

# Development of Advanced Li-ion Battery Pack for EV and PHEV Applications

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## Abstract

Tesla Motors is building a major car company by designing, manufacturing and selling electric cars that are the first to combine high energy efficiency with great driving performance. Tesla's first car, the Tesla Roadster, was launched in July 2006 and boasts a substantial order backlog in advance of when vehicles are scheduled to be delivered. This initial market reception signals a tremendous untapped demand for highly energy efficient cars that are a joy to drive.

At the heart of this drivetrain is Tesla's battery system which combines proven commodity lithium ion battery technology with Tesla's proprietary battery pack design to provide multiple layers of safety and reliability. It is light and durable, while delivering enough power for world-class sportscar acceleration and enough energy for a 200 mile driving range.

**Keywords:** "Battery", "Li-ion", "PHEV", "EV"

## 1. Battery Pack Performance

Over the last 4 years, our battery pack engineers focused on producing a safe battery pack that has world-class performance. We started by using Li-ion cells, which provide a significant advantage over previous EVs using lead acid or Ni-MH technology. We combined these advanced cells with our proprietary battery pack technology to achieve the following performance specs:

- Energy Storage 53 kWh
- Capacity 150Ah
- Total weight 450 kg
- Gravimetric Energy Density 120 Wh/kg
- Continuous output 56kW
- Nominal open circuit voltage 366 volts (297V min, 411V max)
- Auxiliary power available 12 volts@ 200 amps
- Normal charge time 3-5 hours

Using advanced Li-ion cells, our battery pack performance was understandably impressive, but the real trick was making this same pack safe and reliable.

## 2. Battery Pack Safety

When we started out thinking about the Roadster battery pack, many cell manufacturers were understandably nervous about the hazards of a battery pack containing a large number of their cells. The



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burden was on us to demonstrate that we understood and designed for safety, even in the event of a spontaneous cell failure. We did quite a few Fourth of July tests to understand how lithium ion cells (of every stripe) failed, and what happens to adjacent cells in a tightly-packed system. We began to understand the problem more than a year before the famous Sony/Dell fiasco, and set a corporate requirement that no such cell failure would lead to thermal propagation in our ESS.

We then had to figure out how to make our system mass-producible, even at Roadster production volumes. Manual cell connection would be unreasonable. We went through something like 7 generations of design before we had what we consider to be a good, safe, reliable design. We validated this design with outside testing laboratories, and we demonstrated safety to the various cell manufacturers to convince them that they were not at undue risk of liability were they to sell us cells. We demonstrated overall ESS safety in a series of tests to meet the United Nations requirements enforced by the U.S. Department of Transportation. This enables us to ship our battery packs around the world. Recently, we successfully performed the 50-mph rear-end crash test pursuant to FMVSS-305 compliance, which also is primarily concerned with battery safety.