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A Teardown Study of Flood Damaged Electric Vehicles

EV Battery Safety, Part 2

SAE Government/Industry Meeting
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Idaho National Laboratory

Electric Vehicles and Battery Safety (Cont.)

- Recent hurricanes in Florida have revealed that seawater flooded EVs pose major safety concerns to passengers, emergency responders, and recovery personnel.
- The 2022 Hurricane Ian impacted between 3000-5000 EVs to various degrees:
  - 600 EVs were a total loss, ~36 EVs caught on fire.
  - In several instances, the fire erupted while the impacted EVs were being towed on their flatbed trailers.
- Hurricane Idalia in 2023 also caused several EVs to catch on fire, although the numbers were lower than the hurricane Ian due to:
  - A relatively weaker hurricane Idalia, raised public awareness to move EVs to higher grounds.
- Spontaneous EV fires have also been reported after accidental EV immersion (e.g., in boat ramps).

2022 EV Battery Fires at Florida after Hurricane Ian

2023 Hurricane Idalia Caused Fire Damaged EV

EV burns under water after mishap backing jetski down Florida boat ramp

Flood damaged EVs stored 50 ft apart

- A comprehensive understanding of the EV/battery failure mode in saltwater immersion scenarios is required.

https://abc7news.com/hurricane-ian-ev-car-fires-electric-cars-damaged-florida-flood-damage/12356326/. https://www.msn.com/en-us/autos/news/video-ev-tesla-burns-under-water-after-mishap-backing-jetski-down-florida-boat-ramp/ar-AA1k5A8V

Selected EVs for Teardown Study

- 10 Hurricane Ian flood damaged EVs collected:
  - Figure showing the approximate flood line.
  - No observable fire damage from these vehicles.

Vehicle #	Vehicle make, model and year	Auction site
1 (V1)	Tesla Model Y 2022	IAA Clewiston Site 749 3005 County Road 835, Clewiston, FL 33440
2 (V2)	Tesla Model Y 2022	IAA Clewiston Site 749 3005 County Road 835, Clewiston, FL 33440
3 (V3)	Tesla Model 3 2020	IAA Clewiston Site 749 3005 County Road 835, Clewiston, FL 33440
4 (V4)	Porsche Taycan 2022	Copart 2601 Center Road, Fort Pierce, FL 34946-7502
5 (V5)	Lucid Air Grand Touring 2022	IAA West Palm Beach, 14344 Corporate Rd S, Jupiter, FL 33478
6 (V6)	Tesla Model X 2017	Copart 10175 U.S. 17, Arcadia, FL 34269
7 (V7)	Tesla Model X 2020	Copart 10175 U.S. 17, Arcadia, FL 34269
8 (V8)	Tesla Model X 2017	Copart 10175 U.S. 17, Arcadia, FL 34269
9 (V9)	Tesla Model S 2018	Copart 10175 U.S. 17, Arcadia, FL 34269
10 (V10)	Tesla Model 3 2018	Copart 10175 U.S. 17, Arcadia, FL 34269

After Hurricane Ian, these vehicles were stored at the auction sites until June 2023. The vehicles were purchased in early July 2023 and later transported to Auburn Hills, Michigan at Munro & Associate's facility between **July-August 2023** timeframe for the teardown study.

Commonality in Pack Designs

- Some similarities in pack design exist:
  - Packs are categorized in four groups.

Pack Design	Vehicles	Vehicles
1	V1, V2, V3, and V10	Tesla Models 3 and Y
2	V6, V7, V8, and V9	Tesla Models S and X
3	V5	Lucid Air Grand Touring
4	V4	Porsche Taycan

General Observations

- The water intrusion left water marks, debris, sediment, and mold/mildew on the seats, sills, floor, and instrument panel. The high voltage battery casings were exclusively located underneath the EVs. The high voltage battery casings of all the EVs were fully submersed:
  - In a few instances (e.g., for vehicles V4 and V5), the raised penthouse attached to the top of the battery compartment was partially submersed.
- The low voltage battery was either fully or partially submersed. The following table provides a summary of the 12V battery locations, chemistry, and states of submersion:
  - All 12V batteries were found to be completely discharge state without showing any evidence of catastrophic failure.

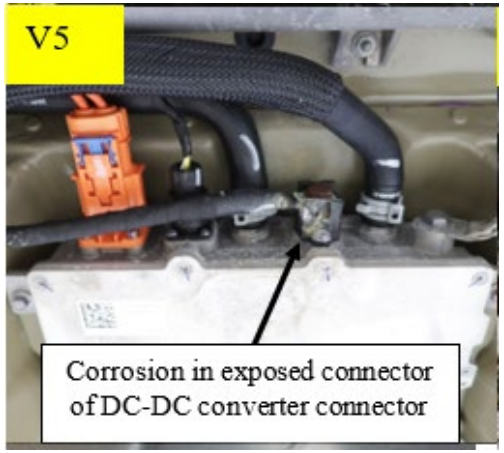
Vehicle number	Vehicle make, model and year	12V battery number, location, and chemistry	State of submersion
V1	Tesla Model Y 2022	One, under wiper cowl, LiB	Partial
V2	Tesla Model Y 2022	One, under wiper cowl, Lead acid battery	Full
V3	Tesla Model 3 2020	One, under wiper cowl, Lead acid battery	Full
V4	Porsche Taycan 2022	One, under wiper cowl, Lead acid battery	No submersion
V5	Lucid Air Grand Touring 2022	Two, under rear passenger seat, in right rear wheel well, both Lead acid batteries	Partial
V6	Tesla Model X 2017	One, under wiper cowl, Lead acid battery	No submersion
V7	Tesla Model X 2020	One, under wiper cowl, Lead acid battery	No submersion
V8	Tesla Model X 2017	One, under wiper cowl, Lead acid battery	Full
V9	Tesla Model S 2018	One, under wiper cowl, Lead acid battery	Full
V10	Tesla Model 3 2018	One, under wiper cowl, Lead acid battery	Full

General Observations: Corrosion

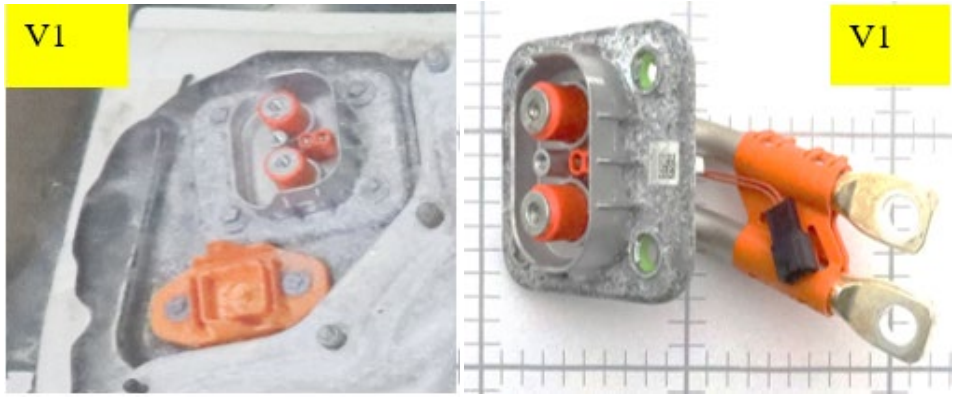
- Distinct corrosion was observed throughout the vehicles where salty or brackish water submersion was present:
  - This includes the metal frames, battery pack exterior, LV systems and harnesses, HV charging connectors, fasteners, etc.

Battery lid surface

12V battery & surrounding



DC-DC converter connector

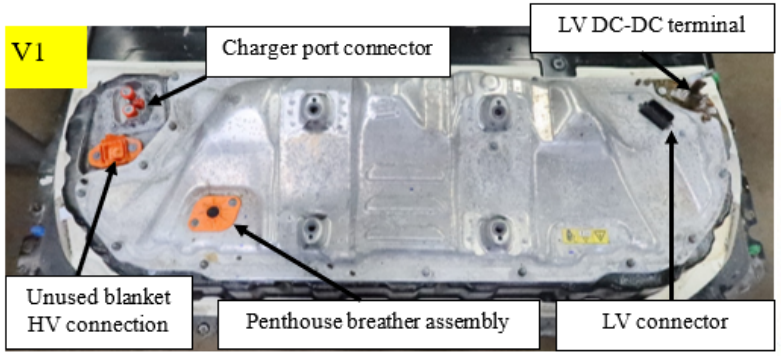


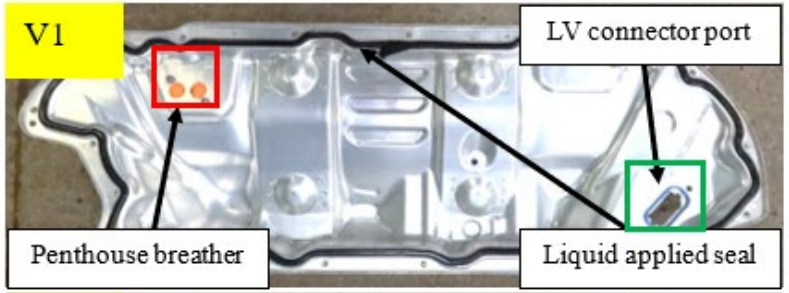
Onboard penthouse charging connector

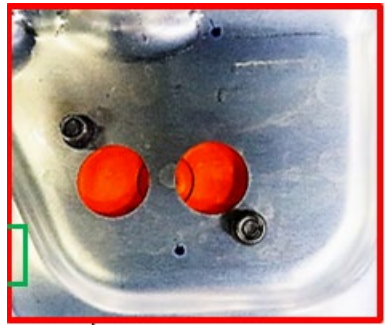
Key Observations- Pack Design 1: Tesla Model 3 & Y

The Penthouse

- The exterior side of the penthouse shows signs of submersion resulting in various levels of corrosion for all four EVs in this design group.
- The low voltage DC-DC converter terminals are exposed on the penthouse and as a result exhibited particularly severe corrosion resulting from galvanic activity.
- The underside of the penthouse lid shows what appears to be residue of dried liquid in two distinct areas, which may be indicative of either condensation or some level of water ingress in V1 and V2.
- Those areas are surrounding or adjacent to the penthouse breather vent and low voltage communication connector.
- The interior surroundings of the low voltage connector opening (silicone seal) in V2 shows witness marks.



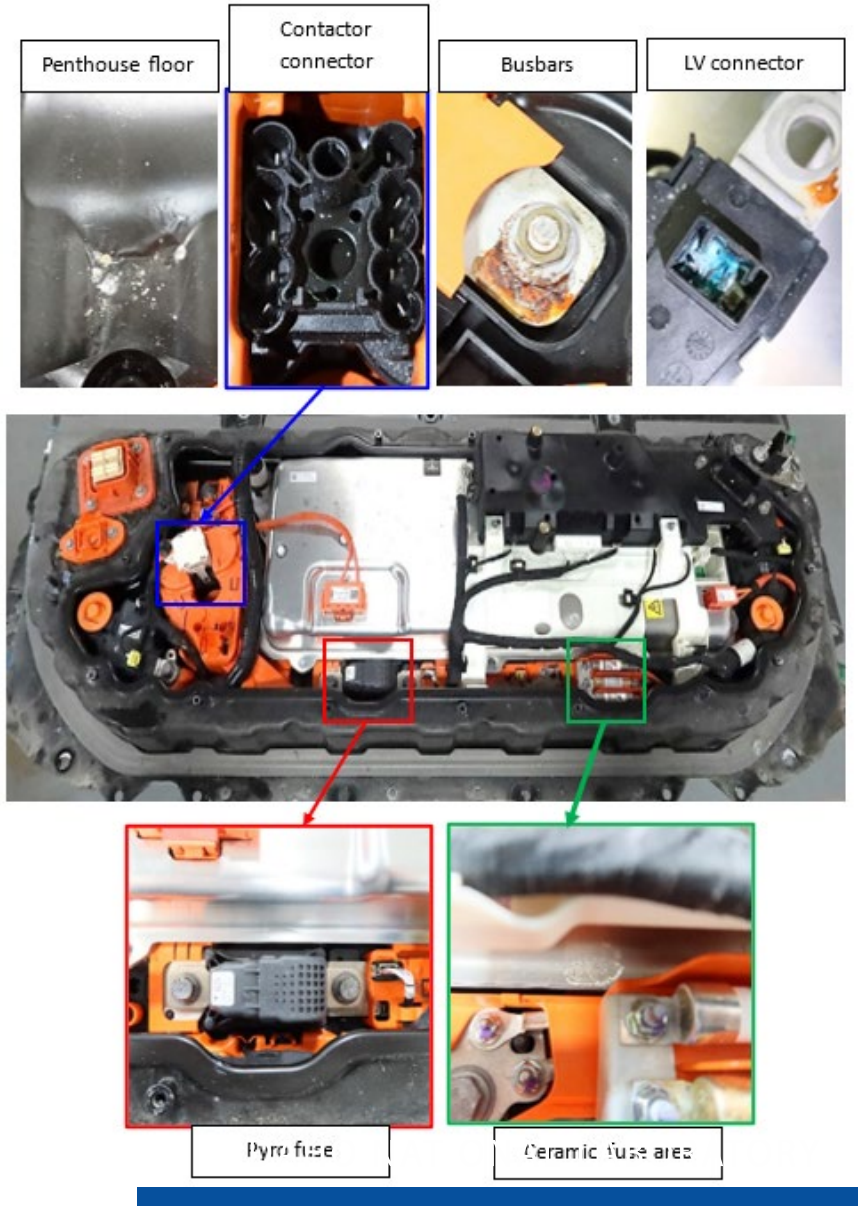




Key Observations- Pack Design 1: Tesla Model 3 & Y

The Penthouse

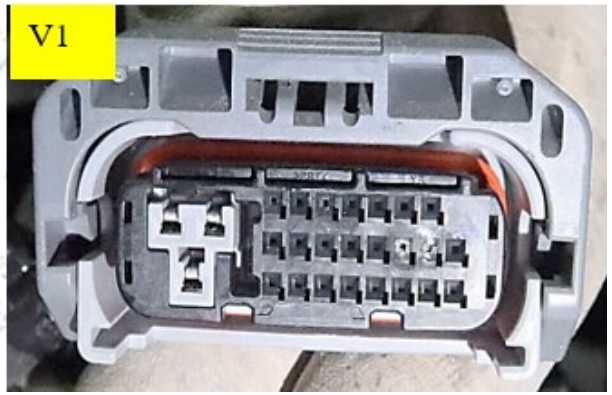
- Distinct corrosion, contamination, water, and water marks on the floor of the penthouse and within several components for V3 (Tesla Model 3) were observed:
  - More specifically, corrosion was noted on the busbar connections, within connectors, on the uncoated aluminum housing of the charger/inverter module, and elsewhere
  - Contactors tested the open-circuit (normal) and found the pyro-fuse had not triggered.
- In this state, it is highly likely that the modules within the penthouse would be unable to function properly in any capacity.



Key Observations- Pack Design 1: Tesla Model 3 & Y

Connectors

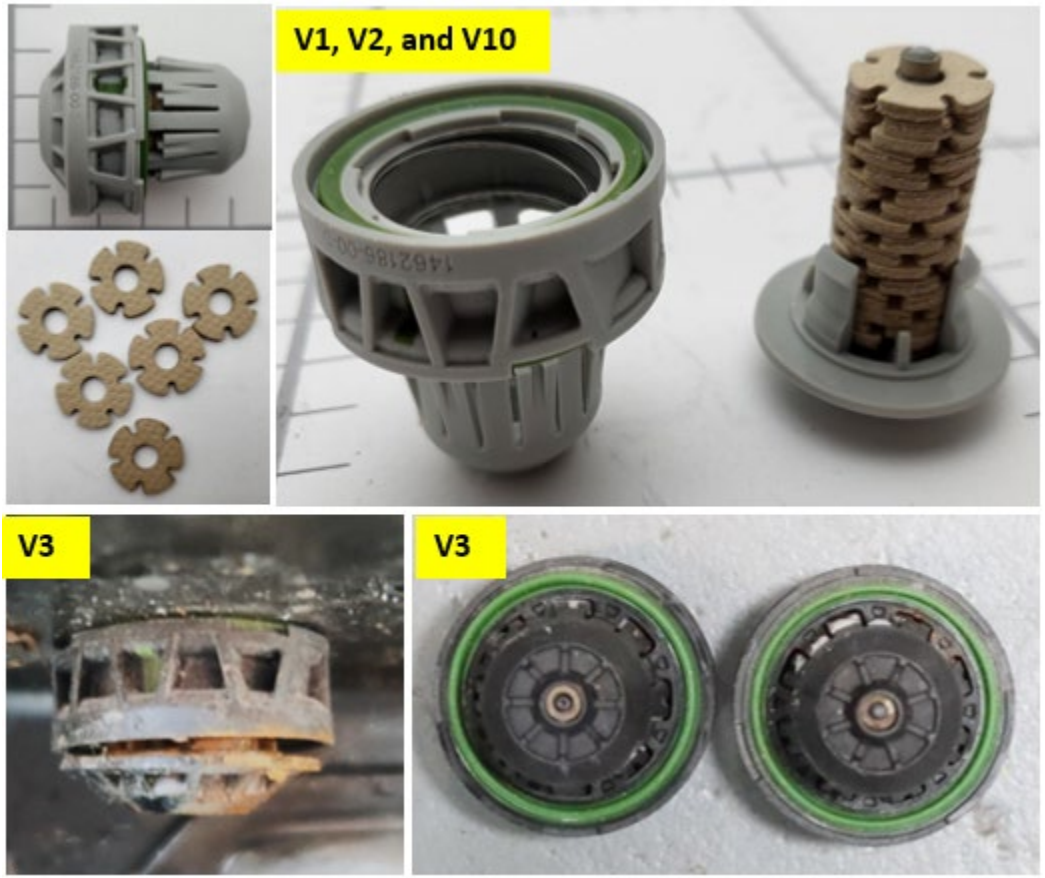
- For V3 (Tesla Model 3), the high voltage connectors of the electronics penthouse were observed to have a high degree of corrosion throughout. The internal surface of the pack where the connectors mount also showed a large amount of contamination.
- The interior, sealed area of the low voltage communication connector on the penthouse of V1 (Tesla Model Y) exhibited what appears to be the dried residue of water intrusion and remnants of light corrosion or contamination surrounding the bases of several pins. Similar corrosion was found on the corresponding terminals of the vehicle wire harness.



Key Observations- Pack Design 1: Tesla Model 3 & Y

Penthouse Moisture Vent or Flood Port

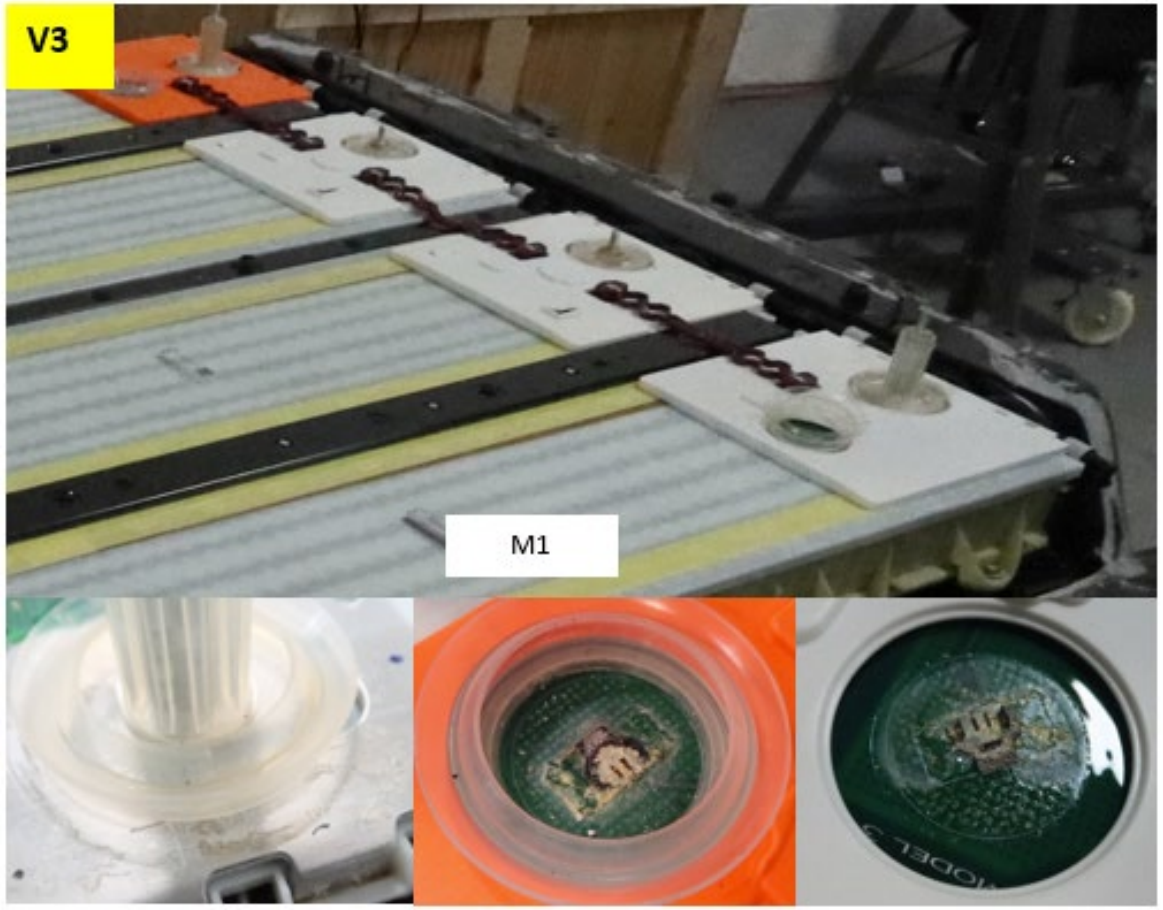
- Two moisture-activated vents, or “flood ports,” as Tesla calls them, are located on the rear right and left sides of the battery pack, mounting through the bottom of the tray into the interior of the penthouse compartment:
  - Cellulose-based wafers are stacked around a central shaft held closed by a spring and will expand in the presence of moisture, compressing the spring and opening the vent.
- For V3 (Tesla Model 3), both vents are observed to have activated and stuck open. While it is difficult to determine if these vents failed in some way and allowed water intrusion into the penthouse space, or if they merely operated as intended and only opened due to exposure to water within the penthouse from another source, they do present a possible point of ingress if at least one of the two are either defective or activated due to exposure to water from outside the pack.



Key Observations- Pack Design 1: Tesla Model 3 & Y

Penthouse Interface Seal

- The areas on the tops of the modules that interface with the electronics penthouse feature **circular gaskets** for sealing between the penthouse and the module space.
- Corrosion and contamination were observed on the surfaces of these sealed areas that are exposed to the penthouse space of V3 (Tesla Model 3).
- One of the gaskets appears to have failed, with some surface corrosion noted around the terminal bus plate of Module 1.
- While 7 out of 8 of the Tesla gaskets presented no apparent failure and the single gasket that failed had limited impact and occurred on a module that did not appear to present any issues, it is very possible that the exposure and corrosion on the BMS circuit board has incurred some form of damage that would negatively impact their function.



Key Observations- Pack Design 1: Tesla Model 3 & Y

Pack Lid Seal

- Water, residue, and contaminates were observed on the pack floor under Module #4 of V10 (Model 3). This water and contaminate intrusion did not appear to contact the cells at any point, though the lower outboard mount fasteners of the module exhibited light corrosion.
- The apparent point of ingress was determined to be a void or gap in the liquid-applied lid perimeter seal at a complex curve near the front-right corner, possibly due to trapped air and/or inadequate clamping load prior to curing of the seal.

Key Observations- Pack Design 1: Tesla Model 3 & Y

Battery pack vent assembly

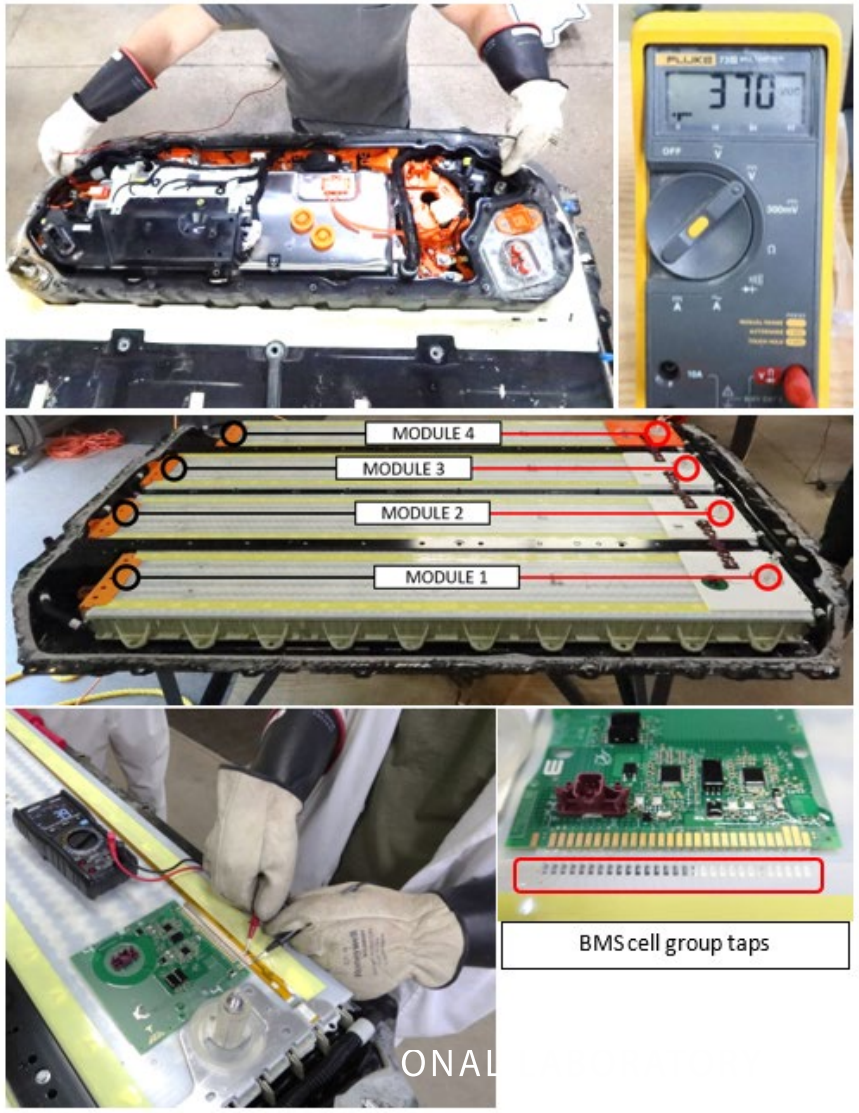
- Examination of the exterior and interior of the vent assemblies for all the vehicles in this design group shows no signs of seal failure or water ingress through the pressure diaphragm.

Key Observations- Pack Design 1: Tesla Model 3 & Y

Pack Compartment

- In general, the pack voltage remains elevated even after more than ten months of storage:
  - Except for V3 (Model 3), the maximum cell group voltage variation remained within 14 mV.
- The Module 3 of V3 measured 3V lower than the identical Module 2. Cell group voltage testing revealed cell group 11 within Module 3 measured 1.06V vs the average cell group voltage of approximately 4.00V.
  - The over-discharged cell group was consequently located, and surrounding materials were removed, and no evidence of any physical damage or watermark was found. The absence of any evidence of water induced damage indicates manufacturing/aging related issues within cell Group 11 that became pronounced when the BMS balancing system was non-operational upon failure of the 12V system.

Vehicle	Pack voltage, V	Module 1 voltage/cell group spread, V	Module 2 voltage/cell group spread, V	Module 3 voltage/cell group spread, V	Module 4 voltage/cell group spread, V
V1	370	88.60/3.85±0.000	96.25/3.85±0.000	96.25/3.85±0.000	88.55/ 3.85±0.000
V2	381	91.30/3.97±0.000	99.30/3.97±0.000	99.30/3.97±0.000	91.30/ 3.97±0.000
V3	383	91.80/3.99±0.014	100.70/4.03±0.013	97.70/3.91±0.581	92.80/ 4.04±0.011
V10	392.6	94.10/4.09±0.002	102.20/4.09±0.005	102.10/4.08±0.006	94.20/4.10±0.004

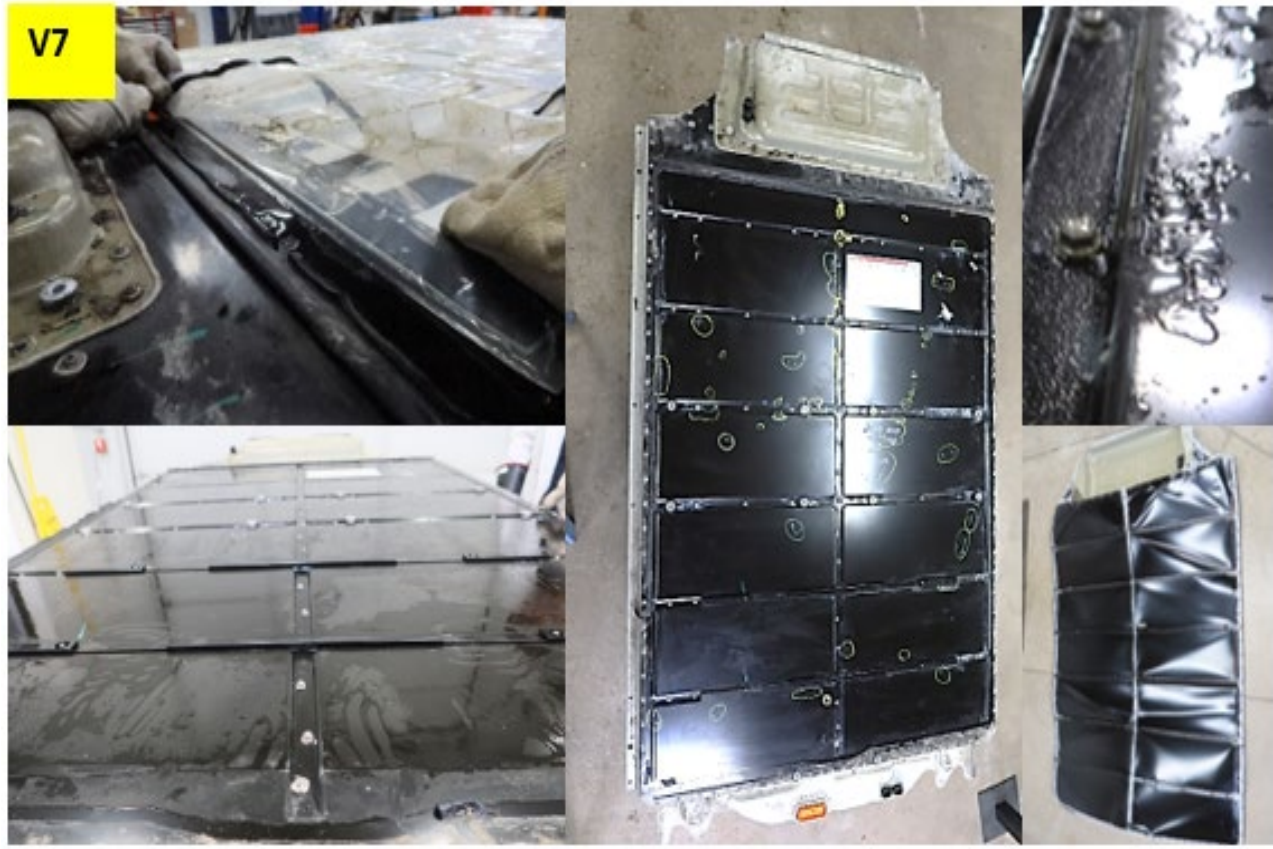


Key Observations- Pack Design 2: Tesla Model S & X

Adhesive-bonded Plastic Sheet

- For V6, the plastic sheet was able to retain its integrity. The plastic sheet in the remaining vehicle packs (V7-V9) failed to retain integrity:
  - Standing water was evident on the pack exterior both on top of and underneath the plastic sheet on the lid. Adhesive beads were penetrated by water in at least one area thereby allowing water across the barrier. A multitude of areas with corrosion/failed environmental coating were noted across the entirety of the lid exterior, evidenced by “bubbling” of the lid coating, and most likely caused by the trapped water compromising the coating. This corrosion also extended to several fasteners exhibiting a rusty appearance.

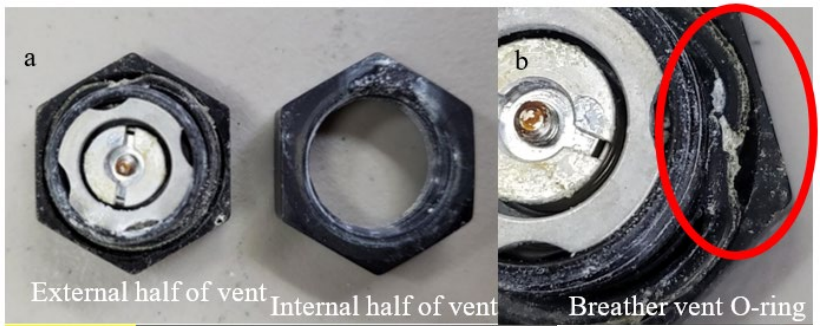
- Despite the numerous areas showing corrosion, the interior-facing underside of the lid exhibited no signs of corrosion, contamination, or damage and the pack interior likewise had no evidence of such.

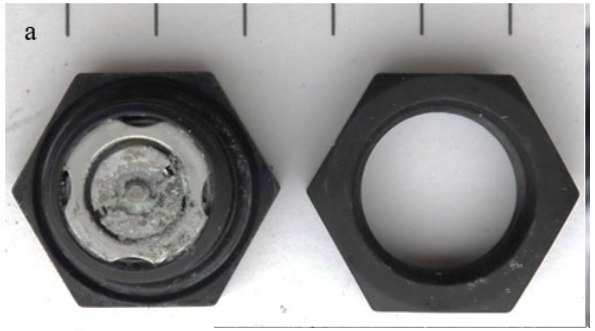


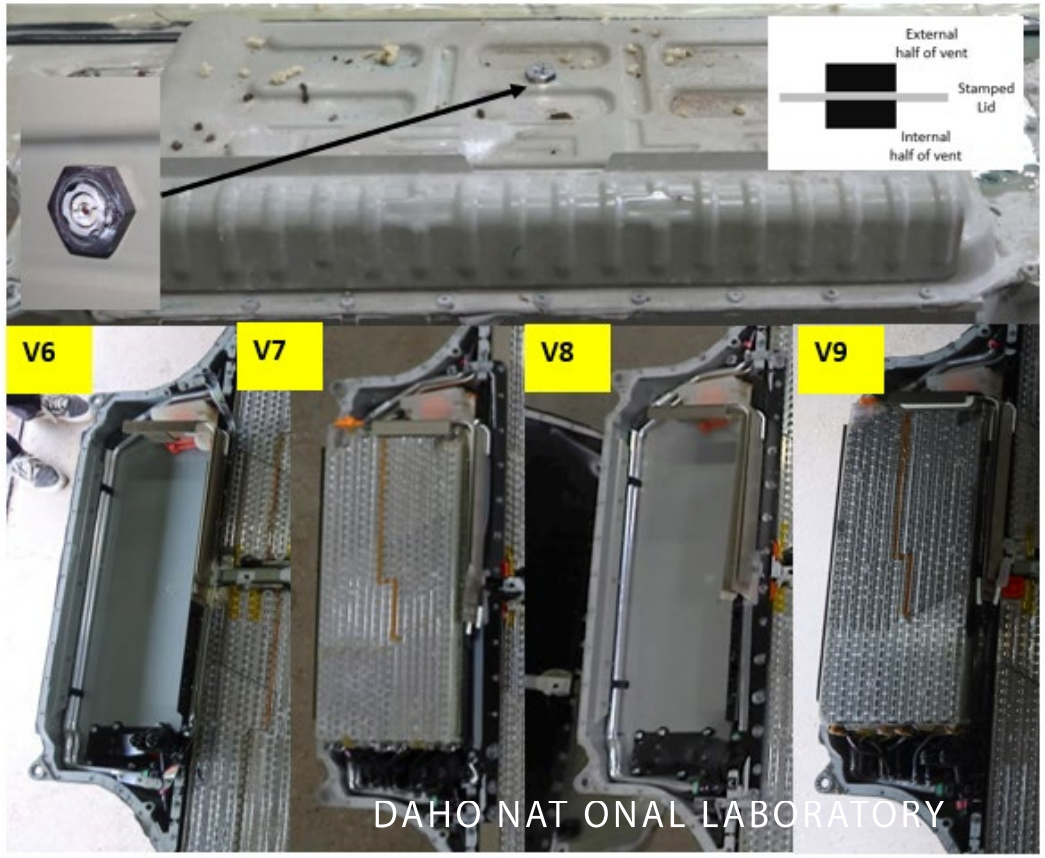
Key Observations- Pack Design 2: Tesla Model S & X

Penthouse Breather Vent

- There is a mechanical breather vent located on the lid in the center of the penthouse of V6 (Model X), V8 (Model X), and V9 (Model S). *Vehicle V7 (Model X) did not have a breather vent*.
- Water ingress and contaminates were observed in the floor of the penthouse space of V6, V8, V9, directly below the breather vent on the lid due to its failure:
  - Modes of vent failure: Compromised section of the O-ring (V6), internal failure (V8 and V9).



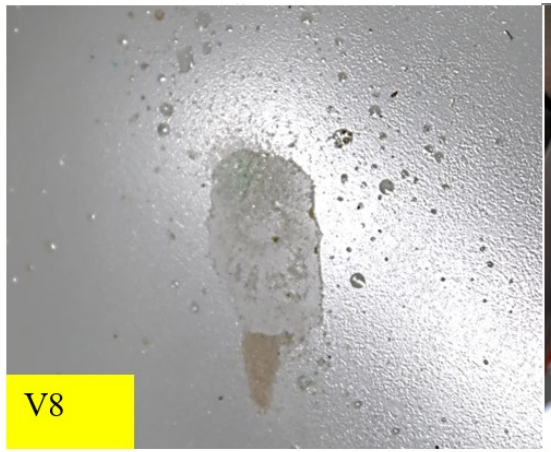


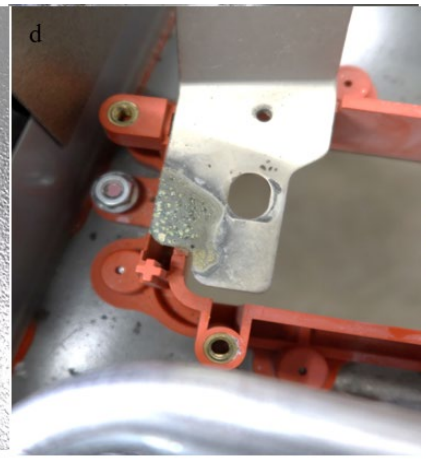


Key Observations- Pack Design 2: Tesla Model S & X

Penthouse Breather Vent (cont.)

- Pictures showing evidence of watermark/sediments, condensation, corrosion, and mold growth.
- V9 pack had water condensation throughout the pack, resulted in distinct corrosion.





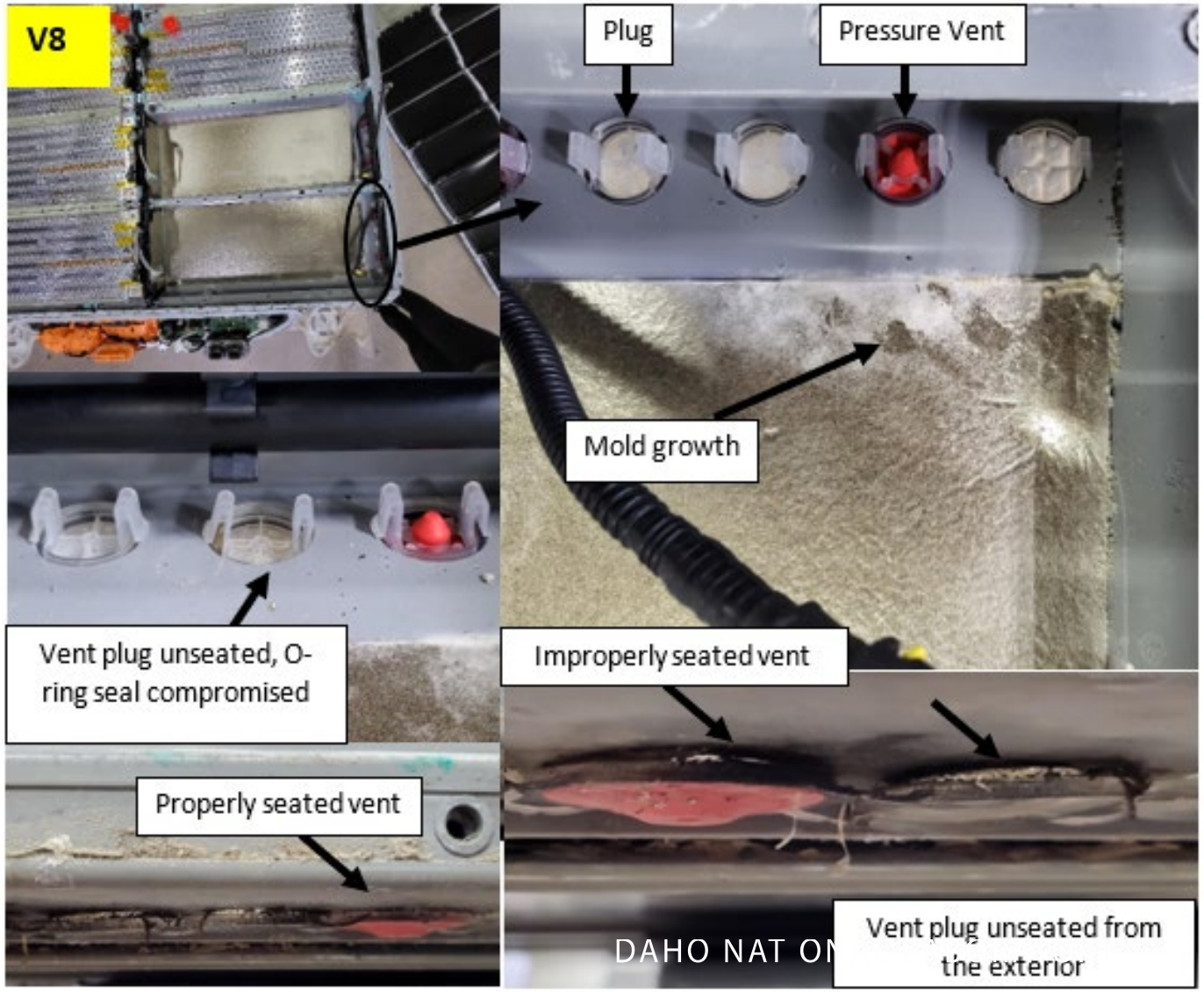
Corrosion on the pyrofuse busbar

The presence of sediment deposits exclusively on the interior side of the pyrotechnic fuse, suggesting that the source of the liquid that encountered the seal is somewhere inside the pack penthouse.

Key Observations- Pack Design 2: Tesla Model S & X

Outboard Vents and Plugs

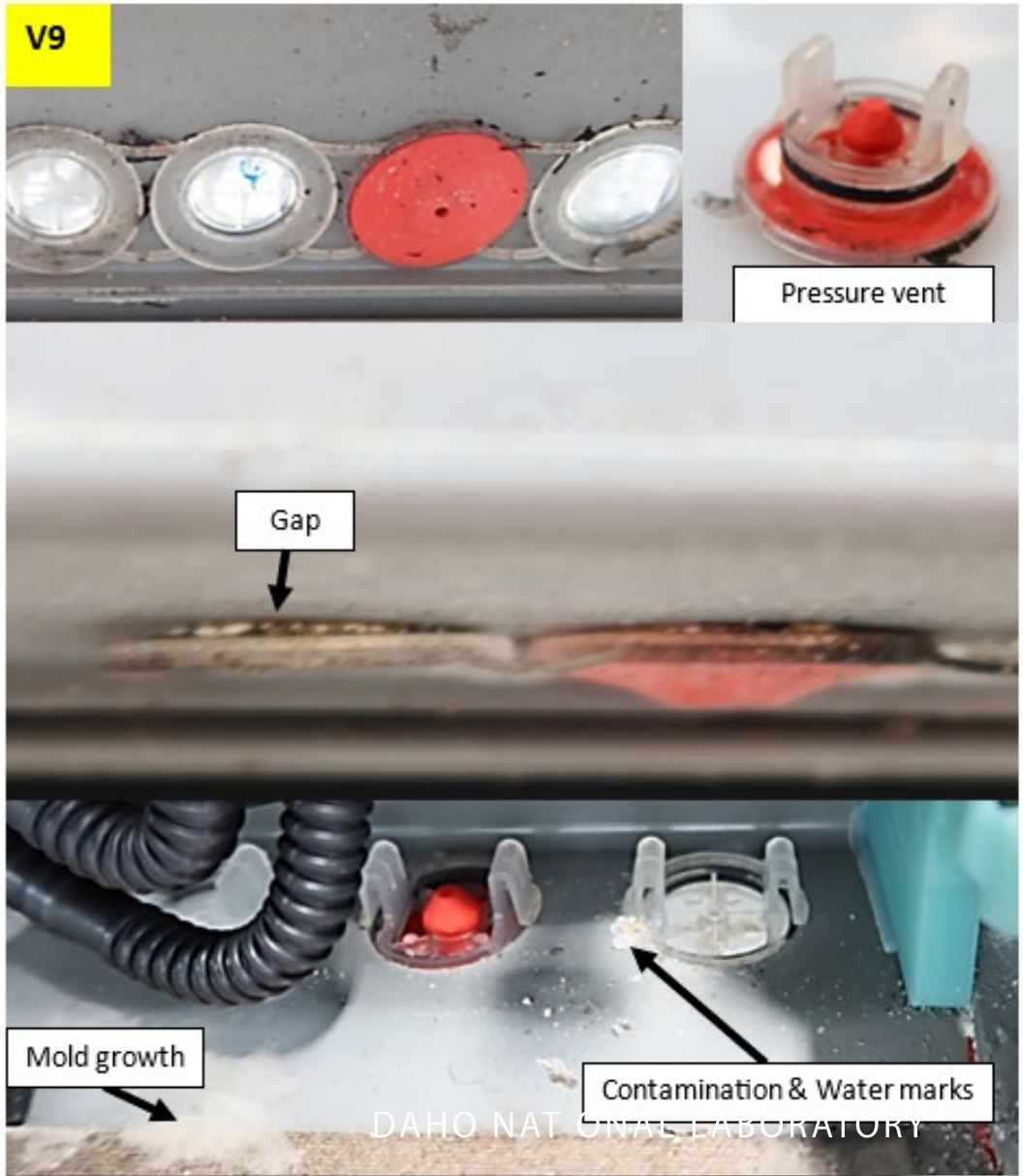
- The side sills of the battery pack for this design group feature snap-in pressure vents and vent hole plugs, each of which seal against the battery pack tray with an O-ring:
  - Close examination of the interior side of the vents revealed certain instances where the retaining features of the snap-in vent bodies had failed, resulting in the vent or vent plug becoming unseated in its hole, thereby compromising the integrity of the O-ring and allowing water ingress
  - Not every component had been unseated from the interior as shown in the figure, rather the exterior faces of the other compromised vents revealed slight misalignment that may have contributed to a compromised O-ring seal.



Key Observations- Pack Design 2: Tesla Model S & X

Outboard Vents and Plugs (cont.)

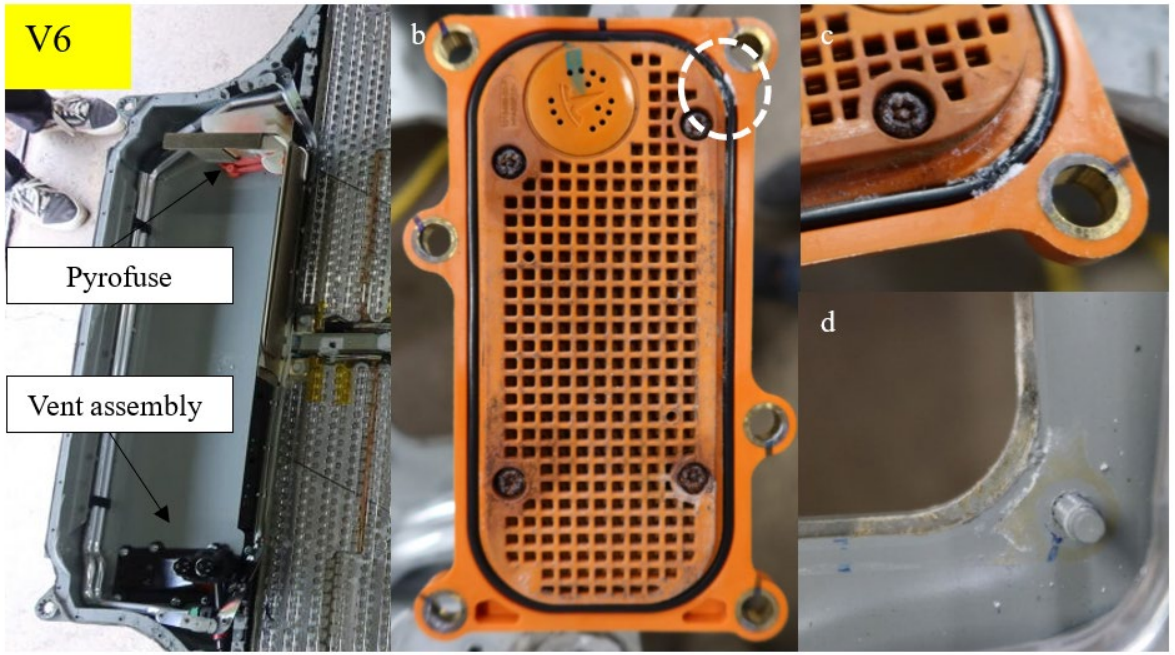
- For vehicle V9 (Model S), every module space within the battery pack displayed signs of water contamination – water, water marks, sediment/residue, and/or mold:
  - These vents and plugs showed varying degrees of evidence of contamination and may be a primary source of water intrusion within the non-penthouse area of the pack of V9.
- For V6 and V7, the plugs and vents were uncompromised.



Key Observations- Pack Design 2: Tesla Model S & X

Battery Pack Vent Assembly

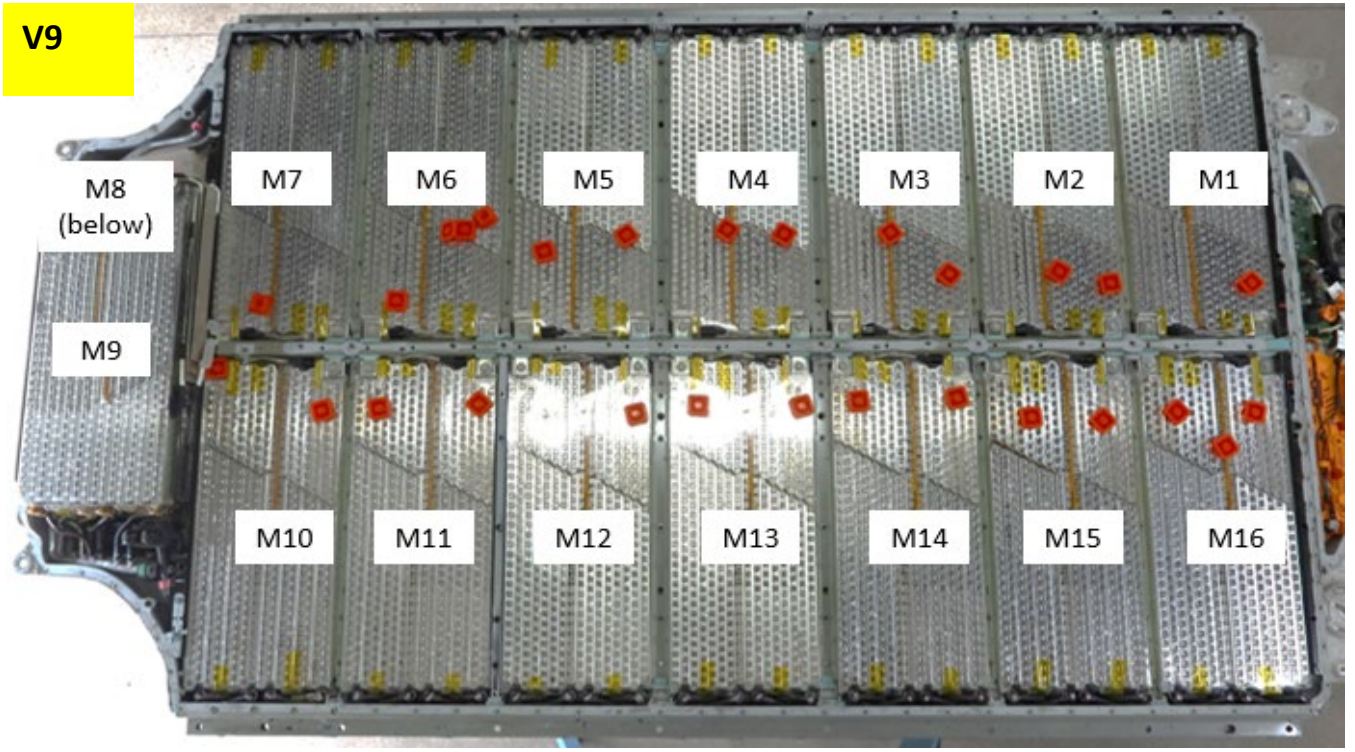
- Upon removal of the vent of V6 (Model X), sediment deposits were observed in a localized area of the injection molded seal:
  - The sediment was present on both sides of the seal.
  - Given the proximity of the breach to exclusively one of the studs used to fasten the vent to the pack, it is possible that insufficient fastener torque resulted in a local reduction in compressive force on the seal, causing this localized leak.
  - The vent assembly of vehicles V7, V8 and V9 is found to be uncompromised.



Key Observations- Pack Design 2: Tesla Model S & X

Battery pack

- Unlike Pack Design 1, which had four larger modules, Pack Design 4 consists of up to 16 smaller modules:
  - For V6 (Model X), V7(Model X) and V8 (Model X), the module voltages were consistent, deviating by at most 0.18V (max-min module voltage) or 44.5 mV 1σ standard deviation
  - For V9 (Model S), voltage of Module M8 (located underneath module M9) measured to be 0.44V, and hence created a wider spread (24.12V) and standard deviation (5.83V).



Vehicle	Pack voltage, V	Module 1 voltage/Max spread, V
V6	305.6	21.82±0.0445/0.18
V7	298.9	18.68±0.027/0.12
V8	346.3	24.72±0.028/0.11
V9	396.6	23.04±5.83/24.12

Key Observations- Pack Design 2: Tesla Model S & X

Battery Module in Penthouse Compartment

- Both Modules M8 and M9 were located directly underneath the penthouse breather vent that failed:
  - The lower battery module, M8, within the penthouse and measuring a mere 0.4V shows evidence of prolonged and severe water contamination, as indicated by large amounts of corrosion and residue throughout the module. Hence, Module M8 may be nonfunctional, unsafe, and completely unsuited for operation
  - The source of the water exposed to this module would appear to be the breather vent on the top of the penthouse lid, which sits directly above both M8 and M9. Given that M8 is located at the bottom of the pack, water likely collected and caused the short which discharged the module. Though also contaminated and corroded, the upper module, M9, voltage measured in line with the remainder of the modules, therefore, it is presumed the water intrusion flowed over the upper module and left it unaffected in comparison to the lower module, which dwelled in the accumulated water.

Key Observations- Pack Design 2: Tesla Model S & X

Battery Pack

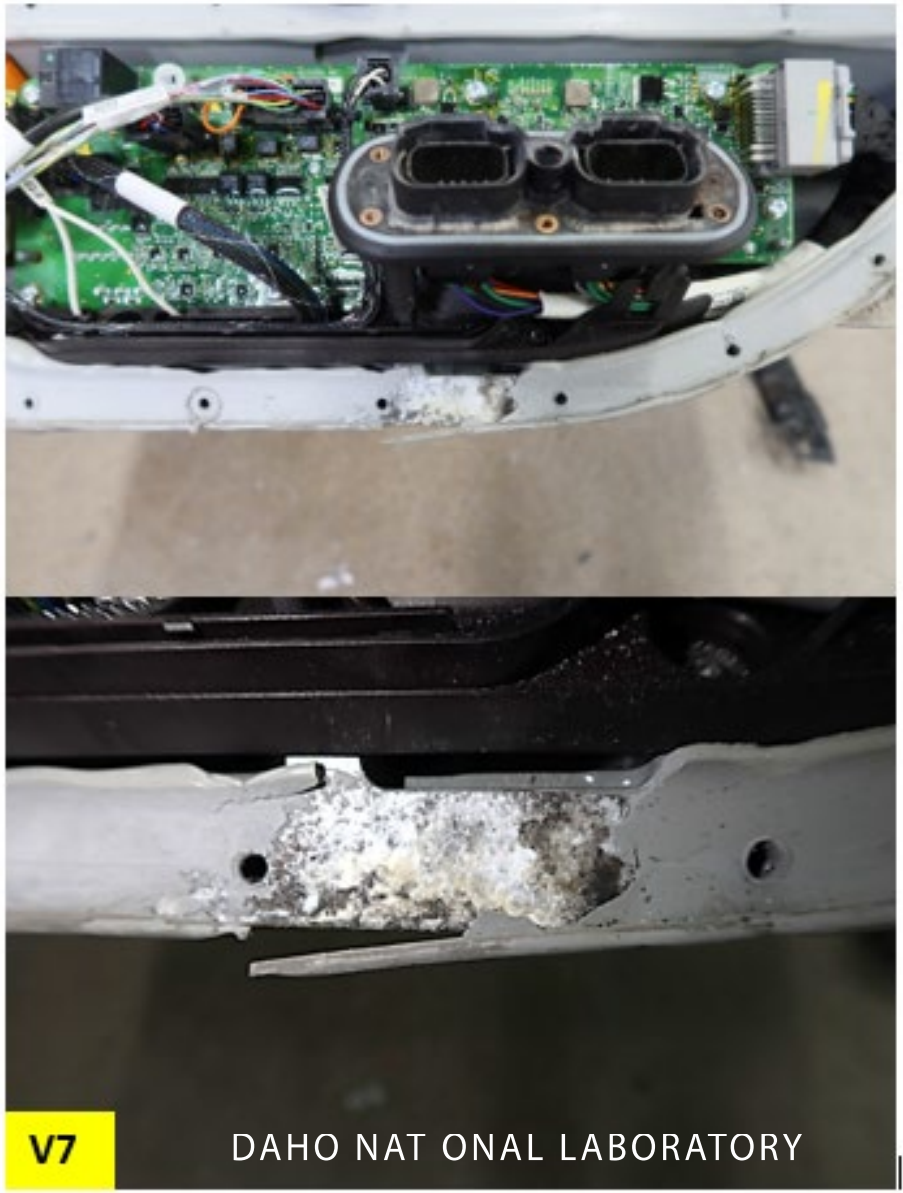
- Isolation fault within the battery of V9 (Model S):
  - While testing for isolation faults by measuring HV connector and module-to-chassis voltages, various abnormal results were observed. These were: (i) a voltage of 0.55V between the external high voltage terminals with contactors open, (ii) a voltage measurement of 218.6V, between battery module M1 to the battery chassis prior to busbar removal, and (iii) 3 to 9V from individual modules to battery chassis after busbars had been removed.
  - The apparent source of the isolation fault appears to be contamination on underside of modules – even with all busbars disconnected and removed, voltage/continuity between module terminals/current collectors and battery chassis was observed.
  - The front of the pack uses aluminum tubing to carry ethylene glycol coolant to the main inlet/outlet ports on the pack lid. Corrosion/crystalline material was observed on the aluminum tubes which contacted the pack tray.
  - Current hypothesis is that the electrolyte degraded the adhesive layer between the battery cells and cooling channel, thereby enabling electrical conductivity from the cells through the cooling channels and the coolant fluid itself to the pack chassis.

These isolation faults were deemed to be of sufficiently high enough resistance to be deemed safe , and probably not in violation of FMVSS-305 (>500 Ohms/Volt).

Key Observations- Pack Design 2: Tesla Model S & X

Power Distribution Unit

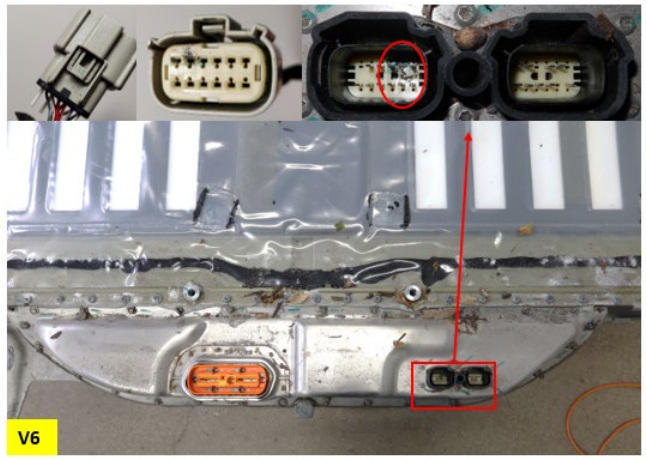
- Upon removal of the power distribution lid, a portion of the sealant bead remained adhered to the lid and exposed an area of corrosion on the mating surface of the tray structure.
- Although spanning the full width of the mating surface, no evidence of water intrusion or corrosion was observed on or below the power distribution components.
- It is most probable that at an undetermined point in time (most likely during the flood event) the coating of the tray structure adjacent to this sealing surface became damaged and then allowed corrosion to begin, progress, and creep under the sealant bead, eventually compromising the complete width of the sealing surface.
- Due to the lack of corrosion or contamination within the interior space, it is most likely that the corrosion progressed AFTER the flood and during storage at a vehicle scrap yard.

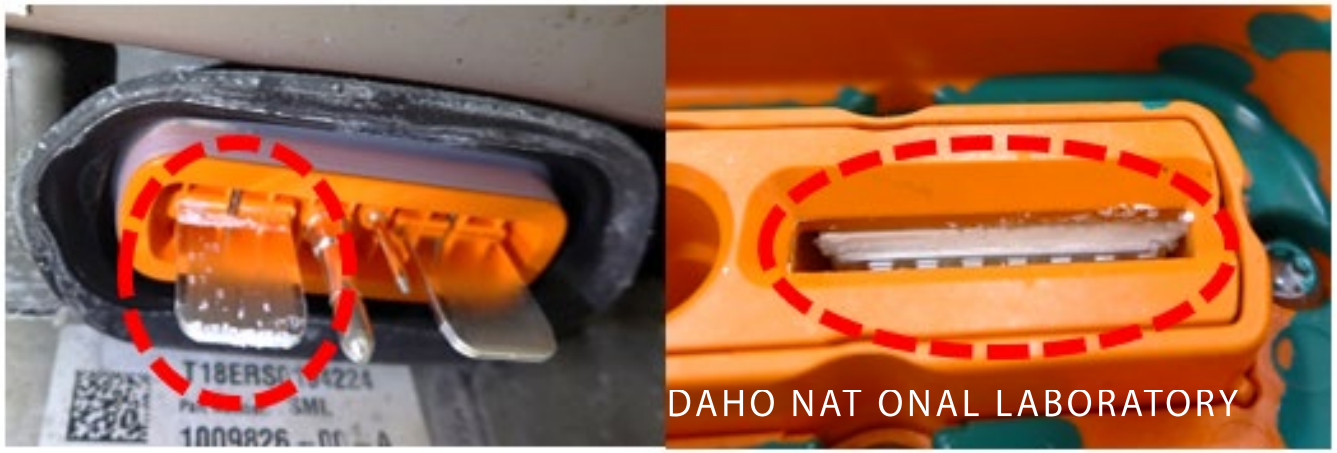


Key Observations- Pack Design 2: Tesla Model S & X

Connectors

- Upon examination of the low voltage connectors after dropping the pack, significant corrosion was noted around several pins in addition to one of the pins having been broken off in the corresponding female body-side connector:
  - The lack of a snap-fit mechanism to ensure proper installation depth of the low voltage connector is likely the mechanism by which the water was able to enter the connector and cause the observed corrosion on the pins and terminals.
- Corrosion was noted inside one of the battery pack high voltage terminals upon removal from the vehicle. The corroded terminal blade displayed white deposits around the base where it protrudes from the injection molded connector housing, suggesting that the ingress originated somewhere on the body-side high voltage harness and crept along the conductor eventually making its way into the high voltage battery connector.





Key Observations- Pack Design 3: Lucid Air Grand Touring

Battery Pack

- Upon lid removal, a small amount of standing water was discovered within the front left-hand corner of the pack interior.
- Upon removing the battery modules, additional standing water was observed below two modules:
  - Further inspection of the battery tray structure and components revealed no damage, corrosion, or contamination of the battery modules or electronics – however, corrosion and contamination were observed on the lid and tray cross beam around the leak source which was determined to be a compromised lid fastener seal.
- The failed lid fastener seal appears to be a manufacturing issue and not damage caused by the flooding or otherwise.
- Given that the locations of the current collectors on the bottom of the battery modules and they are covered by a polymer sheet but otherwise unsealed from the pack interior, it is reasonable to assume that they are at high risk of shorting should the level of water intrusion reach them (~1 cm).

Key Observations- Pack Design 3: Lucid Air Grand Touring

Battery Pack (cont.)

- Pack voltage was measured to be 889V, indicating a nearly full charged state (~91% SOC).
- Module-level voltages were consistent without any variation, indicating that none of the modules had shorted or otherwise been damaged by the water ingress.

Vehicle	Pack voltage, V	Module voltage/Maximum spread, V
V5	889	40.4±0.0/0.0

Key Observations- Pack Design: Porsche Taycan

Battery Pack

- The vehicle, as received, had photo indication that it had been flooded up to the rocker panel, approximately at the floor-level of the cabin. Physical inspection of the interior and exterior of the vehicle revealed minimal debris or evidence of water, suggesting that the flood line height was insufficient to allow ingress to the cabin interior.
- Visual inspection of the exterior of the HV battery pack confirms that most of the exterior was submersed given the sediment in the second row footwell cavities in the pack, however the penthouse module on the top front of the pack showed no signs of corrosion suggesting that it remained above the flood line.

Vehicle	Pack voltage, V	Module voltage/Maximum spread, V
V4	548	19.58±0.023/0.09 Module 1 cell group: 3.26±0.007/0.02 Module 2 cell group: 3.25±0.005/0.01

Key Observations- Pack Design: Porsche Taycan

Battery Pack

- Inspection of the penthouse upon removal revealed that one of the O-rings was installed improperly, as evidenced by a displaced and crushed O-ring and a small witness area in the grease applied around the compromised O-ring:
  - Although no contamination was observed within the pack interior, it is possible that this could have become a leak path if the submersion had reached above the pack lid for an extended period.
- Vents were uncompromised.

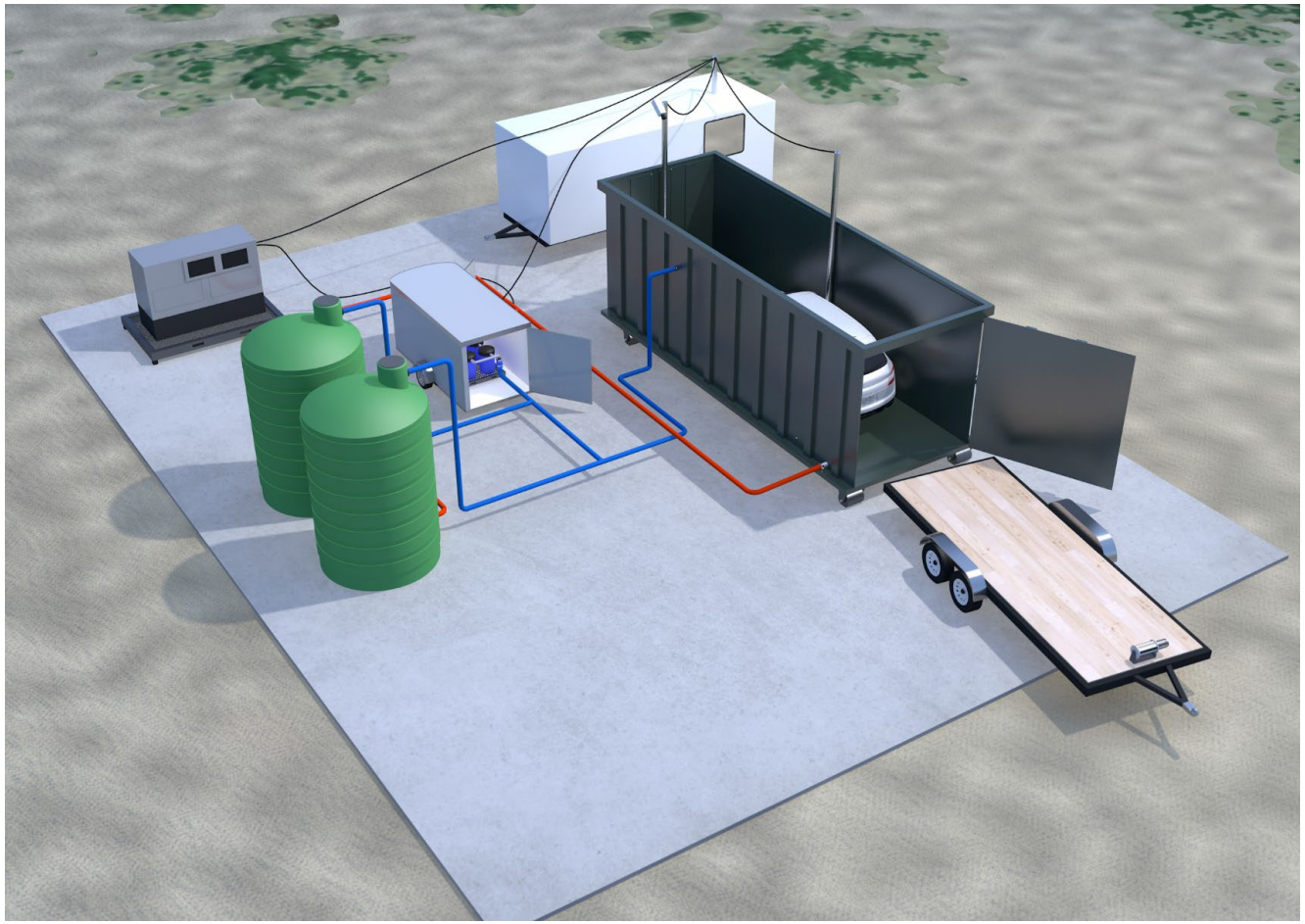
Summary

Vehicle number	Vehicle make, model and year	Key observations- failure points or leak paths	Evidence of water in main battery compartment?
V1	Tesla Model Y 2022	Watermark/condensation near penthouse breather.	No
V2	Tesla Model Y 2022	Watermark/condensation near penthouse breather vent. Corrosion near LV connector seal.	No
V3	Tesla Model 3 2020	Water intrusion in penthouse due to failed penthouse moisture vents and HV connectors. Failed gasket between penthouse and battery compartment.	No
V4	Porsche Taycan 2022	No failure. Pack was submersed, penthouse was not.	No
V5	Lucid Air Grand Touring 2022	Compromised pack lid fastener washer.	Yes
V6	Tesla Model X 2017	Failed penthouse breather vent, pack blowout vent seal breach, breach in low voltage connector.	Yes
V7	Tesla Model X 2020	Pack adhesive bonded plastic sheet breach	No
V8	Tesla Model X 2017	Failed penthouse breather vent and adhesive bonded plastic sheet. Failed vent plugs along the side of the pack structure, corroded lid seal.	Yes
V9	Tesla Model S 2018	Failed penthouse breather vent and adhesive bonded plastic sheet. Failed vent plugs along the side of the pack structure. Battery failure and isolation fault.	Yes
V10	Tesla Model 3 2018	Failed pack lid liquid applied seal, watermark in module space	Yes

- Leak paths due to manufacturing issues, component failure, improper installation of components, etc.:
  - The extents of water leak was not found to be enough to cause any catastrophic damage to the batteries of these 10 survived EVs studied.
- Between the Pack Design 1 (Tesla Models 3 & Y) and 2 (Tesla Models X &S), Pack Design 1 experienced less impact of flood.

Looking Forward

- Additional efforts ongoing to obtain a comprehensive understanding of the flood induced events observed in the field and identifying the root cause:
  - A few more teardowns
  - Controlled immersion tests of EVs with extensive instrumentation:
    - Align evaluation to better guide existing testing procedures (e.g., IPX7, USABC, and SAE)
    - Test, verify, and validate production equivalent leak test procedures (SAE J3277).



Immersion test setup at INL National Security Test Range. Set up will be ready in April 2024.

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Thank you!

Idaho National Laboratory

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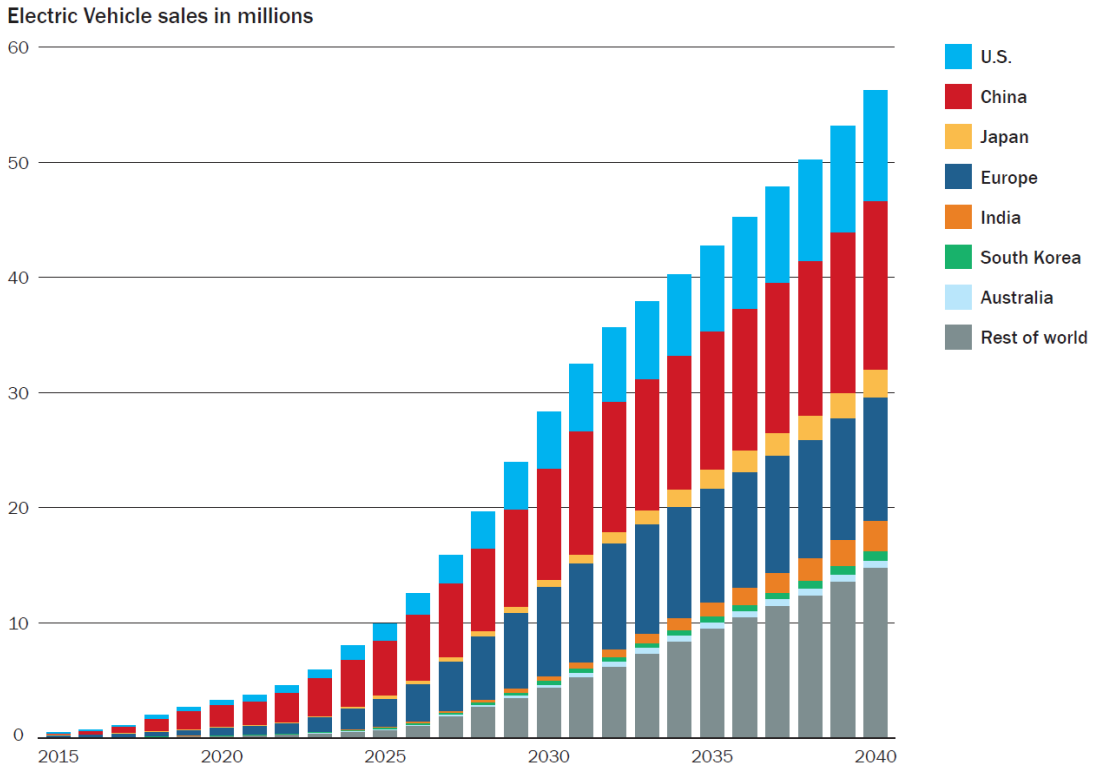
Electric Vehicles and Battery Safety

- Many countries are pushing for rapid expansion of electric vehicles (EVs).
- Most have full or near complete transition targets by 2030-2040:
  - Sales of new EVs in 2022 made up to 10% and 7.5% of all new cars sold worldwide, and in the U.S., respectively.
- EV battery packs store a large amount of energy:
  - 10s of KWhs to up to about 200 kWh.
- Stranded energy at an unknown state due to either collision or natural disaster (e.g., hurricane) could pose major safety concerns to consumers, emergency responders, recovery personnel, etc.



Bloomberg New Energy Finance Long-Term Electric Vehicle Outlook 2019. Page 2 of Executive Summary. https://bnef.turtl.co/story/evo-2020/ page/3?teaser=yes.
National Blueprint for Lithium Batteries

https://www.wsj.com/articles/evs-made-up-10-of-all-new-cars-sold-last-year-11673818385?mod=hp_lead_pos2

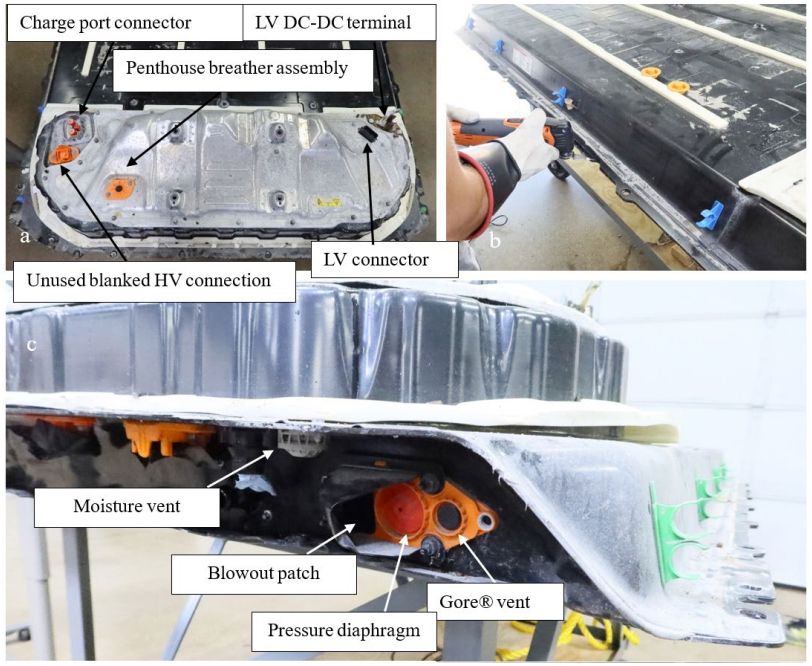
M. Kane, See the top 5 EVs by battery capacity as of Q3 2021 In US, InsideEVs. (n.d.). https://insideevs.com/news/544559/top5-evs-battery-capacity-2021q3/

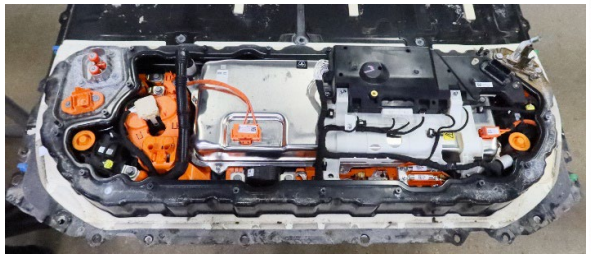
M. Gutman, S. Sweeney, I. Pereira, Hurricane Ian flood damage to EVs creating ticking time bombs in Florida, ABC News. (2023). https://abc7news.com/hurricane-ian-ev-car-fires-electric-cars-damaged-florida-flood-damage/12356326/.

Additional slides

Pack Design 1- Tesla Model 3 and Y

- The battery pack is comprised of the primary tray and lid enclosure which contains the high voltage modules, with a separate “penthouse” compartment mounted to the top rear of the pack.



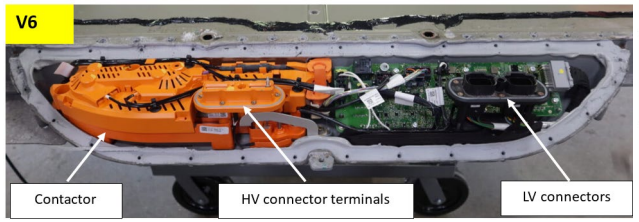


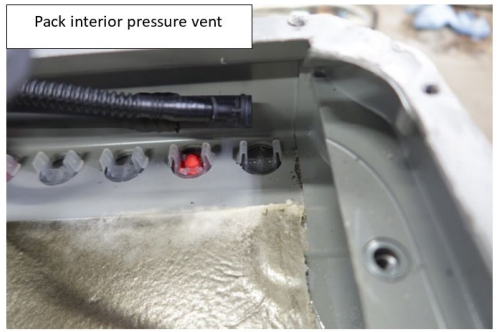
- Each pack has:
  - 96 serially connected cell groups divided up in four modules (96S46P)
  - M1, M4- 23 serially connected cell groups, and M2 and M3 have 25 serially-connected cell groups.
  - Each cell group= 1S46P, 2170 cylindrical cell design.

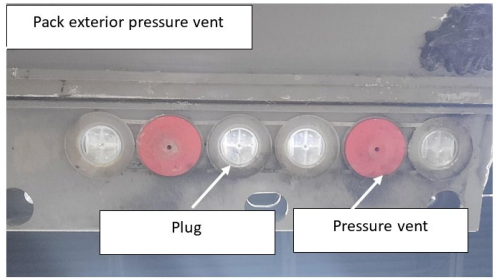
- The penthouse lid has a reusable gasket attached to it with special fasteners for easier service of the components it contains.

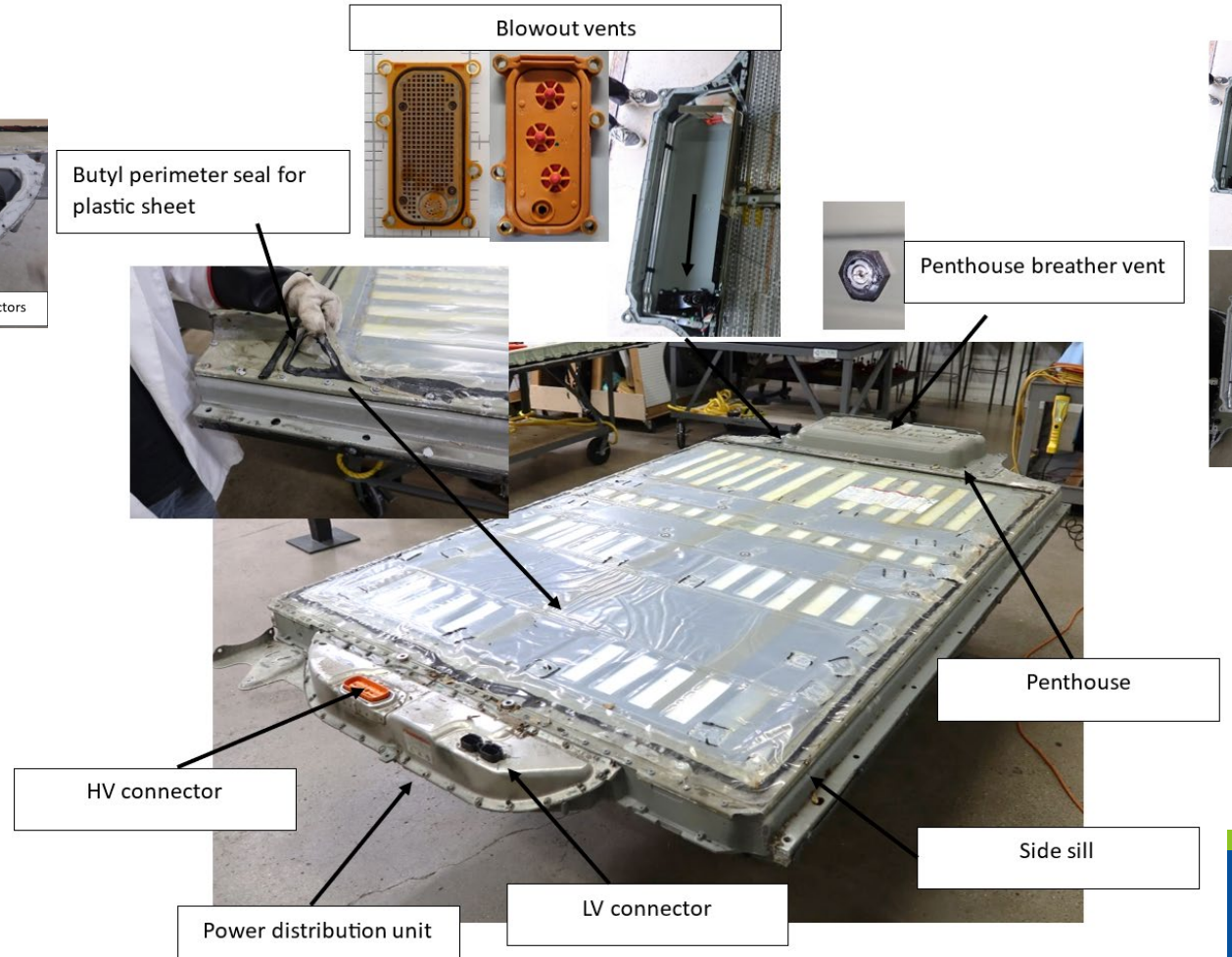
Pack Design 2: Tesla Model X and S

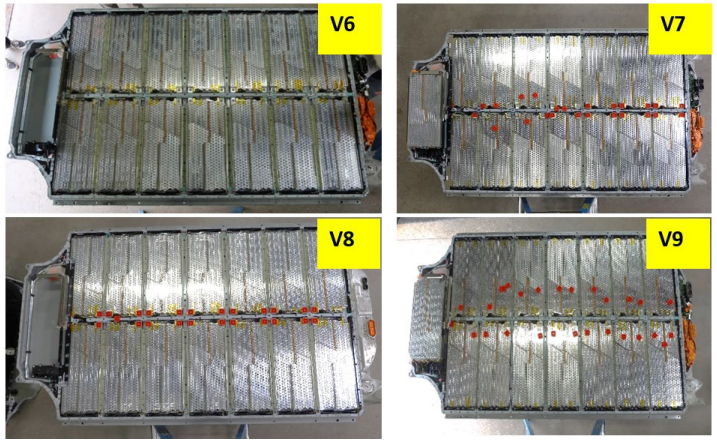
- The battery cover and fastener arrangement for Pack Design 2 is much different than Pack Design 1:
  - Pack Design 2 has the Penthouse in the front of the vehicle, whereas Pack Design 1 has the Penthouse on the rear of the pack
  - There are several pressure vents along both side sills of the pack.







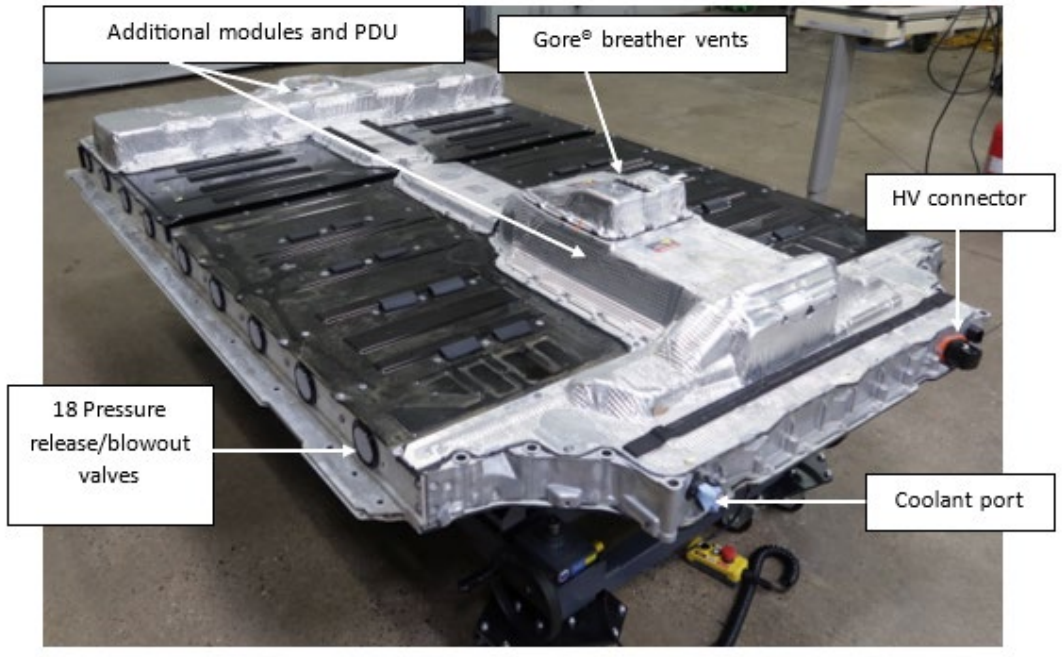


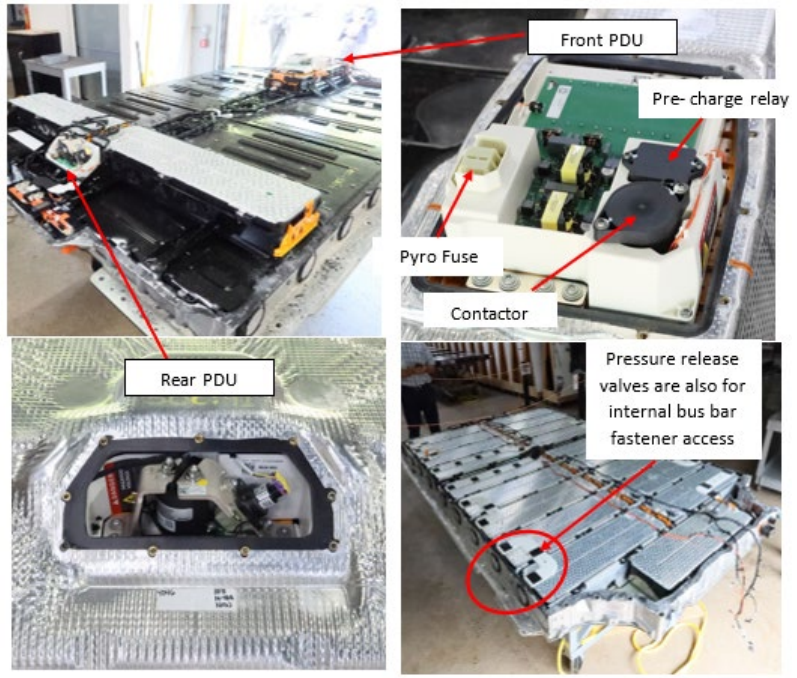


- Up to 16 smaller modules w/ different packaging strategies.
- Unlike the Pack Design 1 from Tesla, the Penthouse in Pack Design 2 contains only the optional battery modules and ancillary components.

Pack Design 3: Lucid Air Grand Touring

- Pack Design 3 has 2 extension housings proud of the main lower pack, for what might be called a dual Penthouse arrangement. Each Penthouse has a small removeable subcover to access the easily serviceable PDU components within.

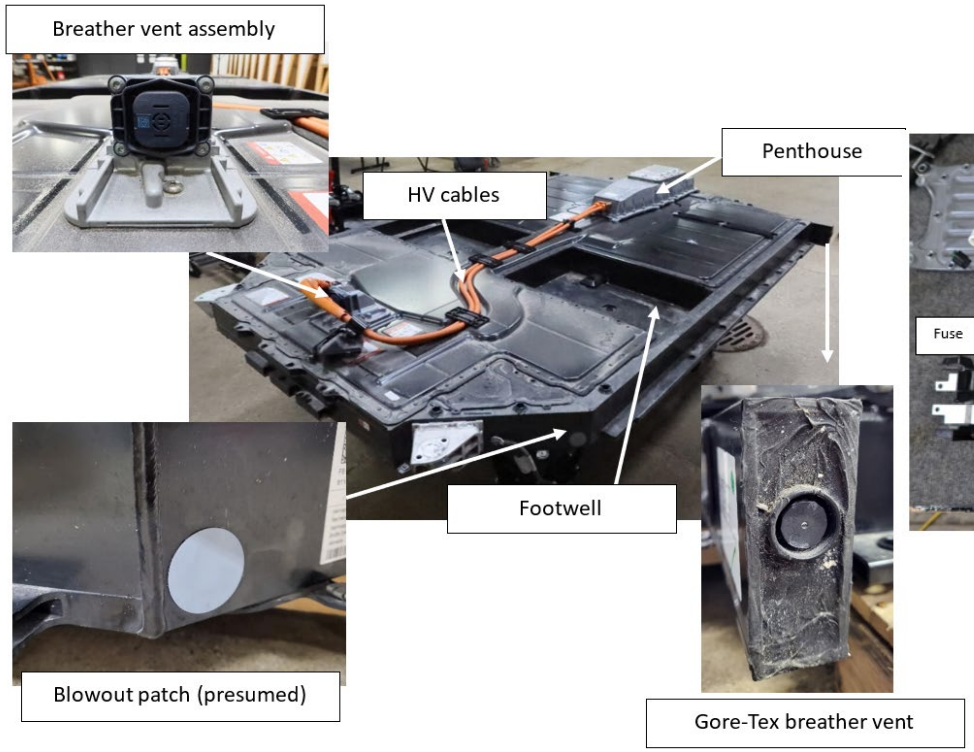


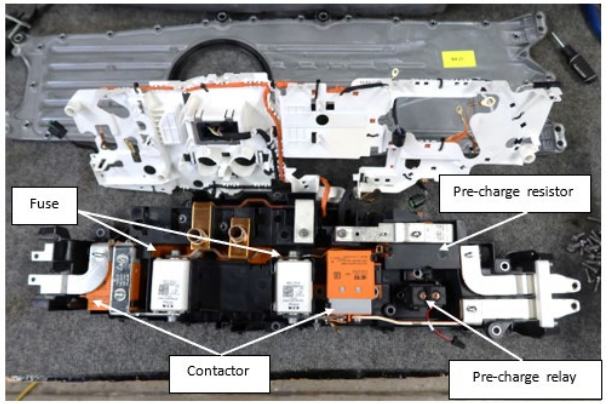


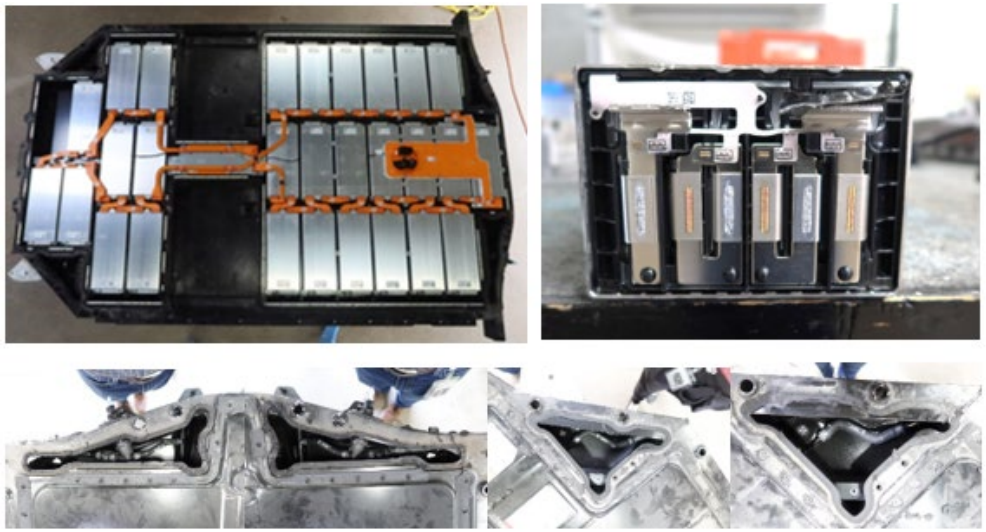
- Each internal battery module has 10 serially connected cell groups of parallel 30 cells each, for a total of 300 cells per module, or 10S30P. 19 of the modules are located in the main/ lower battery compartment with three additional modules located in the Penthouses above, for a total of 22 modules with a pack configuration of 220s30p.
- This pack design seems to have an extraordinary pressure release vent valve capacity (18 large vents, 9 per side sill).

Pack Design 4: Porsche Taycan

- The battery pack is comprised of the primary tray and a lid enclosure which contains the high voltage modules, with a separate “penthouse” compartment mounted to the top rear of the pack.
- The penthouse is a removable and separate enclosure sealed from the main battery pack for easier service of the components it contains.







The pack consists of 28 battery modules. The pouch cells are arranged in a 6S2P configuration in each module for a total of 168S2P or 336 cells. Each corner of the pack has a compartment that houses cooling system components that are serviceable without needing to access the high voltage areas of the pack.

Key Observations- Pack Design 1: Tesla Model 3 & Y

12V battery

- The 12V battery for this pack design is located under the wiper cowl for this and the other pack designs of Tesla EVs.
- V1 housed a LiB, while the other vehicles had conventional lead acid battery to supply the LV power:
  - The LiB of V1 was at least partially submersed
  - The voltage reading from the main external terminals at the time of removal was 0.026V. The prismatic cell voltages were measured at 0.612V, 0.407V, 0.277V and 0.409V, or 1.7V total
  - The 12V battery interior did not display signs of water ingress suggesting that despite submersion the connector seal was uncompromised.
- Snapshots of the 12V lead acid batteries are presented, which shows evidence (marks, debris, sediment, etc.) of full submersion:
  - The terminals of all these batteries showed heavy corrosion. These low voltage batteries measured (~0.05V) to have severely drained.