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
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 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
Tesla Battery Pack Approach

• Tesla supports training of 1\textsuperscript{st} and 2\textsuperscript{nd} responders
  – Publishes 1\textsuperscript{st} 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”