BNSF RAILWAY

Final Report

# Flexible Solutions for Freight Facilities

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Submitted by

San Joaquin Valley AIR POLLUTION CONTROL DISTRICT

BYD Build Your Dreams · café coop · Southern California Edison (An Edison International Company) · gna Gladstein, Neandross & Associates · ITS ConGlobal Integrating Intermodal · Mi-Jack Products · Pacific Gas and Electric Company · SH&H Trucking · SwRI · Taylor · Wabtec Corporation

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# Acknowledgements

Flexible Solutions for Freight Facilities is part of California Climate Investments, a statewide initiative that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment — particularly in disadvantaged communities.

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# Executive Summary

Flexible Solutions for Freight Facilities is a BNSF-led project to demonstrate zero and near-zero emission technologies on locomotives and around rail yards. Wabtec designed, manufactured, and commissioned a single Battery Electric Locomotive (BEL) that was used within a diesel consist [multiple locomotives providing tractive effort] running between Stockton to Barstow, California in commercial operations. The BEL improved the fuel efficiency of the entire consist an average of 12% while simultaneously reducing the consist's criteria pollutant and greenhouse gas emissions when compared to a conventional diesel consist. The project gave BNSF and Wabtec the opportunity to evaluate operational options for maximizing the utility of the BEL.

In addition, zero and near-zero emission equipment was demonstrated at BNSF's intermodal yards in Stockton and San Bernardino. The Stockton and San Bernardino facilities each demonstrated a Mi-Jack hybrid-electric rubber-tire gantry (RTG) crane that features an advanced battery system that achieved a greater than 70% fuel efficiency improvement. The San Bernardino facility also deployed a full-electric side loader built by Taylor Machine Works, Inc. and distributed by Mi-Jack. The project finished with an on-road zero-emission demonstration featuring BYD's Class 8 drayage truck solution, which was used for short-haul drayage operations in San Bernardino. The project also included electrical infrastructure upgrades and electric vehicle supply equipment (EVSE) to charge the series of zero and near-zero pieces of equipment and vehicles.

SJVAPCD has a strong tradition of partnering with businesses to implement cost-effective emission solutions. This partnership with BNSF was critical because, as an experienced and technically savvy operator, BNSF was positioned to identify both the challenges and the opportunities with zero-emission technologies. Flexible Solutions for Freight Facilities was an industry-led initiative to develop opportunities to improve efficiency while furthering SJVAPCD mission of emission abatement. The project commenced in February 2019 and the final demonstrations were completed in March 2021.

# Administrative Overview

## Roles

SJVAPCD, Grantee: Regulatory agency overseeing project administration, planning, contract management, project meeting organization, and conducting oversight for: original equipment manufacturer/integrator, budget and payment tracking, reporting, and data collection.

BNSF Railway, Technology Demonstrator: Class I freight railroad company that owns and operates railways and intermodal facilities of interest that featured the new locomotive technology; operated the BEL and the cargo handling equipment (CHE) deployed under the project; communicating all performance data and potential needs with Wabtec in real time.

ITS ConGlobal, Technology Demonstrator: BNSF's primary operations service provider; operating the BEL for switching, engine repositioning; RTG and side loader operations and maintenance in San Bernardino.

SH&H, Technology Demonstrator: Drayage truck company operated BYD truck to integrate emission-free trucking into the intermodal goods movement operation; this partnership closely monitored the function of the trucking portion of this project.

Wabtec, Technology Provider: Industrial leader and supplier developing the BEL that BNSF operated between Barstow & Stockton; providing technological expertise on system integration of battery technology, AC traction, inverter, V-speed technology and digital product enhancements like trip optimizer and smart horsepower per ton.

Mi-Jack, Technology Provider: Technology provider for the hybrid RTG and as a distributor for the Taylor Machineworks electric side loader, central to the intermodal transfer process; provided application and implementation support as well as ongoing operations training.

BYD, Technology Provider: Technology provider for the electric on-road truck deployed in San Bernardino; lending technology and operational support to SH&H (truck operators).

Southwest Research Institute (SwRI), Data Collection & Analysis: Entity responsible for data collection, which is critical for establishing and certifying the zero-emission expectations for these technologies to accurately account for emission reductions compared to diesel technologies.

Café Coop, Community Based Organization: The CBO provided local community outreach through the coordination of a bi-lingual educational webinar and the development of an educational video to be distributed through social media..

## Communications

The project communications involved two kick off meetings and bi-weekly calls throughout the project period. SJVAPCD and their project partners completed scheduling, agenda coordination, team communications and subcontractor preparation for the preliminary project kickoff meeting which was held in Sacramento on January 8, 2019. For this preliminary kickoff meeting, representatives of all subawardees and their subcontractors were in attendance. Following contract execution on February 22, 2019, the official kickoff meeting was convened with the core team on March 27, 2019. Ongoing communications were held via bi-weekly web conferences where the progress and ongoing timing for all technical and administrative tasks were reviewed.

## Reporting

Pursuant to the contract requirements, quarterly reports were developed to detail the work accomplished, challenges faced, and the projected upcoming work. Draft reports were reviewed with CARB staff prior to being finalized. In addition to the narrative reports, financial, technical reports on subtasks, emissions data, and data collection reports were submitted separately as detailed in further sections.

## Budget and Invoicing

On a quarterly basis, financial summaries of funds requested, cash match, in-kind match and balance of funding were provided. Reimbursement requests were accompanied with the deliverables as detailed in the milestone delivery schedule. Reimbursements were further substantiated with detailed invoicing and payment documentation. All reimbursement documentation and supporting deliverables were reviewed with CARB staff prior to being finalized.

# Technical Overview

## Equipment

This project funded five pieces of equipment/vehicles deployed at BNSF's Stockton Intermodal Facility, Stockton Mormon Yard and San Bernardino railyards including:

**Table 1. Equipment Deployed**

| Item | Location |
|---|---|
| GE Transportation Battery Electric (Wabtec) Locomotive | Stockton |
| Mi-Jack hybrid-electric rubber-tire gantry crane | San Bernardino Intermodal |
| Mi-Jack hybrid-electric rubber-tire gantry crane | Stockton Intermodal |
| Taylor Machine Works, Inc. full-electric side loader | San Bernardino |
| BYD all-electric Class 8 drayage truck | San Bernardino |
| Electrical upgrades and EVSE equipment | San Bernardino Intermodal |
| Electrical upgrades and EVSE equipment | Stockton Intermodal |
| Wayside charger to recharge the BEL batteries | Stockton Mormon |
| Class 8 drayage truck and electric side load | San Bernardino |

# Battery Electric Locomotive

## Roles

As the lead company, BNSF partnered with Wabtec in the development of the BEL for use in the hybrid consist. While BNSF utilized the BEL, all performance data and potential needs were communicated with Wabtec in real time.

## Specifications

**Table 2. Component Specifications**

| Component | Specification |
| --- | --- |
| Energy Source | Lithium-ion batteries |
| No. of Axles | 6 |
| Weight | 430,000 lbs |
| Duration @ Rated Output | 30 to 40 minutes |
| Rated Output | 4400 hp |
| Charging | Wayside charging and regenerative braking |
| Energy Capacity | 2,400 kW-hrs |
| Thermal Management | Air cooled |
| Maximum Speed | 75 mph |

## Milestones with End Dates

**Table 3. Milestones with End Dates.**

| *Milestone* | *Date* |
| --- | --- |
| Battery Module | Q1 2019 |
| Beta Battery Rack | Q2 2019 |
| Power Limited Test Locomotive | Q3 2019 |
| Design Verification | Q4 2019 |
| Full Power Locomotive Complete | Q1 2020 |
| Production Readiness Review | Q2 2020 |
| Locomotive Shipped from Erie | Q3 2020 |
| Revenue Service | Q4 2020 |
| Final Support Provided | Q1 2021 |
| Conclude Revenue Service | Q2 2021 |

## Comparison of Qualitative Operations with Baseline

The BEL is a six-axle locomotive with 4 of the 6 axles being powered. The BEL is rated for 4400 horsepower (HP) line-haul locomotive with very similar dimensions and operational capabilities to an ES44C4, common to the BNSF fleet. It was purpose built as a development platform for this demonstration. The BEL was originally the GECX 3000, a development asset owned by Wabtec that has been the base platform for a variety of different technological applications. Prior to this project, it served as a natural gas demonstration locomotive used with both BNSF's and Florida East Coast Railway's liquid natural gas (LNG) programs. The GECX 3000 was completely reconfigured for use as a battery electric locomotive for this project. The full frame behind the locomotive and auxiliary cab was cleared and a new blower and battery cab arrangement was added where an engine and main alternator used to exist. The new battery system inside the battery cab consists of 18,000 individual cells grouped into modules of 36 cells per module. The modules are then grouped into strings of 25 modules. Each string of modules is then operated by a battery string controller resulting in twenty unique battery strings. Then 5 strings are connected to each of the four traction motors on the four powering axles. This battery system occupies the entire rear portion of the locomotive. The design of the BEL's battery cab is unique compared to a traditional locomotive where the walkway is outside of the engine compartment on an external walkway. The BEL has been designed to allow for walking down the centerline of the

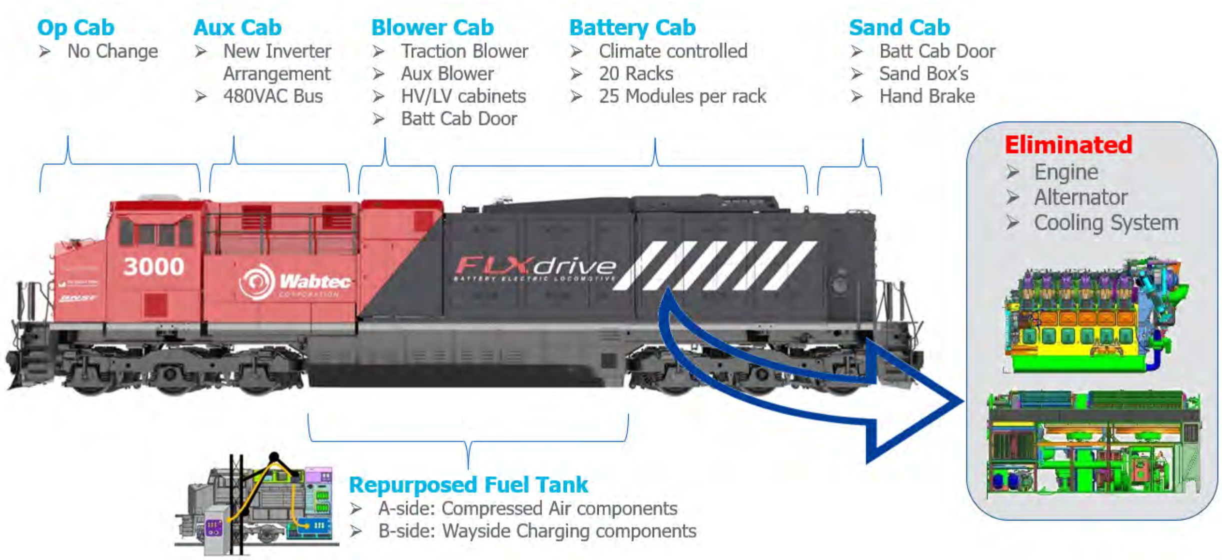


**Figure 1 System Changes made to tech BEL demo locomotive**

locomotive in a climate-controlled enclosure, which provides a central walkway to allow transit between locomotives and easy access to all of the battery racks.

The BEL works in conjunction with two "mate" locomotives (BNSF 3940 & 3965) which were kept adjacent to the BEL for the duration of the demonstration. These locomotives were equipped with special communication hardware and software to form the hybrid consist. The hybrid consist operated in two major modes, tractive effort and dynamic braking. While these operating modes are common functions to all locomotives, the hybrid consist used special algorithms to optimize the use of the BEL. In tractive effort, the BEL did not provide any tractive effort until a throttle notch command over 2 was requested since freight locomotives use discrete throttle positions from 1 to 8. Tractive effort needs for the test hybrid consist above notch 2 were provided by the BEL if it had enough power output and energy storage available. If the BEL was unable to provide the tractive effort needs, the mate locomotives would increase their throttle notches to meet the tractive need. In this way, the BEL energy was used first to offset diesel fuel use as soon as it was available. This contrasts with conventional locomotive consists where all locomotives must simply follow the trainline throttle notch command.

Dynamic braking, the other mode, is a behavior common to all freight locomotives. Generally in this mode, the traction motors are used as generators that provide a braking force to slow the train. Normally this energy is bled off through a bank of resistors. However, in the hybrid consist, this energy can be stored in the BEL system. In the hybrid's dynamic braking mode, the test consist used a similar but reversed algorithm to that of the tractive effort mode to allow it to recoup energy during braking. The BEL would provide the dynamic brake effort first, before the two mate locomotives in the consist. Once the BEL was fully charged or additional braking effort was required, the mate locomotives would supply any needed braking effort. This allowed the BEL to be recharged through regenerative braking during operations.

The test consist used this algorithm in conjunction with the route planning software, Trip Optimizer (TO), to optimize the tractive effort of the BEL. TO is an energy management software system that accounts for the locomotives, train car contents, and route ahead to plan an optimized throttle notch schedule for the train. It effectively acts like a "smart" cruise control system for the train and was the foundation for testing the software in the demo hybrid consist.

## Challenges and Resolutions

The project was delayed one quarter due to the delay in the contract execution between SJVAPCD and California Air Resource Board (CARB). This delay prevented Wabtec from accruing costs against the project and the full development program.

During the design and testing of the Battery Module (BM), testing proved additional protection from thermal events was required to provide a higher level of safety. This re-design was forced to alter the module, battery rack, and battery cabs. The redesign impacted the development schedule by approximately 6-8 weeks.

Due to Covid-19, there were minor interruptions in production. Wabtec provided updates during the twice monthly calls, and the schedule for meeting milestones and final delivery were not altered.

## High-level Operational Findings

The BEL operated from Barstow, CA to Stockton, CA for just over three months of demonstration. The first run of the BEL and test consist in train service was on December 14, 2020. For this run, a team of Wabtec engineers and BNSF battery team members rode the train from Barstow to Stockton. The hybrid test consist performed as intended with the TO system, regenerated energy going back into the batteries through braking, and provided tractive power from the battery system for forward movement. Once in Stockton, the test consist was moved to the wayside charger and the team was able to connect and fully charge the locomotive before the consist needed to return to Barstow on the next outbound train. On the return trip to Barstow, the consist performed as the algorithm modeled, again.

Figure 2 BEL test consist on first run from Barstow to Stockton, CA


Figure 3 Image of BEL While Charging at the BNSF Stockton Mormon Yard

Starting on January 4, 2021 the test consist operated in regular service between Barstow and Stockton in two-week cycles consisting of three round trips planned for each cycle for three months. While regular train operations and delays limited these cycles occasionally, the test consist never caused a delay from BEL operations. Barstow was used as the base of operations as the facility has large locomotive and yard maintenance capabilities which facilitated servicing the equipment. BNSF test car 82 was used as a sleeping and kitchen facility for the duration of testing. Typically, a round trip from Barstow to Stockton and back to Barstow would take just over three days, but in some extremely delayed situations, it took up to 7 days.

Over the course of the demonstration testing, 18 round trips were completed between December 12, 2020 and April 2, 2021. The test consist traveled approximately 13,300 miles during this time. It saved 8,600 gallons of diesel fuel for an average of 12% fuel abatement across the test consist. The variation of the fuel savings was significant ranging from 6.2% to 19.2%. Barstow to Stockton runs had better fuel savings than the return trips as the steep hill at Tehachapi Pass greatly influenced the BEL's capability and impact. The most significant variable of this deviation was the train tonnage. Intuitively this seems logical, as heavier trains would use more fuel, however these trains also have more opportunity for regenerative braking thus more fuel savings due to higher energy recovery. Because of this skewed emission reduction, the gallons abated per trip is not directly correlated with the percentage fuel saved as the train tonnage has a major impact on total fuel consumption.

**It saved 8,600 gallons of diesel fuel for an average of 12% fuel abatement across the test consist**

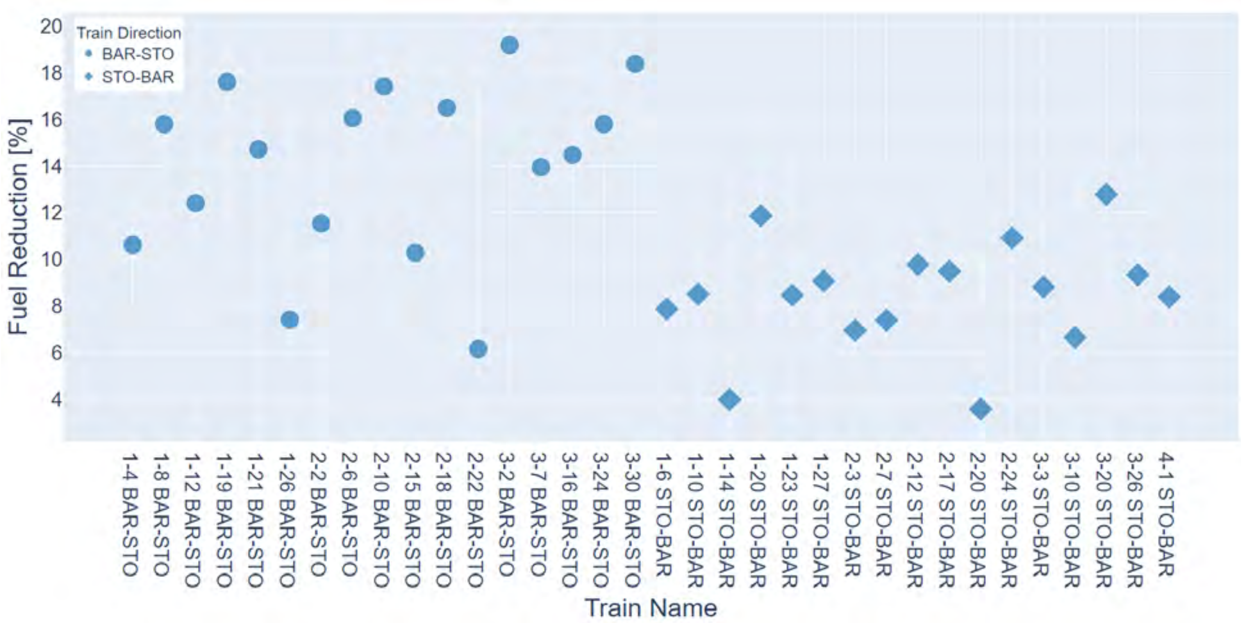


**Figure 4 Graph showing percentage fuel reduction by trip**

Additionally, braking events associated with the train stopping in a siding to allow for traffic to pass were found to be a non-negligible source of regenerative braking.

Each braking event contributed about 200kWh worth of energy to the batteries. While an expected result, it was surprising in magnitude and frequency. This effect can clearly be seen in the characteristic small peak increases in state of charge (SOC) in the state of charge vs distance plot.

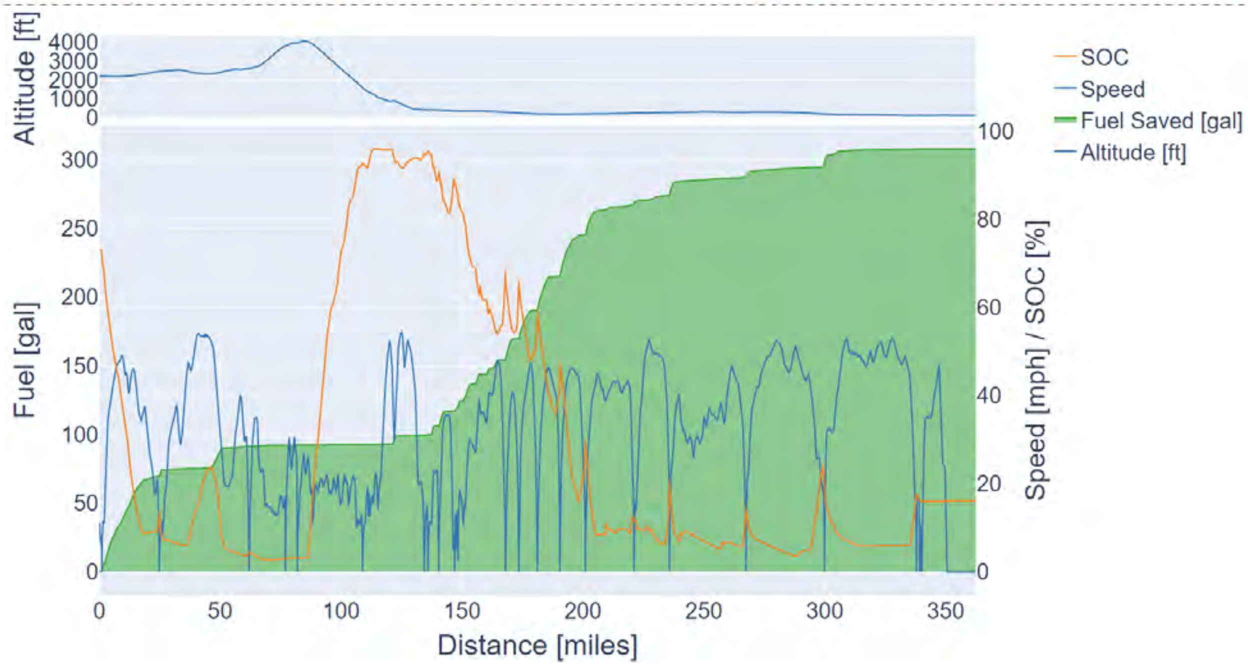


**Figure 5 Characteristic Plot Showing Altitude, SOC, Speed, and Estimated Fuel Reduction for a run Traveling from Bartow, CA to Stockton, CA**

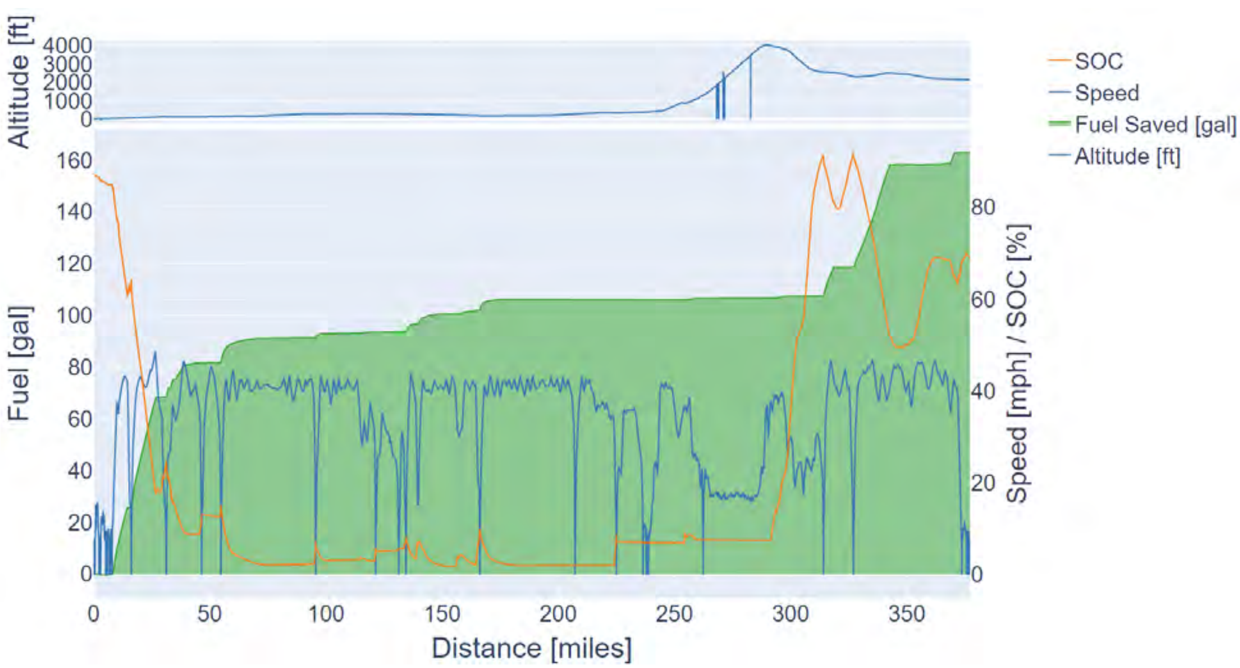


**Figure 6 Characteristic Plot Showing Altitude, SOC, Speed, and Estimated Fuel Reduction for a run Traveling from Stockton, CA to Bartow, CA**

As with any new technology project the BEL encountered issues. Most notably, the wayside charger presented several obstacles in development before the operators trusted the charging system in all conditions. For example:

- The ground fault monitoring system limits needed to be carefully tuned to limit the possibility of personal injury. Even once tuned the detection limits were above those typically regarded as safe for personal protection and the following two mitigations were implemented.
- A robust set of instructions on the operation of the charging station were developed and only specifically trained operators could use it.
- Special personal protection equipment (PPE) and isolation measures were used so that in the event of a failure, no employee was exposed to high voltage conditions.

Since the demonstration's goal was to prove the hybrid consist concept and determine areas of further development, several other items were noted during operational testing. Some of the following issues were known design compromises to meet the tight delivery schedules of the demonstration. While the BEL GECX 3000 was never intended as a full revenue service locomotive, these items will need to be addressed in future generations of this technology.

1. Low energy storage on the BEL meant that it was not capable of fully replacing a locomotive and instead was always an additional unit to the consist. Future versions will need greater energy storage to be a full diesel locomotive replacement.
2. High auxiliary loads (air compressor, fans, blowers, etc.) caused significant battery draw during idle events. While software changes implemented mid-way through the program lessened this effect, future BELs will need to be designed to minimize the auxiliary loads.
3. Eight battery modules and three battery string controllers were replaced during this demonstration. These components were identified by the battery management system as potentially faulty. A postmortem analysis does not give a clear indication of failed components, indicating that the detection system or limits require additional refinement in the next version.
4. The local FRA inspector inspected the BEL and found two exceptions. The BEL has a middle emergency egress ladder. These steps and handrails were not painted a contrasting color. Additionally, the front end "F" stencil was not present. The Barstow locomotive team addressed these issues immediately. No other FRA exceptions were identified during the program. Overall, coordination and communication with both the local and federal FRA teams was excellent and the battery team would like to thank them for the guidance and feedback throughout the program.

5. The BEL charge time was 6-8 hours, ideally the charge power would be increased such that future BELs can charge within 4 hours.

Despite the limitations of a demonstration BEL, the ability to safely operate and prove core functionality on the very first revenue service demonstration run was extremely encouraging. This effort demonstrated that BELs in hybrid consists are a viable concept that deserves further development. The significant amount of development, planning, and coordination lead to the success of the demonstration project. Moreover, the reduction in fuel consumption averaging 12% (maximum 19.2% and minimum 6.2%) is consistent with the modeling expectations for this service. Overall, this demonstration was a fantastic success, and the battery team is very appreciative of the opportunity to technically advance the industry.

## Role in Future Market

BNSF and Wabtec found that the demonstration, by meeting all key objectives, proved the hybrid consist concept as a technically viable approach for emissions and fuel reductions for high horsepower line haul/regional locomotives. After the demonstration between Barstow and Stockton, the GECX 3000 was returned to Wabtec in Erie, PA where it will continue to be used as a developmental platform for the next generation of locomotive battery systems. Any additional road testing will require more development work, which is best addressed in Erie.

Going forward, BEL development will focus on addressing the limitations of this demonstration and building a unit that is a drop-in replacement for a diesel locomotive. The single largest advancement needed for development is the increase in energy storage. It is expected that a two to three times increase in energy storage could allow for the replacement of a diesel locomotive within a hybrid consist application in regional service. It is important to note, that the hybrid consist approach is best suited for areas where grades maximize regenerative braking. Longer distance operations without significant grades are less viable due to the less prominent regenerative braking. As such, initial deployments of BELs will focus on regions, such as the Los Angeles basin, where the terrain and traffic density are advantageous. Once the technology is well proven, hybrid consists with greater than one BEL or all BEL locomotives may be viable. This requires the further increase in energy density (approximately 10MWh) and a significant level of confidence in both the BEL and the charging technology.

Use of BELs in a yard or road switching service is another consideration of economic viability. This demonstration showed that the BEL could perform switching in "yard mode". It is reasonable to conclude that a BEL for yard or local switching is possible.

This service in a railyard makes the charging solution more compelling, as a single charging facility could serve several locomotives. However, the low capital and fuel consumption of current switcher locomotives makes the conversion from the current diesel non-economical. Regardless, switchers present an encouraging opportunity for the development of zero emissions locomotives particularly in environmentally sensitive areas.

# Hybrid Electric Rubber Tired Gantry Crane

## Roles

Mi-Jack provided the technology with ITS ConGlobal as the primary operations service provider by leading the RTG and side loader operations and maintenance in San Bernardino.

## Specifications

**Table 4. Rubber Tire Gantry Crane Specifications.**

| Component | Specification |
|---|---|
| Capacity | 100,000 LBS (45,360 KG) |
| Fuel tank | 150 gallons |
| Emission certified | EPA Tier 4 Final/Stage V |
| Cummins rated power | 113 HP (84 kW) @ 1800 RPM |
| Geometry turbocharging | Variable |
| VAC | 600/3-phase/60Hz |
| Battery | Li-Ion Battery Pack<br>Integrated Battery Management System<br>Automated equalization<br>Shore power charging |
| VDC pack voltage range | 600-800 Volts |
| Electric motor | Variable frequency drive |
| Regenerative power storage | Battery stored regenerative power; dynamic braking resistors controlled by VFDs |

## Milestones with End Dates

**Table 5. Rubber Tire Gantry Crane Milestones.**

| Milestone | Date |
|---|---|
| Production materials procured | Q1 2020 |
| Deliver and commission two hybrid electric RTG cranes | Q1 2020 |
| Complete revenue service operations | Q4 2020 |

## Challenges and Resolutions

The implementation of the new hybrid RTGs at San Bernardino and Stockton were met with cautious optimism. On one hand, operations personnel were eager to see and experience this new technology. On the other hand, there was a high level of skepticism due to the unfamiliarity and lack of experience with the hybrid RTGs. These were natural feelings when it comes to initial experiences with new technology. The goal of a new technology is to be an improvement to the status quo. However, the proof would need to come through the equipment’s performance metrics.

Due to the sheer scale of the hybrid RTG, it was virtually impossible to assemble the hybrid RTGs for testing at the manufacturing facility. As a result, many of the first tests with this new technology were conducted on-site at the train yard hubs. Although there are other older generation hybrid RTGs in the market, these "next generation" hybrids featured a considerable amount of new technology that was unproven. In many cases, it was the new technological features that experienced the most issues seen during testing.

Following the delivery, assembly, and commissioning of the new hybrid RTGs, Mi-Jack representatives conducted a thorough orientation session with the appropriate on-site operations personnel. The crane operators gained some initial exposure to the cranes in a test environment before the unit was positioned over a live track for lifts.

The operational and feature design variances from the existing diesel RTGs were immediately noticeable. For example:

- Some of the maneuvers operators were accustomed to performing with foot pedals were now having to be performed using a joystick. It was an imperative goal that RTG crane operators have pinpoint precision on their handling of containers and trailers, especially when placing units on bare chassis. Crane operators must perfectly align the corner castings with the knobs of the chassis. Operators found this task more difficult with the joysticks versus the foot pedals.
- The large doors covering the engine compartment had ineffective latches. Operators were getting frequent crane faults due to these latches not staying engaged even with the locking mechanism across the center of the door. The maintenance technicians had to use excessive force to shut the doors, causing the catches to bend. Mi-Jack fixed the issue by replicating the rotate-and lock-system of the battery box doors.
- The ladder feet for the e-house were in the way of accessing the slide out pin and looking at an important red-dot alignment on the plug receptacle. User is at risk of hitting one's head on ladder foot when positioning to see the red dot alignment and twist plug to ensure proper securement on the crane. Mi-Jack engineers are investigating options. Moreover, this pin now has a cable attachment, eliminating risk of misplacing pin, which was missing in the initial design.

More importantly, beyond the challenges of getting acclimated to differences in design, a wide range of mechanical, electrical, and control issues surfaced from the onset. Such issues included:

- Overheating batteries
- The diesel genset - for charging the batteries - not starting
- A range of fault alerts

- During a time of high ambient temperatures, the cooling system for the batteries was found to be insufficient. The unit was taken out of operations and a larger air conditioning system was installed.

These issues caused operators to cease use of the hybrid RTGs. This resulted in extended down time of hybrid RTG operations. Additionally, since it is relatively new technology, the remedy process was longer and more complicated than for diesel RTGs. Remedying these issues required diagnosis assessment, efforts to replicate the issues, troubleshooting, testing, and other safety protocols that took extensive time. Mi-Jack dedicated a field support specialist and an electrical engineer to be on-site to help with these remedy efforts.

Mi-Jack discovered that these new technologies required ongoing adjustments and fine-tuning to prevent faults from occurring during operations. The faults were intermittent, and their sources were difficult to pinpoint. Mi-Jack dedicated a field support specialist and an electrical engineer to be on-site to help with these remedy efforts. Due to the sheer scale of this hybrid RTG, it was virtually impossible to assemble the hybrid RTGs for testing at the manufacturing facility. As a result, many of the first tests with this new technology were conducted on-site at the train yard hubs. Although there are other older generation hybrid RTGs in the market, these "next generation" hybrids featured a considerable amount of new technology that was unproven. In many cases, it was the new technological features that experienced the most issues seen during testing.

An additional factor that could be considered was the aggressive project timeline. Mi-Jack acknowledged the shortcomings of this short schedule and lamented that additional production and testing time on this technology would have resulted in fewer hiccups in the initial stages of the demonstration.

In addition, operators of the new hybrid RTG identified some flaws in the physical design. For example, the large doors covering the engine compartment had ineffective latches. Operators were getting frequent crane faults due to these latches not staying engaged even with the locking mechanism across the center of the door. The maintenance technicians had to use excessive force to shut the doors, causing the catches to bend. Mi-Jack fixed the issue by replicating the rotate-and lock-system of the battery box doors. Another design flaw was the ladder feet for the e-house are in the way of accessing the slide out pin and looking at an important red-dot alignment on the plug receptacle. User is at risk of hitting one's head on ladder foot when positioning to see the red dot alignment and twist plug to ensure proper securement on the crane. Mi-Jack engineers are investigating options. Moreover, this pin now has a cable attachment, eliminating risk of misplacing pin, which was missing in the initial design. During a time of high ambient temperatures, the cooling system for the batteries was found to be insufficient. The unit was taken out of operations and a larger air conditioning system was installed. Another issues with the hybrid RTG was the threat of being less efficient than standard equipment, which lessened the service provider's confidence in the hybrid RTGs. The hybrid RTG at San Bernardino became "dead" with a load over a train on a live track. The genset did not automatically turn on when the battery reached the critical low level. Then, when the battery power was completely depleted, the crane became inoperable, which caused a train delay. There was no clear warning to the operator about the battery reaching these critically low levels. The important role of machinery in the eyes of the service provider (aside from safety) is to maintain fluidity and efficiency in the operations of a train yard hub. The hybrid RTG was operating in one of California's busiest hubs with unprecedented record-breaking volumes. Reliability is of the utmost importance when it comes to lift equipment and any failure, no matter how slight or short-term, can result in a service failure on the railroad.

The service providers at both Stockton and San Bernardino had to weigh their options when it came to utilizing the new hybrid RTG. Would they risk incurring less-than-stellar performance levels just to test out this new RTG? Economically, they were in a difficult position. They wanted to honor BNSF's requests imploring them to use the hybrid RTGs on a regular basis, but they often found it difficult to risk service failure by doing so. As a result, in the instances where a crane may have not been needed, it was often the hybrid RTG that was cut first even with it in "good order" status.

Additionally, a few issues on the hybrid RTG at Stockton were specifically related to the charging equipment, all of which have been documented with Mi-Jack. One problem was that operators needed to wait for the genset to shut down before plugging in. While testing the electrical charging operations, users had to wait 20 minutes for the genset to turn off to begin the field testing with the plug. This plug-in delay requirement is not practical and is counter-productive to using electric power over diesel.

Mi-Jack modified software to allow the equipment to be safely plugged in while the genset is running allowing for the EVSE to turn on automatically when the genset shuts down. However, this mitigation tactic somewhat defeats the purpose of plugging into EVSE since the genset has already provided a decent charge to the batteries. To remedy, Mi-Jack is investigating genset auto shut-off when it detects EVSE connection. This would help reduce unnecessary genset operation and allow for better utilization of electric resources.

Other issues related exclusively to the hybrid RTG charging option included the enable switch light being very dim and nearly impossible to see in sunlight and the cord reel not being a reel, but a hanger that slides out on tracks. Mi-Jack engineers investigated modifications to fix these problems, developing a spool that spins to unwind and wind the power cord.

An additional factor to considered was the aggressive project timeline. Mi-Jack acknowledged the shortcomings of this short schedule and lamented that additional production and testing time on this technology would have resulted in fewer hiccups in the initial stages of the demonstration.

## Compare Qualitative Operations with Baseline

All of the factors referenced above contributed to lower than desired utilization. From July 2020 through February 2021, the hybrid RTG at San Bernardino averaged 61 hours of use per month, significantly lower than the 401 hours of average monthly use by the baseline diesel RTG during the same period. The utilization rate was similar at Stockton. From September 2020 through February 2021, the hybrid RTG at Stockton averaged just 55 hours of use per month.

## High-level Operational Findings

In the instances where the hybrid RTG was in good operation and the issues had been ironed out, the hybrid RTG seemed to perform as well as a diesel RTG and its output was similar to diesel on a lifts-per-hour basis. Another benefit to the hybrid RTG is the streamlined Preventative Maintenance (PM) sessions. Though there is an initial learning curve for the mechanics in how to properly conduct routine preventative maintenance, it appears to be simpler, cleaner, and less expensive than preventive maintenance sessions on the diesel RTG. In addition to the air quality benefits, other environment benefits were gained. There were little to no drips or spills of engine fluids with the hybrid RTG nor any diesel leakage from filling vehicle tanks.

All-in-all, the demonstration should be characterized as successful. Much insight was gained that can be applied to future productions. After reviewing all the issues with the hybrid RTG, mitigation strategies implemented can be built-in at the beginning of future projects.

## Role in Future Market

In evaluating the role of the future market for this hybrid RTG, there are considerable uncertainties. Though the concept is viable, the OEM still has some work to do on this model of the 1200REH machine to make it more reliable and to establish greater faith and trust among operators. The lower-than-expected utilization of the hybrid RTG at both Stockton and San Bernardino was a function of both the mechanical failures and the conscious decision among operators to choose a relatively equivalent diesel RTG, just to have greater assurance that the asset doesn't fail them while performing ramp/deramp functions on time-sensitive trains. Other hybrid RTGs are in the market, but some of the newer, unproven features and functionality contributed to the hybrid RTG being somewhat unreliable. However, it's important to note the diligence of Mi-Jack in documenting the issues. It will be important for them to apply the lessons learned on future models.

Longer-term, it will be interesting to see what role the hybrid RTGs play in the market. Theoretically, these hybrid RTGs are long-term fixed assets and can operate for 30 years or more. Should new regulation require a transition to completely zero-emission cargo-handling equipment within a 15-20-year time frame, this creates two significant challenges: 1) at this time, OEMs have yet to develop or market a completely battery-electric RTG crane. The timeline is uncertain on complete electrification of RTG cranes, but when the initial models are released, many rounds of testing and trial and error will likely be necessary; and 2) a requirement to shift to zero-emission may force BNSF to shift away from a low-emission lift equipment (hybrid) that still has many good, productive years left.

Other challenges include duty cycle requirements. Many of the cranes in operation at BNSF's intermodal hubs are in operation nearly non-stop. A battery-electric crane could potentially require the crane to pause productivity for periods of recharging. It's not practical to install charge receptacles trackside because charging a crane would block movement of other cranes working along the tracks. In addition, RTGs require free movement, as opposed to traveling along a fixed path. Therefore, the notion of trying to continue lift operations while plugged in is not viable.

Finally, the incremental cost of the hybrid RTG with relatively low operational saving necessitates grant funding to make the total cost of ownership (TCO) economically viable. Current grant funding programs for cargo handling equipment are focused on zero-emission technologies and baseline emission factors for determining the emission reductions are already low. This translates into the hybrid RTG only being eligible for approximately 10% of the cost, which is not feasible.

At this time, BNSF will continue encouraging greater utilization of the hybrid RTGs at San Bernardino and at Stockton. BNSF and its service providers will continue to work with Mi-Jack in refining the ongoing issues to improve reliability.

# Electric Side Loader

## Roles

Mi-Jack provided the technology with ITS ConGlobal as the primary operations service provider for the side loader operations and maintenance in San Bernardino.

## Specifications

**Table 6. Electric Side Loader Specifications**

| Component | Specification |
| --- | --- |
| Power drivetrain | 615V All-electric battery |
| Multi-speed transmission | Taylor/Dana TE-30, designed for BP trains |
| HD planetary drive | Kessler D-102W axle with wet disc brakes |
| Low voltage electrical system | 24-Volt, heavy-duty batteries |
| High voltage electrical system | 615-Volt |
| Battery capacity | 922 kWh |
| External charging equipment | 200kW, 5-6 Hours full charge time |

## Milestones with Start/End Dates

**Table 7. Electric Side Loader Milestones**

| Milestone | Date |
| --- | --- |
| Procure parts, assemble, and test side loader | Q1 2020 |
| Delivery and commission of side loader | Q1 2020 |
| Complete revenue service operations | Q4 2020 |

## Challenges and Resolutions

The project was delayed one quarter due to the delay in the contract execution between SJV and CARB. This caused the purchase order and delivery of the equipment to be delayed one quarter.

The electric side loader was not equipped to allow SwRI to collect ECM data. This caused a delay in the collection of information on battery charge capacity, range per charge, and fuel efficiency. Mi-Jack and Taylor developed modifications to the controller area network (CAN) to allow for expanded communications.

## Compare with Baseline

On the most active day for the diesel side loader, 53 gallons of diesel fuel were used over 15 hours of operation while performing 299 lifts. The diesel side pick fuel tank had a capacity of approximately 200 gallons, which would run for 56 hours of continuous activity before refueling. Typical refueling of the diesel side pick was once a week. Refueling time was measured in minutes and could be done anywhere in the yard. The diesel side pick operated an average 4.3 hours per operating day and consumed an average of 12.7 gallons of diesel fuel, with a diesel fuel cost of $1.23 per lift to operate.

### High-level Operational Findings

During the demonstration, the electric side loader was never operated up to its full potential. The on-site service provider and operators at San Bernardino never truly embraced this technology as much as BNSF would have chosen. The range of reasons driving this result vary and are explained below.

The side loader operators were accustomed to the baseline diesel side loader, which also was stationed in same lot of the yard. Both machines were used primarily for stacking containers and occasionally the flipping of containers. The crane operators were familiar with the diesel unit and they had confidence in how it would perform. They thought the diesel vehicle was more reliable.

The lack of familiarity of the electric side loader caused many of the operators to shy away from operating it. If given the choice, they generally chose the diesel unit. From April through December of 2020, the diesel side loader averaged 89 hours of operation per month, compared to only 59 hours per month for the battery-electric side loader. With stakeholders not being on-site at the yard, it was difficult for the direct staff to consistently enforce a preferred utilization of the electric side loader. At one point, to encourage greater use of the electric unit, the service provider manager personally kept possession of the keys to the diesel side loader, forcing the operators to ask before using. This would allow the manager greater control over which machine would be used that day if only one side loader was needed. After the conclusion of the demonstration period (Q1 2021), the baseline diesel side loader was disassembled and moved to a different part of the yard for operational necessities. As operators gain experience with the battery-electric side loader, it appears that they were more likely to embrace it.

There was also a logistical hindrance that contributed to lower usage of the battery electric side loader. The initial training instructed the operators to return the electric side loader to the charging station when on break, during lunch, or when not in use. This instruction for consistent "opportunity charging" might have given the false impression that the electric side loader does not have enough battery capacity to make it through a full day of work. The range anxiety and the need to slowly taxi the unit back to the charging station likely resulted in the operators preferentially choosing the diesel over electric. Also, drivers were not accustomed to plugging and unplugging the lift equipment. They mentioned the longer startup time verses a diesel unit that started with a turn of the key that fired up the engine and drove away.

This electric side loader had a substantial battery pack, with a 933 kW-hours capacity, which was modeled to perform approximately 288 lifts over 25 hours of continuous operation. However, the typical daily use was about 3.9 hours. Thus, we implemented a charge once per day procedure that was sufficient to keep the battery powered. The electric side loader only needed to be brought back to the charging station once and required only up to 5 hours to fully recharge, yet typically needed less. The electric side loader used an average of 188 kW-hours of energy per its average 3.9-hour operating day with an electricity cost of $1.41 per lift. Some consideration of cost savings could be given appropriate battery size based upon specific usage patterns of specific hubs.

In addition, several mechanical issues contributed to less-than-desired usage of the electric side loader. Listed are some of the most prevalent issues: system errors, blown fuse on the charger, failure to take a charge from the charger, failed DC/AC convertor, cab air conditioning failure, motor coupler upgrade requirement, and gear shifter breakdown. Though diesel units also experience mechanical issues, these issues that surfaced for the battery-electric side loader contributed to lower confidence in the machine among operators.

As for the mechanics, they appreciated the battery-electric side loader from a PM perspective. It's much less complex and clean. For example, on the battery-electric machine, there are no oil filters to change verses 3 on the diesel loader.

Overall, the battery-electric side loader appeared to have comparable power and productivity as the diesel unit. Battery-electric crane operators enjoyed the quieter and smooth operations and were not subjected to any smell of diesel.

Looking ahead, it will be important for Taylor (and other OEMs) to consider pursuing fully electric components with no hydraulics. This version of the loader is a battery-powered hydraulic machine. If battery power is being converted to run electric pumps, it would be possible to have all-electric and eliminate the hydraulics altogether. Taylor is still working to figure out how to get massive amounts of power to a quick response hydraulic cylinder with an electric motor. It still may take some time to for a prototype to emerge.

## Role in Future Market

Despite not being used to its full potential, the battery-electric side loader appears to be a viable technology. The lower-than-expected hours on this machine was not a function of reliability, but appeared to be due to operators choosing the diesel counterpart over the battery-electric due to charging anxiety. Therefore, going forward, it will be important for OEMs to consider offering varying options on battery capacity to right-size for operators based upon duty cycles and lift requirements.

When utilized, the battery-electric side loader performed well and received few criticisms among its operators. There were no reported issues with the side loader's ability to handle lifts for stacking or flips as the existing diesel side loader does. In early

2021, BNSF moved its diesel side loader from Lot 5 to another part of the hub, leaving the battery-electric side loader as the sole side loader in Lot 5. As a result, the battery-electric side loader has been receiving much more use than during the demonstration period. No significant issues have been reported.

From an operational standpoint, there does not to appear to be any significant obstacles that might deter more widespread deployment in the near future.

# Electric Drayage Truck

## Roles

BYD provided the technology for the electric on-road truck that was deployed in San Bernardino, and SH&H provided the operations.

## Specifications

**Table 8. Electric Drayage Truck Specifications**

| Type | Details |
|---|---|
| Wheelbase | 166.3 inches |
| Curb weight | 26,235 lbs |
| Top speed | 65 MPH |
| Maximum gradeability | 25% |
| Range | 125 miles |
| Maximum power | 483 HP |
| Maximum torque | 1,770 ft-lb |
| Battery capacity | 409 kW-hour |
| Charging power | AC 33kw; DC 120 kW or 240 kW |
| Charing time | AC 13.5 hours; DC 4 or 2 hours |

## Milestones

**Table 9. Electric Drayage Milestones**

| Milestone | Date |
|---|---|
| Assemble and test electric drayage truck | Q4 2019 |
| Deliver and commission one electric drayage truck | Q4 2019 |
| Complete Revenue Service Operations | Q4 2020 |

## Challenges and Resolutions

Due to scheduling conflicts around the holidays, as well as wanting the ChargePoint charger installed prior to training, the electric drayage truck training could not be scheduled prior to the end of the year as anticipated.

Charger repair issue occurred in early March 2020 which caused downtime on the electric drayage truck. There was also a significant decline in anticipated activity at San Bernardino rail yard due to Covid-19, which left the electric drayage truck stationary from late April through mid-June. Multiple stakeholders made efforts to solicit alternative uses, but ultimately none materialized, and the truck resumed activities with those of BNSF's San Bernardino yard.

There was also an administrative issue in 3Q 2020 that paused use of the electric drayage truck for several weeks. The truck needed to be registered as part of the lease agreement. It was originally classified as a demonstration unit and therefore could not be operated on the street for longer periods of time. BYD coordinated with DMV regarding the delays and complications with submitting the proper paperwork and securing registration.

Upon commission, there was a wiring issue that prohibited the trailer marker lights from being illuminated even with the pig-tail lines properly plugged in; the trailer lights illuminated only when the brake pressed.

Another minor issue was the electric drayage truck occasionally going into "limp mode" when hitting a pothole. The dashboard would display a "powertrain" warning light. In these cases, the truck would be limited to 20 mph. Generally, the issue could be resolved by having the driver completely turn off the truck and start it back up again.

## Compare with Baseline

Throughout 2020, SH&H demonstrated good balance between use of the electric drayage truck vs. use of the baseline diesel truck. During that time frame, SH&H completed over 1,200 moves with the electric drayage truck, approximately 10% more than the baseline diesel truck.

The operator feedback indicated that cab accessibility (step-up) is a bit more challenging than a similar diesel unit. Also, the cab space felt a bit more constrained than diesel. It was further noted that the fifth-wheel plate was slightly higher than the fifth-wheel plate on diesel, but ultimately this specification did not cause any issues. Finally, access to the hoses and pigtail was found to be a bit more challenging due to having to climb up and down the cat walk.

## High-level Operational Findings

The commissioning, training and orientation provided by BYD and ChargePoint was well-organized and sufficient to initiate demonstration. Preliminary indications from the operators found that the electric drayage truck was well received and that, for the most part, drivers enjoyed the experience.

Initially, drivers needed to become acclimated to some of the nuances in the change from the diesel alterative, but those were relatively minor and did not have a major effect on the drivers' ability to perform their work with the electric drayage truck. Drivers reported that the electric drayage truck performed with the same level of efficiency and consistency of an equivalent Class 6 or Class 8 diesel drayage trucks. They also stated that the power and torque of the electric drayage truck was similar to diesel. The battery life was sufficient for a full-day's work and never caused the work to stop due to low battery levels.

Perceptions regarding the uncertainty on reliability and charge anxiety appeared to be the most common concerns among drivers regarding the electric drayage truck. Ultimately, the drivers suggested that the electric truck is best suited for short-haul drayage moves.

Following are some key quotes that were received from SH&H's driver of the BYD electric truck:

> *"Although my mind was full of doubts and questions, I became excited to see what it would be like using such a unique platform."*
> *"Living with this truck has proven to be very interesting. It runs very smooth and I did find it to have plenty of power for the task given. Even with its quirks, I must say it was a fun truck to drive overall."*
> *"When everything runs smoothly, it seems this electric option is perfect for what we are using it for."*

## Role in Future Market

Overall, the electric drayage truck met the objectives and expectations for the demonstration. As operator of the truck, SH&H was pleased with its performance and would have preferred to have gotten more use out of the electric truck in 2020. But, due to low drayage demand, they were not able to maximize its potential use. The truest testimony on how well the truck was received may lie in SH&H's decision to purchase the truck from BYD for continued use on drayage moves at the San Bernardino Intermodal Facility.

It will be important to continue assessing various duty cycles and uses of battery-electric trucks. As intended from the beginning, this truck was used exclusively for short-haul drayage moves from BNSF's main lot to an off-site lot just around the corner. Battery capacity was adequate even on the busiest of days and there was not much range anxiety due to SH&H drivers having access to a charger inside the yard they were pulling units from. It will be critical for continued testing to see how these trucks perform within different roles such as longer-haul moves, different freight, different driving conditions, etc.

# Electric Recharging Infrastructure

## Roles

BNSF managed coordination with two utility providers: SCE at San Bernardino for the installation of EVSE and PG&E at Stockton for the installation of wayside charging for the BEL and EVSE.

## Milestones

**Table 10. Electric Infrastructure Milestones**

| *Milestone* | *Date* |
|---|---|
| Completion of all offsite electrical upgrades | Q2 2019 |
| Completion of all required onsite upgrades | Q4 2019 |
| Complete EVSE Installation | Q4 2019 |
| Complete Wayside Charger Installation (Stockton) | Q2 2020 |

## Site Specific Cost and Time Considerations

Location consideration for EVSE is key and can vary dramatically based on the type of the equipment being implemented. Rail yards and heavy-duty truck yards with potential for fully electricity operations, such as distribution centers and ports, can cover several hundred square acres. Upfront capital costs of EVSE installation is only one of many considerations. Available real-estate for EVSE equipment, type of equipment, and proximity to assets can impact performance, efficiency, and Total Cost of Ownership for the life of the asset. Charger location becomes even more important the slower the equipment moves. For example, moving the RTG or the side loader, both of which taxi slowly, can deter the operator to return the vehicle to charging station during breaks and/or lunches and take away from productive work time. The opposite is true for the incumbent diesel units as refueling is an increasingly mobile solution, where the fuel is brought to the equipment where it is located. Unnecessary traversing through an operation for charging necessities also increases the opportunity for safety related incidents.

For the drayage charging station, operation was simple and proved to not be a hindrance but instead an emissions and time efficiency opportunity. Fueling time for the diesel drayage truck averaged 40 minutes and required an additional 8.5 miles traveled round trip. By locating the charge station within the BNSF intermodal yard, this additional travel is removed. The electric drayage operator only needs less than 5 minutes to plug or unplug the vehicle at the start and end of the work shift.

The BYD charger for the side loader location was identified utilizing both the location of work and real estate availability for the EVSE. Even with this consideration of time, the impact of opportunity charging was a hindrance and a concern for the operators. An important problem that showed during the pilot specific work operation within the rail yard was that the work moved away from the charger since installation. The large battery capacity of 970KWh did allow the opportunity to skip charging since capacity was rated at two full 8-hour shifts. This indicates that if charger location is a deficiency in an electric conversion, oversizing the battery can mitigate opportunity charging needs.

Moreover, as equipment sizes increase, traversing slows. For example, the RTG required large workspaces so EVSE must be located further away than what would be considered optimal. The RTG hybrid technology helped minimize opportunity charging needs, but overnight charging did require additional time over the baseline counterpart, which could be left on-site.

The BEL EVSE had more attention drawn to it than lift equipment due to the nature of restricted movement on fixed rails. EVSE location for the BEL needs to consider the length of not only the BEL but the full hybrid consist and the test car used during the pilot. Having enough space to fit three full size locomotives and the test car while not fouling other tracks did create for some inefficiencies (primarily fouling adjacent tracks), which needs to be considered in future demonstrations. Power distribution equipment for larger charging capacity does require a larger real estate footprint. To accommodate this, locating the equipment farther from the actual charging unit may open additional charging location options. Charging time also played a significant role, because, while the BEL was charging on the track, that track is not usable for other train operations. This leads to consideration of developing a charge track that does not impede on yard operations which could create additional operating favorability. The foremost site consideration for EVSE on a locomotive is the ability to fit within existing train operations. Meaning, that the requirement to do something different with a battery electric locomotive as compared to existing diesel locomotives proved to be a significant challenge for train coordination within the yard.

## Utility Coordination

Utility coordination early in the development process of any electrification program is critical to success, specifically on budget and on time project implementation. Utility electric vehicle rate selection continues to improve for different asset types, work applications, fleet size and consumption profiles. To provide optimal rate flexibility selection, early communications with the utility can ensure appropriate electric feeders are installed. Early in this case can mean up to a year in advance of desired opening date. Customer development of a long-range outlook of future electrifications plans at the site are critical in the utility decision making process for asset upgrade upstream on the grid before the metered connection. Utility coordination can impact the total cost of ownership of the life of the project because of the direct impact on fuel costs via rate selection. These rates options can vary based on how the electrical infrastructure is designed for installation. Primarily the ability to utilize a favorable EV energy rate verses using a standard time-of-use rate that would be required, if you planned to utilize existing infrastructure supporting building operations.

Successful utility coordination requires identifying the right players. For this demonstration, this included utility representatives on the engineering and capacity teams, the customer point of contact to provide project deliverables and verifying with the original equipment manufacturer to ensure equipment ratings will be compatible with utility delivery. Meeting together onsite to discuss defining usage needs, long range plans, and specific charger location requirements up to a year in advance of desired implementation is essential to successful deployment. Providing an agenda of these specific deliverables can help facilitate a success project. Following is a sample agenda for the utility coordination meeting regarding charging infrastructure for the drayage truck.

Electrical Infrastructure Site Survey Objectives

Customer/Utility

1. Customer to identify electric meter number and location(s)
2. Utility to confirm available electrical capacity on existing feed at facility
    a. Customer to evaluate EV rate implications using existing feed
    b. If capacity is insufficient or EV rate is desired, utility to develop new primary utility feed
3. Utility to confirm available electrical capacity at identified substation
4. Utility to identify redundancy substation location
5. Utility to identify "before meter" capacity upgrades required
6. Customer to identify "behind meter" upgrades onsite required to tie into utility
7. Customer to understand easement and permit needs
8. Customer to identify utility grant programs
9. Utility to communicate lead times to complete load analysis
10. Utility to communicate lead times to complete construction

Customer/Engineering Consultant

1. Customer to scope EV growth needs for facility
2. Customer/Engineering Consultant to assess location(s) for EVSE(s)
3. Customer/Engineering Consultant to identify location and capacity of existing switchgear for EVSE(s)

4. Customer/Engineering Consultant to identify switchgear/transformer upgrade lead times
5. Customer/Engineering Consultant to identify voltage requirements for EV(s)
6. Customer/Engineering Consultant to identify trenching path for EVSE(s)
7. Customer/Engineering Consultant to identify existing utility locates

Equipment OEM

1. Equipment OEM to communicate lead time for delivery
2. Charger OEM to provide UL listing certification
3. Customer to confirm compatibility of charger and EV
4. Customer to ensure Equipment OEM user safety and operations training scheduled
5. Customer to understand how to obtain usage data
6. Customer to develop and implement maintenance or repair protocol for both the vehicle and charging equipment

## Challenges and Resolutions

TKDA was not able to finalize infrastructure design at Mormon Yard until GE finalized the design for BEL charger. The schedule was revised and approved under Amendment 1, and the wayside charger was fully commissioned by September 30, 2020, three (3) months prior to deployment of the BEL. Stockton Intermodal construction was completed by September 30, 2019, and San Bernardino Intermodal was completed by March 30, 2020. The infrastructure for the drayage truck at San Bernardino was prioritized to ensure that charging was available for the BYD drayage truck that was delivered in December 2019.

Electrical subcontractor T&S installed ground conduit incorrectly according to NEC standards. T&S repulled ground conduit to conform to NEC standards.

## Recommendations for EVSE Construction and Operations for Heavy-duty Applications

Charging best practices require the coordination and communication of both the operational team utilizing the equipment and those with visibility and understanding energy costs variances unlike diesel. The difference can have more than a 5X impact in fuel costs. Strategies to mitigate this energy cost difference can be managed through "Smart" charging that can include a twofold approach – (1) delayed charging activation and (2) slowing down charging speeds or on-site storage to supplement grid power during peak times for those operations that cannot shift charging without impacting operations. These "smart" charging strategies can be managed behind the scenes with a third-party company overseeing the software controlling the charging while also accounting for operational needs. This "smart" charging strategy must be seamless and invisible to operator. If operators are forced to make these decisions on-site at the time of plugging in, results will deviate significantly.

The drayage charging profile lends itself well for grid balancing and cost management improvements, with a baseline assumption of working hours of 7am-4pm Monday-Friday and charging overnight. When leaving, the driver plugs in the truck at the end of the shift between 3:30-4:30pm just before the critical peak electric load of the day. With a charging time of 4-5 hours, the truck was completely charged by midnight leaving up to 4-5 hours of "plugged in time" during the off-peak time, overnight. The ChargePoint Express 250 charging station is a 62.5KW charger and can sufficiently provide power to the vehicle. The savings potential will be to design a delay in charging until post critical peak electric load, usually around 9pm. Technology can exploit this opportunity without changing the driver operational behaviors. The driver will still plug the truck into charger at end of shift but delays the actual charging until the critical peak period is over and more favorable pricing resumes. This shift in charging time can reduce kWh usage costs on avg by 73%. Last June - September peak pricing was an average of $.51/kWh verses off-peak pricing averaging $.13/kWh. Charge time modulation is another pricing strategy, which would require sophisticated back-end software such as the ChargePoint solution. Additionally, energy savings opportunities can be utilized if utilities are able to send direct communications to the charger of real time demand loads to further output management.

For work schedules that do not allow charging time flexibility, Battery Storage can also serve as a strategy to reduce kWh cost. In this scenario, even a 300kW storage battery would allow for battery energy to be utilized until critical peak times are over.

Metering can provide additional insight for future iterations that were not fully optimized for this pilot. Sub metering by asset can provide insights into specific equipment usage profiles. This visibility can help to identify cost savings opportunities from delaying charging compared to when it is called for by the operator. Larger charging applications where multiple different companies may utilize the same charging infrastructure can also be envisioned but will also require the visibility provided by a submeter to help delineate pricing for company using power.

The drayage charger had two separate breakdown occurrences reducing usage. These repairs included replacement of one complete power module and a separate issue requiring power module data repair kit. Both repairs were covered under the Charge Point warranty. This, however, caused the charger to be inactive for 28 days. The delayed repair time was driven primarily from E-Rail Safe and contractor orientation requirements set forth from BNSF and Covid-19 precautions. This repair down time should be considered when comparing to a diesel operation as fueling dispenser down time was not a factor. There are multiple public diesel fueling options, and, until there are multiple public electric charging options available, this must be a consideration.

Separate metering at the individual asset level can also serve as a critical success factor for electrification conversion projects. Unlike traditional vehicles, electric vehicles are not as easily measured in terms of fuel consumption. Combining electric assets on a single electric feed can reduce upfront capital costs for both the user and the utility, yet makes tracking fuel consumption at the asset level impossible. Submetering at each specific asset can provide consumption data at the asset level to track performance and fueling costs. With submetering in place and back end data monitoring cost-saving opportunities can then be identified, such as load shifting, sequential charging, and battery right sizing on future electrification efforts. For example, in a two-shift operation, EVs would naturally all be plugged in and begin and end charging at the same time, leaving plugged in dwell time when charging is not needed. The alternative of individual asset charging moving from one asset to the next can reduce kW demand load and allows for grid balancing opportunities for utilities.

# Outreach and Communication

Due to the Covid-19 pandemic that occurred during the project period, various government restrictions were in place in California that limited in-person outreach and communications events that could take place. Therefore, the majority of the outreach and communications that took place for the project were virtual.

## Café Coop

Café Coop, a non-profit organization located in Stockton, California, fulfilled the role of a Community Based Organization for the Project. They performed local community outreach to residents and key stakeholders located within the area the project took place. As part of the community outreach, Café Coop created an educational video detailing how the BEL works within a line haul consist and briefly went over project as a whole. They also organized and moderated a bi-lingual webinar presentation that informed the public about the project, the roles the project partners played, and how the project impacted the community.

Café Coop collaborated with BNSF and the SJVAPCD to create an educational video. The animated video runs a little over 2 minutes long and gives an overview of the project with a description of how the BEL works within a line haul consist.

The bilingual webinar took place June 10, 2021 at 3:30 p.m. Pacific time, hosted on the Zoom platform with Café Coop acting as the moderator. It lasted an hour and included presentations from the following speakers with time at the end for questions and comments:

- Michelle Buffington, CARB
- Todd DeYoung, SJVAPCD
- Christina Fugazi, Vice Mayor of Stockton
- Dan McNair, Wabtec Corporation
- Michael Cleveland, BNSF Railway

Key messages of the webinar included:

- Funding origination and source
- Need for funding in the San Joaquin Valley to assist with meeting air quality goals
- Project impact on the surrounding communities
- Overview and goals of the project
- BNSF Battery Electric Initiative
- How the BEL works
- Leveraging demonstrated project technology for future widespread use

Café Coop performed the following outreach to promote and inform the public and key stakeholders of the webinar:

- A save-the-date flyer was posted in various places open to the public in the San Joaquin County. Outreach locations included cities, markets, various taco trucks and Starbucks. The flyer was disseminated to residents in various mobile home parks. Café Coop also shared the flier through social media messaging platforms, such as Café Coop's Facebook page.
- Direct phone calls and/or text messages went out to some personal and professional contacts of Café Coop.
- Constant Contact was used to send 1,033 email messages to Café Coop's subscribers with webinar information.
- Café Coop posted an informational webinar flyer to their Facebook page. In addition, SJVAPCD also emailed the flyer to the Stockton AB 617 Steering Committee list.
- Café Coop made announcements at various partner coalition meetings, such as the AB617 Steering Committee, Coalition for Environmental Equity and Economics, and Health Neighborhood Collaborative meetings, regarding the webinar.

<u>BNSF and Wabtec</u>

BNSF and Wabtec made significant efforts to educate and inform on the battery electric locomotive and the project as a whole. These presentations were aimed at industry leaders to explain the goals of the project and encourage critical thinking within the rail industry on the topic of advanced locomotive technologies. Some of the presentations that were given include:

- West Coast Collaborative Meeting – October 2018
- Railway Supply Interchange – September 2019
  - Wabtec project summary and description
  - BNSF Locomotive Maintenance Officers' Association presentation
- BNSF Sustainability Workshop – October 2019
- Transportation Research Board Annual Meeting – January 2020
- H2@Rail Workshop – August 2020
- Transportation Research Board, Rolling Stock Committee – January 2021
- Sustainable Development Technology Canada – February 2021
- NREL-UC-Davis Decarbonization Workshop – April 2021
- Minnesota MFAC Q2 Meeting – June 2021
- Freight 2030 Initiative Presentation – July 2021

Additionally, BNSF has published two industry articles on the project within the Locomotive Maintenance Officers' Association.

- BNSF & GE Pilot Hybrid Locomotive Consist using a Battery Electric Locomotive – 2019
- BNSF & Wabtec Battery Electric Locomotive Demonstration Summary – 2021

# Data Collection

Data collection for this project was completed by Southwest Research Institute (SwRI). SwRI is a not-for-profit research and development company based in San Antonio, Texas. They were chosen as a partner for this project because of their long history of industry leading work in the automotive, heavy-duty on-highway, nonroad engines, and locomotive areas.

Data collection was conducted in accordance with the requirements of the ZANZEFF program. Each piece of equipment was data logged for at least three months of regular operation and for a total of 12 months. Initially, it was planned that the data logging periods would be staged one after another so that the twelve months of data logging would consist of three months of drayage truck operations, three months of side loader operations, three months of RTG operations, and finally three months of BEL operations. Unfortunately, Covid-19 delays and delays in equipment delivery required that some of this data logging be conducted concurrently and drayage truck operations bridged the gap to ensure twelve months of operation.

Each piece of equipment (other than the BEL consist) was individually data logged using SwRI's Rapid Prototyping Electronic Control System (RPECS™). RPECS is a self-contained data logging system that can be adapted to a variety of applications to automatically log and report data to a back-office server. In most cases the RPECS was connected to the vehicle control system through the CAN network. Close coordination with the vehicle OEMs was required so that the appropriate data could be collected from the vehicle control system. The BEL and mate locomotives were data logged with a different system that SwRI commonly uses on locomotives instead of RPECS. This system had similar functions to RPECS, but with a simpler communication with the locomotive information gateway (LIG).

Portable emissions monitoring (PEM) was conducted on each equipment type, except for locomotives, for three days. Gaseous emissions were monitored in both real and simulated equipment service. The specific details of the PEMs are in each of the topical data logging reports. Following the proposed approach, PEMs was not completed on the diesel locomotives in the BEL consist, and emissions were based on characteristic values for Tier 4 Wabtec locomotives at each Notch position

Detailed topical reports on each equipment type were prepared by SwRI and can be found in Appendices A, B, C, and D. It should be noted that SwRI's scope did not cover all aspects of the data collection requirements as detailed in the program solicitation. The results of the BNSF and partner owned data collection items are included in the SwRI Topical Reports, with highlights discussed in the appropriate sections of this report.

### Challenges and Resolutions

Thanks to the strong performance and expertise of the SwRI team, data collection was completed with few issues. Some items did cause delays that negatively impacted the program. These impacts were mitigated, as best as possible, by adjusting the schedule and plan accordingly

- The onset of the Covid-19 pandemic and associated lock downs and travel restrictions delayed the installation of the data collection units on the RTGs and Sideloader. Covid-19 restrictions also delayed the production and receipt of this equipment, further compounding the delay. As mentioned above, the schedule was modified from a series work to a concurrent approach. This change mitigated time lost and allowed the team to successfully complete the milestones on schedule.
- The CAN system on the RTGs and Side loaders needed upgrades to allow internal data parameters such as battery state of charge, battery current and voltage, and lift counts to be broadcasted on the J1939 CAN network. This upgrade required software development and modification of the RTG and side loader control system by Mi-Jack/Taylor. BNSF funded this work and the development added a two month delay in the collection of this information. Until this modification was made, only partial information was able to be collected. The data collection period was extended to account for this delay.

# CCI Employment Reporting Outcome

Using the CARB provided CCI Employment Outcome Reporting Template and the labor hours reported by the project partners, the following number of jobs provided by the project are estimated as follows:

**Table 11. CCI Employment Reporting Outcome**

| *Job Classification* | *Job Education Required* | *Number of Jobs Provided* | *Total Project Work Hours* |
|---|---|---|---|
| **Public Administration** | 4-Year College Completed | 0.4 | 1,740.74 |
| **Transportation and Warehousing** | 4-Year College Completed | 1.2 | 5,792.00 |
| **Manufacturing** | 4-Year College Completed | 43.8 | 204,820.00 |
| **Construction** | Apprenticeship or Other Professional Certification | 8.6 | 17,894.00 |

Labor hours for the construction of infrastructure and EVSE were not reported for the project. For the purposes of the reporting template, it was assumed that 45% of the total cost of construction was for labor. This total was divided by the average hourly prevailing wage rate of an electrician in the two counties to estimate the total project work hours for this job classification.

# Final Observations and Recommendations

Overall annual emissions reductions from this program are shown in the table below. Initial emissions reductions represent only a fraction of the impact that this project has had on BNSF and the industry. This project has allowed BNSF to develop, implement, and evaluate technologies that provide the potential for significant emissions reductions.

**Table 12. Project Emissions Reductions**

| Annual Estimates | BEL | Drayage Truck | Hybrid RTG | Sideloader |
|---|---|---|---|---|
| Days of Operation (assumed) | 263 | 365 | 365 | 329 |
| Fuel Savings [gal] | 35,000 | 2,122 | 14,915 | 4,180 |
| $CO_2$ savings [kg] | 350,000 | 21,854 | 154,265 | 62,800 |
| CO Savings [kg] | 22 | 45 | 220 | 124 |
| Humidity Correct NOx [kg] | 500 | 237 | 47 | 94 |
| Total Hydrocarbons Savings [kg] | 10 | 12 | 5 | 2 |

These estimates of emissions reductions are derived from the SwRI topical data collection reports and expanded out to annual estimates. These estimates are highly dependent on the BNSF San Bernardino Intermodal Facility use profiles, and assumptions made in their derivation, primarily the number of days used. The annual emissions reduction estimates also assume that electrical power to charge the electric versions of this equipment is zero emissions, which is an incorrect assumption based on the current California electrical grid. Additionally, the NOx values represented in the drayage truck are those higher values from the PEMS results, and should not necessarily be characteristic of a truck in that service.

The evaluation of such a diverse group of equipment provided an opportunity to understand the operational impacts across different equipment categories and provide BNSF with valuable information for future purchases. While each piece of equipment was ultimately successful in its role, it was not without challenges and difficulties in implementation. These challenges are not unexpected for new pieces of equipment and instead serve as a guide for any future implementations. The most significant obstacle is the high initial costs of these new technology assets. This large initial capital investment and auxiliary costs associated with charging infrastructure remains a significant barrier in the adoption of this equipment. In some cases, the cost of the initial purchase can be as much as four times that of an equivalent diesel-powered asset. While operational benefits due to more efficient electric propulsion may offset that capital investment, favorable electrical rates are critical in making it economically viable. Most importantly, grant and incentive structures must become robust and bountiful to offset the higher costs of this new lower emitting technology. Special attention must be given to ensure that funding sources are available and suited for these unique pieces of equipment. This is particularly important for equipment like the cargo handling equipment and locomotives that have long development time, low purchase volumes, and long asset life. This equipment is difficult to realize improvements because these three characteristics make the cost of development and implementation very challenging.

When considering the adoption of new equipment technology, BNSF considers the total cost of ownership of that asset. This analysis considers all the significant costs in owning a vehicle and compares those costs to the current equipment providing that role. Fuel, maintenance, repairs, charging, initial purchase price, subsidies, and incentives are all considered in this approach. BNSF uses the best available information from demonstration projects, like this one, to inform the purchase of new equipment. Due to the nature of new technologies, particularly battery vehicles incurring high initial capital costs, the demonstration weighs very heavily in the total cost analysis.

Going forward BNSF will continue to evaluate this equipment in regular service and has no plans of removing any equipment from service (other than the BEL whose demonstration is complete). This equipment will serve as the foundation for the evaluation of BNSF's involvement in future grant programs for additional low emitting assets. It is recommended that funding agencies review the intent of their funding programs to ensure they align the most impactful projects with their limited available funding. As such, the generous funding of large cargo handling equipment like drayage trucks, side loaders, RTGs, and locomotives presents a great opportunity for the reduction of emissions in a single program.

The project team would like to thank the contributions that everyone made to this project across all our organizations. Everyone, from operators to project managers, is proud of what we have accomplished and the foundation we have laid for this impressive equipment. We could not have done it without the hard work and dedication of everyone involved.