The battery technology behind the wheel

Kurt Kelty
Tesla Motors

- Founded in 2003
- >350 employees
- 2 stores opened, 9 more stores planned for 2009
Best-in-Class – The 2008 Roadster

- Zero-emissions electric powertrain
- 0-60 mph acceleration: 3.9s
- Quarter mile acceleration: 12.7s
- EPA driving range: 244 miles
- Carbon fiber body, aluminum chassis
- Full Federal Motor Vehicle Safety Standards (FMVSS) compliant

2009 model price:
- US: $109,000 (Base model)
- EU: €99,000 (Special Signature Edition)
- UK: £82,000 (excluding VAT)
Not long ago, the guys at Top Gear had the chance to enjoy a Tesla Roadster (sadly, the video of that much-discussed event is no longer available). Two things Jeremy Clarkston and crew criticized were the Tesla’s range and brakes. The Roadster has now made a strong counter-claim about its range. Recently, a Roadster was taken to the Rallye Monte Carlo d’Energies Alternatives where it managed to go 241 miles on a single charge, just about the maximum range the Roadster is rated for (244 miles).

The car ended up being the only EV on the race, which went from Valence, France, to Monaco. The course used highways, where speeds of 90 km/h (60mph) were common, two-lane roads at 60 km/h (40 mph), and some 30 km/h (20 mph) mountain roads. Did the Roadster have a problem? Nope. The drivers didn’t even stop to have lunch. The Roadster finally reached Monaco after 387.6 km (241 miles), and the indicator said the car could run for another 61 km (38 miles). An absolute record for a production EV.
Industry Leading EV Powertrain

- Controls and Software
- Proprietary 53 kWh Lithium Ion Battery Pack
- Proprietary 250hp AC Induction Motor and Gearbox
- Power Electronics Module (DC-AC Inverter, Charger)
Manufacturing Strategy

Tesla Roadster
Glider in UK; Final assembly in Menlo Park, CA

TAIPEI, TAIWAN
Motor Manufacture

BAY AREA
Final Assembly
Battery Pack Assembly
Powertrain Integration

HETHEL, UK
Glider Manufacture
Tesla’s proprietary technology has several key components

**BATTERY**
- Battery Pack: 6,831 cells
- 53 kWh
- Battery system safety
- Battery system durability
- Worldwide approval for transport and use
- Pampered battery environment

**MOTOR**
- Proprietary, 3-phase motor design with copper rotor
- 87% average efficiency over operating range
- Max torque available instantly from start; 14,000 rpm redline

**POWER ELECTRONICS MODULE**
- 200 kW 3-phase IGBT-based bi-directional inverter
- Integral 70-amp 120V/240V charging circuitry
- Approx. 3.5 hours for normal charging (Roadster battery)

**CONTROLS AND SOFTWARE**
- Fully integrated vehicle and powertrain control system
- Digital motor control
- Charge control
- Battery state of charge, state of heath and balancing monitoring; battery pack control
Battery Development Detail

**CELLS**
- Lithium ion cells
- Built IP around 18650 form factor
- Internal cell evaluation lab
- Leverage industry battery chemistry investments

**SHEET**
- Sheet: 621 Cells
- Modular, scalable design
- IP in charge balancing and cooling
- Battery longevity (cycle & calendar life)

**BATTERY**
- Battery Pack: 6,831 cells
- 53 kWh
- Battery system safety
- Battery system durability
- Scalable, automated assembly
- Worldwide approval for transport and use
Roadster Battery Pack

- Total 18650 cells: 6831
- Usable Energy Storage: 53 kWh
- Capacity: 150Ah
- Total weight: 450 kg
- Energy Density: 120 Wh/kg
- Continuous output: 53kW
- Nominal OCV: 366 volts
  - (297V min, 411V max)
- Auxiliary power available: 12 volts@ 200 amps
- Normal charge time: 3-5 hours
1. Start with a safe, reliable cell
2. Prevent thermal runaway
3. Prevent propagation of thermal runaway
4. Redundant monitoring & protection
5. Physically protect the battery pack
6. Extensive testing and validation
1. Start with a safe, reliable cell: Li-ion 18650

- Internal PTC element in every cell
- CID device in every cell
- Pressure vent
- High-temperature separator shutdown
- Dimensionally stable steel case

Must Meet UL 1642

“Standard for Lithium Ion Batteries”
1. Start with a safe, reliable cell:

Accelerating Rate Calorimeter (ARC) Test Results

Comparison of Self-Heat-Rate Vs. Temperature
(1 of each cell type)

ARC measures cell internal heat release at high temperatures, giving an indication of thermal stability under failure.
1. Start with a safe, reliable cell: Nail Penetration Test

3 mm diameter steel nail
1. Start with a safe, reliable cell:
Impact Test
1. Start with a safe, reliable cell: Single cell vibration testing

Characterize cells

Perform Vibration Test

- USABC Battery Test Procedures Manual, Procedure #10 - Battery Vibration Test / SAEJ2380

- The vibration envelopes of this procedure correspond to approximately 100,000 miles of usage at the 90th percentile.

Re-characterize cells
1. **Start with a safe, reliable cell**

**Final cell selection**

Battery cell vendors chosen based on:

- Safety performance in Tesla tests
- Reputation: safety & reliability
- Experience and capacity
  - Billions of cells produced to date
- Quality:
  - automated production
  - controlled environment
- Reasonable price
Tesla Approach to Battery Safety/Reliability

1. Start with a safe, reliable cell
2. Prevent thermal runaway
3. Prevent propagation of thermal runaway
4. Redundant monitoring & protection
5. Physically protect the battery pack
6. Extensive testing and validation
1. Start with a safe, reliable cell
2. Prevent thermal runaway
3. Prevent propagation of thermal runaway
4. Redundant monitoring & protection
5. Physically protect the battery pack
6. Extensive testing and validation
3. Prevent propagation of thermal runaway

- Assume any cell will spontaneously go into *thermal runaway*
  - passive & active safety features to prevent propagation
  - passive systems alone prevent propagation

confirmed in repeated tests
3. Prevent propagation of thermal runaway
Tesla Approach to Battery Safety/Reliability

1. Start with a safe, reliable cell
2. Prevent thermal runaway
3. Prevent propagation of thermal runaway
4. Redundant monitoring & protection
5. Physically protect the battery pack
6. Extensive testing and validation
Battery pack sensors

- Multiple temperature sensors
- Accelerometer
- Tilt sensor
- Humidity sensor
- Immersion sensor
- Under/Over voltage
- Over current

Leads to appropriate safety response such as contactors opening
Tesla Approach to Battery Safety/Reliability

1. Start with a safe, reliable cell
2. Prevent thermal runaway
3. Prevent propagation of thermal runaway
4. Redundant monitoring & protection
5. Physically protect the battery pack
6. Extensive testing and validation
5. Physically protect the battery pack

Roadster wrecked at 100kph
Tesla Approach to Battery Safety/Reliability

1. Start with a safe, reliable cell
2. Prevent thermal runaway
3. Prevent propagation of thermal runaway
4. Redundant monitoring & protection
5. Physically protect the battery pack
6. Extensive testing and validation
Cell Test Data Results
Approval received from DoT to ship Tesla 53kWh mass production battery pack by boat, truck or air.
Vibration Testing using USABC Test procedure #10 (same as SAE J2380)

- Suggested test for “traction batteries hard mounted to a chassis of an EV”.
- 38 hours simulate 100,000 miles of driving.
6. Extensive Testing and Validation

Vehicle durability – 40K km

PAVE – 1K km

Each test equivalent to 100K miles driving
Corrosion
Salt splash (part of 40,000km mixed durability)
- 76 times throughout test
- enter 30 km/h
- exit 55km/h

The ESS must be able to withstand the salt spray test specified in the Vehicle Technical Specification as well as SAEJ1211 sections 4.3 and ASTM B 117-73.
Tesla Roadmap
Tesla confirms smart EV battery supply deal

- Posted Jan 13th 2009
- by Sam Abuelsamid, AutoblogGreen
- “The rumors were true. At the Society of Automotive Analysts outlook conference this morning, Tesla CEO Elon Musk announced that his company will supply lithium ion battery packs and charging systems to Daimler AG. The components will be used to power the second-generation smart ed. Daimler will build 1,000 of the electric smarts for field testing beginning this year. Some of those will be coming to the US in 2010. Tesla and Daimler are collaborating on development of the batteries. Musk told ABG that the program began in November 2007 and the first prototype was ready in 40 days.”
100% Electric Powertrains

- High performance
- Zero emissions
- 200+ mile range
- Proprietary technology

Tesla Roadster
250+ produced
1,000+ reservations

Tesla Model S
Luxury Sports Sedan
Market intro: March 26th
Production starts: 2011

OEM powertrains
Leverages zero-emissions electric powertrain

In advanced development, production targeted for late 2011

Designed for exceptional performance, aesthetics and functionality
- 7 passengers: 5 adults + two child seats
- 4 doors + hatchback → Best in class cargo space
- All wheel drive options
- World class design; unrivaled user interface

Target Performance
- 0-60 mph acceleration: 5.7s (standard), 4.4s (sport)
- EPA driving range: 160 miles, 230 miles, 300 miles

Advanced range capabilities
- Usage of multiple advanced cell chemistries
- 45 minute charge capability
- 5 minute battery pack swap capability

Base price $49,900 after Federal Tax Credit
Introducing the Model S Sport Sedan
Model S Sport Sedan
Model S Sport Sedan
Thank You!

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