Lithium Ion Battery Applications & Safety in Transportation

April 2013

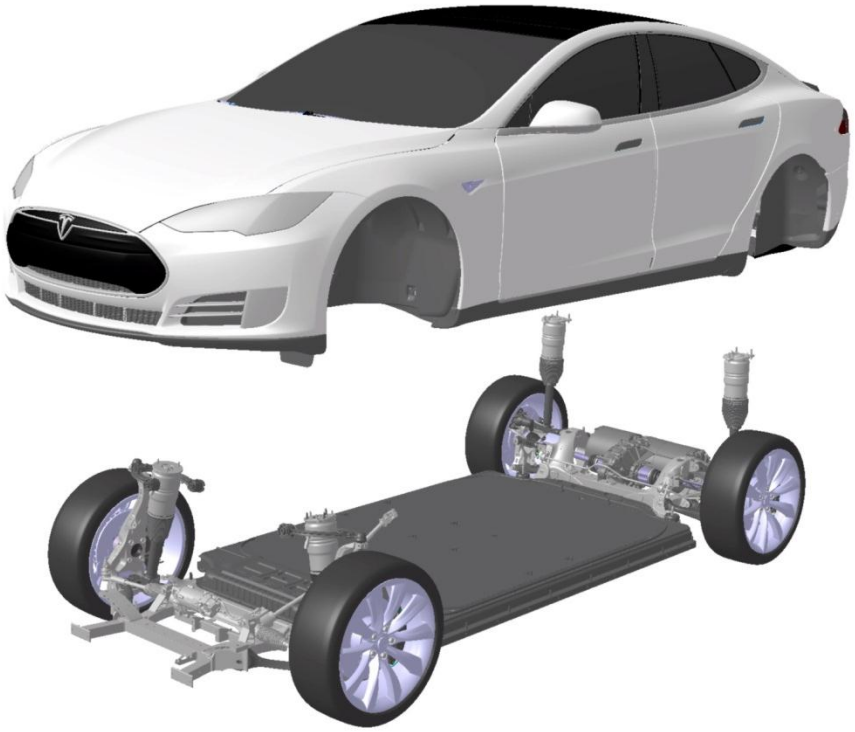
Tesla Fleet Statistics

- Roadster
  - Production began in 2008
  - 55 kWh/245 mile range
  - Approximately 2,500 vehicles
  - More than 15 million cells
  - More than 30 million miles driven
  - More than 40 million cell years

- Model S
  - Production began in 2012
  - 60 or 85 kWh/ up to 265 mile range
  - More than 7,000 delivered vehicles
  - More than 50 million cells
  - More than 12 million miles driven
  - More than 10 million cell years

Tesla Battery Pack Approach

- Cell, module, pack, charger, drive unit, and vehicle designs are not decoupled: they are intimately linked
  - Detailed understanding of cell performance, degradation, and failure under a full range of possible thermal, mechanical, and electrical use and abuse conditions
    - Cycle cells
    - Customized individual cell abuse tests related to module and pack design
    - Cell destructive examination
    - Close working relationship with cell supplier
    - Customized tests of modules
    - Customized tests of packs
  - Tesla tightly controls every component that interacts with the battery pack electrically, mechanically, thermally

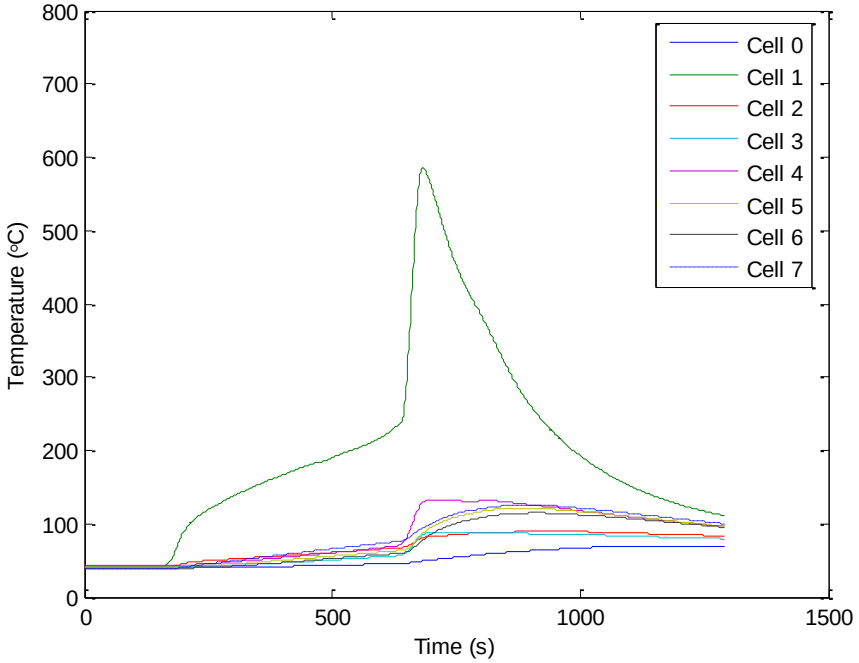


Tesla Battery Pack Approach

- Purchase the highest quality cells, but assume that some will be flawed
  - Mature mass production processes
  - Mature mass production quality control
  - 100,000's cells from multiple production lots used for validation of products
  - Conduct 100% inspection on cells prior to module assembly
    - Detect cells with micro-shorts
    - Use flawed cells to drive cell manufacturing improvements: Tesla and cell manufacturer examine flawed cells
  - Examine any weak cells identified during testing of prototype modules or packs

Tesla Battery Pack Approach

- Assume that some proportion of cells will undergo a thermal runaway reaction for unknown reasons (manufacturing defect, handling damage, etc.)
  - Design battery pack to be robust to single cell thermal runaway (passive propagation resistance)
    - Tesla tests included in SAE J2464
    - 100% SOC, soak at max vehicle temp spec
  - Small cell approach facilitates control over thermal runaway propagation
    - Liquid cooling in contact with every cell



SAE International

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J2464 NOV2009

Issued 1999-03
Revised 2009-11

Superseding J2464 MAR1999

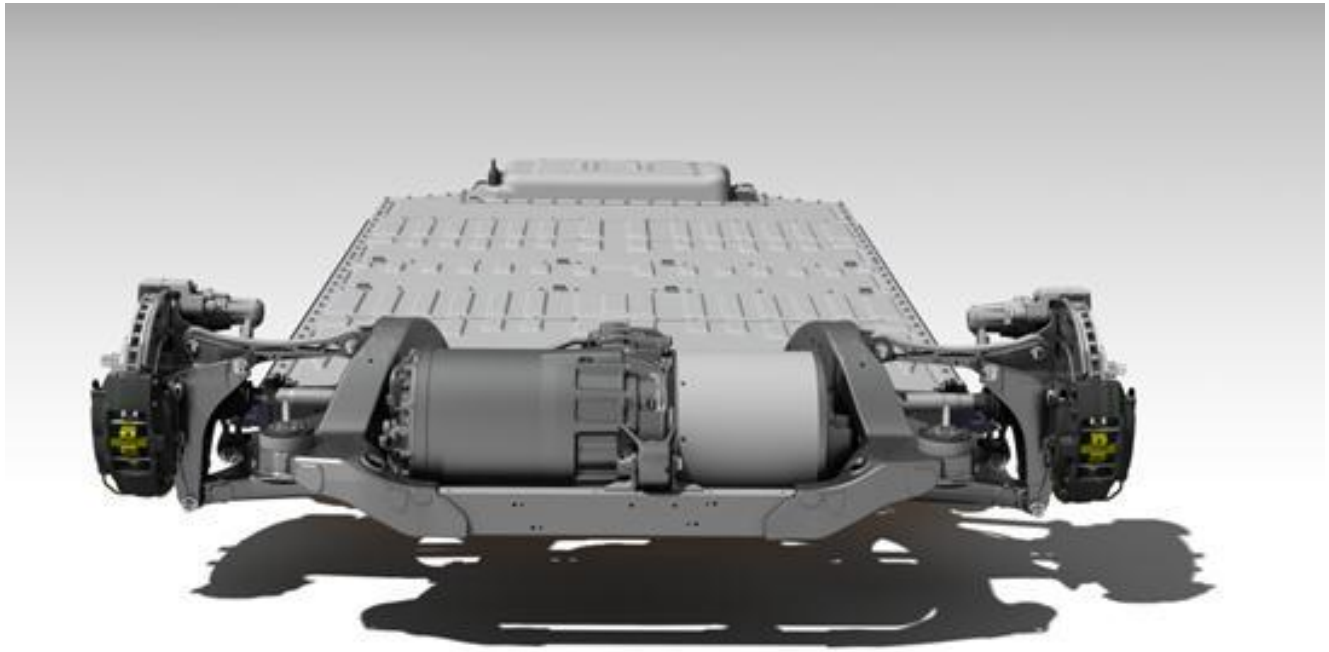
(R) Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing

4.4.5 Passive Propagation Resistance Test (Module or Pack Level)

This test evaluates the ability of a DUT to withstand a single cell thermal runaway event so that a thermal runaway event does not propagate to adjacent cells. It is recommended that the DUT manufacturer first perform these tests at the module level.

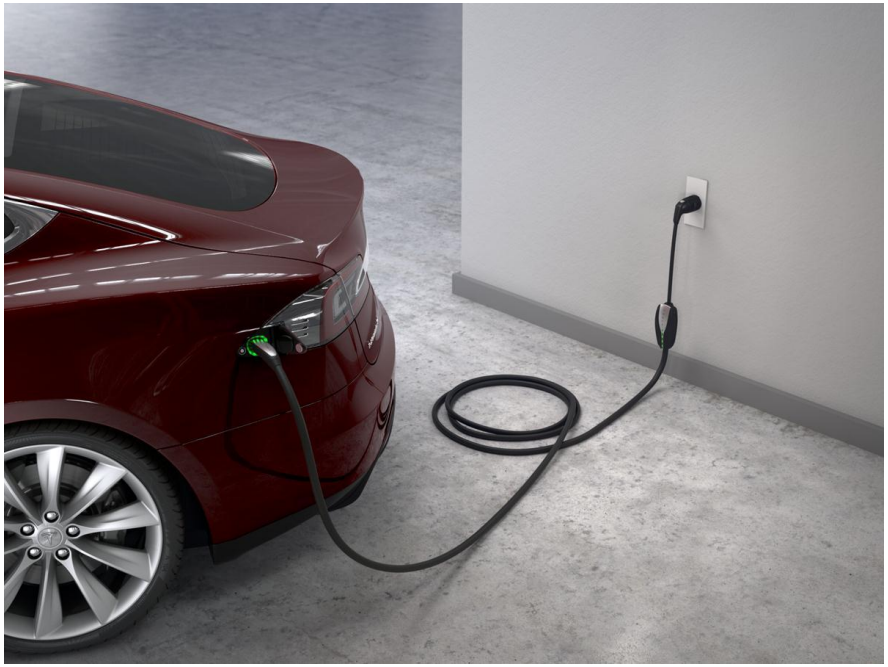
Tesla Battery Pack Approach

- Assume that flaws can occur during module and pack assembly processes
  - 100% testing of modules to detect poor cell interconnects, high self discharge rate cells, etc.
  - 100% testing of packs to detect module assembly flaws
  - Design protection electronics to detect a range of potential problems that could develop over time:
    - Cells that develop high self discharge rates
    - Failure of interconnects
    - Failure of other components



Tesla Battery Pack Approach

- Assume that customers will want to charge the car at a wide variety of locations
  - 120 V residential outlets
  - 240 V residential outlets
  - High rate home or business charging adaptors
  - Public charging stations
  - Supercharging stations
- Integrate the charger into the vehicle
- Design the drive unit to properly discharge or charge the battery (regenerative braking)



Tesla Battery Pack Approach

- Design pack to be electrically robust
  - Cells are designed with mechanisms to prevent
    - Overcharge,
    - Overheating during short circuit
    - Internal short circuits
  - Multiple, redundant firmware & hardware layers to protect cells, modules, and pack from electrical abuse
    - Overcharge
    - Short circuit
    - Over-discharge
  - Extensive sensing to detect fault conditions
    - Temperature
    - Acceleration
    - Humidity
  - Battery pack disconnects to isolate battery pack and prevent charging or discharging if a fault occurs
    - Internal pack problem
    - Collision detected
    - 12V battery disconnected or cut by 1st responders

TESLA

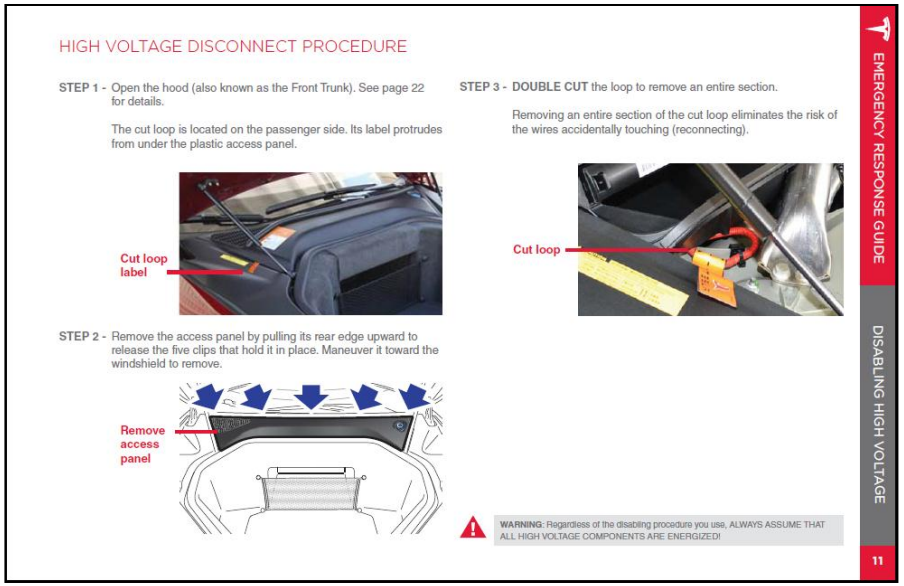
2012 - 2013

MODEL S

EMERGENCY RESPONSE GUIDE

This guide provides rescuers and first responders with the information they need to safely interact with the fully electric Model S. It describes how to identify a Model S, and provides the locations and descriptions of its high voltage components, airbags, inflation cylinders, seat belt pre-tensioners, and high strength materials used in the body structure. This guide also describes the high voltage disabling procedure and special considerations when handling Model S in emergency situations.

The high voltage battery is the only energy source used by Model S. It does not have a traditional gasoline or diesel engine and therefore does not have a fuel tank.



HIGH VOLTAGE DISCONNECT PROCEDURE

STEP 1 - Open the hood (also known as the Front Trunk). See page 22 for details.

The cut loop is located on the passenger side. Its label protrudes from under the plastic access panel.

Cut loop label

STEP 2 - Remove the access panel by pulling its rear edge upward to release the five clips that hold it in place. Maneuver it toward the windshield to remove.

Remove access panel

STEP 3 - **DOUBLE CUT** the loop to remove an entire section.

Removing an entire section of the cut loop eliminates the risk of the wires accidentally touching (reconnecting).

Cut loop

WARNING: Regardless of the disabling procedure you use, ALWAYS ASSUME THAT ALL HIGH VOLTAGE COMPONENTS ARE ENERGIZED!

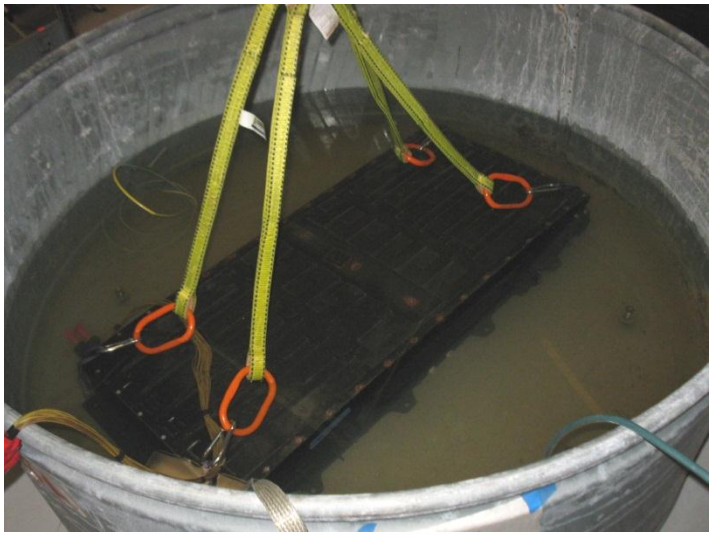
EMERGENCY RESPONSE GUIDE

DISABLING HIGH VOLTAGE

11

Tesla Battery Pack Design Approach

- Design and extensively test packs to be mechanically & thermally robust
  - Design & test cells, modules, and packs to withstand long-term vibration
    - Battery Vibration Test / SAEJ2380
    - Corresponds to approximately 160,000 km of usage at the 90th percentile.
    - 38 hours of vibration comprised of 3 axes (UL 1642 is 4.5 hours total and 2 axes for 18650s)
  - Protect cells from mechanical damage due to collisions or other impacts
    - SAE J2464 crush on modules
    - Crash impact simulation on modules
    - Vehicle crash tests
  - Design and test for robustness to elevated temperature exposure
  - Design and test to resist water intrusion
    - Spray
    - Immersion
    - High humidity / high temperature
  - Design and test to resist chemical exposure
    - Salt fog
    - Corrosive gases (pollution)
    - Common automotive fluids



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Tesla Battery Pack Approach

- Tesla supports training of 1st and 2nd responders
  - Publishes 1st Responder Guides
  - Publishes Towing Guides
  - Partners with NFPA, Fire Departments and Training Providers
    - EV Safety / Extrication video
- Tesla supports development of standard tests to characterize behavior under severe abuse conditions
  - SAE J2464 " to determine the response [of electric or hybrid electric vehicle Rechargeable Energy Storage Systems] to conditions or events which are beyond their normal operating range"
  - UL2580 Section 30: External Fire Exposure Test "to determine an electrical storage assembly's ability to prevent an explosion as a result of exposure to a simulated fuel or vehicle fire external to the energy storage assembly"