



*Off-Road Advanced Technology Demonstration Projects*

# San Joaquin Valley Zero-Emission Cargo Handling Demonstration Project

## Final Report



July 01, 2021

## Acknowledgements

The San Joaquin Valley Air Pollution Control District (District) would like to express its gratitude and appreciation to the California Air Resources Board (CARB) for enabling the District to apply for much needed funding on behalf of San Joaquin Valley (Valley) projects that may have not otherwise been afforded the opportunity to demonstrate advanced technology equipment. The funding provided to the San Joaquin Valley Zero-Emission Cargo Handling Demonstration Project (Project) from CARB has allowed the Port of Stockton (Port) to introduce its first heavy-duty electric off-road equipment and amass enough resources to invest in new advanced clean technology that the Port has been yearning to explore. The two zero-emission battery electric heavy-duty forklifts provided through this Project has also given the Port the necessary foundation to expand the deployment of similar equipment and technology in the future. The Valley has unique needs and challenges compared to other regions and metropolitan areas throughout the State, and with CARB's support, the Valley will continue to make great strides in reducing both greenhouse gas emissions and criteria pollutants by continuing to support agencies with the deployment of the cleanest and most advanced technologies available. The District and our project partners are sincerely appreciative of CARB's selection of this Project.

The District would also like to recognize the following agencies and companies for their participation in the Project and significant contributions to the creation of this report. This project could not have been successfully completed without the full commitment and investment of these organizations. Their contributions to this Project will provide valuable insight and perspective for other agencies interested in the deployment of off-road electric equipment technology.

- ❖ Port of Stockton
- ❖ DD DANNAR, LLC.
- ❖ ChargePoint, Inc.
- ❖ carbonBLU



**Port of Stockton**  
CALIFORNIA

**DANNAR**

**-chargepoint+**



## Preface

In 2007, the California Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007 (AB 118, Statutes of 2007, Chapter 750) was signed into law. AB 118 created AQIP, a voluntary incentive program administered by California Air Resources Board (CARB), to fund clean vehicle and equipment projects, air quality research and workforce training. As required in Health and Safety Code (HSC) Section 44274(a), the Board adopted regulatory guidelines in 2009 for AQIP. The Guidelines for the AB 118 Air Quality Improvement Program (Guidelines)<sup>1</sup> define the overall administrative requirements and policies and procedures for program implementation based on the framework established in statute. Central to the Guidelines is the requirement for a Board-approved annual funding plan developed with public input. The funding plan is each year's blueprint for expending AQIP funds appropriated to CARB in the annual State Budget. The funding plan focuses AQIP on supporting development and deployment of the advanced technologies needed to meet California's longer-term, post- 2020 air quality goals.

In 2012, the Legislature passed and Governor Brown signed into law three bills – AB 1532 (Pérez, Chapter 807), SB 535 (De León, Chapter 830), and SB 1018 (Budget and Fiscal Review Committee, Chapter 39) that established Greenhouse Gas Reduction Fund (GGRF) to receive Cap-and- Trade auction proceeds and to provide the framework for how the auction proceeds will be administered in furtherance of the purposes of AB 32, including supporting long-term, transformative efforts to improve public health and develop a clean energy economy. The suite of implementing legislation offers strong direction for investing a portion of the auction proceeds to benefit disadvantaged communities, including specific allocation requirements in SB 535.

In 2014, the Legislature appropriated \$200 million dollars in GGRF monies to establish a Low Carbon Transportation GGRF program that CARB is implementing in coordination with the AQIP AB 118 programs. In May of 2016, Governor Brown's proposed budget included \$500 million dollars in GGRF monies toward the Low Carbon Transportation program. Projects funded by the Low Carbon Transportation GGRF program must reduce GHG emissions and further the purposes of AB 32, with a strong emphasis on benefiting disadvantaged communities.

In order to identify the priority investments that facilitate GHG emission reductions, the Legislature directed the development of the Cap-and-Trade Auction Proceeds Investment Plan<sup>2</sup>. The Fiscal

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<sup>1</sup> The Guidelines for the AB 118 Air Quality Improvement Program are found in Title 13, California Code of Regulations, Chapter 8.2.

<sup>2</sup> The Cap-and-Trade Auction Proceeds Investment Plan is available at <http://www.arb.ca.gov/cc/capandtrade/auctionproceeds/investmentplan.htm>

Year 2016-2017 Funding Plan for Low Carbon Transportation and Fuels Investments and the Air Quality Improvement Program (FY 2016-2017 Funding Plan), which was released in May 2016, calls for projects that accelerate the development and employment of advanced mobile source technologies and very low carbon fuels to help achieve the State's near-term and longer-term GHG emission reduction goals.

The FY 2016-2017 Funding Plan is designed to build upon previous funding cycles. Due to a decrease in the appropriated funds for Low Carbon Transportation investments, CARB implemented a scaled back version of its FY 2016-17 Funding Plan. The CARB Governing Board approved modifications to the FY 2016-17 Funding Plan and instructed all demonstration funds to primarily focus on projects that support CARB's sustainable freight action plan and benefit disadvantaged communities. Funding was provided for projects that support evolution through three phases of technology advancement: demonstration, commercialization and transition to widespread deployment.

CARB solicited projects for the Off-Road Advanced Technology Demonstration Projects on June 9, 2017 and in response to this solicitation the District submitted the Project application on September 7, 2017. In response to our application submittal, CARB notified the District that the project was selected for funding on November 22, 2017. The District and CARB executed their original grant agreement on June 4, 2018.

## Executive Summary

Heavy-duty off-road equipment is a significant source of greenhouse gas (GHG) emissions and a large contributor to diesel particulate matter (PM) and oxides of nitrogen (NOx) emissions throughout the state of California. PM and NOx emissions are of great interest to the Central Valley because they are sizable contributors to air pollution in the region. Additionally, off-road equipment plays a major role in freight transport and is commonly used in freight support facilities such as distribution centers, warehouses, ports, and intermodal yards. Off-road equipment that is utilized at freight facilities, such as forklifts, handle cargo and materials both off the roads and within the facility. Reducing emissions from off-road equipment such as heavy-duty forklifts is not only necessary to meet federally imposed clean air standards, but also needed to reduce the adverse health effects from their emissions, especially in AB 617 identified communities and disadvantaged communities.

While regulations aim to reduce the emissions impact from off-road equipment, the continued development and demonstration of advanced technologies are necessary to reach California's long-term GHG emission reduction goals, protect public health, and reach attainment with increasingly more stringent federal air quality standards. To help address the immediate need to eliminate these impacts, the Project demonstrated two heavy-duty, 30,000-pound lift capacity, full battery electric forklifts that provided quick economic and environmental benefits to the Port of Stockton. Additionally, the Project also demonstrated the scalability, practicality, and economic viability of widespread transformation of zero-emission heavy-duty cargo handling equipment.

Using funding from CARB and support from the District, DANNAR, ChargePoint, carbonBLU, and the Port led the Project to demonstrate two (2) 30,000-pound Mobile Power Station (MPS) units, deploy ChargePoint DC chargers, and collect data from the MPS units to compare against baseline diesel units. Both units have forklift capacities and are also equipped with individual attachments that enhance their functionality. One unit has a scissor lift attachment and the other has a cargo truck bed. This report documents the full course of the project starting June 4, 2018 through August 31, 2021. The lessons learned and insight gained through this report will serve as a guide for interested parties interested in deploying similar equipment and technology in the future.

# Table of Contents

<b>Chapter 1 Project Overview</b>	<b>7</b>
1.1 Vehicles and Charging Infrastructure	7
1.2 Benefits to Disadvantaged Communities in the San Joaquin Valley	7
1.3 Project Partners	8
1.4 Technology Demonstrator	9
1.5 Data Collection	9
1.6 Amendment to Grant Agreement	10
<b>Chapter 2 Project Implementation</b>	<b>11</b>
2.1 Electric Vehicle Charging Infrastructure	11
2.2 DANNAR Mobile Power Stations-Electric Forklifts	14
<b>Chapter 3 Data Collection</b>	<b>19</b>
3.1 Overview	19
3.2 Unit Comparison: Baseline and DANNAR forklifts	20
3.3 Diesel to Electric Comparison in Lot 900	20
3.4 Rebar Loading Inter-Comparison Test Results	21
3.5 Annual Costs and Emissions Estimate	23
3.6 DANNAR MPS Advantages	26
3.7 DANNAR MPS Limitations	27
<b>Chapter 4 Lessons Learned and Recommendations</b>	<b>28</b>
4.1 Deployment of Electric Vehicle Charging Infrastructure	28
4.1.1 Challenges	28
4.1.2 Recommendations	30
4.2 Mobile Power Station Performance	30
4.2.1 Challenges	31
4.2.2 Recommendations	36
4.2.3 Final MPS Assessment	39
<b>Chapter 5 Future Outlook of DANNAR MPS and Port of Stockton</b>	<b>39</b>
5.1 Purchase Price of Electric Off-Road Equipment	39
5.2 Limited Production of Electric Off-Road Equipment	40
5.3 Charging Infrastructure	41
5.4 Education for Drivers and Maintenance Staff	42
5.5 Zero-Emission Off-Road Equipment for the San Joaquin Valley	42
<b>Chapter 6 Appendix</b>	<b>44</b>
6.1 Data Collection Report	44
6.2 Data Collection Presentation	76

# Chapter 1: Project Overview

The Project is designed to assist with the acceleration of commercialized off-road zero-emission technologies by demonstrating two prototype state-of-the-art battery electric heavy-duty forklifts at the Port of Stockton. This demonstration will also benefit an AB 617 identified community and adjacent disadvantaged communities by significantly reducing greenhouse gas emissions, criteria pollutants, and toxic diesel emissions. The Project consists of the District as the grant administrator, DANNAR as the technology provider, ChargePoint as a project partner providing electric charging infrastructure, and carbonBLU as the third-party designated data collector. The Port will assist by demonstrating the two DANNAR units at their facility. Both units have forklift capabilities, but each unit also carries one additional feature. One of the units has a scissor lift attachment and the other unit has a cargo truck bed.

## 1.1 Vehicles and Charging Infrastructure

The Project included the deployment of two (2) DANNAR battery-electric zero-emission 30,000-pound forklifts and two (2) ChargePoint DC chargers.

DANNAR worked directly with the Port, ChargePoint, and carbonBLU to ensure a successful execution and completion of the Project including forklift specifications, forklift operation, forklift training, repair, charging, and data collection.

- The DANNAR units have the SAE J1772 connector to charge the units

ChargePoint worked with the Port to select the best location for the two DC chargers. The chargers were installed in warehouse 17 at the Port because it was near the area where the DANNAR forklifts were operating. The facility also had enough power to support the two DC chargers without any upgrades.

- ChargePoint DC fast Chargers have an output of up to 125 kW of power. Both charging units have a Combined Charging System (CCS) connector.

## 1.2 Benefits to Disadvantaged Communities in the San Joaquin Valley

The Project equipment operated on-site full-time at the Port located at 2201 West Washington Street, Stockton, CA 95203. According to CalEnviroScreen 2.0 and 3.0, the Port is located in one of the highest Disadvantaged Communities (DACs) in California - top 5% of most disadvantaged.

The demonstration of the two zero-emission heavy-duty forklifts at the Port also benefitted adjacent and surrounding DACs by significantly reducing GHG emissions, as well as eliminating criteria pollutants and exposure to associated toxic diesel emissions. In addition, the Project increased job readiness and career opportunities by providing on-the-job training and workforce development

programs for the Port's operations and maintenance technicians to operate, maintain, and repair zero-emission off-road equipment and vehicles. Driver and maintenance technician training will increase job readiness and career opportunities in the ever-growing electric vehicle and equipment industry.

The Project received strong support from the local community because of the significant environmental and economic benefits it will bring to a community identified in Assembly Bill 617 (AB 617). AB 617 requires the California Air Resources Board (CARB) and air districts to develop and implement additional emissions reporting, monitoring, reduction plans and measures in an effort to reduce air pollution exposure in disadvantaged communities. The Stockton AB 617 community, as approved by the Community Steering Committee in 2019, is approximately 16 square miles, has an estimated population of 132,000 and is impacted across a number of health and pollution indicators. Using the State CES tool, all census tracts located within the Southwest Stockton proposed community rank in the top 5% most disadvantaged communities in California.

### 1.3 Project Partners

#### ***ChargePoint***

ChargePoint's team has extensive experience in deploying charging infrastructure to support the coordination of zero-emission demonstrations and deployments. ChargePoint has a dedicated grant operations team that handled all administrative aspects of the Project, as well as solutions engineers and project managers that have vast experience deploying and providing support for EV charging infrastructure projects. Over the past 10 years, ChargePoint has demonstrated success in scaling its technology with the deployment of over 40,000 charging locations and building a team of over 340 people committed to providing support for the charging stations. ChargePoint's hardware provides a robust and flexible network that enables fleets to scale the various electric off-road equipment that they wish to deploy. ChargePoint is poised to serve the demand for further electric charging stations at the Port, and other facilities across California.

#### ***Port of Stockton***

The Port's team for this Project has extensive experience managing and operating off-road vehicle fleets, including carrying out advanced vehicle projects. The Port intends to scale and transition to a fully zero-emission fleet and install further electric charging stations following the successful demonstration of the two heavy-duty (HD) zero-emission forklifts in this Project.

#### ***carbonBLU***

carbonBLU was added to the Project to serve as a replacement for Bosch who withdrew from the project prior to its completion. carbonBLU has extensive experience in testing and managing data collection equipment. They coordinated with the District, the Port, and DANNAR to accomplish the data collection goals set forth for this Project.

## 1.4 Technology Demonstrator

### **DANNAR**

DANNAR has assembled a world-class team that has deep subject matter, expertise, and experience in the heavy-duty, off-road industry. The founder, Gary Dannar, has spent his career in the heavy-duty industry focusing on cargo handling, agriculture, construction, and commercial technologies. Leveraging his experience and expertise, he led the development of the off-road battery-electric cargo handling mobile platform now known as the Mobile Power Station (MPS). Gary Dannar equipped the MPS with multi-function capabilities after taking into consideration the lessons learned from previous projects and the needs of off-road fleet operators. DANNAR's team has professional experience in advanced technology vehicle and equipment manufacturing; operations and maintenance of advanced fleets; workforce training; sustainability; research and fueling infrastructure; workforce development; and logistics and supply chain management. The Project demonstration is built upon DANNAR's successful prototypes, which helped ensure on-time completion of the Project and mitigate and manage risks.

DANNAR's experience with off-road technology made them poised to immediately scale-up the deployment of zero-emission cargo handling equipment at the Port, as well as other off-road fleets. DANNAR's suppliers and engineering partners, including BMW and LiftKing Manufacturing Corporation, have extensive experience in successful collaborations and ramping up production. They are also preparing for expansion and scalability for California's heavy-duty equipment market, as well as national and international markets.

## 1.5 Data Collection

carbonBLU installed telematics on the two baseline diesel forklifts and utilized the existing telematics on the two zero-emission forklifts to collect the required data. CarbonBLU also collected emission data from the baseline units using PEMS technology and provided a summary of the testing equipment specifications, operations, performance, and energy consumption. In addition, carbonBLU was responsible for accurately documenting any safety concerns, service calls, or equipment maintenance issues encountered during the course of the testing period. Once the data collection process was complete, carbonBLU compared and analyzed the data sets and shared with the District who submitted results to CARB.

ChargePoint collected the data for energy consumption from the two charging stations, which included the amount of electricity, electricity rates, state of charge throughout work shift, charging time, charging source, off-peak load shifting potential, charge frequency, energy consumption rate per work completed, GHG savings, diesel savings, infrastructure reliability, and other data points. ChargePoint's web portal provided the tools necessary to actively monitor and manage all stations, including real-time status for each port; making it easy to view important information in a clear and concise table format.

## 1.6 Amendments to Grant Agreement

The Project included two grant amendments. Grant Amendment 1 was necessary to replace one of the original members of the Project, Bosch, with a new third-party data collector, carbonBLU, and extend the project term to accommodate project delays.

Bosch was an active Project partner throughout its time working on the Project. Bosch and the District, however, could not come to an agreement regarding some of the Project responsibilities and reached an impasse on a portion of the contract terms. Bosch withdrew from the project on March 15, 2019. The amendment process began in April 2019 to include carbonBLU as a new third-party data collector and to extend the date the Project would be completed. Grant Amendment 1 was executed on February 13, 2020.

Below is a summary of all the items that were amended in Grant Amendment 1.

*Table 1 – Summary of Grant Amendment 1*

1. Thien Tran replaced Todd Sterling as the CARB Project Liaison
2. Update to the Project Time Period and Project Schedule
3. carbonBLU added as an active member of the Project team
4. Redistribution of Project funds
5. Redistribution of Match funding from Project Partners
6. Updated Project Tasks

Grant Amendment 2 was implemented to extend the Project timeline due to delays caused by the COVID-19 Pandemic (COVID). COVID affected all the Project partners’ schedules and their ability to conduct in-person tasks. They were also impacted by staff members missed work days due to testing positive with COVID or delays in remote work implementations. In addition, overall commerce and shipping schedules were delayed at the Port. It was determined that the Project would be unable to meet the schedule that was outlined in Amendment 1 with travel being limited throughout the United States and team members adapting to remote work. Thus, the schedule needed to be extended once again. With those impacts on the Project, Grant Amendment 2 was executed on September 10, 2020.

*Table 2 – Summary of Grant Amendment 2*

1. Update to Project Time Period
2. Update to Earned Interest
3. Update to Project Schedule

## Chapter 2: Project Implementation

Successful implementation of the Project required the completion of two primary phases. The first phase involved the strategic installation of adequate charging infrastructure that could sustain the operation of the DANNAR MPSs during their designated work schedule. The second phase entailed the seamless deployment of the electric forklifts to ensure they could operate sufficiently and comparably to existing conventional diesel forklifts.

### 2.1 Electric Vehicle Charging Infrastructure

The proposed installation site for the chargers had adequate electrical capacity to support the new chargers for both electric forklifts. The Port had no previous experience with the installation of electric vehicle charging equipment at their facility prior to this Project, however, they were well prepared to install the two ChargePoint DC fast chargers. Additionally, the Port did not have any experience with electric off-road or on-road vehicles as part of their fleet until the implementation of this Project. The deployment of the electric vehicles and the charging equipment for this Project allowed the Port to garner valuable experience pertaining to electric vehicle infrastructure.

For this Project, two 60 kilowatt DC fast chargers with CCS connectors were provided to the Port. All of the chargers were manufactured and provided by ChargePoint. The chargers were installed at Warehouse 17 at the Port.

#### ***Port of Stockton***

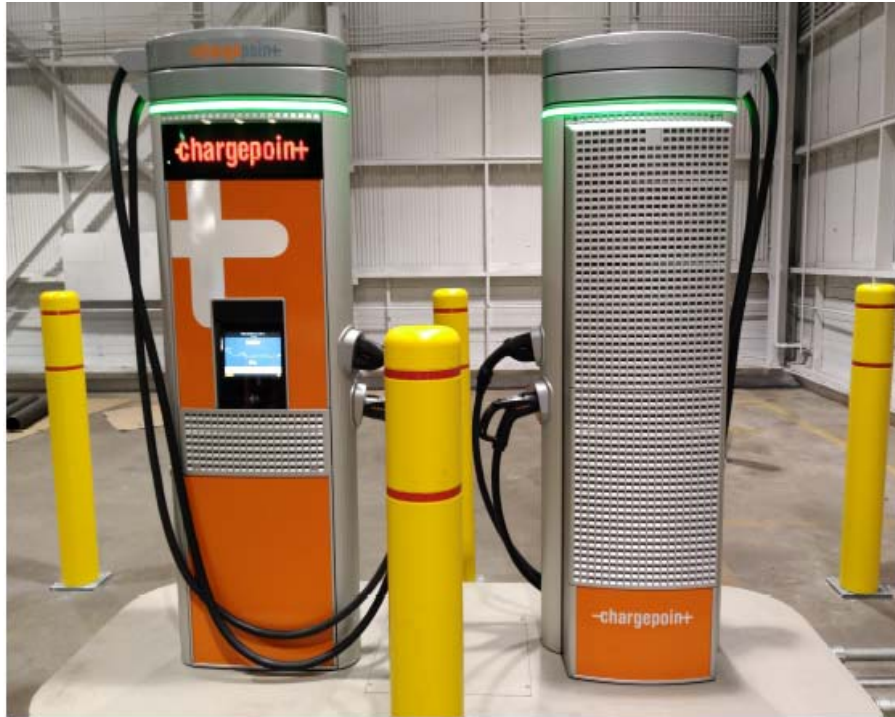
Due to the Port's limited experience in electric vehicle infrastructure, the Port began early discussions with ChargePoint to select the best installation site while taking into consideration the power requirement of the chargers. The Port decided to install a platform to serve as a base for the chargers in Warehouse 17 after collecting all relevant charger measurements from ChargePoint. ChargePoint had initial challenges visualizing the platform, but understood the functionality once they arrived to Warehouse 17 to install the chargers. The Port worked ahead of time with their electricians and ChargePoint to complete any documentation or permit requirements prior to the installation. As a result, the installation of the chargers was a smooth process for both the Port and ChargePoint.

The Port decided to charge the DANNAR units in the evenings, during non-operation time, to facilitate the integration of the units with normal Port functions. The Port also planned to deploy the units during the same duty-cycle as the diesel baseline forklifts to assist with the Project's data collection requirements. The DANNAR units were plugged into the chargers after the rebar shift finished at 5pm to have them fully charged and ready for deployment in the morning. The two MPSs are able to complete an 8-hour shift as part of their workload due to charging at night in the off hours with the battery charged to 100% battery.

The Port originally selected Warehouse 17 as the location to install the ChargePoint chargers because it was centrally located and had the power source to install the chargers without any major

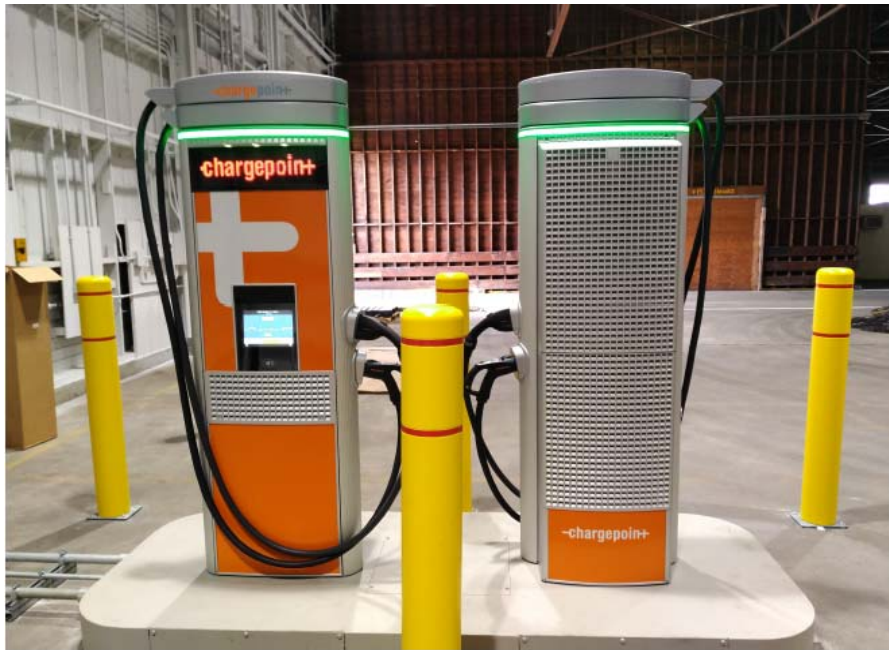
alterations. However, the Port soon learned that the courtyard was a more optimal location because that is where the MPSs were in greater use and need. Since the MPSs were in use for daily rebar operations, it made more sense to drive them to the Port courtyard to recharge, instead of the original ChargePoint station.

*Image 1: Port of Stockton – Charge Point Chargers*



*Note: Anterior view of the two DC fast chargers installed in warehouse 17 at the Port as part of the Project. Two yellow bollards were placed in between and one on each side of the chargers to serve as physical and visual barriers.*

*Image 2: Port of Stockton – Charge Point Chargers*



*Note: Posterior view of the two DC fast chargers installed in warehouse 17 at the Port as part of the Project. Two yellow bollards were placed in between and one on each side of the chargers to serve as physical and visual barriers.*

*Image 3: Port of Stockton – Charge Point Chargers*



*Note: Side view of the two DC fast chargers installed in warehouse 17 at the Port as part of the Project. Two yellow bollards were placed in between and one on each side of the chargers to serve as physical and visual barriers.*

## 2.2 DANNAR Mobile Power Stations - Electric Forklifts

The two DANNAR Mobile Power Stations (MPS) were designed and fabricated with forklift attachments with one MPS having a scissor lift and the second having a dump bed.

DANNAR has developed strong partnerships with leading vehicle, equipment, hydraulics, and charging infrastructure technology manufacturers that are each committed to the success of this Project. In the past few years, DANNAR has collaborated closely with BMW for their state-of-the-art battery technology. With the development of the MPS, BMW batteries were chosen to be part of the units. DANNAR also partnered with LiftKing, a large-scale commercial off-road equipment manufacturer, and provider of the forklift, scissor-lift and dump bed attachments of the MPS units. In the table below, the specifications for the two MPS units deployed at the Port are described.

### *DANNAR Mobile Power Stations – Specifications*

MPS with Scissor Lift	MPS with Dump Bed
<ul style="list-style-type: none"> <li>• Fork Lift Capacity: 30,000-pounds</li> <li>• Scissor Lift Working Height: 18-feet</li> <li>• Mast Height: 173-inches</li> <li>• Fork Tynes: 2.75-inches</li> <li>• Fork Positioners – Individually Operated</li> <li>• Number of Battery Packs – 3</li> <li>• Battery Capacity - 99 kWh</li> </ul>	<ul style="list-style-type: none"> <li>• Fork Lift Capacity: 30,000-pounds</li> <li>• Dump Bed Size: 5-Yard</li> <li>• Mast Height: 173-inches</li> <li>• Fork Tynes: 2.75-inches</li> <li>• Fork Positioners – Individually Operated</li> <li>• Number of Battery Packs – 4</li> <li>• Battery Capacity - 132 kWh</li> </ul>

### ***Building of the MPS***

DANNAR began the building process of the units in the summer of 2018 and were completed during the first half of 2019. The final products were delivered to the Port in July 2019.

The timeline for the building of the DANNAR MPS took 13 months of Computer-Aided Design (CAD) concept architecting, engineering, fabrication, assembly, testing, and delivery. This time frame was a considerable accomplishment for DANNAR because the building phase for most major off-road manufacturers extends far beyond a year. However, this Project did have a significant advantage because the DANNAR MPS designed for this project was based on the 4<sup>th</sup> generation “D4” model MPS that was already in early stages of commercialization. At that point, DANNAR had already invested eight years of product development and testing into the engineering of the D4 model. DANNAR’s engineering partner, BMW, was also well equipped with the necessary EV technology to assist with the D4 model development. Other technologies such as hydraulics and mechanics were well established with DANNAR’s major suppliers. Additionally, unit components needed for the building of the DANNAR MPSs were in high volume production and readily available. The MPS model “D4” served as a source of proven technology and as a baseline for the conceptualization of the 30,000-pound forklift models with scissor lift and dump bed attachments utilized in this project.

*Image 4: Building of the DANNAR Mobile Power Stations*



*Note: View of DANNAR warehouse with black MPS chassis at center.*

*Image 5: Building of the DANNAR Mobile Power Stations*



*Note: Close up view of the black MPS chassis with additional framework for support equipment.*

***Operations and Maintenance Training***

DANNAR provided extensive driver's training to the Port operators to ensure successful operation of the DANNAR MPSs. The training conducted at the Port included but was not limited to MPS operation, charging, maintenance, and data collection. The hand-on training provided to the Port operators and maintenance staff was also combined with classroom instruction. The initial training was performed at the Port's facilities prior to the onset of the COVID-19 pandemic in a traditional in-person setting. DANNAR provided extra in-person and virtual trainings to the Port to compensate cancelled training sessions caused by the pandemic. DANNAR also created an operation and maintenance manual for the MPS to serve as an accessible reference tool for the Port. Additionally, after deployment, the Port requested a start-up guide from DANNAR that shows Port staff how to operate and charge the MPS units. This guide is currently stored in the MPS's cab compartment and can be easily referenced for any new or existing drivers and operators that need assistance with starting or operating the units.

Prior to the MPSs deployment, the Port had some standard processes that it had to fulfill before the new technology could be utilized. The Port must provide tech letters to its operators when any new piece of equipment is deployed at the Port. This letter explains the new equipment's function and use. The tech letter provided by the Port took some time to be negotiated with the Port's operators because the MPSs have multiple functions and have the ability to be deployed in various vocations.

**DANNAR MPSs Rollout**

During the delivery of the DANNAR MPS units and training with the Port Staff in July and August of 2019, the Port began testing and calibrating the two MPSs while providing DANNAR feedback and any possible modifications necessary for their standard operations. The Port has provided mostly positive feedback regarding the two DANNAR MPSs and looked to deploy them at the beginning of October in their rebar truck loading section. The Port ran the MPSs against the diesel baseline in the same line of work.

**DANNAR MPS Deployment**

DANNAR rented office space at the Port after the forklifts were delivered to continue providing support for the project. The Port compared dump and scissor lift features on the DANNAR zero-emission forklifts to equipment currently in use at the Port to analyze functional similarities. The Port also tested steering and breaking sensitivity for the DANNAR zero-emission forklifts while under load.

On February 20, 2020, the Port hosted the District, DANNAR, carbonBLU, and CARB, to provide the project partners an opportunity to view the current functions and capacities of the two DANNAR MPSs. The Port reported that the two DANNAR units had not been deployed for use at the Port because the speed and steering capabilities of the DANNAR forklifts needed improvement. The major concerns were that the steering and lift functions of the DANNAR forklifts were not at par with the baseline forklifts that are typically used at the Port. The goal of the Port is to have the two DANNAR units operate as closely as possible to the baseline forklifts before deployment. In addition, the deployment for the two DANNAR MPSs was delayed because the Port wanted to ensure the safety of Port staff while operating the DANNAR MPSs. This safety entails providing further

operational training, and adhering to occupational codes and laws associated with the operation of similar technology. The Port reported that training for steering functions can be extensive due to Port staff not having any prior experience operating this type of equipment or technology.

DANNAR continued working closely with the Port to further improve the DANNAR MPSs as material handling forklifts.

*Image 7: DANNAR MPSs Operating in the Rebar Area at the Port of Stockton*



*Note: Port operator hauling rebar at the Port Courtyard using the DANNAR MPS with the dump bed attachment.*

*Image 8: DANNAR MPSs Operating in the Rebar Area at the Port of Stockton*



*Note: Wide angle view of Port operator hauling rebar at the Port Courtyard using the DANNAR MPS with the dump bed attachment.*

*Image 9: DANNAR MPSs Operating in the Rebar Area at the Port of Stockton*



*Note: Port operator discharging rebar at the Port's designated drop-off location using the DANNAR MPS with the dump bed attachment.*

## Chapter 3: Data Collection

### 3.1 Overview

carbonBLU is the third-party independent contractor that conducted the Project's data collection, monitoring, and analysis requirements for this Project. carbonBLU installed data-loggers to record daily baseline forklift diesel activity and was provided unfettered access to DANNAR's servers to pull activity information for the two DANNAR units. The two baseline forklifts are both Hyster Model 330s. The specific use of the baseline and DANNAR units occurs in the Port's "900 Lot" in its "West Complex." Bundles of steel rebar were brought to the lot by rail and placed into stacks by large material transport equipment. From those stacks, they were loaded onto flatbed trucks for distribution around Northern California using diesel forklifts rated for loads up to about 30,000 lb. During this project, they were also loaded onto the trucks using the DANNAR units and other electric equipment from other similar projects running at the Port.

The primary purpose of the project was to determine whether the battery-electric DANNAR units (modified for use as a 30,000 lb rated forklift) can feasibly replace the diesel powered 30,000 lb rated forklifts used in the 900 Lot for loading flatbed 18-wheelers with rebar. In this project, a judgement of feasibility requires analysis of costs, ease of use, and efficiency of loading and emissions of greenhouse gases and criteria pollutants. In this chapter, we summarize the results required for a judgement of feasibility and describe the systems compared. The project design was based on the expectation that the baseline and DANNAR were to be used in a similar manner throughout the project. As a result, the data collected from the baseline and DANNAR usage patterns will provide a useful "apples-to-apples" comparison between diesel and electric units. As the project progressed, the Port used the DANNAR units exclusively for loading steel rebar onto trucks at a specific location (Lot 900). The baseline diesel lifts were also used for loading rebar, but also frequently used for other purposes.

The DANNAR units experienced several extended outages and operating issues related to drivability and charging. These DANNAR problems were ultimately resolved, but the data logged during the bulk of the project was not considered representative. In order to enable a fair comparison between the baseline and DANNAR units, the data collection was modified slightly. The costs and emissions of the baseline and DANNAR units would have to be estimated (i.e., modeled) for the project time period, instead of being directly recorded. In addition to the originally planned data collection, a test plan was designed to collect information that would allow the modeling of emissions and costs as if both the baseline and DANNAR units were used exclusively for loading trucks with rebar during the project period.

### 3.2 Unit Comparison: Baseline and DANNAR forklifts

This section summarizes the data used to compare the baseline and DANNAR systems on an “apples-to-apples” basis.

The typical forklift for loading rebar in the 900 Lot is well-represented by the Hyster 330 diesel powered system. The model most recently used for rebar is a 2017 model rented by the Port from Papé Rents, who also services the unit.

The electric forklift is based on a system manufactured by DANNAR called MPS (Mobile Power Station). The base system is designed so it can be modified in many ways and for many uses. The system uses lithium-ion batteries (124 kWh total capacity) sourced from BMW. Proper operation of the heavy forklift required substantial upgrades to the standard hydraulics on the unit. Photos of the two comparison units are shown in Image 10.

*Image 10. Photos and Descriptions of Forklifts Compared*



Baseline Lift: 2017 Hyster 330 (diesel)



Electric Lift: 2019 DANNAR 4 MPS (LiO battery)

### 3.3 Diesel to Electric Comparison in Lot 900

During the course of this project, several pieces of electrical equipment was used in 900 Lot for rebar. Other electric equipment had been introduced at the Port at the same time as the DANNAR units. As a result, to give an idea of the possible overall impacts of using electric equipment for rebar, the overall data for the 900 Lot was analyzed. *Figure 1* summarizes quarterly rebar loading and heavy forklift refueling in the 900 Lot from early 2019 through early 2021.

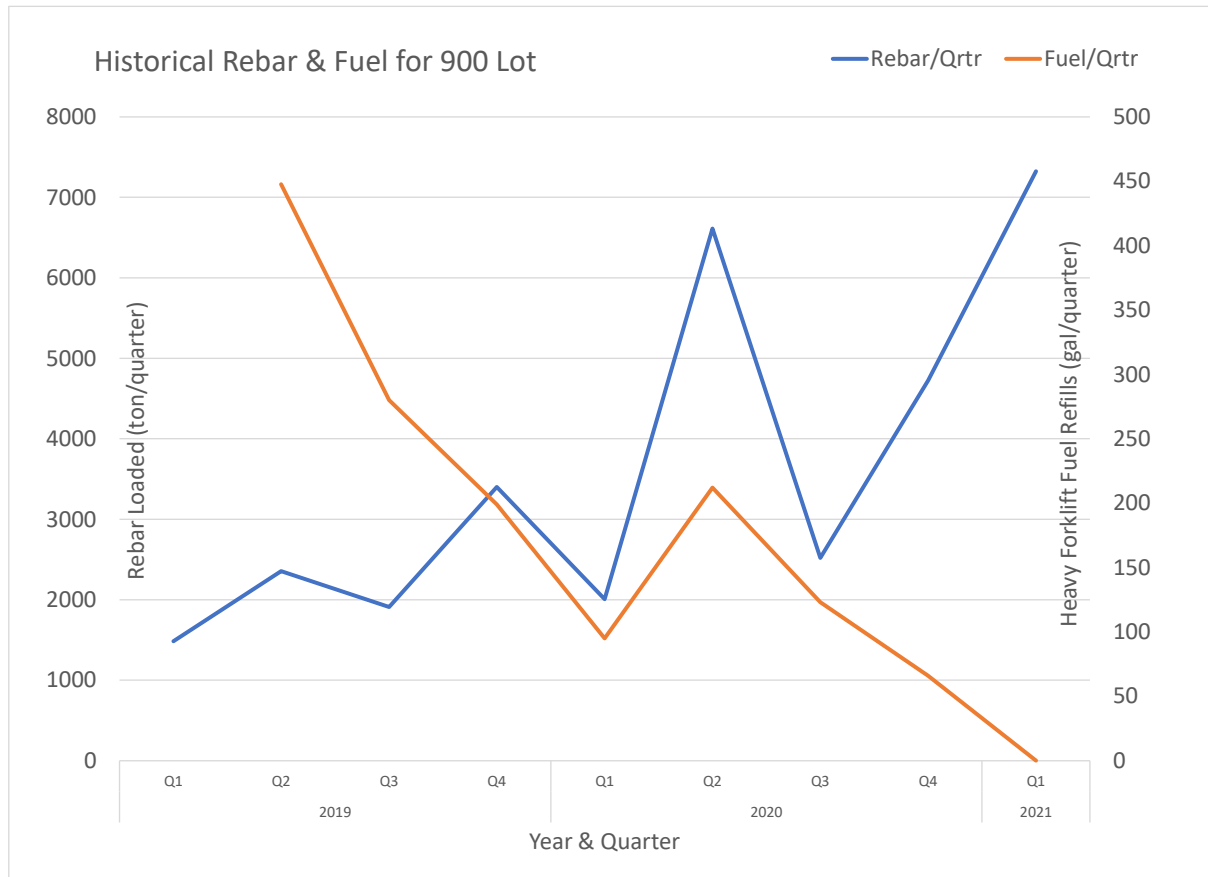


Figure 1. Historical Rebar Tonnage and Heavy-Lift Fuel Refills in the 900 Lot

Electric lifts, including the DANNAR units, have been introduced in the 900 Lot since mid- to late-2019. Figure 1 shows that, despite increased rebar tonnage, fuel use in the 900 Lot has consistently declined as more electric equipment was used. In fact, there were no heavy-lift diesel refills in the 900 Lot during the first quarter of 2021. However, since the electric and diesel equipment was not purely from the DANNAR and diesel equipment used in this project, other data was needed to compare the two units. The emissions tests performed while both the DANNAR and baseline Hyster 330 units loaded rebar provided this comparison data.

### 3.4 Rebar Loading Inter-Comparison Test Results

The duty-cycle of the rebar loading process entails the loading of an average of 2 or 3 trucks in a row and in a predictable manner. In order to compare the DANNAR and baseline units in a fair basis, both systems were tested using the same duty-cycle multiple times. Emissions from the diesel were measured using portable emissions measurement systems typical for compliance testing (gases) and research (particulates). The activity of both the electric and the diesel were also recorded using on-board electronic data loggers.

The two systems were tested multiple times on exactly the same cycle:

- Start in the normal parking location,
- Drive to the stack of rebar,
- Load the first truck with three loads of 8-tons each,
- Load the second truck the same way,
- Drive back to the normal parking spot.

Since both the baseline diesel and the electric systems were used for the same work, the test data provide a much more reasonable and accurate inter-comparison than the on-board logger data from the project. Table 3 summarizes the results of the inter-comparison tests.

Table 3

Average Test Results for Baseline Diesel Forklift (Hyster 330)

Duration	Test Totals			
	Fuel	CO2	NOx	PM
<i>sec</i>	<i>kg</i>	<i>g</i>	<i>g</i>	<i>mg</i>
629	1.35	4304	8.30	82.0

Average Test Results for Electric Forklift (Dannar 4 MPS)

Duration	Test Totals	
	Fuel	CO2e
<i>sec</i>	<i>kWh</i>	<i>g</i>
987	5.86	1751

It took the baseline forklift 10.5 minutes (629 seconds) on average to complete the cycle while it took the DANNAR unit 16 minutes (987 seconds) on average. The significantly slower result for the DANNAR was due to steering and control issues. Many of these issues are related to the “prototype/first-design” aspect of the DANNAR units and are likely to be remedied through continued programming tweaks and minor modifications. However, some aspects of the DANNAR units cannot change such as the mechanical differences between the steering strategy of the conventional diesel forklifts and the DANNAR units. These design differences are a shortcoming for the DANNAR units when used as a forklift where tight maneuvers and true “inching” are important, such as loading trucks.

On average, the baseline unit used about 1.4 kg of fuel to complete the test cycle while the DANNAR used 5.9 kWh of battery storage. The diesel fuel tank has a capacity of about 130 kg (41 gal) of diesel and the DANNAR unit has a battery capacity of about 100 kWh. The baseline unit used a bit more than 1% of its fuel capacity to load 2 trucks and the Dannar used a bit less than 6% of its fuel capacity. Based on these results, the most trucks these systems could load when starting with a full

tank/battery is 185 for the diesel and 33 for the DANNAR unit.

No battery degradation from the DANNAR units was observed or expected during the testing period. The battery systems were not exercised enough during the 8 hour work day to exhibit degradation. The DANNAR units recharged at a rate of about 60 minutes per 33 kWh battery pack using the DC Fast Chargers in Building 17. This equates to 3 hours for the scissor lift and 4 hours for the dump DANNAR unit to reach a full state of charge (SOC) refill. The units were charged at night during the course of this project and were fully charged in the morning.

On average, the baseline diesel forklift emitted over 4300 grams of CO<sub>2</sub> to load 2 trucks with rebar. For the same task, the DANNAR unit caused the emission of a little more than 1750 grams of CO<sub>2</sub>-equivalent due to it drawing the power stored in its batteries from the California electric grid. Note that CO<sub>2</sub> is not the same as CO<sub>2</sub>-equivalent. CO<sub>2</sub>-equivalent includes all greenhouse gases. As a result, if other GHGs (e.g., nitrous oxide and methane) had been measured in the baseline exhaust, the results would have been slightly worse for the baseline system.

In addition to the diesel emitting almost 2.5 times more CO<sub>2</sub> than the DANNAR unit, the diesel also emitted criteria pollutants in the vicinity of its operation (i.e., 8.3 grams of NO<sub>x</sub> and 82 milligrams of fine particulates). These quantities are extremely low. For example, even after several years of operation, there were no soot deposits in the exhaust pipe of the baseline forklift. In normal operation around the port, it is doubtful if human senses would ever detect the exhaust from these units.

However, criteria pollutants can be harmful if inhaled in high enough concentrations or with continuous exposure. Under the right conditions, criteria pollutants can also interact with other atmospheric pollutants to create photochemical smog and secondary particulates. As a result, one major advantage that the DANNAR units have is that battery-electric systems emit no pollutants in the vicinity of operations and cannot impact the exposure of people to harmful exhaust pollutants in the workplace.

## 3.5 Annual Costs and Emissions Estimate

The average costs and emissions for comparing the baseline and DANNAR systems during the project period are presented in this subsection.

### **3.5.1 Equipment Costs**

The baseline forklifts at the Port are typically purchased by the Port via a “rent to own” arrangement with Papé Rents. The Port purchased the baselines units using a special offer from Papé Rents that is not available to most owners. As a result, instead of using the Port’s special prices, a typical price for the baseline system and estimate annual capital costs using a loan model were used to mimic the Port’s rental model. The Port typically rents the units for 3 years before it is owned by the Port

outright. The typical price of a 2017 Hyster 330 lift as configured by the Port is \$240,000. If financed with a 3-year loan, paid monthly at a 3% annual percentage rate, the 36 payments would be about \$7,000 monthly. Typical maintenance plans for these systems cost about \$400 monthly.

The DANNAR units for this project cost the Port an average of \$375,000 each. These were highly modified systems, configured for lifting loads of up to 60,000 lb, which was “a first” for a DANNAR unit. As a result, these designs included unusual costs and design strategies and software that were not yet optimized. (Optimization of the software is an iterative process over an extended usage period.)

As a result, the costs of the DANNAR units utilized in this project are significantly higher than the costs that would be incurred for similar future models. As a point of reference, an unmodified DANNAR unit with an equivalent battery pack would cost around \$220,000. However, for this comparison, the higher price of \$375,000 is used. Using the same financing approach used for the diesel units, the 36 payments to purchase a DANNAR unit would be about \$10,900 /monthly.

### ***3.5.2 Planned Maintenance Costs***

Planned maintenance costs for the DANNAR units is not yet known. However, they are thought to be extremely low by comparison to the diesel units. DANNAR personnel indicated that a study by the University of Nebraska estimated that only 2 labor hours per month would be needed. Using this information, it is estimated about \$100 per month would be charged under a maintenance service plan.

According to the Port of Stockton, a typical maintenance plan for the baseline units is \$400 per month.

### ***3.5.3 Fuel Costs***

The red dye diesel the Port uses in their equipment is not subject to road taxes, hence its cost is about \$0.4 less than the average cost for on-road diesel. This comes out to about \$3.10 per gallon. The electricity rates at the Port are estimated to be \$0.234/kWh during Peak hours (from 4 to 9 PM for PG&E) and \$0.133/kWh during Off-Peak times. Given the timing of the Peak rate hours, we estimated the electricity rate for recharging the DANNAR units to be the average of the Peak and Off Peak rates, or \$0.184/kWh.

### ***3.5.4 Fueling Infrastructure Cost Considerations***

Infrastructure costs for refueling can be significant. However, fractional costs of refueling infrastructure and labor attributable have not been estimated for the DANNAR and baseline units. The re-charging of battery-electric equipment at the Port is still evolving due to significant and unresolved communications issues between some of the equipment and chargers arising near the end of the project period. Since the fractional costs of infrastructure are not a major influence on

purchasing individual pieces of equipment, they are only briefly discussed below.

Off-road diesel equipment at the Port is re-fueled by a fuel truck owned and operated by the Port. The battery-electric systems are re-fueled by a newly installed network of recharging stations around the Port consisting of both slow-charge AC and fast-charge DC stations.

Since the charging stations are located near where the electric equipment is used, the labor and equipment maintenance needed for re-charging the electric equipment is likely to be less than the costs for re-fueling the diesel equipment– and the diesel labor and maintenance are recurring expenses. The infrastructure costs for installing the charger network is much higher for the DANNAR system in comparison to the diesel infrastructure costs. However, the purchase and installation are a one-time expenses and associated recurring expenses, such as replacement of worn parts, will be minor compared to the diesel system.

### ***3.5.5 Driving Labor Costs***

The baseline and DANNAR units have a significantly different speed of completion for the typical truck load, so the annual labor cost was estimated between the units. According to the Port, a reasonable driver labor rate is \$28/hr.

### ***3.5.6 Emissions Estimates***

Annual emissions are calculated by estimating annual rebar loading volume and then using the Emissions Inter-Comparison Test results to extrapolate the emissions per rebar truckload into annual emissions.

The quarterly historical throughput of rebar in Lot 900 was obtained from the Port for 2019 and 2020. The quarterly rates varied substantially over the 2-year period, averaging out to about 3127 tons/quarter. If the type of trucks that transport rebar from the 900 Lot were to be fully loaded with that amount of rebar, a total of 131 truckloads per quarter would be required.

During the Emissions Inter-Comparison Tests, each test cycle entailed the process of fully loading two hypothetical trucks. Since the average emissions from that test program are representative of a typical “high-traffic” loading day, the “per test” emissions were multiplied by one-half the number of trucks per year to estimate the emissions in a year.

### ***3.5.7 Summary Table***

Table B summarizes the costs and emissions of the baseline and the DANNAR units modeled using the above findings. Input assumptions are given first followed by the annual cost items. In the outputs section, the total annual costs are shown in two parts: during and after the purchase debt is serviced. Finally, the emissions totals are presented.

		<b>900 Lot: Annual Rebar Loaded</b>		
		12507 tons		
		<b>Annual truck-equivalents</b>		
		522 truckloads		
		<u>Baseline Diesel</u>	<u>Dannar</u>	
Inputs	Driving Labor:	1277 \$/yr	2003 \$/yr	
	Annual Fuel:	110 gal/yr	1529 kWh/yr	
	Cost of Fuel:	342 \$/yr	281 \$/yr	
	Planned Maint:	4800 \$/yr	1200 \$/yr	
	Equipment Cost:	240,000 \$	374,500 \$	
	<i>36-month note at 3% APR, so...</i>			
	Debt Service:	83,760 \$/yr	130,680 \$/yr	
		<b>Total Costs: First 3 years (paying debt)</b>		
		90,179 \$/yr	134,163 \$/yr	
		<b>Total Costs: Thereafter (no more debt)</b>		
		6419 \$/yr	3483 \$/yr	
Outputs	<b>Emissions</b>			
	Equivalent CO2:	1123 kg/yr	457 kg/yr	
	Local NOx:	2166 g/yr	0 g/yr	
	Local PM:	21 g/yr	0 g/yr	

Table 4: Input and Output values for Baseline and DANNAR units

Table 4 shows that it costs substantially more to run a DANNAR unit instead of a diesel forklift for the first three years of use. Due to capital cost of the equipment, a DANNAR unit owner would spend about \$130,000 more. After the debt had been fully paid, the DANNAR unit would cost about \$3,000 less per year.

The issues of cost and emissions for loading rebar in the 900 Lot are important. However, it is clear that the volume of rebar at the Port, at around 500 truckloads per year, is not high enough to keep forklifts busy more than a few days a week. As a result, equipment that can be used for other purposes, will also score higher on the “feasibility” rating for the Port.

### 3.6 DANNAR MPS Advantages

The following bulleted list summarizes the advantages of using the DANNAR units as replacements for the baseline units that load rebar at the Port of Stockton:

- The DANNAR units would cause the emission of much less CO<sub>2</sub>. This includes CO<sub>2</sub>-only for the baseline units, while it includes all greenhouse gases for the DANNAR units. If other GHG gases (e.g., N<sub>2</sub>O and CH<sub>4</sub>) were to be included, the comparison would become slightly worse for the baseline system.
  - DANNAR = 457 kg CO<sub>2</sub> yearly (i.e., 1,530 kW-hr of electricity)
  - Baseline = 1,120 kg CO<sub>2</sub> yearly (i.e., 110 gal of diesel)
- The DANNAR units would cause the emissions of no criteria pollutants in the vicinity of workers. The baseline unit was very low emitting for diesel equipment, but not zero-emitting. As a result, it is possible that workers would be exposed to slightly more criteria pollutants while operating the baselines than the DANNAR units – especially in enclosed areas.
- The DANNAR units can be used as “mobile recharge stations,” in case the Port plans to have them fully charged and ready to help when other battery-electric equipment has depleted their batteries too far from a stationary charger. These events are expected to be infrequent.
- The DANNAR units have attachments that should prove useful for the Port maintenance crews. For example, the scissor lift is expected to be helpful for overhead lighting maintenance.
- After the purchase payoff (years 4 and later), the DANNAR units would cost substantially less than the baseline units (including maintenance, fuel and driver labor).
  - DANNAR = \$3,480 yearly
  - Baseline = \$6,420 yearly

### 3.7 DANNAR MPS Limitations

The following bulleted lists the limitations of using the DANNAR units as replacements for the baseline units that load rebar at the Port of Stockton:

- For moving rebar during the purchase payoff period (the first 3-years), the DANNAR units would cost substantially more than the baseline systems (including purchase financing, maintenance, fuel and driver labor).
  - DANNAR = \$134,000 yearly
  - Baseline = \$90,200 yearly
- The problems experienced by the DANNAR units are seen as typical of a new application for this relatively young DANNAR MPS base system. These 30,000 lb rated lifts have not been done by DANNAR before, so it is natural that these first designs would experience issues after initial deployment. By the end of the project period, all problems had either been resolved or a clear resolution was in the works.

- The DANNAR units do not maneuver like forklifts, so they take about 60% longer to load rebar onto trucks than the baseline units – about 10 minutes per truck for the baseline and about 16 minutes for the DANNAR. This slower performance is not expected to negatively impact rebar due to the relatively low volumes at the Port of Stockton. However, in a service that required maximized throughputs or highest movement efficiencies, the standard forklift steering and control system (including electric forklifts) is inherently quicker.
- The DANNAR batteries hold enough power to last several high-volume days of loading rebar at the Port. This is mainly because the total throughput of rebar is relatively low. The average-volume day for rebar during the project period was 2 truckloads. A high-volume day was 8 to 10 truckloads. A fully charged DANNAR could load approximately 33 trucks before recharging while a fully fueled baseline lift could load about 185 trucks before refueling.
- The Port has traditionally purchased equipment that can be put to many uses around the facility. When the equipment is not being used by the Port, they rent it to their tenants to generate additional revenue. For example, in addition to loading rebar, the Hyster 330 lifts are sometimes rented to the Longshoremens for moving rice bags. In the near-term, renting to tenants will not likely be possible with the DANNAR units. They are different enough from traditional off-road equipment that one tenant would require about a 6-month training and transition process to incorporate them into their operations. This reduces the value of these units for the Port, relative to the baseline units.

Further data collection support materials can be found in **Appendix 6.1 and 6.2**.

## Chapter 4: Lessons Learned and Recommendations

This project had several challenges that have provided valuable learning opportunities for future deployments of Mobile Power Stations (MPS). Below is a description of those challenges and recommendations provided by the participating Project partners through correspondence, interviews, and Project status reports.

### 4.1 Deployment of Electric Vehicles Charging Infrastructure

The Port of Stockton had no previous experience with electric vehicle technology prior to the start of the Project, and given this, the Port had unique challenges with the process of installing electric vehicle infrastructure.

#### 4.1.1 Challenges

ChargePoint delivered two DC fast charging products to the Port during the initial phase of the Project. The chargers were designed without any customizations or unique features. ChargePoint has extensive experience with charging infrastructure, but the nature of the installation at a port for

a heavy duty forklift was a first for ChargePoint. Since the Port is a federally governed agency, ChargePoint had a very swift and easy installation at the Port facility. The local fire department did play a role in ensuring that the installation adhered to relevant safety codes.

An initial challenge faced by the Port was finding the best method to install the chargers indoors without pouring new concrete. The Port used guidance provided by ChargePoint regarding station anchoring requirements to design and build a custom metal platform that was 10 inches off the ground. ChargePoint used the platform to successfully bolt down the chargers on the day of installation.

A second challenge faced by ChargePoint was connecting to reliable cellular reception for both charging stations. The chargers are designed to connect to the strongest cell carrier from one of the three major carriers of AT&T, Verizon, or T-Mobile. The ChargePoint stations were programmed to connect with AT&T but the strongest signal came from the Verizon cell tower next to the Port. ChargePoint solved this issue by exchanging the existing SIM cards with cards that connected with the Verizon cell tower. During that time, the charging stations continued to function even though the connection was at first unreliable. The stations continued to dispense energy and upload the charging data to the ChargePoint cloud from previous sessions when connection was restored.

Once the Mobile Power Stations were deployed, the chargers encountered initial connection difficulties with the DANNAR MPS batteries. BMW i3 batteries used by the DANNAR units are known to be compatible with the ChargePoint chargers, so no initial challenges were expected. However, the MPS were unable to charge using the charging stations at the Port once the units were delivered. DANNAR consulted with staff engineers to diagnose and solve the connection challenges. DANNAR made adjustments to the charge controller to repair any connections that were not communicating through the CCS combo standard connector.

Once the DANNAR units were deployed, the Port of Stockton decided to install a new set of AC Level II chargers in Lot 900 at the Port. That location was closer to where the DANNAR units were in use and would allow for the units to be charged at the job site rather than having to drive back across the facility to the warehouse for charging at night. In addition, the new chargers served as an alternative charging source for the DANNAR units when the ChargePoint chargers in Shed 17 were not functioning.

In the beginning of October 2020, the ChargePoint chargers began experiencing difficulties with charging the DANNAR units. ChargePoint found that the CCS connector on both chargers was broken. DANNAR enabled AC Level 2 charging functionality on both DANNAR MPSs to allow the units to use the ChargePoint Level 2 chargers located in the Port Lot while the ChargePoint chargers were repaired. There were delays in the repair of the chargers because there was a disagreement between the Port and ChargePoint on who should pay for the repair. After further discussion, ChargePoint agreed to fix both units at no cost to the Port. This repair was completed in the middle of February 2021.

## 4.1.2 Recommendations

ChargePoint has made the following recommendations to address the prominent challenges it encountered.

### **Hold on electrical infrastructure training until all charging equipment is available**

ChargePoint initially planned to provide hands on training to the Port staff. Unfortunately, this was not possible because the DANNAR units were not ready for fast charging at that time. ChargePoint adjusted by providing virtual training and sharing online materials. ChargePoint believes that training would have been more effective if the DANNAR units had been ready to use and charge.

### **Designate a staff member as a point of contact to monitor charging equipment**

The Port had a smooth transition into the charging technology because they designated specific staff members to handle all charging needs of the DANNAR units. They also had an electrician on staff during the installation of the infrastructure that facilitated the transition and training.

### **Provide a help guide to assist with any issues that can be solved locally**

The ChargePoint dashboard provided to the Port has a help function that leads to an instruction manual for all of the software features. This feature can be used to assist in answering any software related questions and help the facility with solving charging problems quickly and locally.

ChargePoint also has ChargePoint University as a tool to help interested parties learn more about electrical vehicle infrastructure. Every ChargePoint certified installer is required to go through ChargePoint University.

### **Install additional chargers on site that can be used if primary chargers malfunction**

During the course of this project, the ChargePoint chargers malfunctioned and the Port was unable to use the DANNAR units for a limited time. The installation of an additional set of chargers for a different project on Lot 900 at the Port allowed for the DANNAR units to continue to function.

## 4.2 Mobile Power Station Performance

The two Mobile Power Stations used in this project had a 30,000 pound capacity and were expected to be fully functional through an 8-hr shift without having to recharge. The Port planned to refuel the units after hours using the ChargePoint chargers located in Shed 17 at the Port of Stockton.

The hands-on experience of utilizing the MPS on actual Port functions helped the Port staff better understand the technology, and ultimately helped them determine if the MPSs met the Port's operational needs.

## 4.2.1 Challenges

The project began experiencing challenges during the assembly of the units. DANNAR was unable to deliver the forklifts on schedule because key materials were needed by DANNAR to complete the units. The materials were held up by customs at the Canadian border due to tariffs imposed on Chinese goods by the US government. DANNAR noted that these type of delays are extremely rare were mainly caused by the political climate between the United States and China and not necessarily because the material were in short supply. The MPSs were delivered to the Port in July 2019. Once the units were at the Port and able to reach full-charge, the Port found that the units mast, speed, and lift capacities were not satisfactory and not at par to a standard diesel forklift. DANNAR technicians made several improvements to the forklifts throughout the span of the project, but the Port decided to designate the DANNAR units to limited functions due to them not being able to perform as equally as a standard diesel forklift. The Port found that the units were not as efficient as they had first envisioned but are optimistic in the benefit of having electrical units as part of their fleet and are exploring other functions where the DANNAR units can serve further and better use.

### ***Challenges and Set Backs During Development***

The initial MPS design illustrated a single axle with single tires that had a rated load capacity of 30,000 pounds. When DANNAR requested quotes from designated suppliers, the delivery dates were far beyond the estimated delivery date of the MPSs to the Port. Upon further examination, DANNAR determined that the use of single tires in a vehicle with a 30,000 lb rating was not a common practice in the heavy duty industry. DANNAR learned that all the units at the Port of Stockton and many other facilities utilized axles with dual tire configurations.

It is beneficial for fleets to have a common industry standard to facilitate repairs and increase supply. Due to these benefits, DANNAR decided to change the design of the MPS to include a dual tire configuration. The design change also prevented the project from encountering further delays due to the extended time that it would have taken for single wheel configuration materials to arrive.

Early in the building process of the MPS units, DANNAR decided to order a mast that was rated higher than 30,000-pounds due to availability. The higher rated forklift mast was no downside to the Port, since it would mean extra durability and longer operating life for the MPS units.

The decision of selecting a higher load forklift mast and a different axle configuration triggered challenges for the project timeline. However, the benefits that these changes brought to the overall MPS design and functionality far outweigh the challenges.

A brief summary of these changes are as follows:

- Different and larger axles, which required sourcing from Italy instead of Canada
- Different axles required revision to chassis frame for proper mounting
- Larger forklift mast also required different mounting to chassis frame

- Different axle mounting, along with new mast mounting was not compatible
- Original spec'd four wheels, had to change to dual (8) solid rubber wheels coming from China
- Axles from Italy and wheels from China, both negatively impacted by tariffs and unfortunate circumstances at customs.

The table below is an overview of the two MPS build description, showing major project development tasks, timelines, and those tasks that experienced significant delays with unusual challenges.

*DANNAR Build Description – Timeline*

Name	Start	End	Task Duration	If Delayed, Reason Cited
Concept Plan	5/1/2018	8/31/2018		
Design Engineering	9/10/2018	11/30/2018		
Systems Design & Architecture	10/8/2018	12/21/2018		
Electrical Design & Architecture	11/5/2018	1/4/2019		
CAB - Concept & Design	12/3/2018	1/4/2019		
Manufacturing & Assembly Planning	1/7/2019	1/25/2019		
Frame Fabrication	12/10/2018	3/4/2019	Delayed	New axle required frame redesign
CAB - Fabrication	1/21/2019	3/4/2019		
Attachments Delivery (CAB, Scissor Lift & Dump Bed)	2/25/2019	3/29/2019	Delayed	Supplier prototypes delay
CAB - Testing	4/8/2019	4/26/2019		
Attachments Delivery (Forklift Mast)	5/3/2019	5/3/2019	Delayed	Tariffs and custom delays - Canada, Italy
Material Delivery (Tires)	5/6/2019	5/6/2019	Delayed	Tariffs and custom delays - Canada, China
Material Delivery ( Frame, Saddlebag, Axles, Etc)	1/14/2019	5/15/2019		
Assembly - Unit 1	1/14/2019	6/7/2019		
Shipping - Delivery 1st Unit	6/26/2019	6/28/2019		
Assembly - Unit 2	4/15/2019	7/12/2019		
Testing - Unit 1	6/10/2019	7/19/2019		
Testing - Unit 2	7/15/2019	7/19/2019		
Shipping - Delivery 2nd Unit	7/24/2019	7/30/2019		

**Hydraulic Challenges**

The hydraulic system technology utilized by the MPSs is a combination of conventional and new technology. When the DANNAR units were deployed, the Port requested DANNAR to make refinements to the hydraulic steering and mast lift speeds to meet the Port's standards. DANNAR

requested Parker Hannifin (Parker), the hydraulic systems manufacturer for the MPSs, to assist in resolving these issues. Parker's top fluid power engineers visited DANNAR's facility in Muncie, Indiana, to determine the source of the problem. The parts required to solve the issues were quickly manufactured in Finland and shipped to the Port. Technicians from DANNAR and Parker planned to arrive at the Port the following week to install the replacement parts, but non-essential travel was halted due to the COVID-19 emergency. As a result, the Port had to wait until travel restrictions were lifted before Parker's technicians could install the replacement parts.

### ***MPS Performance Challenges***

On July 28, 2020, DANNAR discovered that the PTCAN fleet logger on one of the DANNAR MPSs (D404) was not sending updates. The logger was replaced on August 6, 2020, but the issues persisted. DANNAR decided to build and install a new fleet logger box to correct the problem. The Port continued to use the DANNAR MPSs equally until one of the units started experiencing charging issues, steering problems, and hydraulic functions in early September. The Port continued to use the second unit until mid-September, but also halted the use due to charging issues. The Port parked both units and informed DANNAR about the ongoing issues. DANNAR fixed the problems in both units with the exception of the charging challenges.

In the first week of November 2020, two DANNAR team members were sent out to the Port to address intermittent unintended braking issues on the MPS with the dump bed attachment and a warning fault on the MPS with the scissor lift attachment. The dump bed MPS issues seemed to be caused by a connector terminal corrosion. The corrosion was removed by cycling the connectors and adding inhibitor gel. For the scissor lift unit, the error message on the screen was successfully corrected by cleaning the connector terminals, adding inhibitor gel and recycled connector. Shortly afterwards, the scissor lift had the intermittent unintended braking issues, as well, but was soon corrected.

In February 2021, the Port operators reported that the dump bed MPS was having issues hoisting 8 bundles of 30' rebar (12,000 lbs) above 6ft high and stopped at the 6-8ft level. This is a concern to the Port staff because many Port operations involve the lifting of materials and supplies above 6 feet. Most of the diesel units of the Port have the ability to hoist rebar above the 8 ft level. The Port also tested the lift abilities of the dump bed MPS without any rebar to test if the removal of material would make a difference. They found that the empty forks on the dump bed unit were able to hoist the full height of mast. In addition, the Port discovered that the dump bed MPS was able to hoist 20' rebar (8,000 lbs) without any complications as opposed to the 30' rebar. The scissor lift MPS was also tested and it was able to fully lift the 30' rebar (12,000 lbs) without any issues. Operators and maintenance staff also reported random braking issues with both machines. It was reported that the brakes were locking up at random times whether there was a load or not on the machines. The MPSs would operate for a few days without braking issues; however, the issues resumed and continued to occur intermittently. Due to the current limitations of the DANNAR units, the Port's productivity is hampered because they must restrict the number of operations the DANNAR units can perform. The DANNAR team is aware of the issues and working on solutions. Fortunately, the two MPS units remained in service at the Port despite the ongoing issues.

**COVID Challenges**

The COVID outbreak significantly impacted DANNAR's ability to provide further adjustments to the DANNAR MPSs due to travel cancellations. DANNAR has worked closely with the Port to further improve the DANNAR forklifts as material handling forklifts. DANNAR techs made several trips to the Port to improve the DANNAR MPSs speed, steering, and lift capacities. These trips came to a sudden stop in mid-March 2020 after the COVID outbreak halted non-essential travel across the United States. DANNAR reported that all trips to California were cancelled until further notice and no further improvements to the MPSs could be made until travel within the United States was fully restored. DANNAR worked with their component vendors to find a suitable timeframe to visit the Port and make the necessary adjustments so that the two MPSs could begin deployment and commence data collection. The Port would not deploy the DANNAR MPSs until the lift, steering, and speed functions were improved.

DANNAR was also unable to make trips to the Port during the months of April and May 2020 due to COVID travel restrictions, and resumed travel in mid-June 2020.

In December 2020, the State of California issued a travel warning limiting out of state travel to essential travel only due to COVID. This impacted DANNAR's ability to travel to the Port and make any repairs, updates, or provide training until the travel ban was lifted. DANNAR engineers and technicians are based out of their Muncie, Indiana facility, but they do have a sales representative in San Jose, California, who was able to visit the Port and provide feedback to the DANNAR staff in Indiana. DANNAR was also able to use some virtual tools such as Zoom to work with the Port and resolve issues remotely.

## 4.2.2 Recommendations

DANNAR and the Port have made the following recommendations to address the prominent challenges they encountered.

**Allow more flexibility with product configuration and autonomous vehicle control**

In the off-road construction industry, electronic joy sticks are the preferred control, or even wireless control. DANNAR did not incorporate these designs in the MPS at the Port because they allowed the Port to drive most of the product configuration. The Port, however, wanted a vehicle that mimicked a standard diesel forklift that included a wheel control and cab. These adjustments prevented the MPS from reaching their full technological potential that could have been achieved if more innovation was allowed.

**Design a vehicle model that facilitates technological transition for organizations with no prior advanced technological experience**

The Port requested for the MPS to have similar features to a standard diesel forklift because it would provide comfort and familiarity to the Port operators. Manufacturers may have to decide how they can cooperate with industries with no prior advanced technological experience but should also design a model that provides a seamlessly transitioning to EV technology. In this project, DANNAR designed a product what would meet the operational needs of the Port and also parallel the functions of a standard diesel forklift. The model did not completely satisfy the Port's needs because it did not fully match the functions of a standard diesel forklift. The mistake in this design was building a model that would imitate an existing piece of equipment and not focusing on other features that can only be achieved by EV technology.

**Test charging infrastructure prior to deployment**

Retrospectively, DANNAR admitted that many of the initial charging issues could have been prevented if they had tested the charging compatibility between the DANNAR MPSs and the ChargePoint chargers. They should have sent a part of the units to ChargePoint or ChargePoint should have sent a charger to Indiana to perform some testing for equipment compatibility.

DANNAR did verify that ChargePoint chargers charge BMW i3 cars, but they did not have the opportunity to test this with the MPS, which also uses BMW i3 batteries. That was a mistake and it should have been verified.

**Test MPS units prior to deployment**

The Port believes that many technical issues could have been avoided if the DANNAR units had been tested before they were delivered to the Port. The Port recommends DANNAR to perform at least 40 hours of testing at a similar facility and make any needed adjustments prior to delivery.

**Add safety features to the MPS prior to deployment**

The Port of Stockton was satisfied with the build quality but they had to make some adjustments to the MPSs such as changing the rails and adding safety steps for the operators.

**Install charging infrastructure near area where MPS is in greater use**

The original ChargePoint chargers were located in Shed 17, but since the MPSs were in use for daily rebar operations, it made more sense to drive them to the Port courtyard to recharge, instead of the original ChargePoint station.

They originally selected Shed 17 as the location to install the ChargePoint chargers because it was centrally located and had the power source to install the chargers without any major alterations. However, the courtyard was a more optimal location because that is where the MPSs were is greater use and need.

**Improve supply chain by increasing manufacturing of domestic products and materials**

Tariffs set by the American government on Chinese goods such as steel and axels impacted the timely delivery of material required to complete the build of the MPS. As a result, the delivery and deployment had to be delayed as well as the project timeline. This set back is occurring again for DANNAR, but this time with microchips. Many electric vehicles that require controllers on board and computational intelligence use microchips manufactured on foreign land. Supply delays are not normal, but industry is changing dramatically, and is exposing a break in the supply chain.

The solution is to do everything in-house. DANNAR believes American manufacturing is starting to see the value of that. If a product is required in mass supply, it is always ideal to vertically integrate as much as the process as you can.

**Train new staff before vehicle deployment**

DANNAR approached the training to the new technology at the Port by compiling training materials such as books to compliment the in-person training performed at the Port. DANNAR staff also stayed on site for a few days to answer any remaining questions. This approach was not effective because they found themselves needing to retrain. This training experience helped DANNAR be more prepared for new trainings with other projects.

The main change DANNAR would have made with this project is start immediately on the training and assign a project site manager whose sole responsibility would be to take care of the project. DANNAR would also start developing materials before the machines got built and work early with staff personnel to make sure DANNAR would bring the program that they were wanting and the outcome would be predictable. At the Port, DANNAR focused on the product first and then put a training program around that. This approach has been completely reversed with new projects and DANNAR has not had any issues moving forward.

**Address vehicles issues by targeting the root of the problem**

At the beginning of the project, DANNAR responded as quickly as it could to address the issues experienced at the Port. Since then, DANNAR learned that showing up quickly is not always the best approach.

DANNAR found that it was best to first fully understand the issues occurring with the MPS and discuss these concerns with management. Some of those issues could have been resolved locally with local organizations in California, or handled by another technician that was more appropriate for the situation.

DANNAR also found that responding quickly prevented them from addressing the root problem. DANNAR has shifted focus and is now implementing six sigma problem analysis and resolution to solve issues. Since then, they had more effective visits. DANNAR also made it a goal to fix a problem on the first visit and not have to return a second time. DANNAR has integrated lessons learned from this project with other ongoing projects and will continue to do so in the future.

#### **Partner with local agencies to service the vehicles**

DANNAR found that partnering with local agencies was an effective approach to servicing the vehicles. Every state typically has a county or two that has facilities and technicians that are well known amongst the people in that area. It makes better sense to allow another agency that is more familiar with the individual needs of the facility to service the equipment. Although, the technology is relatively new, there are still some aspects of the build that are similar to standard equipment, so local agencies are able to use previous knowledge to service the vehicles. More complex request can continue to be addressed by DANNAR until local industries begin to adapt to the new technology.

#### **4.2.3 Final MPS assessment**

The Port of Stockton's expectations, when joining this Project, was to have the DANNAR units operate as closely as possible to the baseline forklifts and serve as direct replacements. However, after several repairs and adjustments made by DANNAR, the Port determined that this direct replacement was not possible due to the current limitations of the MPSs as discussed in sections 3.7 and 4.2.1. The Port has determined that the DANNAR MPSs have considerable potential and uses for other tasks such as maintenance operations, but are currently not suited to replace the operations of standard diesel forklifts that have been used at their facilities. Continuous feedback from end users such as the Port can steer manufacturers like DANNAR to develop and tailor future equipment to better meet the needs of specific end-users. DANNAR has already begun utilizing the feedback from the Port to make such adjustments with current clients and other ongoing projects.

## **Chapter 5: Future Outlook of Electric Off-Road Equipment and Port of Stockton**

Emerging and new technology in any industry is typically assessed at great lengths whether it can meet industry's needs in a practical, and very importantly, cost-effective manner. Wide-spread acceptance of such technology can only be achieved if both can be met. Electric off-road equipment is poised to be the next technology that can be used in widespread applications to help reduce greenhouse gas emissions and criteria pollutants if barriers to adoption can be alleviated.

### **5.1 Purchase Price of Electric Off-Road Equipment**

Historically, the largest barrier towards adopting electric off-road equipment, including the DANNAR MPS, is the initial purchase price. Depending on the equipment make and configuration, a 30,000-pound diesel lift truck can cost a few hundred thousand dollars. The DANNAR MPS base unit is a

similar price without attachments and dependent battery configuration. However, once the added attachments and battery configurations are included, the cost of the units can cost significantly more than a conventional diesel unit. However, the advantage that the DANNAR unit has is its multi-functional capacities. The MPS is not only a heavy-duty forklift, but can also be a scissor lift, dump truck, and a mobile power station for vehicle charging. It also has the potential to hold numerous other attachments. The MPS is a tool that can be used to perform the various types of works needed at a facility while limiting the amount of heavy-duty equipment.

While incentive funding provided by the California Clean Off-Road Voucher Equipment could help reduce the price of a DANNAR MPS 4.0 by up to \$200,000, the program is no longer accepting applications due to lack of funds. As a result, there remains a significant incremental cost premium on the purchase price of electric equipment and without current state funding or incentives, fleets looking to acquire zero-emission heavy-duty equipment will continue to purchase or rent conventional diesel equipment.

Many entities, especially those in the San Joaquin Valley, work with limited budgets on an annual basis. Although many companies and public agencies recognize that electric off-road equipment is a much cleaner option, these fleets are often bounded to make fiscally pragmatic decisions because of limited funds in their budgets. Limited funding also prevents many agencies from investing in cleaner technology because of the higher purchase price. The funding under CARB's *Off-Road Advanced Technology Demonstration Projects* gave the Port the opportunity to take their first steps towards electrifying their off-road equipment fleet and building electric vehicle infrastructure by allowing them to leverage the funds they had budgeted. If prices for electric off-road equipment remain high, continued local, state, and/or federal incentive funding is needed to assist agencies with investing in such technology.

Should incentives be limited or unavailable, prices for electric off-road equipment needs to be competitive or on par with conventional fueled equipment. Electric off-road equipment can provide long-term savings from reduced fuel costs and less maintenance. However, the much higher upfront cost of electric units will deter many entities from making the decision to purchase them, especially since the technology is unfamiliar in comparison to conventional units.

Large scale electric equipment orders is the key to lower prices. When a large order of the same electric equipment is made, a manufacturer can make manufacturing efficiencies to streamline the build of the units, and in turn, can lead to reducing the price of the units. In addition, prices may be reduced as more manufacturers enter the market and can offer competitive vehicles at lower costs.

## 5.2 Limited Production of Electric Off-Road Equipment

During the initial application submittal and implementation of this Project, there were only a few manufacturers producing near commercial ready electric heavy-duty lifts. In addition, most of these companies were entering a new market compared to conventional fueled off-road manufacturers that have decades of manufacturing experience and development.

The interest for the DANNAR MPS has transcended various markets, in addition to the Port, such as the military, public works, and other fields. The market for equipment, such as the MPS, continues to grow and with additional funding from projects such as CARB's Zero and Near Zero-Emission Freight Facility Project, of which the Port is a participating fleet member, manufacturers will continue to further develop commercial ready zero-emission off road equipment.

DANNAR has been approached by several investors looking to finance growing companies and emerging technologies. The interest in DANNAR products is likely fueled by political discourse, green outlook, or the financial benefits that electric equipment will bring to a company. Additionally, the maintenance costs compared to conventional fueled vehicles is much lower, thus fleet managers are looking towards electric technology since it might yield more cost saving benefits than typical equipment.

### 5.3 Charging Infrastructure

In addition to a higher purchase price, fleets looking to invest in electric vehicles must also make significant investments to install infrastructure needed to charge the equipment. This is a task that is not required for conventional fueled vehicles, such as diesel and propane. Fortunately, the Port for this Project had sufficient power at its site to install electric vehicle chargers. If fleets wish to convert a large portion of their equipment to electric, they also need to assess if their facility has the power to charge all of their future equipment. In addition, agencies must also take into consideration the potential delays caused by charger maintenance and/or repairs that require their equipment to be offline for a lengthy period. Facility operations may be stalled if there are no chargers available to charge the electrical equipment.

The Project provided ChargePoint the first opportunity to participate in a project to charge off-road equipment. The limited experience did not affect ChargePoint because the BMW battery packs that were installed in the MPSs units are common and have worked historically well with ChargePoint chargers. As a results, manufacturers of electric off-road equipment are looking to use technologies that are well established in other electrical equipment such as light-duty vehicles so that there is an easy transition to the new technology.

To alleviate the cost barrier related to infrastructure installation, agencies have the option to utilize local electric vehicle charger incentive programs from air districts, utility companies or state incentive programs such as Carl Moyer, and the California Low Carbon Fuel Standard Credit Program (CLCFSCP). CLCFSCP generates credits that can be sold for revenue to offset the cost of charging electric vehicles once the infrastructure and vehicles are in service. If agencies wish to seek federal funding, the chargers must meet Buy America requirements or will not be able to access those funds.

## 5.4 Education for Drivers and Maintenance Staff

The Port did not own heavy-duty electric off-road equipment prior to this project, so this was its first experience with an electric manufacturer. The Port agreed that DANNAR provided thorough initial trainings and continued to provide detailed follow-up trainings to new operators during the course of the project. DANNAR used the feedback provided by the Port to develop more efficient training materials that will be used for future projects.

DANNAR also provided the Port maintenance staff with the training necessary to properly repair and maintain the equipment. However, due to the unfamiliarity of the technology, the Port would often reach out to DANNAR when an issue arose with an MPS and would halt the use of the unit until DANNAR staff members arrived at the Port. This would often lead to delays in getting the units back into service. Due to the evolving nature of off-road technologies, electric equipment manufacturers should be prepared to provide ongoing maintenance training to their customers so that they are able to stay up to date with the new equipment entering the market. Training programs are also needed to provide a reliable workforce for the growing EV industry. DANNAR is currently working with the local community college and universities in Indiana for engineer internships. The Port is also working with local workforce development, to establish trainees to work on this new type of equipment. These partnerships can be very beneficial to the community at-large and the fleets as they would open the doors for students to eventually apply for higher paying technical jobs repairing and maintaining new, clean technology.

## 5.5 Zero-Emission Off-Road Equipment for the San Joaquin Valley

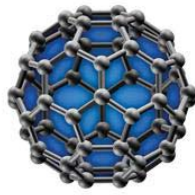
The ecosystem of zero-emission technology in the off-road industry can only flourish with the support and commitment from zero-emission off-road manufacturers, regulatory agencies, utility companies, charger manufacturers, and public agencies. A healthy, symbiotic relationship between each is necessary to advance zero-emission technology, especially in regions like the Valley where socio-economic disparities are pressing issues. The Valley is home to some of the most disadvantaged communities in all of California, including the area where the Port is located, which is a state recognized AB 617 community. Innovative clean technology is needed to improve the livelihood of residents on those communities. Unfortunately, many regional public agencies do not have surplus funds in their budgets to deploy costly clean technology, as much as they understand its importance and benefits to the local community.

Many Valley companies must overcome countless barriers in order to garner enough resources to undertake a project such as this one. This Project demonstrates that an agency, such as the Port, is willing to take the first steps in integrating zero-emission technology into its fleet for the benefit of its communities. The Port took the chance and opportunity to explore and experience a heavy-duty electric off-road forklift for the first time, and it is now able to utilize what it has learned to prepare for an expansion of more similar forklifts and other advanced technology off-road equipment.

Zero-emission equipment, such as the heavy-duty electric forklifts utilized in this Project, has growing demands in the Valley and can soon become the dominant technology in the off-road heavy duty industry. Many regional public agencies and companies are already developing plans to move towards using clean air technologies to minimize their carbon footprint and reduce their use and dependence on fossil fuels. Given the region's unique air quality challenges, regional public agencies and companies are eager to make these significant investments with the support of agencies such as the California Air Resources Board.

## 6.0 Appendix

### 6.1 Data Collection Report



**To:** David Lopez, SJAPCD  
**From:** Andrew Burnette  
**Copy:** Josh Pietak  
**Date:** 5/19/2021  
**Subject:** Test Plan for Comparing Baseline Forklift to Danner "Replacement"

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This Test Plan is for tests to collect data for comparing emissions and costs of using a Danner electric forklift in place of the conventional (baseline) forklift at the Port of Stockton. This is to occur under CARB Grant G16-DEMO-07.

During the past year, Port personnel have used Danner forklifts alongside the conventional forklifts for moving loads of steel rebar from stacks in the 900 Lot (in the West Complex) onto flatbed trucks. These tests are to measure the emissions and fuel used by the baseline forklift and the energy used by the Danner lift for doing the same work.

**Typical Duty-Cycle:**

The duty-cycle of the Danner units is simple. They are only used for putting up to three, 8-ton loads of rebar onto flatbed truck that come to the 900 Lot. The trucks are scheduled in groups of 1 to 3. There is usually a significant waiting time between groups of trucks. Most days one or two groups come to be loaded. Sometimes the lifts are used to take rebar off of trucks and put it into stacks (the reverse of their usual task). But that is rare. They are not used to move rebar from rail cars to stacks, which is how rebar frequently comes to the 900 Lot.

The test cycle will be designed based on the above duty-cycle. Using information from interviews with the forklift operators, a typical test cycle that captures the essence of the typical duty-cycle will be designed. The test will be replicated as many times as possible during the test day. The first test of the diesel unit will be a cold-start and subsequent tests will be tested as during a typical day of usage. So, for the diesel unit some will be warm-start and some hot-start.

During the moderate weather expected in the spring, we do not think the battery powered forklift will be affected by previous test usage, so tests of the electric lift will be conducted as is possible between tests of the diesel lift.

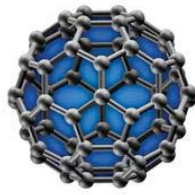
**Baseline Lift:**

The baseline lifts that previously performed the rebar loading task are Hyster 330, diesel powered lifts that conform to the 2016 emissions standards. They are powered by Cummins 6.7 L engines. The port fuels them with "red" (no road tax) number 2 diesel.

**Required Data:**

The data are to be used to estimate greenhouse gas emissions differences between electric and diesel lifts. They should also support the estimation of cost differences between the two rebar handling methods. The electric lift does not cause emission of criteria pollutants locally. SJAPCD has requested that we also measure all typical criteria pollutants from the diesel lift for informational purposes.

To facilitate intercomparison of the results, we should demonstrate that the two lifts are used for the same tasks during testing. We should obtain energy consumption data (electric for Danner and diesel fuel for Hyster). We should measure the concentrations of diesel exhaust components. (Greenhouse gas emission factors for producing the electric power consumed by the Danner lift will be obtained apart from testing via the California Air Resources Board.)



For the diesel lift, the data required are:

- DateTime (1-Hz)
- Criteria pollutant concentrations to allow calculation of emission factors on a “gram per kilogram of fuel” basis using gaseous and particulate analyzers
- An independent measure of engine speed to facilitate the synchronization of emissions and engine data
- Mass flow through the engine to allow calculation of fuel consumption during the test
- Ambient air conditions (temperature, humidity and barometric pressure)
- GPS data for vehicle location and speed
- Engine Control Unit data for calculating mass flow through the engine, tracking driver demand, vehicle speed and engine speed (for synchronization with the independent engine speed above)

For the Dannar lift, the data required are:

- Vehicle network data to track energy consumed to do the tests
  - o DateTime (1-Hz)
  - o Battery voltage
  - o Battery current
  - o State of Charge

#### **Diesel Emissions Measurement:**

A portable emissions measurement system that measures exhaust gases (gaseous PEMS) will be used to measure CO<sub>2</sub>, CO, O<sub>2</sub>, NO, NO<sub>2</sub> and total hydrocarbons in the diesel exhaust. The system is of the type used for on-road compliance tests and for in-use emissions research. It is manufactured by Sensors, Inc of Saline, MI and its model name is SEMTECH-DS. A brochure about the SEMTECH-DS is attached in an appendix.

A PEMS that measures exhaust particulate in real-time (PM PEMS) will be used to quantify the PM in the diesel exhaust. The PM PEMS is manufactured by 3DATX of Buffalo, NY and its model name is parSYNC. It uses three PM measurement methods simultaneously and a proprietary algorithm to determine PM concentration. It also measures CO<sub>2</sub>, CO, NO and NO<sub>2</sub>. At this point is used mainly in research and is slated for use in inspection/maintenance programs around the world, especially in Europe and China. A brochure about the parSYNC is attached in an appendix.

#### **Diesel Engine Control Unit:**

Data from the ECU of the Hyster will be recorded using a HEM OBD mini logger. Information on HEM data logger is attached in an appendix. It will be configured to log data on the CAN network of the forklift to track, at a minimum, engine speed and mass air flow. All publicly available parameters will be recorded.

#### **Dannar Electric Lift Data:**

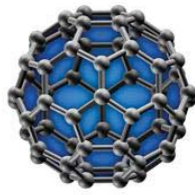
Data reported on the CAN network of the Dannar system will be recorded using CSS CAN loggers. Information on the CSS logger is attached in an appendix. Dannar has provided proprietary information for decoding the Battery System voltage and current and the SOC of the high-voltage batteries in the CAN data stream. All other parameters that Dannar has provided decoding information for will also be recorded.

#### **Test Preparation:**

The day before testing, the PEMS and data loggers will be installed and tested. They systems will be left installed and powered-on overnight. The day of testing the analyzers will be quality-assured. The diesel lift will not be started until all is ready and its first test has begun recording.

#### **Quality-Assurance:**

Before tests, the emissions analyzers will be checked for zero and calibration drift using certified calibration gases. In the field, the PEMS data will be reviewed in “real-time” for reasonableness. Between



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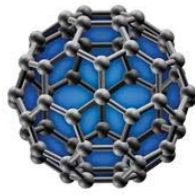
each test, the analyzers will all be checked for zero drift. After tests are completed, but before removing measurement equipment, the analyzers will be checked for both zero and calibration drift. Then the data will be post-processed (without time-alignment or zero drift correction) and reviewed.

**Data Handling:**

As the data are collected, the files will be copied and backed-up to a remote flash drive or other media. Test records will remain on the original media they were recorded on, as well.

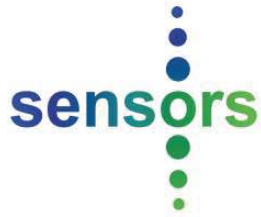
**Post-Processing:**

PEMS data will be time-aligned and evaluated for zero-drift correction. Then data from the PEMS and from the CAN loggers will be synchronized and parameters necessary for the comparisons between diesel and electric will be combined into a single data sheet. The original, quality assured data will remain in separate files for delivery to SJAPCD, along with the final data sheet and analysis results.



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**SEMTECH-DS INFORMATION**



Emissions  
Measurement  
Solutions

# SEMTECH<sup>®</sup>-DS

On Board, In-Use Emissions Analyzer

On Board  
Emissions  
Analyzers

Test Cell  
Emissions  
Analyzers

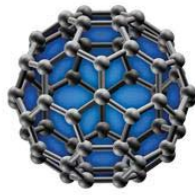
Emissions  
Testing  
Services

Environmental  
Applications



Since its introduction in 2002, Sensors' SEMTECH-DS has set the standard for Portable Emissions Measurement Systems (PEMS). Capable of monitoring the raw exhaust from both spark ignition and compression ignition engines, the DS measures CO, CO<sub>2</sub>, O<sub>2</sub>, NO, NO<sub>2</sub> and THC, ensuring compliance with EPA's CFR 1065. Sensors works closely with environmental regulatory agencies and engine manufacturers throughout the world, ensuring that the DS continues to define and raise the global standards for in-use vehicle emissions measurement solutions.

The DS comes complete with SENSOR Tech-PC, a powerful emissions software package, primarily intended for controlling the SEMTECH-DS and performing emissions calculations. Built-in flexibility with both digital and analog I/Os enables the user to interface with a number of auxiliary devices, and to set up the system in accordance with specific application needs. A wireless Ethernet connection can be used for communications between SENSOR Tech-PC and the SEMTECH-DS.



SEMTECH-DS  
On Board, In-Use Emissions Analyzer

## System Features and Benefits

**Heated FID Sampling:** The exhaust sample is maintained at 191°C, using a heated sample line, filter and pump, so as to minimize the loss of hydrocarbons prior to entering the FID chamber for analysis.

**Sample Conditioning:** A compact sample conditioning system is completely contained within the unit, minimizing contamination of the analyzers.

**NO and NO<sub>2</sub> measurement:** Proprietary NDUV measures NO and NO<sub>2</sub> separately and simultaneously.

**Vehicle ECM Data:** Vehicle ECM parameters are recorded with the emissions data, with support for 10 different protocols.

**Pressure Compensation:** Sample pumps operate at constant volume, regardless of ambient pressure, ensuring that transport times are independent of altitude.

**Calibration Utilities:** Easy setup and interface to zero calibrate, span and audit all gases, perform leak tests and purge the system.

**Test Setup Utility:** Offers the user maximum control over test parameters, detection levels and calculation limits.

**Post Processor:** Time aligns data and calculates real time mass emissions, raw emission concentrations and fuel economy.

**Shock Resistant Design:** Meets MIL-STD 810F for shock and vibration.

## Sample Installations



Heavy Duty Truck



Excavator



Passenger Car

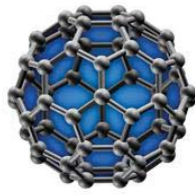


Snowmobile



Span Screen of SENSOR Tech-PC





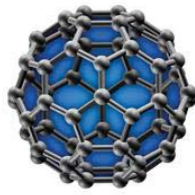
## SEMTECH-DS System Specifications

Gas	CO	CO2	NO	NO2	THC			
Range	0 - 8%	0 - 20%	0 - 2,500 ppm	0 - 500 ppm	0 - 100 ppmC	0 - 1,000 ppmC	0 - 10,000 ppmC	0 - 40,000 ppmC
Resolution	10 ppm	0.01%	1 ppm	1 ppm	0.1 ppmC	1 ppmC	1 ppmC	10 ppmC
Accuracy	±3% of reading or ± 50 ppm	±3% of reading or ± 0.1%	±3% of reading or ± 15 ppm	±3% of reading or ± 10 ppm	±2.0 % of reading or ±5 ppmC	±2.0 % of reading or ±5 ppmC	±2.0 % of reading or ±25 ppmC	±2.0 % of reading or ±100 ppmC
Linearity	Intercept ≤0.5 % of range 0.990 ≤Slope ≤1.01 SEE ≤1.0 % of range r <sup>2</sup> ≥0.998			Intercept ≤1.0 % of range 0.985≤Slope ≤1.015 SEE ≤1.0 % of range r <sup>2</sup> ≥0.998	Intercept ≤0.5 % of range 0.990 ≤Slope ≤1.01 SEE ≤1.0 % of range r <sup>2</sup> ≥0.998			
Repeatability	±2 % of reading or 20 ppm	±2 % of reading or ±0.05 %	±2 % of reading or 5 ppm	±2 % of reading or 5 ppm	±1.0 % of reading or ±2 ppmC	±1.0 % of reading or ±2 ppmC	±1.0 % of reading or ±10 ppmC	±1.0 % of reading or ±40 ppmC
Noise	±20 ppm	±0.02%	± 2 ppm	± 2 ppm	± 2 ppmC	± 2 ppmC	± 10 ppmC	± 40 ppmC
Span Drift	±2 % of reading or 20 ppm	±2 % of reading or 0.1 %	±2 % of reading or 20 ppm	± 10 ppm	±1.0 % of reading or 3 ppmC	±1.0 % of reading or 3 ppmC	±1.0 % of reading or 15 ppmC	±1.0 % of reading or 60 ppmC
Zero Drift	±0.005 % (50 ppm)	±0.1 %	± 10 ppm	± 10 ppm	± 5 ppmC	± 5 ppmC	± 10 ppmC	± 20 ppmC
Response Time	T90 ≤ 3 seconds	T90 ≤ 3 seconds	T90 ≤ 2 seconds	T90 ≤ 2 seconds	T90 ≤ 2 seconds	T90 ≤ 2 seconds	T90 ≤ 2 seconds	T90 ≤ 2 seconds
Flow Rate	2 lpm	2 lpm	3 lpm	3 lpm	2 lpm	2 lpm	2 lpm	2 lpm
Data Rate	0.833 Hz	0.833 Hz	up to 4 Hz	up to 4 Hz	up to 4 Hz	up to 4 Hz	up to 4 Hz	up to 4 Hz

Ambient operating temperature: 0°C to 45°C  
 Storage temperature: -40°C to 60°C  
 Sample flow rate: 8 SLPM  
 Sample rate: 1 Hz  
 Warm up time: 60 minutes, at 20°C ambient  
 Power requirements: 12VDC , 70A during warm-up, 30A at steady state  
 Communications: 802.3 (10BaseT) and 802.3u (100BaseTX) wired, and 802.11b or 802.11g (DSSS) wireless Ethernet  
 Chassis dimensions: 36cm x 43cm x 55cm (HxWxD)  
 Weight: 35.4kg (78 lbs)

NOTE: Specifications are subject to change without notice. While due caution has been exercised in the production of this document, possible errors and omissions can occur.

R 05/09



carbon **BLU**

**PARSYNC INFORMATION**



The integrated  
Portable Emissions  
Measurement  
Systems (iPEMS)  
that represents the  
next generation.



The parSYNC® PLUS includes a PM Sensor Cartridge AND a GasMOD™ Sensor Cartridge, which is easy to change out while in the field.

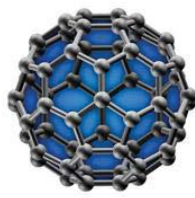
The software and hardware embedded in the parSYNC® PLUS is completely customizable and extremely valuable for the 3DATX user community. This broad spectrum and flexibility of analytical and reporting functions for fleet managers, manufacturers, consultants and regulatory compliance specialists is particularly useful as state, federal, and international Governments ramp up new emissions standards.

501 John James Audubon | Suite 200  
East Amherst, NY 14228

**3DATX.COM**



info@3DATX.com  
1.844.303.3289



# TECHNICAL INFORMATION

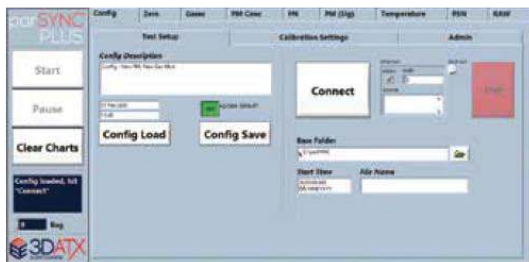
## parSYNC® Series Comparison

Specification	PTI	RDE	PLUS
Small Size and Lightweight	✓	✓	✓
Rugged & Weatherproof	✓	✓	✓
Low Power Consumption	✓	✓	✓
Wireless/Bluetooth Capabilities	✓	✓	✓
Easy to Maintain & Operate	✓	✓	✓
Replaceable PM/PN Sensor Cartridge*	✓	✓	✓
Replaceable GasMOD™ Sensor Cartridge*	✓	✓	✓
Real Driving Emissions (RDE) Compatible		✓	✓
Customizable			✓
Network Configured	✓		

\*PTI unit includes choice of 1 PM/PN sensor cartridge OR 1 GasMOD™ sensor cartridge OR Both

### Features and Benefits of the 3DATX parSYNC® PLUS iPEMS Unit

- Small-size/Light-weight = Easy transport to job site
- Low Power Consumption = A full day of testing
- Rugged, water tight, weather proof construction
- Wireless/Bluetooth capabilities
- Easy to maintain and operate
- Simple and elegant calibration process (CA/GE™ Particulate System, BAR97 Hi/Lo, etc)
- The only commercially available PM/PN-PEMS with a real-time particulate calibration system
- Fully automated LabVIEW® based software (customizable for specific requirements)
- Replaceable PM/PN Particulates Sensor Cartridge
- Replaceable GasMOD™ Sensor Cartridge (NO/NO2/CO2,NOX/CO2/CO, NOX/CO2/HC, etc.)



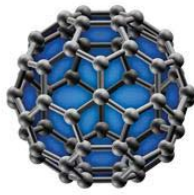
## We Make Transportation Decisions Easy



[info@3DATX.com](mailto:info@3DATX.com)



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## HEM OBD MINI-LOGGER INFORMATION

### HEM Data

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To discuss your application with an application engineer please call **800 436-4330** or email [info@hemdata.com](mailto:info@hemdata.com).

#### HEM Data Products

#### Navigation

### OBD Mini Logger™

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[DAWN Mini-Logger Video](#)



Click image to enlarge.

#### Overview

The DAWN OBD Mini Logger™ is a compact, low-cost data logger to acquire CAN bus data from cars and trucks. The logger installation is simple since it snaps directly on the J1962 OBD connector. The logger is so small that it fits in the palm of your hand.

DAWN software comes standard with the OBD-II database which defines over 100 parameters according to the SAE J1979 standard; 40+ being available on a typical car. It also includes the full J1939 database. The [DawnEdit™](#) software determines which parameters are available on the vehicle to create a unique database for each vehicle model. The user selects which parameters to acquire. Also, the user can add custom messages and parameters in DawnEdit to acquire proprietary messages.

The OBD Mini Logger can simultaneously acquire four types of messages:

1. Generic OBD-II – standard on all cars and light trucks after 1996 (mode \$01) as defined by J1979
2. Enhanced OBD – similar to a service scan tool database; specific to each OEM (mode \$21 and \$22)
3. Normal messages – transmitted for normal vehicle operation; no request messages required (These can be any CAN format including J1939 and CANOpen)
4. Direct Memory Reads (DMRs) – highly proprietary (mode \$23); reads controller's memory

[Acquiring Data Beyond Standard OBD-II Parameters...](#)

Soft LED indicators show the logger status without distracting the driver. A real-time clock with a battery backup syncs with GPS.

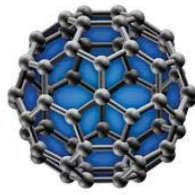
The [DAWN Mini-Logger Video](#) demonstrates how to configure the logger and convert the messages to scaled engineering parameters.

#### Standard Parameters

[List of OBD-II parameters](#)

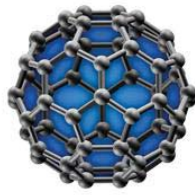
#### OBD Mini Logger Specifications

Protocols	
ISO 15765-4 (CAN, 11-/29-bit)	Yes
SAE J1850 PWM & VPW	Yes
ISO 9141-2	Yes
ISO 14230-4 (KWP)	Yes
SAE J1939	Yes
No. of Protocol Ports (Channels)	Two CAN channels (250, 500, 1000kbps)



<b>Real-time PC data</b>	Yes
RT Connections to PC	WiFi
<b>Stand-alone Logger</b>	Yes
Store Messages	Yes
On-board Storage	4GB internal storage. 64 GB option. <a href="#">How to estimate data size</a>
Auto Start-up	Yes
LEDs for status	RGB
Operating system	Proprietary RTOS
GPS (NMEA 0183)	Option. Internal to Mini Logger.
Wireless (WiFi)	Option. Internal to Mini Logger.
Cellular modem	Option. Internal to Mini Logger.
Real-time clock	Yes
<b>Analog Inputs</b>	
Internal Temperature Sensor	Yes
3-axis MEMS Accelerometer	+/-2.3 g. Resolution of .018g
Vehicle Battery Voltage	Yes
Expansion	Optional ADAQ Mini
<b>Environment</b>	
Size (inches)	OBD Connector: 1.9W x 0.70H x 1.5L
Size (mm)	48W x 18H x 38L
Supply Current:	80 mA. Up to 200mA with WiFi
Operating Temperature C	-40 to +70
Operating voltage	4 to 36V
Over/Under Voltage protection	100V including input capacitors to prevent a short circuit. Approved by several OEMs
Power Draw while sleeping	3 mA
<b>Warranty</b>	1 Year

**Data Storage & Transfer**



The OBD Mini Logger comes standard with 4GB internal storage (up to 64GB option). Manually transfer message files to a PC using USB. The oldest file is removed if the logger runs out of disk space. [How to estimate data size](#)

### Automated Data Transfers with WiFi and Cellular

WiFi or cellular are options to automate the file transfers to a website or local server. Files are removed from the logger after a successful transfer. If you prefer to use an HEM Data website to store and display data [click here](#) for a description of features and benefits. For details on the WiFi and cellular options [click here](#).

### GPS

GPS data is an option for the OBD Mini Logger. GPS Data syncs with vehicle data on conversion. [Click here](#) for details on GPS that is housed within the Mini Logger.

### Stand-alone Data Logger or Real-Time Display

If you need real-time display of the data on a PC or smartphone, then you can use the [DAWN Mini Streamer™](#) and logger together. The smartphone can then upload the necessary information over cellular to a website for summary and analysis. The Mini Streamer sends OBD, CAN and J1939 data.

### Analog Data

The [Mini ADAQ](#) acquires analog data directly from sensors and outputs CAN data to a Mini Logger. Input types including voltage, current, temperature (thermocouple & thermistor), digital, frequency, PWM, and inclination. [Click here](#) for ADAQ details. The logger can store analog and vehicle data simultaneously.

### Hybrid Test Data

To learn about DAWN and hybrid test data see [this page](#).

### Future Enhancements

Check with HEM Data for availability for support of these future enhancements: Bluetooth, and smartphone.

### Options

Options include:

- [Internal GPS receiver and antenna](#)
- [Internal WiFi receiver and antenna](#)
- [Cellular](#)
- [DawnPlot](#)
- [Enhanced OBD \(EOBD\) databases](#) relating transmitted messages to parameters of interest

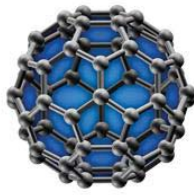
### Connectors



OBD Mini Logger

J1962 Automotive Adapter

J1962 Pin	J1962 Pin Description
1	Discretionary* (GMLAN SW CAN Line)
2	+ line of SAE J1850
3	CAN2+, (GMLAN MS CAN H),
4	Chassis/Case Ground
5	Signal Ground
6	CAN+, GMLAN HS CAN H
7	K Line of ISO 9141-2
8	Discretionary*
9	Discretionary* (GM ALDL)
..	.. .. .



11	CAN2-, (GMLAN MS CAN L), Short to ground
12	Discretionary*
13	Discretionary*
14	CAN- (GMLAN HS CAN L), Short to ground
15	L line of ISO 9141-2
16	Unswitched Vehicle Battery Positive

**Logger Comparison**

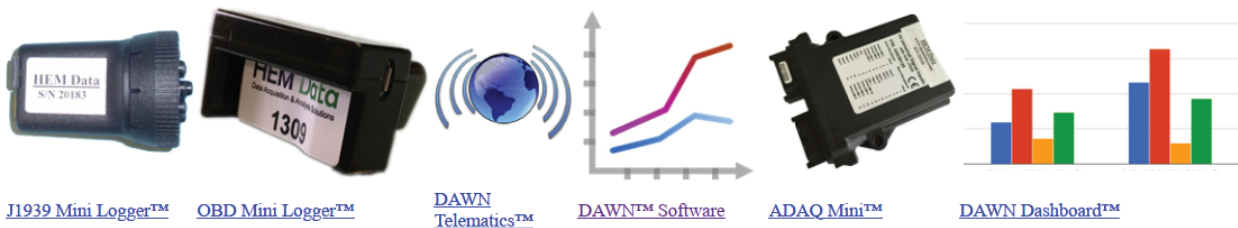
Feature	OBD Mini Logger	J1939 Mini Logger
16 pin J1962 OBD Connector	Yes	Needs an adapter cable
9 Pin J1939 Deutsch Connector	Needs an adapter cable	Yes
CAN channels (networks)	2	Version 3=1; version 4=2
OBD-II J1979 support	Yes	No
J1939 Support	Yes	Yes
J1708 Support (older HD protocol)	No	Yes
Legacy OBD protocols	Yes	No
Raw CAN (Normal messages, CANopen)	Yes	Yes
Cellular	Yes	No
WiFi	Yes	Yes
GPS	Yes	Yes
External uSD card for data storage	Version 3	Version 3 & 4
Internal data storage only	Version 4	No

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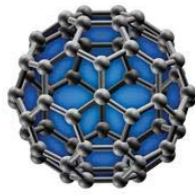
- [DAWN Products](#)
  - [OBD Mini Logger™](#)
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 800.436.4330 • 248.559.5607



## CSS CAN LOGGER INFORMATION



### CLX000

Low cost CAN logger & interface



**PLUG & PLAY:** Log data out-the-box. Standalone. Power via CAN connector



**STREAM:** Stream data in real-time to PC via USB in Wireshark



**STANDALONE:** Log CAN data to 8-32 GB SD card (no PC needed). RTC (CL2000)



**FREE SOFTWARE:** All software is 100% free. DBC convert data via simple Windows GUI tool



**COMPACT:** Only 7 x 4 x 2 CM. 50G. 3 LEDs. Mini USB port for SD extraction + streaming



**LOW COST:** Lowest cost CAN logger & interface on the market

The plug & play CLX000 is a simple-to-use CAN logger. The device logs CAN data to an 8-32 GB SD card or streams it via USB to a PC.

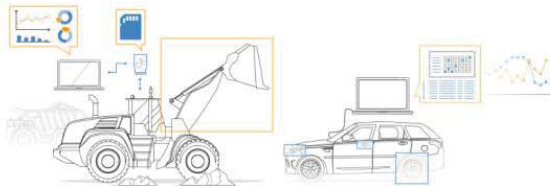
For the CL2000, data is date & time stamped via a real-time clock with battery backup.

The CLX000 is used in blackbox logging, reverse engineering or simple telematics use cases. For logging or WiFi use cases, see also the '2nd generation' CANedge series.

### Compact CAN logger + interface

The CLX000 lets you log raw CAN data to an 8-32 GB SD card - 100% standalone with no PC required:

- Power via CAN connector (<1W power consumption)
- Auto-detect bit rate - no configuration required
- Log raw CAN data in simple \*.CSV format
- Easily extract data from the SD card via USB
- Configure device via simple CONFIG.INI file
- Silent mode, filters, transmit lists, cyclic logging
- Timestamp data via real-time clock (CL2000)
- Stream data in real-time via USB in Wireshark
- DBC convert logged/streamed data via free software



### Technical specs

#### GENERAL

Safety	CE, FCC, IC certified
Warranty	1-year warranty
Support	Free, fast & high quality support
Origin	Denmark
Software	100% free
Documentation	Online/PDF <a href="#">documentation</a>

#### CAN BUS

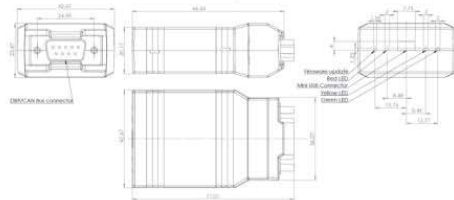
Channels	1 x CAN (Classical)
Protocols	J1939, OBD2, CANopen, NMEA2000, ...

#### DATA LOGGING

SD CARD	8-32 GB SD card (extract via USB)
Real-Time Clock	1 ms resolution (CL2000)
File format	CSV-style plain text format
Safety	100% power safe
Configuration	Simple configuration options

#### MECHANICAL/SUPPLY

Connectors	1 x DB9 (adapter cables available)
Input supply	+7V to +32V DC via DB9
Consumption	<1W
Dimensions	66.7 x 42.7 x 23.5 mm (L x W x H)
Weight	50 G
LEDs	3 external LEDs (PWR, DATA, MEM)
Temperature	-20 degC to +65 degC
IP rating	IP40



Trusted by engineers at leading OEMs

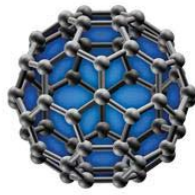


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**To:** David Lopez, SJAPCD  
**From:** Andrew Burnette  
**Copy:** Josh Pietak  
**Date:** 30 June 2021  
**Subject:** Report on Data Collection for Grant G16-DEMO-07

---

### **Introduction:**

This Data Collection Report covers all activity by carbonBLU under a contract with the San Joaquin Air Pollution Control District and funded by CARB Grant G16-DEMO-07. The purpose of the grant award was to assess the feasibility of using a modified Danner 4 MPS (battery-electric powered) to replace “baseline” diesel forklifts in certain, specific use at the Port of Stockton.

The specific use occurs in the port’s “900 Lot” in its “West Complex.” Bundles of steel rebar are brought to the lot by rail. They are moved onto the 900 Lot into stacks by large material transport equipment. From those stacks, they are loaded onto flatbed trucks for distribution around northern California using diesel forklifts rated for loads up to about 30,000 lb. During this project, they were also loaded onto the trucks using the Danner systems and some other electric equipment from other, similar projects running at the same time.

carbonBLU (cB) was contracted by SJAPCD to replace a grant team member as a third-party data collection service provider. Having come to the project late, cB spent significant effort coming up to speed on the project and determining how best to fulfill the role committed to by the former team member.

The guide for our activities was embodied by a bulleted list in Appendix F of the grant contract. So, this report is organized largely in accord with that bulleted list. First, we summarize the Baseline-to-Danner comparison results, then we summarize the “Appendix F” results. Details behind the results are contained in the appendices to this document.

### **Baseline-to-Danner Comparison:**

The primary purpose of the project is to see whether the battery-electric Danner system (modified for use as a 30,000 lb rated forklift) can feasibly replace the diesel powered 30,000 lb rated forklifts used in the 900 Lot for loading flatbed 18-wheelers with rebar. Feasibility is subjective. Here, a judgement of feasibility requires; costs, ease of use, efficiency of loading and emissions of greenhouse gases and criteria pollutants. In this comparison summary, we first describe the systems compared, then we summarize the results required for a judgement of feasibility.

#### *Comparison Units: Baseline and Electric Forklifts*

The typical forklift for loading rebar in the 900 Lot is well-represented by the Hyster 330 diesel powered system. Of these, the most used for rebar is a recent model (2017) rented by the Port from Papé Rents, who also services the unit.

The electric forklift is based on a system manufactured by Danner called MPS (Mobile Power System). Their base system is designed so it can be modified in many ways, for many uses. In this case, it was outfitted with a forklift on the front and a manlift on the back. It used lithium-ion battery backs (124 kWh total capacity) sourced from BMW, had a large counterweight added on the end opposite to the forklift and had “dually” wheels all around to distribute the much larger than normal weight of these modifications. Proper operation of the heavy forklift required substantial upgrades to the standard hydraulics on the unit. Photos of the two comparison units are shown in Table 1.

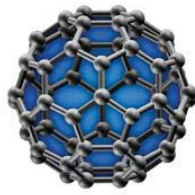


Table 1. Photos and Descriptions of Forklifts Compared



Baseline Lift: 2017 Hyster 330 (diesel)



Electric Lift: 2019 Danner 4 MPS (LiO battery)

*Overall Diesel to Electric Comparison in the 900 Lot*

The data required to make this comparison include historical rebar throughput in the 900 Lot, cost of ownership and use for both units and information for estimating typical emissions caused by the loading of rebar with both systems. Much of this information came from the records of the Port. But an emissions test was contractually required for comparing the emissions. This was accomplished by designing a typical duty-cycle for putting rebar on trucks and performing that duty-cycle multiple times with each system. Emissions from the baseline system were directly measured and those from the Danner were estimated by recording the electric power used and applying carbon-intensity estimates for electric power from the California grid.

Not only the equipment in this project are used in the 900 Lot for rebar. Other electric equipment has been introduced at the same time as the Danner units. So, to give an idea of the possible overall impacts of using electric equipment for rebar, we looked at overall data for the 900 Lot. Figure 1 summarizes quarterly rebar loading and heavy forklift refueling in the 900 lot from early 2019 through early 2021.

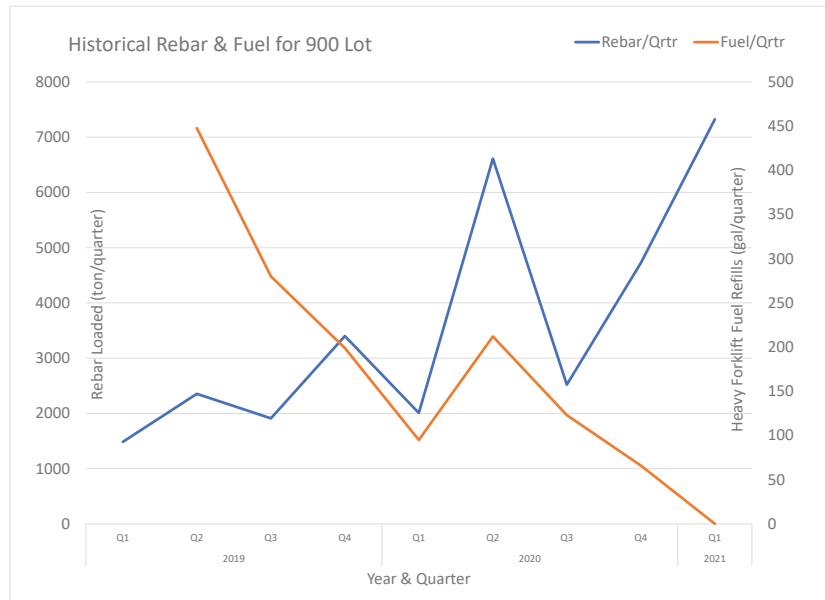
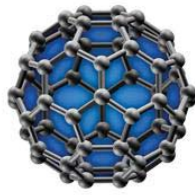


Figure 1. Historical Rebar Tonnage and Heavy-Lift Fuel Refills in the 900 Lot



Electric lifts, including the Dannar units, have been introduced in the 900 Lot since mid- to late- 2019. The plot shows that, despite increased rebar tonnage, fuel use in the 900 Lot has consistently declined as more electric equipment is used there. In fact, there were no heavy-lift diesel refills in the 900 Lot during the first quarter of 2021. However, since the electrics were not purely from Dannar and since the diesel for heavy lifts was not used exclusively in the Hyster 330s or only for rebar loading, we must use other data to compare baseline to Dannar. The emissions tests performed while both the Dannar and the baseline Hyster 330 did exactly the same work provided those data.

*Rebar Loading Intercomparison Test Results*

The duty-cycle of the Dannar units is simple, when they did load rebar, on average they would load 2 or 3 trucks in a row and in a predictable manner. So, to compare them on a fair basis, both the baseline diesel Hyster and the Dannar systems were tested using the same duty-cycle multiple times. Emissions from the diesel were measured using portable emissions measurement systems typical for compliance testing (gases) and research (particulates). The activity of both the electric and the diesel were also recorded using on-board electronic data loggers. A copy of the test plan for those measurements is provided in Appendix A.

The two systems were tested multiple times on exactly the same cycle:

- start in the normal parking location,
- drive to the stack of rebar,
- load the first truck with three loads of 8-tons each,
- load the second truck the same way,
- drive back to the normal parking spot.

Since both the baseline diesel and the electric systems were used for the same work, the test data provide a much more reasonable and accurate intercomparison than the historical data from the Port. The conduct and results of the comparison test program are described in a report delivered to the SJAPCD under separate cover<sup>1</sup>. Table 2 summarizes the results of the intercomparison tests.

*Table 2. Summary of Diesel to Electric Intercomparison Tests: Loading Two Trucks*

Average Test Results for Baseline Diesel Forklift (Hyster 330)

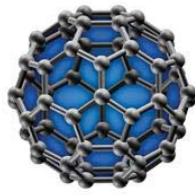
Duration	Test Totals			
	Fuel	CO2	NOx	PM
<i>sec</i>	<i>kg</i>	<i>g</i>	<i>g</i>	<i>mg</i>
629	1.35	4304	8.30	82.0

Average Test Results for Electric Forklift (Dannar 4 MPS)

Duration	Test Totals	
	Fuel	CO2e
<i>sec</i>	<i>kWh</i>	<i>g</i>
987	5.86	1751

It took the baseline forklift 10.5 minutes (629 seconds) on average to complete the cycle while it took the Dannar system 16 minutes (987 seconds) on average. The significantly slower result for the Dannar was because of how it steers and other control issues. Many of these issues are related to the “prototype/first-design” aspect of the Dannar and can probably be remedied through continued programming tweaks and minor modifications. But some cannot, such as the mechanical differences between the steering strategy of conventional forklifts and the Dannar system. These design differences

<sup>1</sup> See report titled, EMISSIONS INTERCOMPARISON TESTING RESULTS, dated June 30, 2021.



are a shortcoming for the Danner system when used as a forklift where tight maneuvers and true “inching” are important, such as loading trucks.

On average, the baseline unit used about 1.4 kg of fuel to complete the test cycle while the Danner used 5.9 kWh of battery storage. The diesel fuel tank has a capacity of about 130 kg (41 gal) of diesel and the Danner unit has a battery capacity of about 100 kWh. So the baseline unit used a bit more than 1% of its fuel capacity to load 2 trucks and the Danner used a bit less than 6% of its fuel capacity. Based on these results, the most trucks these systems could load when starting with a full tank/battery is 185 for the diesel and 33 for the Danner.

On average, the baseline diesel forklift emitted over 4300 grams of CO<sub>2</sub> to load 2 trucks with rebar. For the same task, the Danner system caused the emission of a little more than 1750 grams of CO<sub>2</sub>-equivalent due to it drawing the power stored in its batteries from the California electric grid.

In addition to the diesel emitting almost 2.5 times more CO<sub>2</sub>-equivalent than the Danner, the diesel also emitted criteria pollutants in the vicinity of its operation (i.e., 8.3 grams of NO<sub>x</sub> and 82 milligrams of fine particulates). These quantities are extremely low. For example, even after several years of operation, there were no soot deposits in the exhaust pipe of the baseline forklift. In normal operation around the port, it is doubtful if human senses would ever detect the exhaust from these units.

However, criteria pollutants can be harmful if breathed in high enough concentrations or with continuous exposure. Also, under the right conditions, they can interact with other atmospheric pollutants to create photochemical smog and secondary particulates. This secondary aspect of their harmfulness is also contributed to by the generation of electricity in California. So, one major advantage for the Danner is that battery-electric systems emit no pollutants in the vicinity of operations and cannot impact the exposure of people to harmful exhaust pollutants in the workplace.

#### *Estimate of Annual Costs and Emissions*

##### *Cost Inputs*

##### *Equipment Costs*

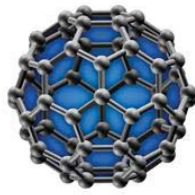
The baseline forklifts are typically purchased by the Port via a “rent to own” arrangement with Papé Rents. They get a special deal from Papé, probably not available to most owners. So, instead of using the Port’s special prices, we chose to use a typical price for the baseline system and estimate annual capital costs using a loan model that mimics their rental model. Their rentals typically last 3 years before the equipment is owned by the Port outright. We used this same approach to model the costs of obtaining the Danner system as well. The typical price of a 2017 Hyster 330 lift as configured for the port is \$240,000. If financed with a 3-year loan, paid monthly at a 3% annual percentage rate, the 36 payments would be about \$7,000 monthly. Typical maintenance plans for these systems cost about \$400 monthly.

The Danner systems for this project cost the Port an average of \$375,000 each. These were highly modified systems, configured for lifting loads of up to 60,000 lb (which was “a first” for Danner). So, these designs included unusual costs and design strategies and software that were not yet optimized. (Optimization of the software is an iterative process over an extended usage period.)

As a result, the costs used here are undoubtedly higher than would be incurred for later similar orders (should they occur). As a point of reference, an unmodified Danner system with an equivalent battery pack would cost around \$220,000. But for this comparison we use the higher cost. That, along with the same assumptions for financing, results in 36 monthly payments of \$10,900 to purchase the Danner system.

##### *Planned Maintenance*

Planned maintenance costs for the Danner systems is not yet known. But they are thought to be extremely low by comparison to the diesel systems. Danner personnel said a study by the University of



Nebraska estimated that only 2 labor hours per month would be needed. So, we have estimated about \$100 per month would be charged under a maintenance service plan.

#### *Fuel Costs*

The red dye diesel the Port uses in their equipment is not subject to road taxes, hence its cost is about \$0.4 less than the average cost for on-road diesel. This came out to about \$3.10 per gallon during the 2-years being modelled here. For recharging batteries, the Port provided their electricity rates, which are \$0.234/kWh during Peak hours (from 4 to 9 PM for PG&E) and \$0.133/kWh during Off-Peak times. Given the timing of the Peak rate hours, we estimated the electricity rate for recharging these units to be the average of the Peak and Off Peak rates, or \$0.184/kWh.

#### *Fueling Infrastructure Considerations*

Infrastructure costs for refueling can be significant. However, in this case we have not estimated the fractional costs of refueling infrastructure and labor attributable to these two systems. The re-charging of battery-electric equipment at the Port is still evolving, with significant and un-resolved communications issues between some of the equipment and chargers arising near the end of the project period. Since the fractional costs of infrastructure are not a major influence on purchasing individual pieces of equipment, we only briefly discuss them here.

Off-road diesel equipment at the port is refueled by a fuel truck owned and operated by the Port. The battery-electric systems are refueled by a newly installed network of recharging stations around the port consisting of both slow-charge AC and fast-charge DC stations.

Since the charging stations are located near where the electric equipment is used, the labor and equipment maintenance for refueling the diesel equipment is most likely larger than for recharging the electric equipment – and the diesel labor and maintenance are recurring expenses. The infrastructure costs for installing the charger network is much higher than for the diesel system. But the purchase and installation are one-time expenses and associated recurring expenses, such as replacement of worn parts will be minor compared to the diesel system.

#### *Driving Labor*

The two systems have a significantly different speed of completion for the typical truck load, so we estimated the annual labor cost difference between the systems. According to the Port, a reasonable driver labor rate is \$28/hr.

#### *Emissions Inputs*

Annual Emissions are calculated by estimating annual rebar loading volume and then using the Emissions Intercomparison Test results to extrapolate the emissions per rebar truckload into annual emissions.

The quarterly historical throughput of rebar in the 900 Lot was obtained from the Port for 2019 and 2020. As presented previously (in Figure 1) the quarterly rates varied substantially over the 2-year period, averaging out to about 3127 tons/quarter. If the type of trucks that transport rebar from the 900 Lot were to be fully loaded with that amount of rebar, a total of 130.5 truckloads per quarter would be required.

During the Emissions Intercomparison Tests, each test cycle included fully loading two hypothetical trucks. Since the average emissions from that test program are representative of a typical “high-traffic” loading day, we simply multiply those “per test” emissions by one-half the number of trucks per year to estimate the emissions in a year.

#### *Summary of Annual Costs and Emissions*

Table 3 summarizes the costs and emissions of the baseline and the Dannar systems as we modeled them using the assumptions above. Input assumptions are given first. Then the annual cost items are presented. Then, in the Outputs section, the total annual costs are shown in two parts: during and after the purchase debt is serviced. Finally, the emissions totals are presented.

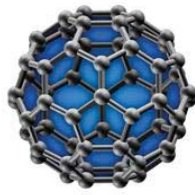


Table 3. Comparison of Modeled Costs and Emissions Between Baseline and Dannar

		<b>Annual Rebar Loaded</b>	
		12507 tons	
		<b>Annual truck-equivalents</b>	
		522 truckloads	
		<u>Baseline Diesel</u>	<u>Dannar</u>
Inputs	Driving Labor:	1277 \$/yr	2003 \$/yr
	Annual Fuel:	110 gal/yr	1529 kWh/yr
	Cost of Fuel:	342 \$/yr	281 \$/yr
	Planned Maint:	4800 \$/yr	1200 \$/yr
	Equipment Cost:	240,000 \$	374,500 \$
		<i>36-month note at 3% APR, so...</i>	
	Debt Service:	83,760 \$/yr	130,680 \$/yr
		<b>Total Costs: First 3 years (paying debt)</b>	
		90,179 \$/yr	134,163 \$/yr
		<b>Total Costs: Thereafter (no more debt)</b>	
		6419 \$/yr	3483 \$/yr
Outputs	<b>Emissions</b>		
	Equivalent CO2:	1123 kg/yr	457 kg/yr
	Local NOx:	2166 g/yr	0 g/yr
	Local PM:	21 g/yr	0 g/yr

Under these assumptions (which, for the Dannar, are probably high due to capital cost over-estimate), for the first three years of use, there is substantially more cost of running the Dannar instead of a diesel forklift. So, in paying the capital cost of the equipment, the Dannar owner would spend about \$130,000 more. But after the debt had been fully paid, the Dannar would be about \$3,000 less per year.

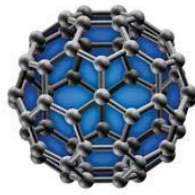
The issues of cost and emissions for loading rebar in the 900 Lot are important. But it is easy to see that the volume of rebar, at around 500 truckloads per year, is not high enough to keep forklifts busy more than a few days a week. So, equipment that can be used for other purposes, will also score higher on the “feasibility” rating for the Port.

**Other Baseline and Dannar Uses**

The Port has traditionally purchased equipment that can be put to many uses around the facility. And, when it is not being used by the Port, they prefer that their equipment be widely understood and usable, so they can rent it to their tenants to generate additional revenue. For example, in addition to loading rebar, the Hyster 330 lifts are sometimes rented to the Longshoremen for moving rice bags.

In the near-term, renting to tenants will not likely be possible with the Dannar units. They are different enough from traditional off-road equipment that the Longshoremen (for example) would require about a 6-month training and transition process to incorporate them into their operations. This is due to union policy. But the Port has said they will likely be used by Port maintenance crews around the port (the manlift option was mentioned as especially useful).

Since they can be also used as a mobile recharge station, they will likely also be used for emergency recharging of other battery powered equipment. The Port expects that sometimes battery-electric units



will have their batteries drained to the point that they are unable to reach a stationary recharge station. So the Danner units are to be kept fully charged and ready to respond to those situations.

### **Other Data Collection**

This section is to fulfill the requirements in the Contract, Appendix F. We list the Appendix F bullets verbatim from the contract and describe or show the data collected to fulfill each requirement. The Appendix F bullets are italicized, and many answers are subdivided into a “Baseline” part and a “Danner” part.

*Vehicle specification (e.g., manufacturer, model, model year, gross vehicle weight, fuel capacity etc.)*

#### Baseline

The baseline vehicle was a Hyster 330 forklift using diesel fuel conforming to the off-road standards for 2017. Its fuel tank has a nominal 42-gal capacity, and it is rated to lift 33,000 lb loads.

#### Danner

The Danner is a battery-electric multi-use vehicle outfitted as a combination of a 30,000 lb forklift with a manlift on the back (in one case) and with a dump on the back (in the other case). The manlift version has three, 33 kWh Lithium-Ion battery packs (for a nominal 99 kWh capacity) and the dump has four of the same battery packs (for a nominal 132 kWh capacity).

*Full propulsion system specification, including legible engine label photos.*

#### Baseline

Full documentation was provided in the first quarterly report to SJAPCD. Refer to “CARB-Grant-G16-DEMO-07\_StatusReport-01-v5.pdf” sent via email in early December, 2020.

#### Danner

Both Danners are fueled by BMW Lithium-Ion battery packs (for the BMW i3 Series). The prime mover is made by UQM and is rated at 950 N-m of torque. The custom hydraulics package was designed and provided by Parker Hydraulics and the axles are by Dayna. The normal single wheels have all been upgraded to dual wheels to better distribute the road pressure from the added weight of the large capacity forklift attachment (rated at 30,000 lb) and the large counterweight required for such lifts. Photos of the two units are shown here, in

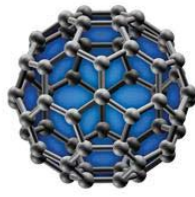


Table 4. The units have no engine labels, so their serial numbers are recorded in the captions below their photos.

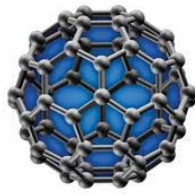


Table 4. Photos of the Dannar Units



Unit with 30,000 lb forklift and manlift  
(SN: MPD413219003)



Unit with 30,000 lb forklift and dump  
(SN: MPD409919004)

*Vehicle usage, e.g., hours of operation per day, days of operation per year, odometer reading.*

#### Baseline

The baseline systems were used in multiple areas besides the 900 lot. And even when located in the 900 lot they were often used for other actions besides rebar loading. Therefore, it is a more accurate picture for comparison to the Dannar systems to use the Intercomparison Test Report results. However, the actual usage of the baseline systems was captured in logger data from July 2020 until February 2021. These were provided via upload to share drive. The more accurate extrapolation of activity in the 900 lot is summarized in the first section of this report and more fully described in the Intercomparison Test Report, provided under separate cover.<sup>2</sup>

#### Dannar

The loggers in the Dannar systems recorded activity from July 2020 until May of 2021. However, as for the baseline systems, the Danners were not used as they will be in their final deployment. So, to get a more accurate picture of annual use expected for these systems, refer to the Intercomparison Test Report, provided under separate cover.<sup>3</sup>

*GPS data (must be able to distinguish between key off and key on but not moving) if vehicles are operated outdoors.*

#### Baseline

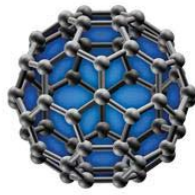
GPS is included in the logger data to help distinguish between when being operated in the 900 lot or elsewhere. Ability to distinguish between key-off and key-on, not moving is included.

#### Dannar

The Dannar was not equipped with GPS. Other than for training drivers, they were only used for a specific and well-defined duty in the 900 lot – loading rebar onto flatbed trucks. Otherwise, they were idle or being recharged.

<sup>2</sup> See report titled, EMISSIONS INTERCOMPARISON TESTING RESULTS, dated June 30, 2021.

<sup>3</sup> *ibid*



*General description of daily use of vehicles/equipment.*

The duty-cycle of the Dannar units is simple. They are only used for putting up to three, 8-ton loads of rebar onto flatbed truck that come to the 900 Lot. The trucks are scheduled in groups of 1 to 3. There is usually a significant waiting time between groups of trucks. Most days one or two groups come to be loaded. According to the operators, sometimes the lifts are used to take rebar off of trucks and put it into stacks (the reverse of their usual task). But that is rare. They are not used to move rebar from rail cars to stacks, which is how rebar frequently comes to the 900 Lot.

*Duty cycle logging and load analysis.*

This is described in the first section of this report, where we describe the duty cycle of the forklifts that load rebar in the 900 Lot. Also, at the end of the first section of this report, the total load over the year is described in our comparison of the efficiency and cost of using the two forklift types for loading rebar in the port.

*Average speed and idling time (if not already captured in the duty-cycle logging, also applicable to yard trucks).*

Baseline

Average speed is not applicable off-road material handling equipment. Idling time is minimized since trucks are prepared for receiving rebar loads before the forklifts are sent to load the trucks. Also, this information is included in logged data.

Dannar

Same as for baseline, except this information is not included in the logged data.

*Odometer reading (beginning and end of each shift, also applicable to yard trucks).*

Not applicable for off-road material handling equipment. Hours of operation can be imputed from activity logger data, but these are not considered representative due to the combined, parallel use of the baseline and the Dannar systems.

*Measure or estimate the weight of each load/lift (applicable to forklifts and top handlers); weight of load per container moved (applicable to yard trucks).*

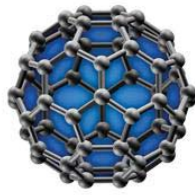
This was estimated from the well-defined duty cycle of loading rebar in the 900 lot. The layers of rebar stacks are each 8-tons, so each forklift load onto a truck is the same. A maximum of three loads are put onto each flatbed truck. The maximum is usually loaded.

*Workflow modifications with advanced technology vehicles/equipment, if any.*

Workflow was not modified significantly. However, the Dannar cannot make as tight of turns as a conventional forklift. It, therefore, must make more position adjustments (forward and reverse) during the positioning process. This causes the loading process to go from about 10.5 minutes with the baseline systems to a little over 16 minutes with the Dannar.

*Performance during normal work week vs, peak (i.e., holiday, overtime, double shift, high temperature or low temperature etc.)*

Not applicable. No holiday work or peak times apply for the 900 lot and rebar.



*Vehicle productivity/performance profile (acceleration, lift/lower speed. Ramp speed) — beginning (full battery/tank) vs. end of shift (low battery/tank),*

Baseline

Due to the low volume of rebar, performance profile is not expected to change during a shift. The baseline forklifts are not allowed to run low on fuel. They are typically filled after having used a small fraction of their tank. For example, the Hyster 330 has a 42 gal tank, the average fill during 2019 was less than 8 gal and only 7 out of 77 fills were over 15 gal.

Dannar

Same comment as for the baseline – there was no perceived (or expected) change in performance during a shift. Once the current charging issues are worked out, we do not expect the Dannar systems to ever be allowed to get near low SOC values. They will be kept fully charged so they are ready for unexpected rescue calls to recharge stranded battery-electric systems. Also, the Dannar uses an average of slightly less than 6% SOC to load two trucks. The highest quarterly-average truck volume during the past two years was 4 trucks/day, so the Dannar is not expected to ever reach a low SOC.

*Comparison of an appropriate productivity metric with advanced technology vs, baseline vehicles (i.e., forklift/Lifting equipment: pallets moved per shift or day; yard tractor: container pulls per shift or hour).*

The productivity metric in this study was loading two flatbed trucks with three loads of rebar each (a total of 24 tons/truck). This is a typical duty-cycle for loading rebar in the 900 lot.

Baseline: The baseline system took an average of 10.5 minutes to complete the task, using 1.35 kg of diesel.

Dannar: The Dannar system took an average of 16.4 minutes to complete task, using 5.86 kWh of battery power.

*Battery degradation (battery charge capacity/power output over the length of the project).*

None was observed or expected. The battery systems were not exercised enough during the project to exhibit degradation.

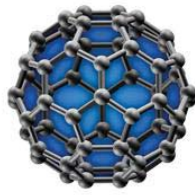
*Amount of fuel/electricity; date; fuel price per unit when a vehicle/equipment is fueled (include electricity rates as applicable).*

Baseline

The average cost of red dye diesel used by the Port during 2019 and 2020 was approximately \$3.10 per gal. There was no method to track individual fill events for baseline systems. Fuel fill records were obtained from the port for 2019 and 2020. Those refill data are only linked to “type” of forklift, not to individual forklifts.

Dannar

The Peak electricity rate at the Port (PG&E hours are 4 pm until 9 pm) was \$0.2338 per kWh. The Off-Peak rate was \$0.1334 per kWh. The recharge events during the project were not as would be expected during normal operation. There were several chargers installed in the 900 lot (AC Slow Charge type), but they were never fully functional with the Dannar systems. So the Dannar systems recharged less frequently than normal and at a remote location (Building 14, about 1.5 miles one-way) on DC Fast Chargers.



*State of charge (SOC) throughout work shift (minute-by-minute), if applicable.*

The work shifts during the project were abnormal. The Dannar systems were used by the Port for loading an undetermined number of trucks. Therefore, a more accurate estimate of SOC was recorded during the emissions comparison tests, in parallel with the baseline system. Those results were presented in the first section of this report and under separate cover in the Intercomparison Testing Report.<sup>4</sup>

That report shows that the Dannar system with 100 kWh capacity discharged slightly less than 6% of its capacity on average, to load two trucks. So, for a heavy day where six trucks were to be loaded only by the Dannar, its SOC is expected to decrease by less than 20%.

*Refueling time/charging time,*

A limited amount of charging event information is available in data received from ChargePoint. There were a few events recorded for the Dannar systems which include SOC, time to charge, etc. These data were provided via share drive.

The logger data from the Dannar units include charging information with more resolution than the ChargePoint data. These data were provided via share drive as well. They show that on the DC Fast Charge units in Building 14, the systems recharge at a rate of about 60 minutes per 33 kWh battery pack. The equates to a full SOC refill from zero time of 3 hours for the manlift unit and 4 hours for the dump unit.

*Distance traveled to refuel/charge if fueled off-site.*

Baseline

The baseline system is fueled wherever it is parked using a fuel tanker owned by the Port.

Dannar

Normally, the Dannars in the 900 Lot would only travel 50 meters or so, to be recharged on slow chargers installed there. But those chargers were not communicating properly with the Dannar systems during the project. So, recharging the Dannars required driving approximately 1.5 miles (one-way) to building 14 for charging on a fast charger. The slow charger communications issues are expected to be solved in the near future.

*Refueling/charging source (e.g., on-site energy storage, grid, delivery, etc.).*

Baseline: Fuel tank truck owned by the Port.

Dannar: California electrical grid via stationary, slow-fill AC chargers.

*Off-peak and/or renewable energy load shifting potential (e.g., battery recharging optimization with smart meter).*

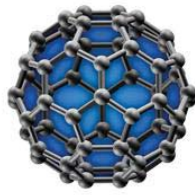
The stationary chargers in the 900 lot are generally not occupied. So they should be available at advantageous times for using Off-Peak electric rates.

*Refueling/charge frequency.*

Under normal usage, the Dannars would most likely be charged the night after they are used for any reason. The port has stated they want to use these as portable recharge stations and their procedure

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<sup>4</sup> See report titled, EMISSIONS INTERCOMPARISON TESTING RESULTS, dated June 30, 2021.



would be to keep them filled for emergencies. This was not possible during the project since the chargers in the 900 lot were not properly communicating with the Danner systems. They had to be driven about 1.5 miles to the fast chargers in Building 14, so these drives were minimized.

*Fuel efficiency, energy consumption rate per work completed/distance driven and Fuel/energy consumption while idling (if applicable).*

The typical duty cycle for these systems was well defined and very repeatable. It was loading two flatbed trucks with three loads of rebar each (a total of 24 tons/truck).

Baseline: The baseline system took an average of 10.5 minutes to complete the task, using 1.35 kg of diesel. Idling time during the loads is minimal and not significant.

Danner: The Danner system took an average of 16.4 minutes to complete task, using 5.86 kWh of battery power.

*List of systems for both baseline and advanced technology vehicles/equipment for which preventative maintenance is regularly scheduled and anticipated frequency of scheduled maintenance.*

#### Baseline

Major engine and drivetrain components: Every 500 hours.

Hydraulic oil: Change every 3000 hr (up to 6000 hr with sampling/testing).

#### Danner

Hydraulic oil: Change every 2000 hr

*Type of maintenance: scheduled and unscheduled.*

No maintenance related to use in the 900 lot was performed. The hours of usage were too low during the project to attribute any maintenance to the project.

*Repairs: date, description of problem, description of repair performed, parts replaced, costs of parts replaced, costs of labor.*

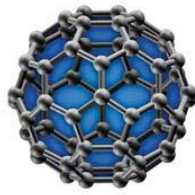
No true repairs were performed during the project, on either the baseline or the Danner. All interventions occurred on the Danner units and were related to "prototype/first-design" issues. There were no costs to the project because of these modifications. They had to do with:

- drained low-voltage batteries due to new users not properly shutting down the system
- troubleshooting communications issues with the slow charger stations
- modifications to the hydraulic system to improve lift speed of the forks
- driving procedure modifications to eliminate the incidence of random braking
- modifying programming to improve steering accuracy
- adding steps and other safety features requested by the operators

*General description of daily use of vehicles/equipment.*

#### Baseline

None of the baseline systems went out of service. However, one of them was moved from the 900 lot because there was not enough rebar volume to keep both busy and it was needed elsewhere.



## Dannar

One of the Dannar units went out of service for an extended period due to recharging issues and procedural errors. Its batteries went completely dead and some parts were replaced. It was never put back into service before the end of the project since the other unit was still functional and was not being fully utilized. The rebar throughput in the 900 lot was easily accommodated by the baseline Hyster and the one Dannar unit.

*Date of service call, description of problem, description of repair performed, parts replaced, odometer reading.*

No true repairs were performed during the project, on either the baseline or the Dannar. All interventions occurred on the Dannar units and were related to “prototype/first-design” issues. There were no costs to the project because of these modifications. They had to do with:

- drained low-voltage batteries due to new users not properly shutting down the system
- troubleshooting communications issues with the slow charger stations
- modifications to the hydraulic system to improve lift speed of the forks
- driving procedure modifications to eliminate the incidence of random braking
- modifying programming to improve steering accuracy
- adding steps and other safety features requested by the operators

*Time out of service.*

One of the Dannar units went out of service for an extended period due to recharging issues and procedural errors. Its batteries went completely dead and some parts were replaced. It was never put back into service before the end of the project since the other unit was still functional and was not being fully utilized. The rebar throughput was easily accommodated by the baseline and the one Dannar unit.

*Service response time to new trouble call.*

There were no trouble calls during the project that did not have to do with “prototype/first-design” issues. For the calls that did occur, Dannar was responsive, typically arriving within a week or two from their headquarters in the Midwest. They became even more responsive after hiring a person based in Northern California.

*Description of any accidents or incidents, including collisions, maintenance and fueling incidents.*

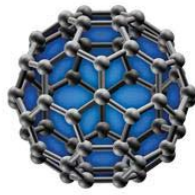
There were no accidents during the project.

*Tailpipe emissions test for vehicles/equipment that are not 100% zero emission, and their respective baseline vehicles/equipment using PEMS technology.*

The emissions tests were conducted in May 2021 and are described in detail in the Intercomparison Test Report delivered under separate cover.<sup>5</sup> A summary of those results are given in the first section of this report. Refer to Table 2 for the summary information.

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<sup>5</sup> See report titled, EMISSIONS INTERCOMPARISON TESTING RESULTS, dated June 30, 2021.



*Infrastructure facility description, including station throughput/capacity for both fueling/charging station and maintenance bay.*

Barring an enormous leap in rebar volume throughput, the facilities in the 900 lot are sufficient for recharging both Danner systems and two other battery-electric systems using the AC chargers in the lot. Existing maintenance bays can be utilized since battery-electric systems require much less maintenance than conventional systems.

*Infrastructure reliability.*

Other than an ongoing communications issue between some battery-electric systems and the AC chargers, there were no reliability issues with the charging infrastructure. All parties expect the communications issue to be resolved soon and without charge to the project.

*Capital costs for advanced technology vehicles and baseline vehicles, or cost of vehicle upgrade.*

This information is detailed in the Intercomparison Test Report and summarized in the first section of this report. See Table 3 and supporting text for a summary of those data.

*Infrastructure/facility capital costs or cost of facility modification/upgrade, for both fueling/charging station and maintenance bay.*

The capital cost of the AC slow chargers is \$4,100 each and for the DC fast chargers is \$36,570 each.

The infrastructure installed in the 900 lot for recharging electric systems was funded under multiple projects. Deconvoluting the fraction devoted to the 900 lot and the backup chargers used is not possible.

*Detailed operating costs for both baseline and advanced technology vehicles/equipment.*

This information is detailed in the Intercomparison Test Report and summarized in the first section of this report. See Table 3 and supporting text for a summary of those data.

*Detailed maintenance costs for both baseline and advanced technology vehicles/equipment, including parts and labor (total labor cost and mechanic labor cost in \$/hour).*

This information is detailed in the Intercomparison Test Report and summarized in the first section of this report. See Table 3 and supporting text for a summary of those data.

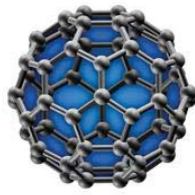
*Fueling infrastructure and maintenance infrastructure O&M costs (e.g., type of maintenance, costs for parts and labors, problems).*

#### Baseline

We estimate it costs approximately \$40 per 10 gal refuel for the baseline forklifts. That includes labor (at \$25/hr), cost of fuel (at \$3.10/gal) and cost of fuel truck maintenance (at 1/100<sup>th</sup> of a \$200/month service contract).

#### Danner

The O&M costs of the electric charging infrastructure are minimal and can be neglected due to the sharing of the chargers by multiple vehicles. The only items needing periodic replacement are the coolant for the AC chargers (once every 5-years at \$500) and the connector plugs used to connect to the vehicles (rated to last at least 10,000 plug/unplug cycles).



*O&M costs for facility safety systems related to hydrogen and fuel cells (e.g., type of maintenance, costs for parts and labors, problems), if applicable.*

Not applicable to this project.

*User/fleet experience of the advanced technology vehicles/equipment, e.g., vehicle availability, power, capacity to meet fleet operation demand, O&M challenges, service parts availability, perceived safety, refueling experience and any barriers.*

These user inputs are summarized in the first section of this report and described in more detail in the Intercomparison Test Report, provided under separate cover.<sup>6</sup>

*Describe the workforce training programs, if any, related to the use and maintenance of the advanced technology vehicles. Evaluate the effectiveness of such programs and the costs associated with them.*

These training programs are still under development. The systems are not yet to the point of design where the training can be finalized. However, drivers have been trained to drive these systems and can use them with reasonable efficiency after three or four test drives. We estimate the incremental cost of training (relative to that of a conventional forklift) at \$300 per driver, including labor and materials.

*Describe warranty claims and insurance policies, as well as the experience of working with vehicle/equipment manufacturers in the instance of an accident or a major period of unexpected down time (as applicable).*

Baseline

Not applicable. No warranty claims or troubleshooting were required.

Dannar

All interventions occurred on the Dannar units and were related to “prototype/first-design” issues. There were no costs to the project because of these modifications. They had to do with:

- drained low-voltage batteries due to new users not properly shutting down the system
- troubleshooting communications issues with the slow charger stations
- modifications to the hydraulic system to improve lift speed of the forks
- driving procedure modifications to eliminate the incidence of random braking
- modifying programming to improve steering accuracy
- adding steps and other safety features requested by the operators

*The vehicle manufacturer response/service for warranty claims and/or trouble shooting.*

Baseline

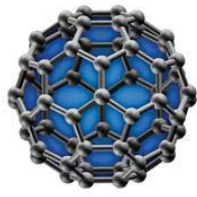
Not applicable. No warranty claims or troubleshooting were required.

Dannar

Dannar was responsive, typically arriving within a week or two from their headquarters in the Midwest. They became even more responsive after hiring a person based in Northern California.

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<sup>6</sup> See report titled, EMISSIONS INTERCOMPARISON TESTING RESULTS, dated June 30, 2021.



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APPENDIX A

TEST PLAN: LOT 900 BASELINE TO ELECTRIC INTERCOMPARISON

This appendix is provided under separate cover.

## 6.2 Data Collection Presentation

PowerPoint presentation conducted by Andrew at carbonBLU during the Project final meeting on May 19, 2021

# Port of Stockton Baseline Comparison Tests

Diesel and Danner forklifts for moving rebar in the 900 Lot

# Baseline Diesel

- Hyster 330
- Red Diesel
- 2016/17 Emissions
  - Meets them without using DPF
  - SCR



# PEMS System

- Gaseous PEMS
  - Semtech DS by Sensors, Inc.
  - GPS
- Particulate PEMS
  - parSYNC by 3Datx
- Forklift ECU Data
  - HEM-data logger

# Dannar Test Unit



# Test Cycle

- Start at forklift parking area
- Drive to “truck” loading area
- Move 3 loads (8 tons each) of rebar from a stack to the “trailer bed”
- Repeat for a second “truck”
- Drive back to parking area and stop

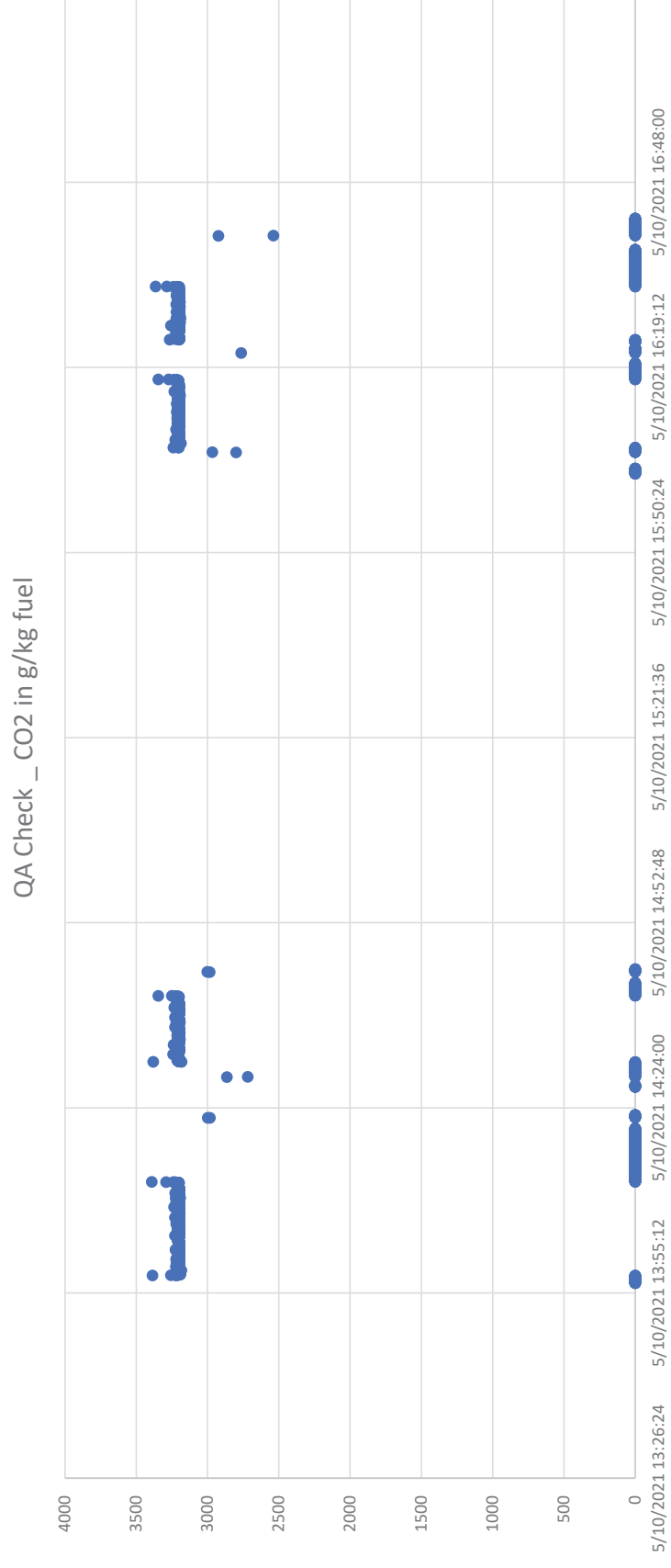
# Overall Test Day

- Drive test cycle with baseline. Cold-start.
- Drive test cycle with Dannar.
- Drive test cycle with baseline. Warm-start.
- Drive test cycle with Dannar.
  - Driver problems
- Break & Load actual trucks
- Drive test cycle with baseline. Warm-start.
- Drive test cycle with baseline. Hot-start.

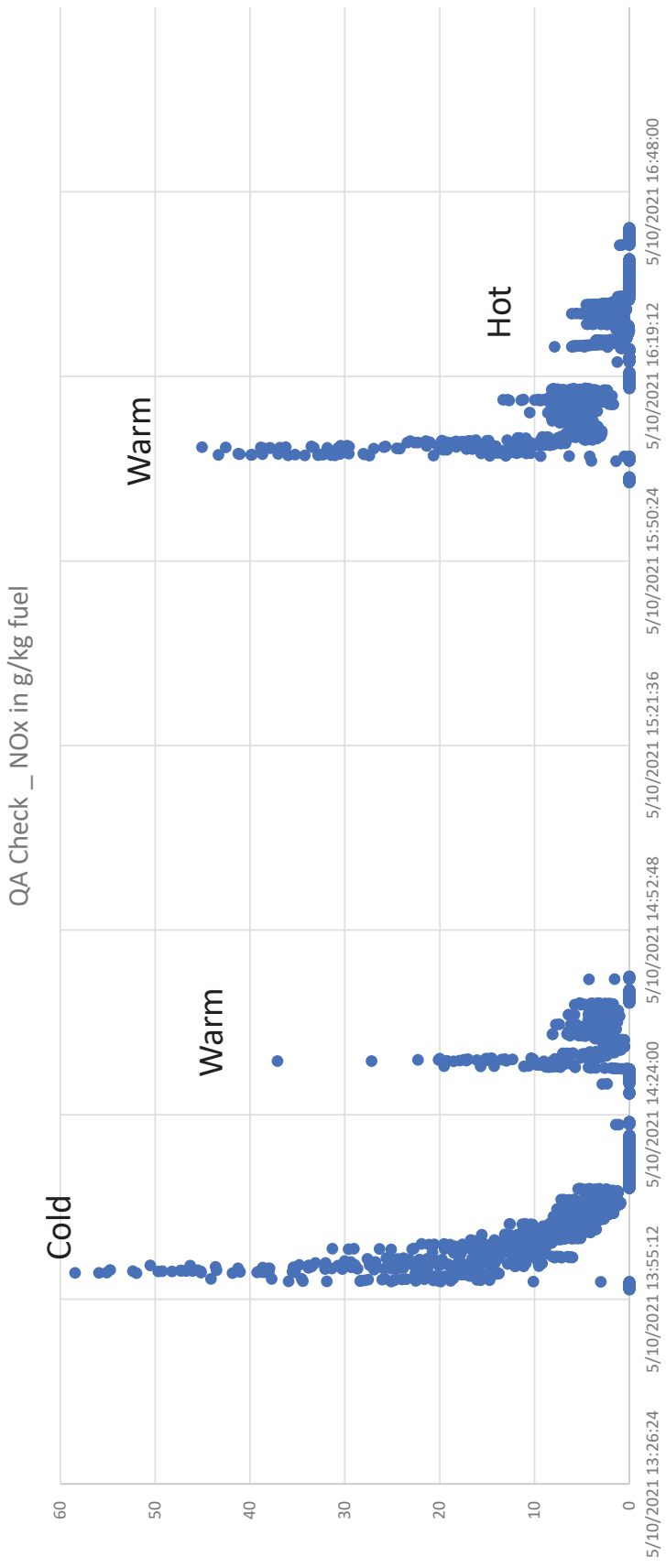
# Track of Tests (baseline unit)



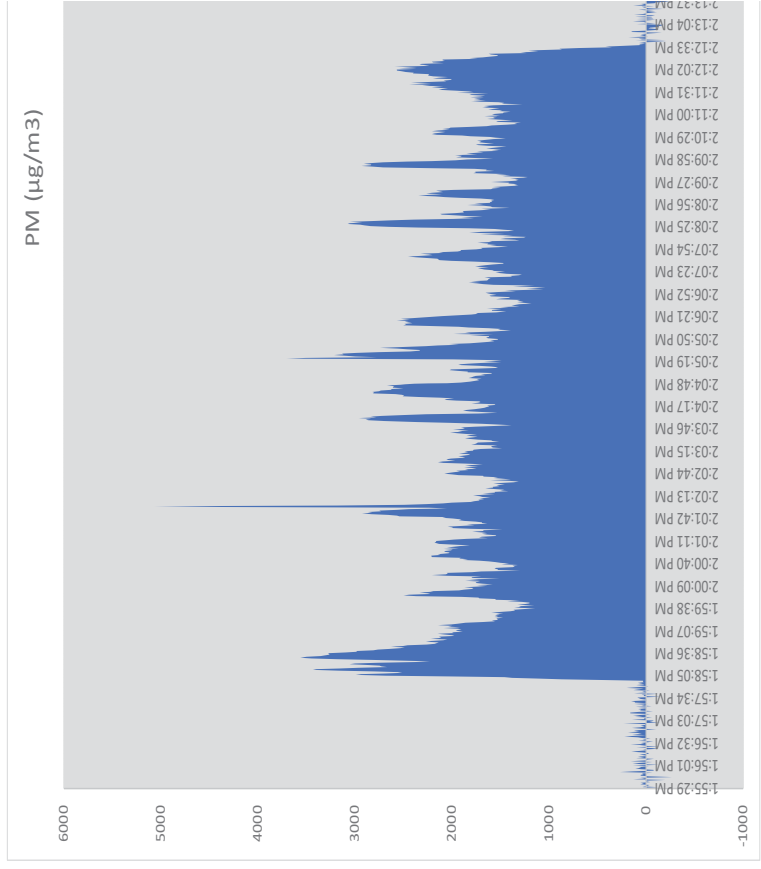
# Baseline CO2



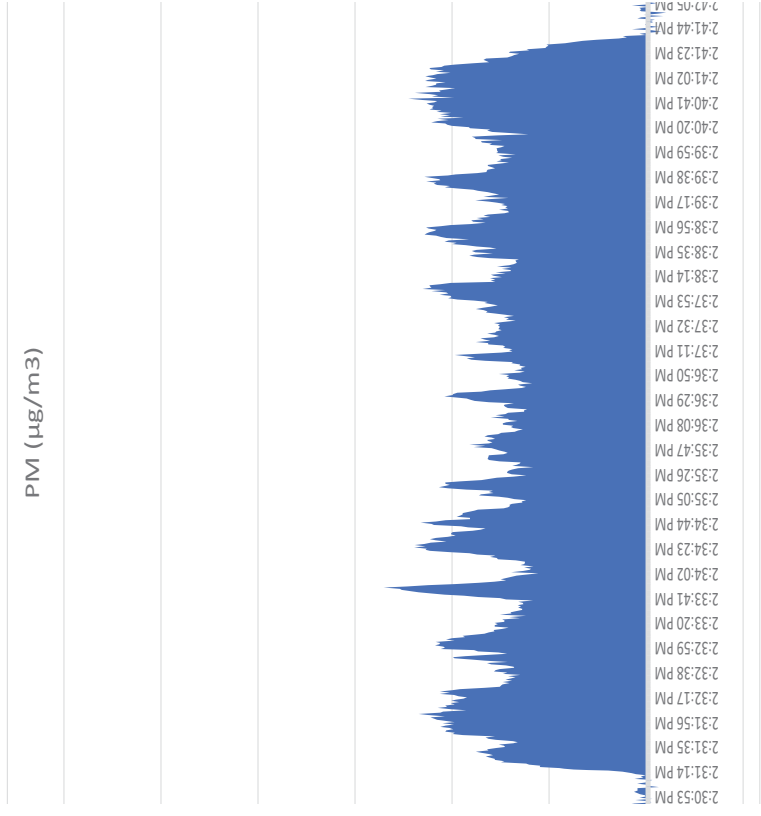
# Baseline NOx



# Baseline PM

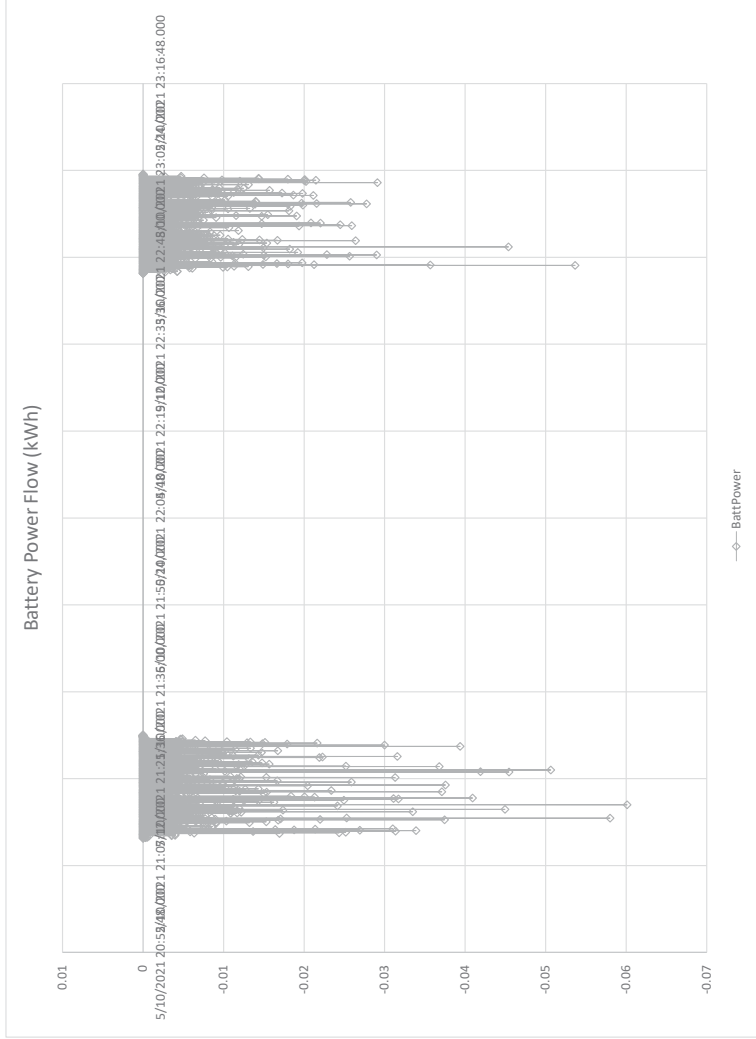


Cold-Start



Warm-Start

# Dannar Power Consumption



# Annual Emissions Inventory

- Total Rebar Moved Per Year
  - Finalize numbers from Port for total rebar moved in the 900 Lot per year
- Baseline Emissions & Costs
  - Use annual fuel consumed and measured emission factors to calculate annual baseline emissions for moving the above annual rebar
  - Use annual fuel consumed, tax-free diesel cost, maintenance costs and debt-service/rental to calculate annual cost
- Danner “Emissions” & Costs
  - Use CA grid emission factors to calculate CO<sub>2</sub>e for test
  - Extrapolate the test result to an equivalent for moving the above annual rebar
  - Use annual power consumed (calculated in previous bullet), cost of grid power, maintenance costs and debt-service/rental to calculate annual cost.

# Dannar Issues

- Drivers do not compare favorably to forklifts for rebar moves
  - Random braking issue
  - Steering “rezero”
  - Takes longer to maneuver
- Mostly “prototype” issues?
  - Probably can iteratively improve over time

# Project Activity Data

- Baseline
  - Since July 2020
- Dannar
  - Since October 2020

Questions?