement
	pub	DeviceClockStatus
	pub	DevicePowerMeasurementList
	pub	DevicePowerPortList
	pub	DevicePowerStatusList
	pub	DiscoveredConnectionList
	pub	GetConfigPowerSwitchResponse
	pub	RequestResponse
	pub	ReserveConfigReply
	pub	StandardConfigMaster
	sub	CopyConfigRequest
	sub	DeviceAnnouncement
	sub	GetConfigContentsRequest
	sub	PowerSwitchRequest
	sub	ReleaseConfigRequest
	sub	ReserveConfigRequest
Load / LOAD	pub	ActiveDiagnostics
	pub	ConfigReservationState
	pub	DeviceAnnouncement
	pub	DeviceClockStatus
	pub	DevicePowerMeasurementList
	pub	DevicePowerPortList
	pub	DevicePowerStatusList
	pub	DiscoveredConnectionList
	pub	GetConfigPowerSwitchResponse

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Device Role	Pub/Sub	Topic Name
	pub	RequestResponse
	pub	ReserveConfigReply
	pub	StandardConfigMaster
	sub	CopyConfigRequest
	sub	DeviceAnnouncement
	sub	GetConfigContentsRequest
	sub	ReleaseConfigRequest
	sub	ReserveConfigRequest
MicrogridController / MC	pub	ActiveDiagnostics
	pub	CopyConfigRequest
	pub	DeviceAnnouncement
	pub	DeviceClockStatus
	pub	GetConfigContentsRequest
	pub	MicrogridConnectionList
	pub	OperatorIntentState
	pub	PowerSwitchRequest
	pub	PrimaryControlRequest
	pub	ReleaseConfigRequest
	pub	RequestResponse
	pub	ReserveConfigRequest
	pub	SecondaryControlRequest
	pub	SourceTransitionRequest
	sub	ActiveDiagnostics
	sub	ConfigReservationState
	sub	DeviceAnnouncement
	sub	DeviceClockStatus
	sub	DevicePowerMeasurementList
	sub	DevicePowerPortList
	sub	DevicePowerStatusList
	sub	DiscoveredConnectionList
	sub	EngineState
	sub	GetConfigPowerSwitchResponse
	sub	GetConfigPrimaryControlResponse
	sub	GetConfigSecondaryControlResponse
	sub	GetConfigSourceTransitionResponse
	sub	OperatorConnectionList
	sub	OperatorIntentRequest
	sub	RequestResponse
	sub	ReserveConfigReply
	sub	SecondaryControlCapabilities
	sub	SourceTransitionState
	sub	StandardConfigMaster

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Device Role	Pub/Sub	Topic Name
MicrogridSystemManager / MSM	pub	DeviceAnnouncement
	pub	DeviceClockStatus
	pub	OperatorConnectionList
	pub	OperatorIntentRequest
	sub	ActiveDiagnostics
	sub	DeviceAnnouncement
	sub	DeviceClockStatus
	sub	DevicePowerMeasurementList
	sub	DevicePowerPortList
	sub	DevicePowerStatusList
	sub	EngineState
	sub	MicrogridConnectionList
	sub	OperatorIntentState
	sub	RequestResponse
	sub	SourceTransitionState
	sub	StandardConfigMaster
Source / SRC	pub	ActiveDiagnostics
	pub	ConfigReservationState
	pub	DeviceAnnouncement
	pub	DeviceClockStatus
	pub	DevicePowerMeasurementList
	pub	DevicePowerPortList
	pub	DevicePowerStatusList
	pub	DiscoveredConnectionList
	pub	EngineState
	pub	GetConfigPowerSwitchResponse
	pub	GetConfigPrimaryControlResponse
	pub	GetConfigSecondaryControlResponse
	pub	GetConfigSourceTransitionResponse
	pub	RequestResponse
	pub	ReserveConfigReply
	pub	SecondaryControlCapabilities
	pub	SourceTransitionState
	pub	StandardConfigMaster
	sub	CopyConfigRequest
	sub	DeviceAnnouncement
	sub	GetConfigContentsRequest
	sub	PrimaryControlRequest
	sub	ReleaseConfigRequest
	sub	ReserveConfigRequest
	sub	SecondaryControlRequest

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Device Role	Pub/Sub	Topic Name
	sub	SourceTransitionRequest
Storage / STOR	pub	ActiveDiagnostics
	pub	ConfigReservationState
	pub	DeviceAnnouncement
	pub	DeviceClockStatus
	pub	DevicePowerMeasurementList
	pub	DevicePowerPortList
	pub	DevicePowerStatusList
	pub	DiscoveredConnectionList
	pub	GetConfigPowerSwitchResponse
	pub	GetConfigPrimaryControlResponse
	pub	GetConfigSecondaryControlResponse
	pub	GetConfigSourceTransitionResponse
	pub	RequestResponse
	pub	ReserveConfigReply
	pub	SecondaryControlCapabilities
	pub	SourceTransitionState
	pub	StandardConfigMaster
	sub	CopyConfigRequest
	sub	DeviceAnnouncement
	sub	GetConfigContentsRequest
	sub	PrimaryControlRequest
	sub	ReleaseConfigRequest
	sub	ReserveConfigRequest
	sub	SecondaryControlRequest
	sub	SourceTransitionRequest

Table 7 - Device Role to Topics

7 TMS DDS Topic Flows

This section expands on the individual topics described in the previous section by outlining the sequence of steps involved in compound interactions between the various TMS device roles. It describes the relationships between when device roles are expected to publish or receive subscribed data for various scenarios supported by TMS.

Assumptions

1. Read is familiar with UML sequence diagrams. In the following illustration, the message name matches the TMS topic names. The class name matches a TMS device role.
2. All TMS devices are connected to the same communications network.

7.1 Device Discovery
The following sequence diagram illustrates the topics used during device discovery.
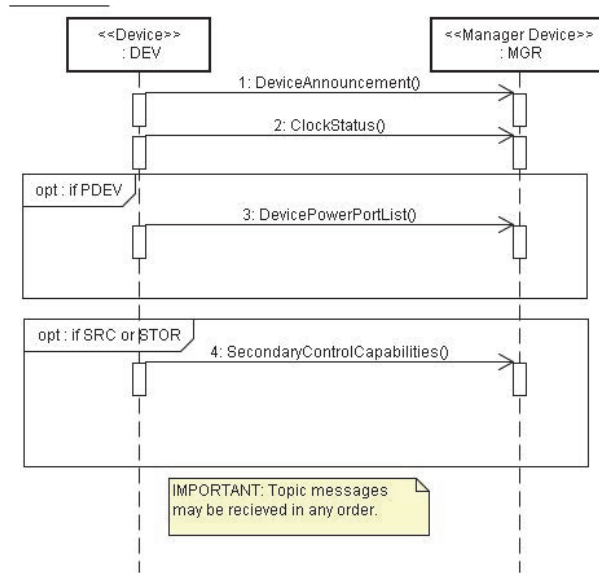
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Figure 5 - Device Discovery

7.2 Source Startup

The following sequence diagram illustrates the topics used by a SRC device during startup.
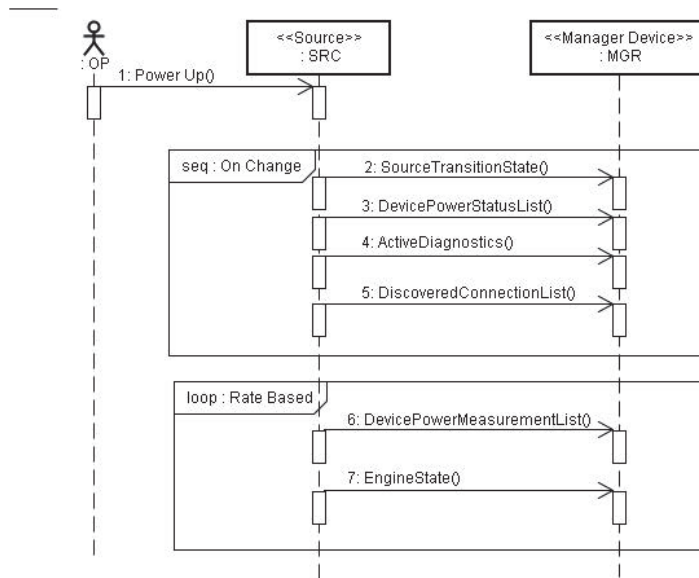
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Figure 6 - Source Startup

7.3 Topology Discovery

This following sequence diagram illustrates the topics exchanged during initial topology discovery. The topic flows can vary depending on the set of TMS device roles involved and the timing of device state changes.
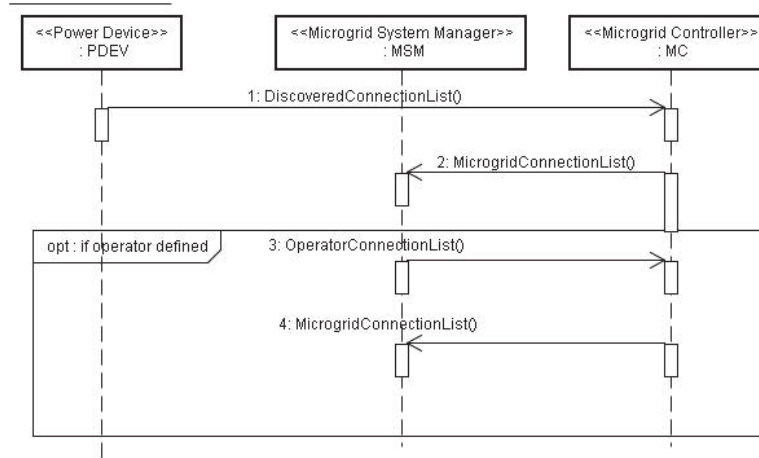
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Figure 7 - Topology Discovery

7.4 MSM Operator Intent

The following sequence diagram illustrates the steps required to create and active an Operator Intent. .
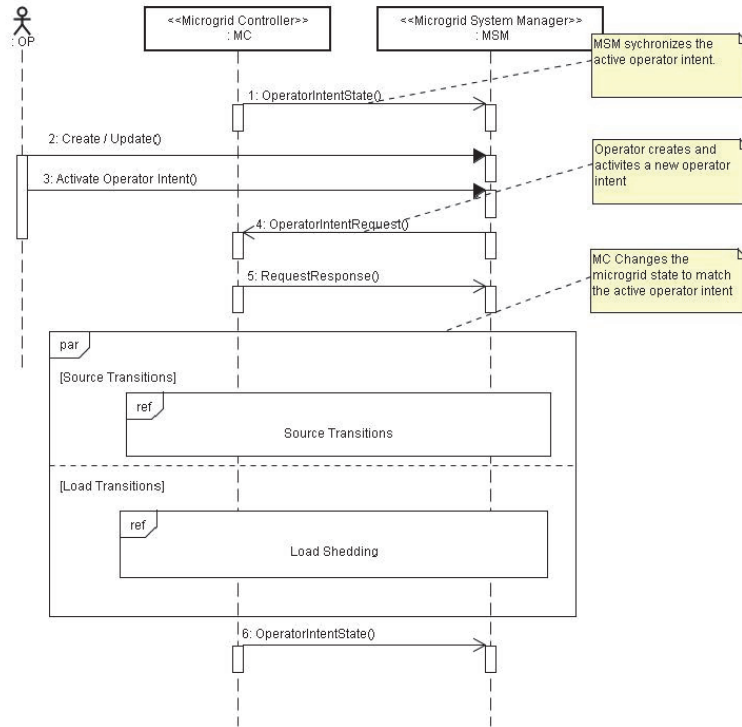
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Figure 8 – MSM Operator Intent

7.5 Microgrid Controller Source Transition

The following sequence diagram illustrates the topics exchanged when the MC decides to add or remove a SRC device from the current power sharing set of devices.

The following sequence assumes that device configuration ID (configId) is set to CONFIG_ACTIVE.
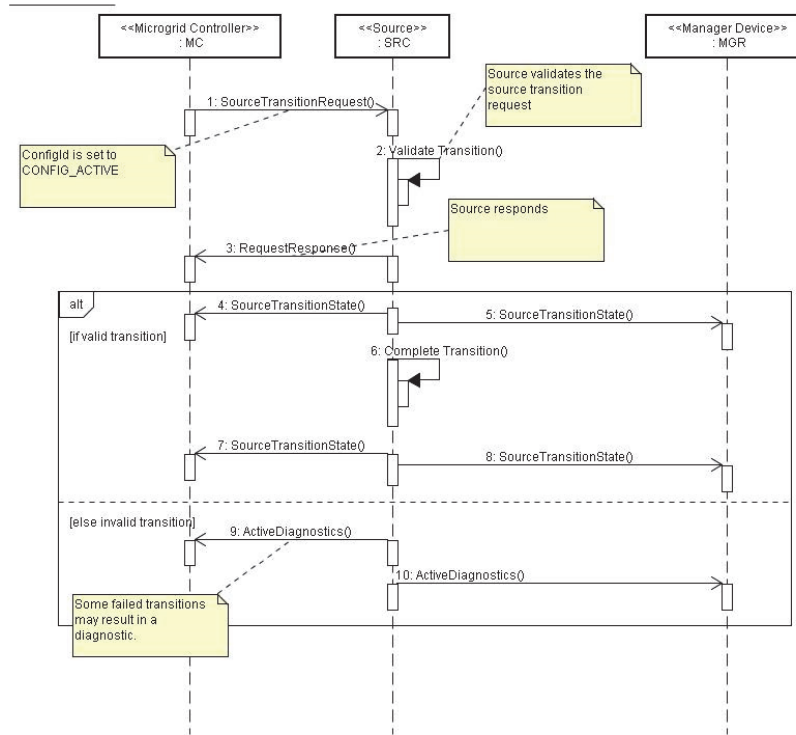
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Figure 9 - MC Source Transition

7.6 Microgrid Startup

The following sequence diagram illustrates initial microgrid startup.
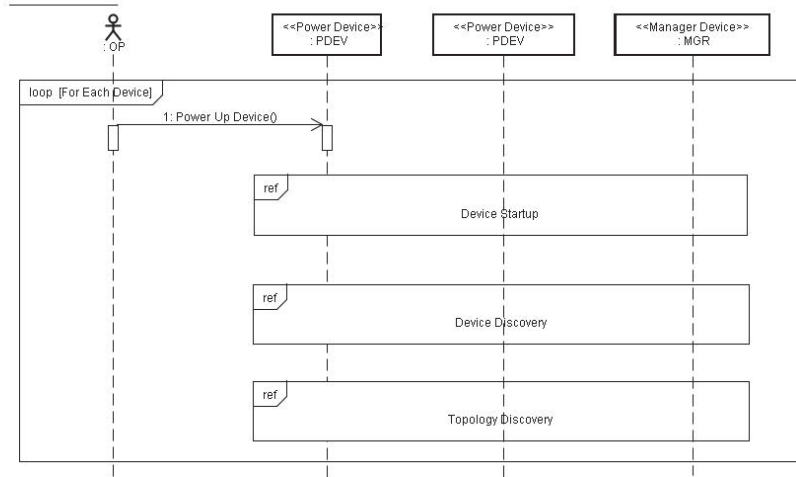
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Figure 10 - Microgrid Startup

7.7 Device Configurations

This section illustrates sequence diagrams related to device configurations.

7.7.1 Get Device Configuration Contents

The following sequence diagram illustrates the topics used by the MC to get the contents of a device configuration.
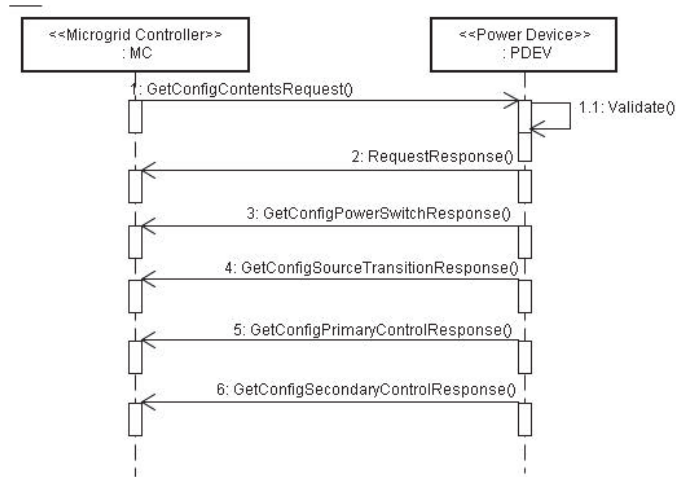
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Figure 11 - Get Configuration Contents

7.7.2 Reserve, Copy and Release

The following sequence diagram illustrates the topics used to reserve, copy, and release a device configuration.
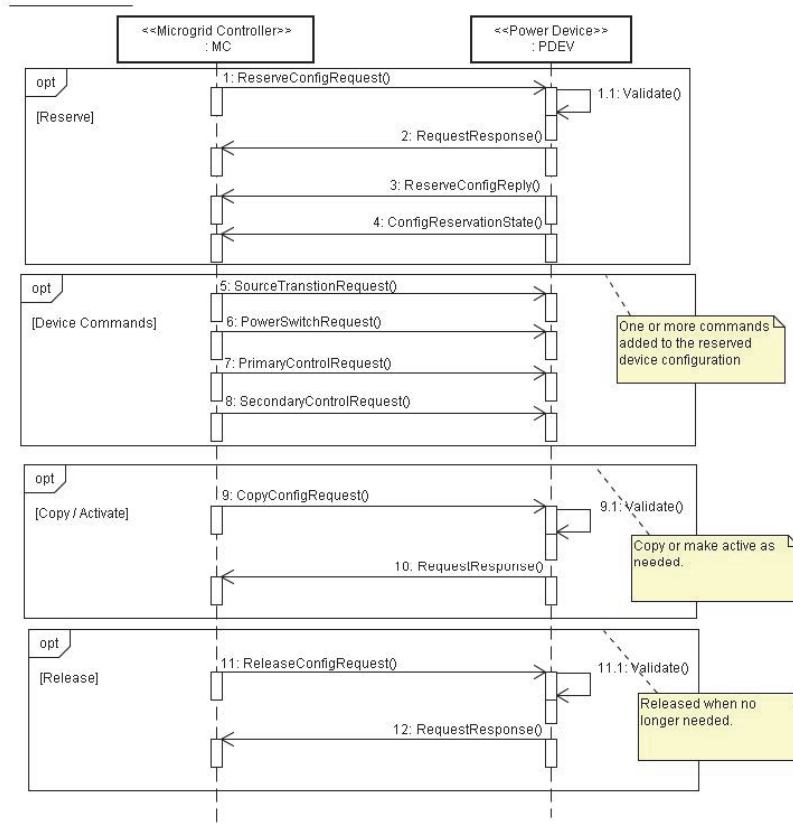
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Figure 12 - Reserve, Copy, Release Device Configurations

7.8   MC Election

The TMS allows for one or more MC's (Microgrid Controllers) to participate in a single microgrid.   The MC Election process is used to determine which MC is the elected "master" or Master Microgrid Controller (MMC).   See the Consensus Protocol section of the Data Model appendix for details on how an MMC is determined.

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8   TMS Development Considerations

8.1   OMG DDS Vendor Interoperability

This section covers OMG DDS vendor interoperability lessons learned by the TMSC team.   Refer to vendor specific documentation for additional details.

a) The tms.idl only defines bounded sequences and strings because RTI bindings do not currently support unbounded strings.

b) The RTI proprietary shared memory transport must be disabled on hosts that are running DDS domain participants from other vendors.   This is because RTI assumes all domain participants on the same host are RTI participants.

c) If using PrismTech, the following configuration must be enabled to interoperate with Twin Oaks.
`<ExplicitlyPublishQosSetToDefault>true</ExplicitlyPublishQosSetTo Default>`

d) Twin Oaks IDL compiler generated API includes a short and full data type name.   The full data type name must be used to interoperate with other DDS vendors.   An example of the full type name if "`tms.EngineState`"   where the IDL module name is prepended to the nested data type name.   The short data type name is just "`EngineState`".   The type name is used when creating a topic.

e) The QOS partition name defaults to different values across DDS vendors.   If the partition names do not match across two domain participants, the publishers and subscribers will not match resulting in no data being exchanged. The partition name should always be specified using the vendor specific method to avoid the default values not matching.

8.2   TMSC Tools

TMSC is planning to make the following tools available.

8.2.1   TMS Data Monitor (TDM)

The TMS Data Monitor subscribes to all TMS topics and displays a list of TMS devices (publishers) along with the published data.

The OMG DDS uses a binary data format so the TDM logs and displays the data as JSON.   The JSON representation follows the hierarchy defined in the IDL and includes the attributes names as they appear in the IDL.   Primitive attributes values (numeric, character, string, and boolean) are displayed in their natural format.   IDL enumeration values are represented as integer by DDS but the TDM includes the string name of the enumerator as it appears in the IDL.

8.2.2   EIO MSM (Future)

A TMS compliant implementation of the Microgrid System Manager (MSM) will be provided in the future by EIO to support development and testing of TMS devices. Energy Informed Operations (EIO) is a R&D project of the CERDEC Command, Power, and Integration (CP&I) Power Division.

8.3   Additional Tools

In addition to the TMSC provide tools, may other tools exist.   This section includes a sample used during TMS development.

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8.3.1 OMG DDS Vendors

Some OMG DDS vendors include tools to monitor DDS domain participants and topic data.

8.3.2 Wireshark

Wireshark includes plugins that decode the OMG DDS wire protocol.

Appendix T: Coritech Fast Charger Product Brochure

CORITECH VGI SERIES

Electric Vehicle DC V2G Fast Charger

BI-DIRECTIONAL

Provides DC fast charging and reverse power flow (V2G) capability for grid-tie applications to allow vehicles to act as power sources.

DC LEVEL 1 & 2 CHARGING

Coritech VGI Series chargers provide up to 30 kW (Level 2) charging with SAE J1772-CCS and CHAdeMO connectors. Maximum charging capacity of 60 kW is available with dual inverter and rated cable (See VGI-60 model).

V2G SUPPORT

VGI Chargers provide full communications capability for connectivity to Utility ISO's, Aggregators and Microgrid Controllers using high speed and secure Ethernet-Based protocols.

CORITECH VGI-30

- 200-600 Vdc, Plug-in Electric Vehicle Battery Charging

- SAE J1772 CCS Compliant for DC Level 1 and Level 2 Charging and * Reverse Power Flow. CHAdeMO option available

- Outdoor Weather Rated Type-3R Enclosure

- 480 Volt 3-Phase Grid Power Connection

- Volt/VAR Optimization (VVO) for grid stabilization and power factor correction

OVERVIEW

Plug-in electric vehicles are commercially available today with most vehicles having Level 1 and Level 2 AC charging capability only. AC charging requires on-board chargers within the vehicle to convert AC power to DC power, which the vehicle battery requires. The use of on-board chargers adds burden to the vehicles in the form of size, weight, cost and heat. In addition, AC charging at 240 Volts AC has limitations to the amount of power or Kilowatts that can be delivered to the vehicle. This limitation results in lengthy, undesirable charging times to "fill up" the vehicle's battery. DC Fast Charging is a method in which the charger is placed off-board and the AC power conversion to DC takes place within the external stationary charger thus reducing burden on the vehicle.

Coritech VGI Series DC Fast Chargers contain state-of-the-art power electronics (bi-directional inverters) which efficiently convert AC-to-DC power for charging and DC-to-AC for sending vehicle battery power to the utility grid for Vehicle-to-Grid (V2G) operation. The inverters are UL-Approved and meet UL-1741 requirements for utility connected power inverters. Coritech chargers provide many safety features including over-current protection, ground fault detection and emergency shutdown capability to assure safe and reliable fast charging of electric vehicles. An easy to use color touchscreen operator interface guides the user through a simple procedure to initiate each charging session.

CORITECH ◆ SERVICES

CORITECH VGI SERIES

Bi-Directional DC EV Charger Features

TECHNICAL SUPPORT

Coritech provides full technical support for all hardware and software. Chargers are all equipped with remote access support to allow dial-in diagnostics and troubleshooting support.

VEHICLE INTEGRATION

Coritech provides integration and engineering services and support to develop hardware and communications integration between the vehicle and charger. Coritech has developed a communications interface which conforms to SAE standards for electric vehicle charging including SAE J1772 and J2847 and ISO-15118.

TURNKEY SOLUTIONS

Coritech can provide a turnkey solution through their network of partners to supply infrastructure, vehicles, chargers and aggregator software and systems.

For more information on any of our products or services please visit us on the Web at:

AGGREGATOR CONTROL

Coritech chargers provide the ability for each vehicle's charging activity to be controlled from a remote grid "Aggregator" system which manages overall grid performance, health and stability. Aggregators also can communicate with local utility ISO's for participation in the energy markets.

FAST DC CHARGING

Coritech VGI Series chargers provide the fastest power transfer available today for DC charging, limited only by the maximum current capacity of the industry standard SAE J1772-CCS or CHAdeMO connector.

V2G – VEHICLE TO GRID

One of many benefits to owning electric vehicles is to have the ability to use the vehicle as an additional energy source when not in use. Electric vehicles contain large batteries which store significant amounts of energy. This energy can be used to provide power back to the utility AC power grid for many benefits such as offsetting power demand, reducing peak demand charges, stabilizing the grid during power outages and high demand periods.

VVO – VOLT VAR OPTIMIZATION

Coritech chargers provide the ability to influence the stability of the grid by providing VVO to contribute or absorb reactive power (kVAR) to influence the grid power factor.

Technical Specifications

- Utility Grid Connection: 480 Vac, 3 Phase, 44A Max.
- Vehicle Connection: SAE J1772-Combo CCS or CHAdeMO
- Aggregator Connection: Ethernet, Modbus TCP/IP, SEP 2.0
- Dimensions: 36 x 24 x 81 inches
- Weight: 400 lbs Approx.
- Volt/VAR Optimization: -18 to +18 kVAR
- Battery Voltage Range: 200-600 Vdc
- Battery Charging Power*: 30 kW 60A Max
- Reverse Power Flow V2G*: 30 kW 60A Max
- Operator Interface: 7" Color Touchscreen
- Environmental:
  - Enclosure: Outdoor Rated Type 3R
  - Operating Temp: -20 to +120 Degrees Fahrenheit
  - Humidity: 0-95%
- Safety: Over-Current Circuit Breaker, GFCI, DC Isolation
- Emergency Shutdown Pushbutton

SERVICES AVAILABLE

Technical Support
Installation and Setup
Maintenance
Application Support
Hardware Support
Guaranteed Warranty

Certifications and Standards

- UL1741, IEEE1547a, IEC62109-1,2
- UL2202, UL2231-1, UL2231-2

CORITECH
SERVICES

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Royal Oak, MI 48073
Phone 248.549.3300
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* Technical specifications shown for VGI-30 Model. Power limits are based on individual vehicle battery voltage range, to utilize full 30kW capacity of the charger the battery voltage must be greater than approx. 500Vdc. Digital communications between vehicle and charger assures that power transfer is always within safe operating limits of both charger and vehicle.

Appendix U: Coritech Fast Charger User Manual

EV FAST CHARGER
VGI-30-DC-CHA User Manual

Discover the future, today.

2019 Revision 1

Table of Contents

Important Safety Instructions

Carefully read the following instructions along with charging instructions in your vehicle owner's manual prior to operating this charger with your electric vehicle.

OPERATING SAFETY GUIDELINES

⚠ **Warning**—Use this charger to charge electric vehicles equipped with a CHAdeMO charge port only.

⚠ **Warning**—Make certain that the charging cable is positioned so it will not be stepped on, tripped over or otherwise subjected to damage or stress.

⚠ **Warning**—Do not operate the charger with any visible damage to the cable or enclosure/pedestal. Contact Coritech Services immediately for service.

⚠ **Warning**—This device should be supervised when used around children.

⚠ **Warning**—Do not put fingers into the electric vehicle connector.

ADDITIONAL SAFETY GUIDELINES

⚠ **Danger**—To avoid an electric shock during servicing, verify that the charger's external AC and DC Disconnects are open (off). A minimum wait time of five (5) minutes is required after both AC and DC Disconnects remain in the off position during all service periods.

⚠ **Danger**—The enclosure contains exposed high voltage conductors. The enclosure access doors must remain closed, except during installation, commissioning, or maintenance by trained service personnel. Do not open enclosure doors if extreme moisture is present (rain, snow, or heavy dew).

⚠ **Danger**—Ensure that the equipment is adequately installed and grounded per this manual and all applicable codes.

⚠ **Danger**—Do not leave foreign objects in the charger enclosure. Keep the area around the enclosure clear of trash, debris, and other combustible materials.

⚠ **Warning**—Personnel Qualification: Inspections and operations requiring access to lethal AC or DC voltages should only be performed by qualified personnel.

⚠ **Warning**—All field wiring must conform to the codes set forth in the National Electric Code ANSI/NFPA 70, and/or applicable codes per Authority Having Jurisdiction (AHJ).

⚠ **Warning**—The charger contains ESD-sensitive equipment. Failure to use ESD control measures while servicing the equipment may result in component damage and void the warranty.

⚠ **Warning**—The VGI-30-DC-CHA charging station weighs approximately 400 pounds. Follow all safety rules when transporting or installing. Failure to do so could result in personal injury or equipment damage.

<div style="background:gray;">

Introduction

</div>

The Coritech VGI-30-DC-CHA Charger provides enhanced fast V2G charging capability to electric vehicles equipped for DC Fast Charging, in compliance with CHAdeMO version 1.2 and V2H Guideline 2.1 standards.

OVERVIEW

Most commercially available plug-in electric vehicle chargers require on-board chargers within the vehicle to convert AC power to DC power. The use of on-board chargers adds a burden to the vehicles in the form of size, weight, cost and heat. In addition, AC-charging at 120/208/240 Volts AC limits the amount of power that can be delivered to the vehicle. This limitation results in lengthy, undesirable charging times to "fill up" the vehicle's battery. DC Fast Charging is a method in which the charger is placed off-board (external to vehicle), and the AC power conversion to DC takes place within the external charger, thus reducing burden on the vehicle.

Coritech VGI Series DC Fast Chargers contain state-of-the-art power electronics (galvanically isolated bi-directional inverters) which efficiently convert AC-to-DC power for charging, and DC-to-AC for sending vehicle battery power to the utility grid for Vehicle-to-Grid (V2G) operation. The inverters

are UL-Approved, meeting UL-1741 requirements for utility-connected power inverters. Coritech chargers provide many safety features including over-current protection, ground fault detection and emergency shutdown capability to assure safe and reliable fast charging of electric vehicles. An easy- to-use color touchscreen operator interface guides the user through a simple procedure to initiate each charging session.

FEATURES

- 100Vdc–500Vdc, Plug-in Electric Vehicle Battery Charging

- Outdoor Weather-Rated Type-3R Enclosure

- 480 Volt 3 Phase AC Grid Power Connection

- Volt/VAR Optimization (VVO) for grid stabilization and power factor correction

OFF-BOARD AC TO DC CONVERSION
Externalizes power electronics for vastly more efficient charging.

BI-DIRECTIONAL
Provides DC fast charging and reverse power flow (V2G) capability for grid-tie applications to allow vehicles to act as power sources.

V2G SUPPORT
Provides full communications capability for connectivity to Energy Management Servers (EMS), and Utility ISOs.

V2G Smart Grid Operation

V2G Technology

This charger has the ability to provide automated V2G Smart Grid operation with an external Energy Management Server (EMS). The EMS can be used for:

- **Microgrid Management:** Manage overall grid performance, health and stability. Vehicle charge rates can be optimized for maximum charge efficiency with multiple vehicle types, and adapt to situations in a complex environment including vehicle charging clients, a solar photovoltaic array, battery storage system, and communications with local utility Independent System Operators (ISOs).

- **V2G (Vehicle to Grid):** An EMS can communicate with local utility ISOs for participation in the energy markets. One of many benefits of owning an electric vehicle is the ability to use the vehicle as an additional energy source when not in use. Analogous to distributed computing, the energy stored in an electric vehicle can be used to provide power back to the utility AC power grid for many benefits such as offsetting power demand, reducing peak demand charges, and stabilizing the grid during power outages and high demand periods.

- **VVO (Volt Var Optimization):** Coritech chargers provide the ability to influence the stability of the grid by providing VVO, which changes grid power factor by contributing or absorbing reactive power (kVAR).

If no EMS is integrated with the charger, then the station will charge at the rate requested by the vehicle. If an EMS is present, *vehicles that do not support V2G* will still charge at EMS-controlled rates, but be unable to discharge. Please contact Coritech Services to determine if a particular vehicle is capable of V2G Smart Grid operation with this charger.
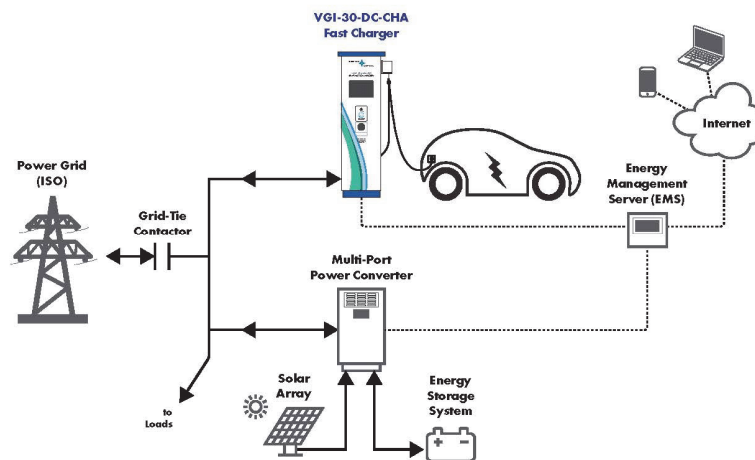
Specifications

- Util. Grid Connection: 480Vac, 3Ph, 47A Max.
- Real Power: 30kW*
- Volt/VAR Optimization: -18kVAR–18kVAR
- Vehicle Voltage Range: 100Vdc–500Vdc
- Vehicle Charging Power†: 30 kW 60Adc Max
- Reverse Power Flow V2G†: 30 kW 60Adc Max
- Enclosure: Outdoor-Rated, Type 3R
- Operating Temp: -20°F–120°F
- Dimensions: 41" x 26" x 81.75"
- Base Dimensions: 33" x 21"

- Weight: 400 lbs Approx.
- Humidity: 0–95%
- Operator Interface: 10" Color Touchscreen
- Vehicle Connection: DC Charging Connector conforming to CHAdeMO 0.9, 1.0 specifications
- Energy Management Server (ESM) Connection: Ethernet, Modbus TCP/IP, SEP 2.0, MQTT
- Safety: Over-Current Circuit Breaker, GFCI, DC Isolation, Emergency Shutdown Pushbutton

The VGI-30-DC-CHA is a 30kW model, but can be configured for lower power levels (for example: CHA-10K for 10kW), or other custom real and reactive power combinations.

† Technical specifications shown for VGI-30 Model. Power limits are based on individual vehicle battery voltage range; to utilize full 30kW capacity of the charger the battery voltage must be approx. 500Vdc. Digital communications between vehicle and charger assures that power transfer is always within safe operating limits of both charger and vehicle.

CERTIFICATIONS AND STANDARDS

- CHAdeMO 1.2, V2H Guideline 2.1
- UL1741, IEEE1547a, IEC62109-1,2
- UL2202, UL2231-1, UL2231-2

- CSA SPE-1000-13,
  CSA C22.2 N.107.1-16,
  CSA C22.2 N.281.1-12,
  CSA C22.2 N.281.2-12

Components

1. Outdoor-Rated, Type 3R Enclosure
Rugged indoor/outdoor enclosure provides protection to personnel against access to hazardous parts; also provides protection against rain/sleet/snow.

2. Operating Screen
10" touchscreen for display of charge session data.

3. Charging Connector
(CHAdeMO Charge Connector) Charge connector with cable that extends up to 18 feet.

4. Cable Retractor
Spring-loaded cable reel retracts charge cable back up for next use.

5. Top Access Panel
Contains control components for the unit.

⚠ **Warning**—only qualified, trained personnel should open this panel. This panel contains elements which could present electrically dangerous hazards.

6. Emergency Stop Button
Pressing will interrupt current charging session and all high power will be terminated.

7. Lower Access Panel
Contains a galvanically isolated bi-directional inverter and installation connections (480Vac and high-voltage DC).

⚠ **Warning**—only qualified, trained personnel should open this panel. This panel contains elements which could present electrically dangerous hazards.

CORITECH
SERVICES

Operation

BEGINNING A CHARGING SESSION

1. Press the release button on the top of the charge connector handle to release.

2. Insert the charge connector into the vehicle charging port. The connector will lock into place. On the screen, press the **Start** button.

3. The Overview screen on the charger will change to reflect that a new charging session has been initiated. Parameters will be exchanged with the vehicle and a cable check will be performed. After safety checks, contactors will close and vehicle charging will be underway.
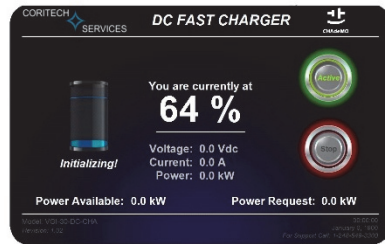
During a charge, the charge connector will not unlock by pressing the release button. It can only be removed after the session has been ended either manually or automatically.

MANUALLY ENDING A CHARGING SESSION

To manually end a charging session before charging has completed, press the Stop Charge Button on the display screen. In an emergency, press the red Emergency Stop Button on the left side of the charger.

AUTOMATICALLY ENDING A CHARGING SESSION

1. The charging session will complete automatically once SOC (State of Charge) has reached 100%, which is shown on the Overview screen. At this moment, the charger will cease charging the vehicle, the connector will unlock, and the screen's status message will go blank.

2. Return the charge connector to the holster socket on the charger.

Using the Touchscreen

OVERVIEW SCREEN

The Overview Screen automatically opens when a charging session is underway. This screen displays all relevant values to the charging session: progress of vehicle State of Charge, voltage, current, power, and EMS Power Request. The operator can manually end the session at any time or view faults.
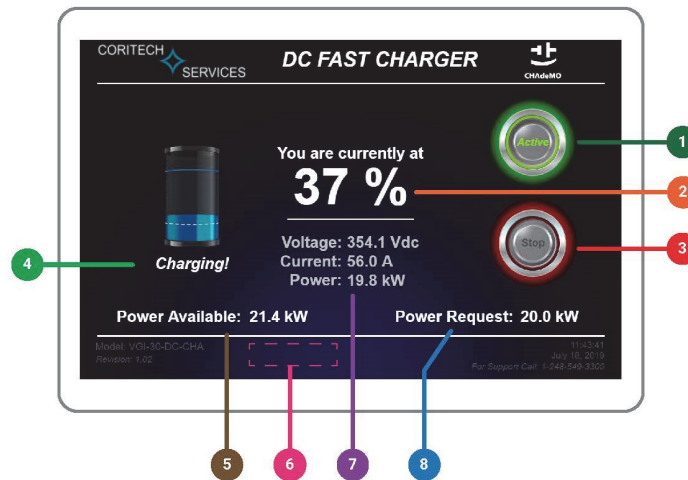
1. START CHARGE
Pressing this button will initiate a new charging session.

2. STATE OF CHARGE INDICATOR
Vehicle battery State of Charge (SOC). When the SOC reaches 100%, the charge session will end.

3. STOP CHARGE
Pressing this button will immediately end the active charging session.

4. STATUS MESSAGE
Displays one of the four active modes: Initializing, Charging, Discharging and Idle. When no car is connected, the status message area is blank.

5. POWER AVAILABLE
Displays the vehicle-determined amount of power that can be drawn from the vehicle.

6. ALARMS AND STATUSES DISPLAY AREA
Any alarms or status reports are displayed at the bottom of the screen; multiple items will form a list that cycles through its members.

7. CHARGER VOLTAGE, CURRENT, POWER
Voltage, current and power for the charging session.

8. CHARGER POWER REQUEST
This is determined by the Energy Management Server (EMS), which coordinates its determination with the vehicle.

Charger Mounting

INSTALLATION CONSIDERATIONS

The VGI-30-DC-CHA Charger is a stand-alone pedestal design intended to be mounted to a concrete pad with conduit connection for wiring through the bottom of the enclosure. See drawings for base mounting-hole dimensions and fastener instructions. The base has two pockets for lifting by forklift, 2.88" x 7.75" each.

Approximate weight: 400 lbs.
Required area to be kept clear around unit: 30" minimum

Clearance in base for conduit

~400 lbs.

VGI-30-DC-CHA Base

Stud anchor for concrete
1/2"-13 Stainless Steel

0.750"
minimum

Electrical Connections

The VGI-30-DC-CHA Charger has electrical connections for the electrical service, neutral deriving transformer circuit breaker status, and connections to a Grid Interface Connection Box (GICB). All electrical connections to the charger are located in the lower enclosure.

The VGI-30-DC-CHA Charger is a three-phase 480 Vac power device. It requires a 3-wire electrical service (no neutral connection), as all power is made between phase legs. **The VGI-30-DC-CHA must be installed with external 3-wire AC circuit protection rated at 480Vac, sized in accordance with local electrical codes. Likewise, the gauge of the wire must be sized in accordance with NEC ANSI/NFPA 70, and/or applicable codes per AHJ.**

This product must be connected to a grounded, metal, permanent wiring system, or an equipment- grounding conductor must be run with the circuit conductors and connected to either the equipment-grounding terminal or lead on the product.

⚠️ *WARNING: Do not connect to a three-phase 480Vac floating delta electrical service. If service is floating delta, a neutral deriving transformer ("zigzag") must be used to anchor each phase in reference to ground. Contact Coritech Services support if your electrical service is floating.*

Left view

1. AC Power Connections (Electrical Service)
L1, L2, L3: 480 Vac

2. Main Ground Lug (Electrical Service)
Equipment ground connection.
Caution: proper ground connection must be installed per National Electric Code ANSI/NFPA 70, and/or applicable codes per AHJ.

3. Jumper
Between 7361 and 7370
If neutral deriving transformer is being used, this jumper must be removed.

4. DC Power and Control
Neutral Deriving Transformer
7361: zigzag breaker status
7370: zigzag breaker status
GICB (Grid Interface Connection Box)
7470: island acknowledge
7480: island acknowledge return
7490: island command return
7500: island command

CORITECH
SERVICES

<div style="background: gray; padding: 1em;">

Maintenance
</div>

ENCLOSURE FAN FILTER MAINTENANCE

There are three fan filters inside the unit that protect components from particulate buildup. Once per year, these filters should be removed and cleaned.

⚠ **Warning: only qualified, trained personnel should open this panel. This panel contains elements which could present electrically dangerous hazards.**

2. INVERTER FAN FILTER
This filter is located beneath the inverter in the bottom cabinet. It is accessed by unscrewing one knob.

⚠ **Danger**—To avoid an electric shock during servicing, verify that the charger's external AC and DC Disconnects are open (off). A minimum wait time of five (5) minutes is required after both AC and DC Disconnects remain in the off position during all service periods.

⚠ **Danger**—The enclosure contains exposed high voltage conductors. The enclosure access doors must remain closed, except during installation, commissioning, or maintenance by trained service personnel. Do not open enclosure doors if extreme moisture is present (rain, snow, or heavy dew).

⚠ **Warning**—Personnel Qualification: Inspections and operations requiring access to lethal AC or DC voltages should only be performed by qualified personnel.

1. UPPER CABINET CIRCULATION EXHAUST AND FAN INLET FILTERS
These filters clean inlet air and exhaust air from the upper cabinet; both are located in the upper cabinet's ceiling. They are accessed by opening the upper cabinet and sliding the filters in or out.

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Appendix V: Coritech Fast Charger Memory Map

Coritech VGI System ModBus TCP Interface
V1.00
1/2/2020

Customer:

Notes:
- Energy Management Server (EMS) is the Modbus master
- VGI System is a Modbus slave
- Both master and slave have a heartbeat used to determine communication status.
- Initial communications are established by the EMS periodically polling for the slave.
- If EMS heartbeat remains static for TBD time all commands will be ignored.
- Default IP adresses are 192.168.0.10 for the VGI EVSE and 192.168.0.250 for the EMS. Port is 610. Unit identifier is 0xFF. IP addresses TBD by customer

Write Registers
These registers are written to by the EMS providing status and control to the VGI EVSE.

Begin Register Tables

Variable	Modbus Register	Bit Offset	Value Type	MIN	MAX	FACTOR	Number of Bits	Unit	Value Table	Enumeration	Update Time	Access Permissions	Comment
EMS_Heartbeat	32400	0	Unsigned Integer	0.0	255.0	1.000	8	NA	NA	0xFF	1000ms	w	Increments by 1 every 1000ms. The intent of the heartbeat is to determine if the EMS is active or not, if the heartbeat remains static for the set time (EMS_Control_CommLossDelay) it is determine the EMS is not active.
EMS_SystemStatus	32400	8	Unsigned Integer	0.0	255.0	1.000	8	NA	Status	0xFF		w	
EMS_Control_CommLossDelay	32402	0	Unsigned Integer	0.0	65535.0	1.000	16	Seconds	NA	0xFFFF		w	Time the EMS_Heartbeat may remain static before determining loss of EMS communications. Set to 65534 to disable.
EMS_EVPowerCmd	32404	0	Signed Integer	-30000.0	30000.0	1.000	16	Watts	NA	0x7FFF		w	Power Command to charge (positive value) or discharge (negative value)
EMS_EVMaxSOCSetpointCmd	32410	0	Unsigned Integer	0.0	100.0	1.000	8	%	NA	0xFF		w	This is a State of Charge max setpoint command, the EVSE will not a charge above the setpoint. This is useful to prevent the vehicle from terminating the charge session when reaching 100% SOC.
EMS_EVMinSOCSetpointCmd	32411	0	Unsigned Integer	0.0	100.0	1.000	8	%	NA	0xFF		w	This is a State of Charge min setpoint command, the EVSE will not a discharge below the setpoint.

End Register Tables

Read Only

Begin Register Tables — These registers are read by the EMS for VGI System status.

Variable	Modbus Regist	Bit Offset	Value Type	MIN	MAX	FACTOR	Number of Bits	Unit	Value Table	Error Enumeration Value	Update Time	Access Permissions	Comment
VGI_Heartbeat	40400	0	Unsigned Integer	0.0	255.0	1.000	8	NA	NA	0xFF		r	Increments by 1 every 10ms
VGI_SystemStatus	40400	8	Unsigned Integer	0.0	255.0	1.000	8	NA	Status	0xFF		r	Startup - EVSE startup delay active / OK - No error(s)/fault(s) active / Error - error(s)/fault(s) active
VGI_CommLossDelay	40402	0	Unsigned Integer	0.0	65535.0	1.000	16	Seconds	NA	0xFFFF		r	Current setting of the comm loss delay. If 65534 comm loss delay disabled.
VGI_EVPowerCmd	40403	0	Signed Integer	-32000.0	30000.0	1.000	16	Watts	NA	0x7FFF		r	Current setting of the EV power command
VGI_EVMaxSOCSetpointCmd	40409	0	Unsigned Integer	0.0	100.0	1.000	8	%	NA	0xFF		r	Current setting of the EV Max SOC command
VGI_EVMinSOCSetpointCmd	40409	8	Unsigned Integer	0.0	100.0	1.000	8	%	NA	0xFF		r	Current setting of the EV Min SOC command
VGI_ACPort_LineVoltageAvg	40200	0	Unsigned Integer	-	-	1.000	32	Volts	NA	0xFFFFFFFF		r	
VGI_ACPort_PhaseCurrentAvg	40202	0	Unsigned Integer	-	-	0.1000	32	Amps	NA	0xFFFFFFFF		r	
VGI_ACPort_RealPowerSum	40204	0	Signed Integer	-	-	1.000	32	Watts	NA	0xFFFFFFFF		r	
VGI_ACPort_ReactivePowerSum	40206	0	Signed Integer	-	-	1.000	32	Vars	NA	0xFFFFFFFF		r	
VGI_ACPort_ApparentPowerSum	40208	0	Unsigned Integer	-	-	1.000	32	VAs	NA	0xFFFFFFFF		r	
VGI_ACPort_LineFrequency	40210	0	Unsigned Integer	-	-	0.001	32	Hz	NA	0xFFFFFFFF		r	
VGI_ACPort_VoltagePhaseA	40212	0	Unsigned Integer	-	-	1.000	32	Volts	NA	0xFFFFFFFF		r	
VGI_ACPort_VoltagePhaseB	40214	0	Unsigned Integer	-	-	1.000	32	Volts	NA	0xFFFFFFFF		r	
VGI_ACPort_VoltagePhaseC	40216	0	Unsigned Integer	-	-	1.000	32	Volts	NA	0xFFFFFFFF		r	
VGI_ACPort_CurrentPhaseA	40218	0	Unsigned Integer	-	-	0.1000	32	Amps	NA	0xFFFFFFFF		r	
VGI_ACPort_CurrentPhaseB	40220	0	Unsigned Integer	-	-	0.1000	32	Amps	NA	0xFFFFFFFF		r	
VGI_ACPort_CurrentPhaseC	40222	0	Unsigned Integer	-	-	0.1000	32	Amps	NA	0xFFFFFFFF		r	
VGI_EVBatt_Voltage	40260	0	Unsigned Integer	-	-	1.000	32	dcVolts	NA	0xFFFFFFFF		r	
VGI_EVBatt_Current	40262	0	Signed Integer	-	-	0.1000	32	dcAmps	NA	0xFFFFFFFF		r	
VGI_EVBatt_Power	40264	0	Signed Integer	-	-	1.000	32	dcWatts	NA	0xFFFFFFFF		r	
VGI_EVBatt_MaxDischargePower	40266	0	Signed Integer	-	-	1.000	32	dcWatts	NA	0xFFFFFFFF		r	Max Discharge power determined by the vehicle
VGI_EVBatt_MaxChargePower	40268	0	Signed Integer	-	-	1.000	32	dcWatts	NA	0xFFFFFFFF		r	Max Charge power determined by the vehicle
VGI_EVBatt_BatteryStatus	40270	0	Signed Integer	-	-	1.000	8	NA	Status	0xFFFFFFFF		r	NA - Vehicle Disconnected / Startup - Vehicle connected and charge session begun / OK - Vehicle ready for charge/discharge / Error - Charge session terminated due to error/fault / Shutdown - Charge session terminated/shutdown
VGI_EVMaxSOCSetpoint	40272	0	Unsigned Integer	0.0	100.0	1.000	8	%	NA	0xFF		r	
VGI_EVMinSOCSetpoint	40272	8	Unsigned Integer	0.0	100.0	1.000	8	%	NA	0xFF		r	
VGI_EVSOC	40273	0	Unsigned Integer	0.0	100.0	1.000	8	%	NA	0xFF		r	Actual SOC reported by the vehicle.
VGI_EVBatt_PowerDirection	40274	0	Unsigned Integer	-	-	1.000	8	NA	Power	0xFF			

Begin Value Tables

Value Table	Enumeration Value	Description
Status	0x0	NA
Status	0x1	Startup
Status	0x2	OK
Status	0x3	Error
Status	0x4	OK - Local
Status	0x5	OK - Remote
Status	0x6	Shutdown
PowerDirection	0x0	NA
PowerDirection	0x1	In
PowerDirection	0x2	Out

End Value Tables

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The objective of the Autonomous Transport Innovation (ATI) technical research program is to investigate current gaps and challenges and develop solutions to integrate emerging electric transport vehicles, vehicle autonomy, vehicle-to-grid (V2G) charging and microgrid technologies with military legacy equipment. The ATI research area objectives are to: identify unique military requirements for autonomous transportation technologies; identify currently available technologies that can be adopted for military applications and validate the suitability of these technologies to close need gaps; identify research and operational tests for autonomous transport vehicles; investigate requirements for testing and demonstrating of bidirectional-vehicle charging within a tactical environment; develop requirements for a sensored, living laboratory that will be used to assess the performance of autonomous innovations; and integrate open standards to promote interoperability and broad-platform compatibility. This final report summarizes the team's research, which resulted in an approach to develop a sensored, living laboratory with operational testing capability to assess the safety, utility, interoperability, and resiliency of autonomous electric transport and V2G technologies in a tactical microgrid. The living laboratory will support research and assessment of emerging technologies and determine the prospect for implementation in defense transport operations and contingency base energy resilience.

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