Evaluation report

BuildZero Testevent 2024

BUILD ZERO TESTING

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Event overview

This report evaluates the key learnings and insights of the BuildZero Test event. On November 25 to 27 ENI, BMWT, and ElaadNL joined forces to host the first-ever BuildZero Test event, an event focused on testing the charging of mobile electric construction equipment. This event was held at the ElaadNL Test Lab in Arnhem, a facility known for its research into charging infrastructure for electric vehicles, including passenger cars, e-trucks and construction vehicles. BMWT is the trade association of importers and suppliers of construction machinery, warehouse equipment, road building machinery and transport equipment. ENI (Emissionfree Network Infrastructure) is a foundation with 45+ members from the whole value chain of emission free heavy duty machinery.

The construction industry is transitioning towards zero-emission operations, and with this shift comes significant challenges, particularly the ability for all electric vehicles and equipment to charge seamlessly, meaning the devices are interoperable among each other. Interoperability is essential for scaling zero-emission construction, as highlighted in ElaadNL's recent Outlook report, which also emphasized the growing demand for power in this sector. Therefore the focus of this first event was to together discover the challenges in interoperability between the different actors on the construction site. Hereby making the next step together towards Zero Emission Construction.

ElaadNL-Outlook-Bouw-2024.pdf

During the three-day event, tests were conducted on four construction vehicles, three charging stations and one battery system, all provided by different manufacturers. These tests simulated real-world conditions on construction sites in a controlled environment. The test where conducted by the engineers of the manufacturers under guidance from technical experts from ElaadNL. This allowed participants to evaluate interoperability and identify potential areas for improvement. In total 23 engineers joined testing.

In addition to the technical testing, knowledge-sharing sessions were held, featuring insights from industry experts.


BUILD THE FUTURE

Testing focus

Equipment

Heavy Duty Construction vehicles

Four construction vehicles of the following manufacturers participated:

- Catterpillar (Pon Cat)
- Liebherr (Wynmalen & Hausmann)
- Volvo (SMT Netherlands)
- Komatsu (Van der Spek Vianen)

All four machines were excavators weighing approximately 20,000 kg. Three of the machines were equipped with steel track belts, while one had rubber wheels. All machines were compatible with CCS2 charging plug.

DC charging stations

The following three charging stations manufacturers participated to the BuildZero Test event, each with a DC CCS2 station with output powers ranging from 40 kW to 350kW.

- ABB
- Kempower
- Autel

Battery charging system

During the event, UMS participated with one battery charging system. A battery charging system is equipped with an integrated battery pack, which can be used to charge a vehicle via a CCS2 plug. Additionally, the battery pack itself features a CCS2 inlet, allowing the batteries to be recharged.

When the system charges a vehicle, it functions as a charging station. Conversely, when the system is being charged by a charging station, it operates as a vehicle. Therefore, in the results, the system is categorized as either a charging station or a vehicle, depending on the mode it is in.

Test System ElaadNL

ElaadNL also participated during the Test event with its own 350kW EV/EVSE testing system. This system could be used as a testbench for either a vehicle or a charging station.

Test Protocol

The test event consisted out of 8 test rounds of one and a half our each. During each test round 4 testing duos were made. The duos consisted out of a vehicle-charger, vehicle-battery system, charger-battery system or one of the three categories together with ElaadNL. Every test round 4 different combinations were made. So, at the end all parties have tested together.

What was tested in a test round was according to the preferences between the parties. However, ElaadNL offered a test plan featuring various test scenarios to facilitate a structured testing process. This test plan is provided below.

General behavior

To evaluate the overall behavior of the battery, vehicle, and charger combination, the following aspects should be tested:

- Does the connector establish a reliable connection with the vehicle or battery each time it is plugged in? Are there any instances where the plug failed to make a proper connection and required adjustment?
- Does the locking mechanism of the cable work?

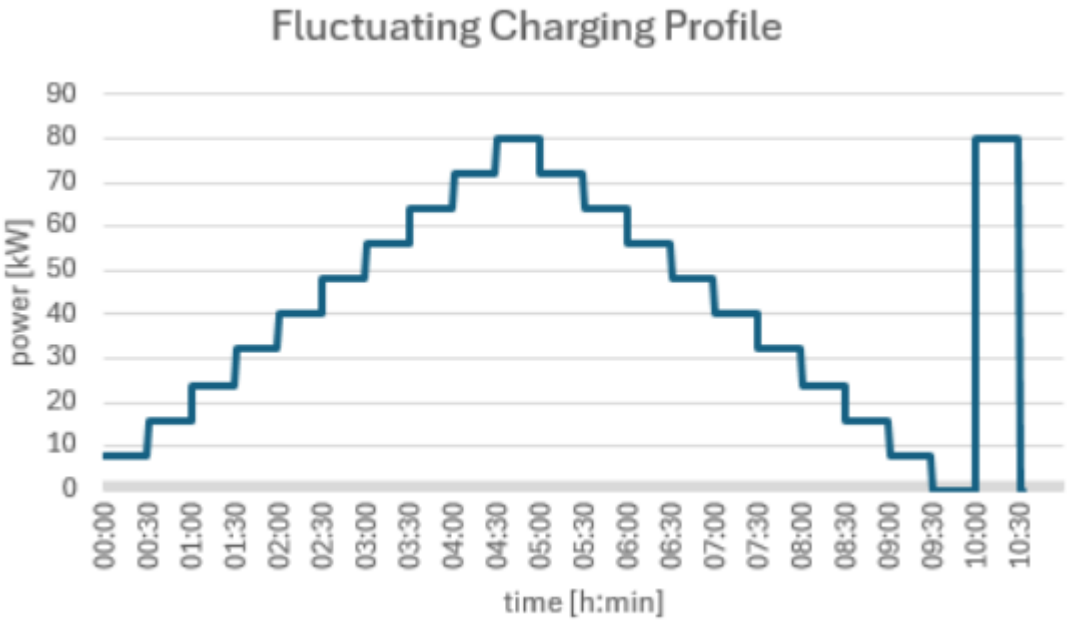
Supported Protocols

To determine which charging protocols the devices supports, it is recommended to initiate a charging session at a fixed speed for each protocol.

- Testing the possibility of conducting a charging session of 40 kW using the DIN 70121 SPEC.
- Testing the possibility of conducting a charging session of 40 kW using the ISO 15118-2
- Testing the possibility of conducting a charging session of 40 kW using the ISO 15118-20 (Not possible during this event because the lack of PKI's)

Smart charging

Smart charging is essential at construction sites to efficiently manage limited power resources, prevent overloading, and prioritize charging based on operational needs. Therefore, it is crucial that combinations of chargers, batteries, and vehicles support smart charging. We recommend testing the following profile to evaluate the capability of charging at different power levels.



General insights

EV charging basics standardization

During the event it was very noticeable that there was no vehicle standardization regarding the location of the charging port and the LED colours used to signal the status of the charging process.

- The charging ports where located at the left and the right of the vehicle and in the front and the back.
- Regarding the LED colours one of the vehicles used yellow during the initialization, the others used green. During charging, one used blue and others flashing green. And one of the vehicles used blue when charging was suspended from vehicle side. Based on experience from ElaadNL, the following colours are commonly used, ElaadNL is also recommending to use those colours:
    - Green: ready to charge
    - Blue: charging
    - Red: error

Both cases can lead to issues when machines from different manufacturers are used at a location and/or by the same operator. For instance, the placement of a charging station might need to be altered because of the location of the charging port. Or an operator might assume an incorrect charging status because of the differences in colour use. Therefore we recommend more standardisation of these charging basics.

Vehicle charging safety

Regarding the charging safety the following observations were made during the test event.

- All vehicles had a (emergency) stop button in the cabin, one also had an emergency stop button at the charging port.
- All charging stations where equipped with an emergency button.
- On one of the vehicles multiple stickers with a QR code where present, which directly linked to a safety instruction for the vehicle.

It is positive to see all chargers are equipped with emergency buttons which immediately stop the charging of the vehicle. The vehicles are also all equipped with a stop button in the cabin, so together with the emergency button on the station an operator is always near a stop button if he is in or close to the vehicle. This is a good thing, but as later turned out not all stop buttons in the vehicle behaved as a true emergency stop (see 3.3.2). This could be improved. The difference between a stop button and an emergency button is that a stop button is used to operate a machine and stops the charging session in a controlled manner. An emergency button, on the other hand, is used in case of emergencies and immediately interrupts the charging session. Frequent use of the emergency button can lead to issues with the charger or the vehicle, as the charging power is disconnected abruptly. It should be clear whether the button is a stop button or an emergency button. If

it is an emergency button, it should function accordingly by immediately disconnecting the power.

Also, the addition of a QR code linking to the safety instructions is a great addition in case of an emergency and therefore recommended to become standard procedure.

Test results

Interoperability tests

Protocol support

During the event the 4 vehicles, 3 charging systems and 1 battery system, which could perform the role of an EV and a charging system, were tested on their interoperability. The vehicles and charging stations all supported the most basic protocol: DIN 70121. Also, all supported the more advanced ISO 15118-2, which has more advanced features like delayed and paused charging. None supported the latest 15118-20 protocol, which includes bidirectional charging. A vehicle will send a list of supported protocols with a prioritization to the charging station, after which the charging station can decide which one of the supported protocols will be used. An overview of the potential features of the different charging protocols can be found in table 1 below. How many devices supported the different charging protocols can be found in table 2.

Table 1: features of different charging protocols

DIN 70121	**ISO 15118-2(0)**
Fluctuating charging profiles possible	Fluctuating charging profiles possible
Pausing a charging session is not described in this standard. It is possible to pause a charging session by setting the charging current to 0 amperes; however, the session will remain active. As a result, the inverters in the chargers stay active without delivering active power, and consequently, the charger draws reactive power from the grid. In addition to this, other issues may arise. For example, the charging station may continue delivering power to the battery when 0 amperes is requested.	Pausing a charging session is described in those standards. Therefore it is possible to pause or delay a charging session without drawing reactive power from the grid.
	Plug and charge
	Vehicle to grid(V2G) only for ISO 15118-20

Table 2: protocol support of devices under test

Protocol	Vehicle(+battery)	Charging station(+battery)
DIN 70121	5	4
ISO 15118-2	5	4
ISO 15118-20	0	1

Overall interoperability results

During the testing 18 different vehicle – charging station combinations were made. In three occasions the charging station manufacturer had to make some changes to get charging to work. As most manufacturers were not able to manual select the protocol to be used during the testing, and most vehicles were using DIN 70121 as priority, the number of tests on 15118-2 were limited. Also, as only a single device supported 15118-20, no interoperability could be tested on that protocol. All tested vehicle and charging station combinations could set up a successful charging session on the DIN 70121 protocol. On 9 of those combinations a smart charging session was successfully tested, 6 via an OCPP smart charging profile, 3 via manual setting the charging speeds. The drawback of performing the test manually instead of using OCPP is that, in the field, the charging stations will most likely be controlled by OCPP. Therefore, testing with OCPP better reflects the real-world scenario.

Even though on DIN 70121 pausing the charging is not supported, 1 station was able to do this anyhow and truly go to 0A DC . As only at one station could force the use of 15118-2, this was only tested in 4 combinations. Smart charging was tested manual on 3 combinations without a charging pause test. The results are summarized in table 3.

Table 3: Interoperability test results per protocol

Protocol	# of tested combinations	# successful
DIN 70121	18	18 (3 after changes)
+ Smart charging	9 (6 via profile, 3 manual)	9
+ pausing	6	2 (1 station)
15118-2	4	4
+ Smart charging	3 (manual)	3
+ pausing	0	0
15118-20	0	0

Conclusion

All vehicle – charging station combinations tested were able to charge during the test events, though in three cases some changes were needed, and smart charging worked fine on the tested combinations. It stood out that at all vehicles the DIN 70121 protocol had the highest priority, even though they could support 15118-2. As the station will normally follow the vehicle's priority protocol, this meant that in most occasions only the more basic DIN 70121 protocol could be tested. This limited the testing abilities and will also mean that in practice the more advanced features of ISO 15118-2 communication will not always be usable.

Additional safety test

CP/PP loss

One of the charging station manufacturers brought an additional test device to interrupt the CP or PP communication. If such an interruption happens, the charging power needs to be reduced in a gradual, timely manner before stopped completely to avoid the opening of switching gear while high currents are present and to prevent voltage peaks. On the three vehicles tested this worked fine. There was not enough time to test this with the 4th vehicle.

Emergency shut down vehicle

The same charging station manufacturer that was able to do the CP/PP loss test, also tested and measured the way the power stopped when the stop/emergency button was pushed. As this is an emergency situation, power should be cut immediately. Two vehicles were tested, one vehicle manufacturer did not allow this test because of the possible strain on the power switch and there was not enough time to test this with the 4th vehicle. The results:

- One EV only had a regular stop button, which did not respond like an emergency button. So, not directly cutting off the charging power but a controlled stopping sequence.
- One EV had an emergency button which did cut the power immediately. The vehicle did not change the CP state afterwards (remained at 6V, which signals it is charging).

Emergency shut down impact on charging station

One of the charging stations was tested on an emergency stop from vehicle side using ElaadNL its Keysight DC electric vehicle emulator. When pushing the emergency button, the voltage in the charger went up with 100V. As this increase may only be 10% of the voltage at that moment (which was far below 1000V), the allowed limit was crossed which might lead to defects in the station or even dangerous situations.

Conclusion

As these construction vehicles will be used in harsh environments it should be considered to test how they behave if an issue with the connection occurs, in this case tested via a CP/PP communication loss. It was positive to see all tested EVs passed.
Regarding the emergency shut down it is apparently unclear if a true emergency button should be present at the EV and how the charging should be stopped when pushed. As it should only be pushed in a true emergency, we recommend that the charging should be stopped immediately. Afterwards, the vehicle should go to a non-charging CP state, so the charging station will not try to restart the charging process again. And the charging station itself needs to keep the voltage surge below the allowed limit.

Power quality test

Voltage dip test

Voltage dip tests were performed on one of the charging stations using the Keysight AC emulator setup from ElaadNL. Via these AC emulators, ElaadNL can control the quality of the voltages from the AC grid connection to the charging station under test. During these tests, the voltages on the three phases were brought from 230V to 100V with different phases and number of phases dipping to 100V. It was noticed that if one phase dipped to 100V, the current intake on the other phases increased with 70A from 120 to 190A. The manufacturer explained this had to do with a voltage balancing mechanism in the station, which makes the station use more power from the phases with the highest voltage. As a higher voltage means there is less usage on that phase, voltage balancing is a good thing to balance the grid, but in this case the increase in current was very high which can lead to tripping of overcurrent protection devices or other malfunctions.

Conclusion

Especially because the power feed at construction sites might be less than optimal, it is important to test the DC charging stations on their immunity to voltage issues. If the station completely stops charging after a short dip, or if it takes in too much current and trips the overcurrent protection, the vehicle will not be charged. To further investigate power quality related issues it is possible to plan a test week at the ElaadNL Testlab.

General conclusions and recommendations

The main outcome of the event was that all vehicles were able to charge on all the charging stations at the end of the event, so interoperability was achieved. Half of the vehicle-station combinations were also capable of setting up a successful smart charging session. Completely pausing a charging session to 0A was only supported by 1 charging station.

Looking back at all the test results and conclusions above the following additional conclusions and recommendations can be made:

- There is a need for more standardization regarding the vehicle's charging port locations, LED status colors and emergency button location and function.
- The vehicles supported the more advanced ISO 15118-2 protocol, but were all set to the more basic DIN 70121 protocol by default. This will limit the availability of more advanced charging features in the field, like full smart charging support including pauses. Therefore we recommend that vehicles are set to the most advanced protocol as default, and only fall back to the more basic protocol if an interoperability issue with the more advanced protocol occurs.
- As the power feed at construction sites might be less than optimal, it is important to test the DC charging stations on their immunity to voltage issues. This is possible at ElaadNL and therefore we invite all DC charging manufacturers to bring their charging stations to ElaadNL to have them tested on this, and other, power quality related, phenomena.

Test process improvement suggestions

During the BuildZero test event the following possibilities for improvement were noted or suggested on the testing process:

Improvement of predefined tests:

- Electric vehicles and charging stations should both be able to select the protocol to be tested. As the vehicle sets the priority, this primarily lays on that side. However, it would also be useful if the station testers can forcibly select the protocol to be used by the station.
- The smart charging profile did not work on all charging stations. It will be better to share the smart charging profile(s) to be used well in time so the station manufacturers have enough time to test the profile and make changes to it if needed.
- Manufacturers should be challenged to come to these type of events to (also) test their latest software developments, even if it is still in beta. This will make for more interesting testing, resulting in better input for further development of for instance 15118-20 functionalities.
- Advice manufacturers to monitor the communication from their device to the backoffice and/or the internal logging during testing, especially during and after an error state.
- As a charging issue might occur spontaneous during a charging session, a longer test period was suggested during the event to better find these kind of issues. For this an overnight slow charging test had been performed on 1 station which had positive results. If done outdoors this can be made a regular test.
- Add a charging pause from vehicle side in the test protocol. It was noted that a vehicle requesting 0A can be seen as an invalid value by the charging station.

Additional noted/suggested tests:

- Parties should test the CP/PP loss and the emergency button behaviour and measure the current flow and the possible voltage surge in their device.
- Test how the station and vehicle behave during a power loss of the station.
- Test the consistence of the time to start charging. It was noted that this could differ during tests of the same station-vehicle combination.
- Test the power quality immunity of the charging stations. This can be done outside of the test events in the regular Elaad Testlab process.
- Test the power flow interoperability between the charging stations and battery systems. To prevent power delivery issues, the timings and power levels between the two need to be near perfectly aligned, which should be tested.
- Test the communication interoperability between charging infrastructure and Energy Management Systems (EMS)

- High current CCS testing; there are parties that are looking into increasing the current on CCS to 800-900A, allowing for higher charging speeds.
- Add Megawatt Charging System (MCS) testing when available
- Test the charging in harsh environmental conditions, like with mud and water, or increase the contact resistance between inlet and plug in a more controlled way.
- Add a dedicated test slot with the Keysight system with all participants, to test the implementation of the different communication protocols and log the behavior of the device.

Event Evaluation

Communication

Most parties had no comments on the communication before or during the event. There were two improvement suggestions however: one party was not aware that there was already a test slot during the presentations, and one party commented that they would like to have received the list of participants and the testing protocol earlier in advance to better prepare.

Location

All participants where very positive about the location. The only suggested improvement was related to the access to the toilets. A badge or code would have been handy to enter the Testlab again afterwards.

Safety

Safety in the testlab itself was very well arranged. Participants were positive about the physical safety measures and the checks by the Elaad staff. In the tent outside some improvement possibilities were noted. There were no physical safety measures available there, like a general safety button to cut the power outside and a place with safety equipment like a fire extinguisher and an electric shock rescue hook. One of the participants in the tent did bring a hook.
Also, during the safety presentation a demonstration of the usage of these physical safety measures should be given.

Usefulness

All parties think these kind of events are very useful to test and debug and directly communicate with the other engineers. An important reason given for these kind of events is that there are a lot of different interpretations of the protocols. It was mentioned that this is especially the case when vehicles are converted to electric.

Future test events

All participants asked were interested in future test events. One participant mentioned to also attend with smaller machines that could also do AC charging next time, and an observer mentioned they would like to join next time with a piling machine.

As improvement suggestions for a future event multiple participants mentioned they would like to receive the test protocol earlier and have the ability to give input to it. They would especially like to add more edge cases, the input they already had was added to chapter 4. As adding tests would also require more time, the test slot periods would also have to increase. It was also mentioned that all parties should attend with test engineers

and relevant test/measurement equipment and have the ability to perform changes in the firmware at the spot.

Other suggestions

There is a need for a guideline for charging on construction areas. Some mentioned subjects are electrical safety (CEE connectors are taken out while powered and cables/connectors can be easily damaged, and this is combination with wet steel plates), how to calculate the amount of power needed while also taking into account other connected (construction) equipment, lengthy cables and multiple cables connected to cover longer distances.

Final remark

At Elaad, it is also possible to test your charger, vehicle, or battery system outside of the BuildZero test week. Elaad tests equipment on:

- Interoperability
- Smart charging
- Power quality
- Cybersecurity

For more information, please visit the ElaadNL website:
https://elaad.nl/en/topics/tests/