Opportunities and Challenges for E-Mobility and Batteries

Dr. Alejandro Santis, Bern University of Applied Sciences, SCCER Mobility
SCCER School, Engelberg, Friday October 20th 2017

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A BRIEF HISTORY OF ELECTRIC VEHICLES

From Europe to North America to Asia, the history of electric mobility is a demonstration of the world's persistent ingenuity and adaptation in transportation. The future of electric mobility — still to be written — will stand, in part, on the advances made in these earlier periods.

1888
German engineer Andreas Flochmann builds the first four-wheeled electric car.

1889
The first commercial electric vehicles enter the New York City taxi fleet. The car maker, Pope Manufacturing Co., becomes the first large-scale EV manufacturer in the United States.

1908
The petrol-powered Ford Model T is introduced to the market.

1912
The electric starter, invented by Charles Kettering, obviates the need for the hand-crank, making it easier for more people to drive petrol-powered cars.

2006
Oil prices reach more than USD 145 per barrel.

1932–39
Robert Anderson, of Scotland, builds the first prototype electric-powered carriage.

1934
Thomas Davenport, of the United States, invents and installs the first direct-current electrical motor in a car that operates on a circular electrified track.

1946
The U.S. Congress introduces legislation recommending electric vehicles as a means of reducing air pollution.

1997
The BEV Nissan LEAF is launched.

1999
The “La Jamais Contente,” built in France, becomes the first electric vehicle to travel over 100 km per hour.

2001–
Nissan LEAF wins European Car of the Year award.

2008
Oil prices reach more than USD 145 per barrel.

1801–1850
THE BEGINNING
The earliest electric vehicles are invented in Scotland and the United States.

1851–1900
THE FIRST AGE
Electric vehicles enter the marketplace and find broad appeal.

1901–1950
THE BOOM & BUST
EVs reach historical production peaks only to be displaced by petrol-powered cars.

1951–2000
THE SECOND AGE
High oil prices and pollution cause renewed interest in electric vehicles.

2001–
THE THIRD AGE
Public and private sectors recommit to vehicle electrification.

Governments around the world are setting ambitious targets for light vehicle CO₂ emissions

- EU target of 130 g CO₂/km (5.6 L/100 km petrol) effective as of 2012, with a moderate phase-in allowed until 2015
- Long-term EU proposal of 95 g CO₂/km (4.1 L/100 km petrol) for 2020; 2025 initial proposal 68-78 g (2.8 L/100 km petrol) but decision postponed
- In the US, fleets must improve to 93 g CO₂/km in 2025 from the 152 g CO₂/km threshold in 2016
ICE and the different types of EVs

- **ICE powertrain**
- **Transmission**
- **Electric powertrain**
- **FC powertrain**
- **Battery**

**Internal combustion engine, ICE**

**Hybrid electric vehicle (P) HEV**

**Range extended electric vehicle, REEV**

**Battery electric vehicle, BEV**

**Fuel cell electric vehicle FCEV**

**ICE primary source of propulsion**

**ELECTRIC MOTOR primary source of propulsion**
In the long-term EV adoption remains uncertain, driven by regulation (Europe)

Very strict regulation leads to BEV and FCEV world

<table>
<thead>
<tr>
<th>Year</th>
<th>ICE</th>
<th>HEV</th>
<th>REEV</th>
<th>BEV</th>
<th>FCEV</th>
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<td>30</td>
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2° climate goal leads to a 3 technology world

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Little change in regulation leads to a world of hybrids and BEVs

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Very strict CO₂ emission reduction to 10 g/km in 2050, representing the global warming goal of a maximum increase of 2 degrees Celsius transferred to the transportation industry¹

Strong CO₂ emission reduction to 40 g/km in 2050 – a scenario that foresees a continuation of increasingly restrictive emission standards¹

Moderate CO₂ emission reduction to 95 g CO₂/km in 2050. This would imply that regulation as of 2020 will not get much tighter. Only the tank-to-wheel standard will shift to a well-to-wheel standard¹

¹ For further details on scenarios, refer to Appendix 1

SOURCE: McKinsey – Boost! Powertrain KIP
Very strict regulation leads to BEV and FCEV world

- Cap of 10 g CO₂/km in 2050
- ICE (optimized)
- BEV
- FCEV
- REEV

ICE remains dominant until 2025, but loses market share to xEVs
In the long run, BEVs dominate smaller vehicles and FCEV larger vehicles
HEV / REEV as bridging technology

SOURCE: McKinsey – Boost! Powertrain KIP

2° climate goal leads to a 3 technology world

- Cap of 40 g CO₂/km in 2050
- ICE (optimized)
- BEV
- FCEV
- REEV

ICE remains dominant until 2025 but loses market share to xEVs
Over time, BEVs, REEVs and FCEVs dominate small, medium and large vehicles, respectively
xEVs lead to singular drivetrain scenario

Little change in regulation leads to a world of hybrids and BEVs

- Cap of 95 g CO₂/km in 2050
- ICE (optimized)
- HEV
- REEV
- BEV

ICE remains dominant until 2035+
BEV will only become economically competitive post-2030, no infrastructure for FCEV is built
Long-term HEV and REEV / BEV existence leads to a dual powertrain scenario
Evolution of the global electric car stock, 2010-16

Notes: The electric car stock shown here is primarily estimated on the basis of cumulative sales since 2005. When available, stock numbers from official national statistics have been used, provided good consistency with sales evolutions.

Source: IEA, EV global Outlook 2016
So, is the EV really staying?

Volkswagen announced the planning to launch as many as 30 environmental friendly models and one million EV sales annually by 2025. **Volkswagen ID concept with 600 km driving range unveiled in Paris** (09/2017).

The Swedish carmaker has spun out Polestar into a separate division to focus on high performance electric cars. On Tuesday, the company revealed plans for the first three vehicles under the name, and details of a **new all-inclusive pay-monthly service** that it believes reduces the “hassle” of car ownership (17/10/2017).

China is considering legislation to require automakers to sell a specific quota of zero- and low-emission vehicles. The figure would start at 12 percent of overall deliveries > 30k units in 2020 and rise from there in successive years (09/2017).

[https://www.ft.com/content/6d471382-b30f-11e7-a398-73d59db9e399?mhq5j=e5](https://www.ft.com/content/6d471382-b30f-11e7-a398-73d59db9e399?mhq5j=e5)
Main hurdles for e-mobility: All Battery related!

- Study: Integrated Fuels and Vehicles Roadmap to 2030 and beyond (2016)

**Purchase price**
The current purchase price of electric vehicles is significantly higher compared to vehicles equipped with conventional powertrains.

**Charging time**
Despite existing rapid-charging stations, the charging of a battery electric vehicle takes 20-25 minutes and therefore significantly longer than fueling of a conventional car.

**Risk**
Recent accidents (e.g. burning battery of a Tesla Model S) lead to security concerns, e.g. regarding maturity of the technology.

**Infrastructure**
The current density of charging stations is low compared to conventional gas stations and therefore leads to a different usage behavior for electric vehicles (e.g. ~2,000 charging stations vs. ~14,000 gas stations in Germany).

**Vehicle range**
Due to limited battery capacity, the maximum range of an electric vehicle is significantly lower compared to a vehicle with conventional powertrain.

Source: Roland Berger
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Source: Roland Berger
As of April 7, 2016, one week after the event, Tesla Motors reported over 325,000 reservations, more than triple the 107,000 Model S cars Tesla had sold by the end of 2015.

Tesla reported the number of net reservations totaled about 373,000 as of 15 May 2016 after about 8,000 customer cancellations and about 4,200 reservations canceled by the automaker because these appeared to be duplicates from speculators.

According to [http://model3counter.com/](http://model3counter.com/), there are now (October 19th 2017) 554'502 reservations.
Adoption of technology in the US (1900 to present)
Comparing Elon Musk's Tesla Model 3 with Henry Ford's iconic Model T

Exhibit 10: Tesla's estimated production ramp is very similar to that of Ford's Model T 100 years ago
Tesla vehicle deliveries vs. Ford's Model T

- 2015 Model S: 50,446
- 2016 all: 83,922
- 2017 Q1+Q2: ca. 51,000

*Model T Year 1 is 1910; Tesla Year 1 is 2013.*

Source: Company data, Goldman Sachs Global Investment Research.
Economies of scale, EV battery experience curve

Batteries make up a 1/3 to 1/2 of the production costs of an electric vehicle

LITHIUM-ION EV BATTERY EXPERIENCE CURVE COMPARED WITH SOLAR PV EXPERIENCE CURVE

Note: Prices are in real (2014) USD.

Source: Bloomberg New Energy Finance, Maycock, Battery University, MIT

http://energypost.eu/cheap-can-energy-storage-get.pretty-darn-cheap/
E-Mobility Market – new Factories required
Scenario with sustainable Growth

**EV Sales**

- **EMEA**: 5 - 10 Mio.
  - 25%

- **AMER**: 5 - 10 Mio.
  - 25%

- **APAC**: 5 - 10 Mio.
  - 50%

**Battery Capacity Demand**

- **2016**: 30 GWh
- **2020**: 200 - 400 GWh

- **25 - 50 FACTORIES**
**REQUIRED WORLD WIDE UNTIL 2020**

*One factory = 8 GWh/year = 200,000 EVs

Sources: Bain, BCG, JRC, McKinsey
Currently only approximately 20 percent of its 1-million-square-foot facility is already up and running.

Its projected capacity for 2018 is 50 GWh/yr of battery packs and its final capacity upon completion of entire factory is 150 GWh/yr. This would enable Tesla to produce 1,500,000 cars per year (2020 ?)

Location of proposed Gigafactories in Europe

Northvolt (32 GWh/yr)
TBA, SWEDEN
(Possible location Sweden)

A123
Germany

Nissan (3 GWh/yr)
SUTHERLAND, UK
Operational, proposed battery production

Jaguar Land Rover
BMW & Ford JV
TBA, Europe

BMZ (34 GWh/yr)
KARLSTEIN-GROBWELZHEIM, GERMANY
Operational, expanded production by 2020

Kreisel Electric
Austria

Accupower
Austria

San Jose
Lithium Project

Daimler (2 GWh/yr)
KAMENZ, GERMANY
Operational proposed expansion

Tesla Gigafactory
TBA, EUROPE
EV assembly at Tilburg,
Netherlands, operational and expanding

Johnson Matthey
POLAND

LG Chem (3 GWh/yr)
NEAR WROCLAW, POLAND
Production, 2019

SAMSUNG SDI (3 GWh/yr)
NEAR BUDAPEST, HUNGARY
Production H2, 2018

SAMSUNG SDI
ZEITLING, AUSTRIA
Operational

Legend:
- Stated Future Projects
- Under Construction
- Current Li Battery Plants
Lithium-Ion Battery Megafactories currently being build

- LG Chem
  - Capacity: 7GWh
  - Nanjing
- TESLA
  - Capacity: 35GWh
  - Nevada
- FOXCONN
  - Capacity: 15GWh
  - Anhui
- BYD
  - Capacity: 20GWh
  - Various
- Boston Power
  - Capacity: 10GWh
  - Various

*Benchmark estimates, not all data disclosed by companies  **Instant planned capacity stated for graphical purposes, slower ramp up expected

Source: Roland Berger
Price development of battery cells [EUR/kWh]

- Batteries make up a 1/3 to 1/2 of the production costs of an electric vehicle.
Energy density depends largely on the chemistry of the electrode materials

Energy densities in the market:

1990-1991:
LCO/C at ca. 100 Wh/kg

2017:
NCA/C-Si at ca. 250 Wh/kg

<table>
<thead>
<tr>
<th></th>
<th>2.2Ah</th>
<th>2.9Ah</th>
<th>3.2Ah</th>
<th>3.5Ah</th>
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<tr>
<td>Samsung SDI</td>
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<td>29E</td>
<td>32E</td>
<td>35E</td>
</tr>
<tr>
<td>LG Chem</td>
<td>MF1</td>
<td>MG1</td>
<td>MH1</td>
<td>MJ1</td>
</tr>
<tr>
<td>Panasonic</td>
<td>EA</td>
<td>PF</td>
<td>BD</td>
<td>GA</td>
</tr>
</tbody>
</table>

Source: Shmuel-de-Leon, 12/2016
Strategies to increase Energy Density

- Ni content higher 50%
- Thinner collectors, higher loadings
- Increase Ni-content
- Optimize cell design
- Operating window
- New Anode materials
- Raise upper cut-off voltage
- Replace standard graphite anodes
Both –high Nickel as well as high voltage appropriate measures to increase ED

- Resulting Energy Densities on cell level

**Graphite anode**

**Silicon-based anode**

650mAh/g

<table>
<thead>
<tr>
<th>Voltage Range</th>
<th>Gravimetric Energy Density [Wh/kg]</th>
<th>Volumetric Energy Density [Wh/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.7 – 4.2 V</td>
<td>260</td>
<td>720</td>
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<tr>
<td>2.7 – 4.35 V</td>
<td>240</td>
<td>660</td>
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<tr>
<td>2.7 – 4.35 V</td>
<td>220</td>
<td>600</td>
</tr>
<tr>
<td>2.7 – 4.35 V</td>
<td>200</td>
<td>540</td>
</tr>
<tr>
<td>2.7 – 4.35 V</td>
<td>180</td>
<td>540</td>
</tr>
</tbody>
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Source: umicore
Main hurdles for e-mobility: All Battery related!

- Study: Integrated Fuels and Vehicles Roadmap to 2030 and beyond (2016)

Total costs of ownership

Risk
Recent accidents (e.g. burning battery of a Tesla Model S) lead to security concerns, e.g. regarding maturity of the technology

Source: Roland Berger
Ca. 25 % battery capacity loss within 1-2 years of operation; All the affected cars were from Arizona, and experienced "the loss" after the Leaf had been driven for between 21,812 km (13,633 miles) and 27,200 km (17,000 miles). The owners filed complaints with Nissan, and the manufacturer’s official response was “We’re aware of a few isolated cases where a very small number of consumers are reporting a one-bar loss. (We’re talking less than 5 units versus the 12,000 on the road in the U.S.).”

18,588 owners were covered by the settlement. Some brought their Leaf vehicles to Nissan to repair the battery to at least 70% capacity or, if not possible, get the battery replaced.

Source: www.autoevolution.com
Towing
During the 8 years or 100,000 miles (160,000 kilometers) Hybrid warranty period, towing is covered to the nearest Chevrolet servicing dealer if your vehicle cannot be driven because of a warranted Hybrid specific defect. Contact the GM Roadside Assistance Center for towing. See Roadside Assistance Program in the Owner's Manual or Roadside Assistance Program or 327 for details.

Drive Motor Battery Coverage
Propulsion Battery Warranty Policy (Bolt EV)
Like all batteries, the amount of energy that the high voltage "propulsion" battery can store will decrease with time and miles driven. Depending on use, the battery may degrade as little as 10% to as much as 40% of capacity over the warranty period. If there are questions pertaining to battery capacity, a dealer service technician could determine if the vehicle is within parameters.

Repair (If Necessary)
Chevrolet has a network of certified dealers who are trained to perform repairs on Bolt EV if your vehicle needs battery service.

Replace (If Necessary)
If warranty repair requires replacement, the high voltage battery may be replaced with either a new or factory refurbished high voltage battery with an energy capacity (kWh storage) level at or within approximately 10% of that of the original battery at the time of warranty repair.

Your Electric Propulsion battery replacement may not return your vehicle to an "as new" condition, but it will make your vehicles fully operational appropriate to its age and mileage.

Other Electric/Hybrid Components
High Voltage Wiring, Hybrid Powertrain and Battery Control Modules, Air Compressor Control Module, Accessory DC Power Control Module, High Voltage Battery Disconnect Control Module, Drive Motor Generator Power Inverter Module, Battery Charger Control Module.

Brakes
Brake Modulator Assembly

Electric/Hybrid Drive Unit
Electric drive unit assembly electric motors, and all internal components, including the auxiliary fluid pump, auxiliary pump controller, electric motor, and 3-phase cables.

What is Not Covered
In addition to the "What is Not Covered" section of the 2017 Chevrolet Limited Warranty and Owner Assistance Information, the Chevrolet Bolt EV specific warranty does not cover the following items:

Wear Items
Wear items, such as brake linings, are not covered in the Chevrolet Bolt EV specific warranty.
CEO Elon Musk once referred to a battery pack Tesla was testing in the lab. He said that the company had simulated over 500,000 miles (ca. 800,000 km) on it and that it was still operating at over 80% of its original capacity.
Main hurdles for e-mobility: All Battery related!

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**Vehicle range**
Due to limited battery capacity, the maximum range of an electric vehicle is significantly lower compared to a vehicle with conventional powertrain.

Source: Roland Berger
Range of E-Vehicles priced under USD 50’000

![Graph showing the range of all-electric car EPA rated per full charge. Models include Chevrolet Bolt EV, Tesla Model 3, BYD e6, 2017 Volkswagen e-Golf, Hyundai Ioniq Electric, 2017 Ford Focus Electric, BMW i3 94 A-h, Nissan Leaf 30 kW-h, Kia Soul EV, Mercedes-Benz B250e, Nissan Leaf 24 kW-h, Fiat 500e, 2016 Volkswagen e-Golf, Chevrolet Spark EV, BMW i3 60 A-h, 2016 Ford Focus Electric, Smart electric drive, 2016 Mitsubishi i-MiEV, and 2017 Mitsubishi i-MiEV. The range varies from 59 to 238 miles.]

- Future model
- 2016/17 model year
Range, what consumers want

- 28% Don’t Need >209 km of Range
- 55% Don’t Need >306 km of Range
- 75% Don’t Need >354 km of Range

Among non-owners, 45% responded that they needed 354 or more km of range on a single charge.
Range, what consumers want

- 43% Don’t Need >209 km of Range (before 28%)
- 60% Don’t Need >306 km of Range (before 55%)
- 70% Don’t Need >354 km of Range (before 75%)

The felt “need” for more range appears to be price sensitive.

Source: “Electric Cars: What Early Adopters And First Followers Want”, CleanTechnica; 2016
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Source: Roland Berger
Implications for charging infrastructure

- Basic belief from interviews and pilot results: In the first years, home charging will dominate

- **Early adopters**
  - Home charging and semipublic dominates

- **Home and semipublic**
  - Home and corporate charging dominate; cars are mostly charged at home or at corporate locations

- **Public**
  - Public infrastructure will **not be built up densely**; first installations mostly triggered by public authorities

SOURCE: McKinsey
DC-charging stations: CCS, Tesla and CHAdeMO

https://ccs-map.eu/

https://www.tesla.com/supercharger

http://chademo-map.com/
DC-charging stations: CCS, Tesla and CHAdeMO

Number of places reserved for EV
2 parking spaces for electric vehicles only
parking space numbers: 1, 2

CHADEMO
Accelerated 20KW 380V DC 50A
Cable is attached to the charge point

TYPE 2
Accelerated 22KW 380V AC-TRI 32A

COMBO CCS EU
Accelerated 20KW 380V DC 50A
Cable is attached to the charge point

http://chademo-map.com/
Game Changer: CASE
Connected, Autonomous, Shared & Service and Electric Drive
New players and business models

- The Apple Car effort, known as Project Titan, now employs over a thousand engineers.
- The Google self-driving cars have clocked more than 1.1 million miles since 2009.
- Teslas 'gigafactory' has the potential to not only serve Tesla’s growing demand for lithium-ion batteries, but also to be a major source for the entire electric car and off-the-grid power industries.
- Uber CEO Travis Kalanick has long envisioned a future where his company’s cars operate autonomously and is now deploying a test vehicle in Pittsburgh.
The long-term vision of the self-driving car involves moving from an ownership model to a service model, in which large numbers of people simply call cars whenever they want them. The new business model from Google favors the Robo-Taxi model, where car rides will be provided on demand. Google also wants to dominate the market for providing maps and software for the self-driving car.

**Winners**
- Semi And Fully Autonomous Car Adopters
- Component Suppliers And Sensor Manufacturers
- Rental & Ride Sharing Companies
- Public transport system (last mile)

**Losers**
- Traditional Auto Manufacturers
- Taxi Services And Professional Drivers
- Auto Insurance Companies (?)
- Auto Service Industry
- Public transport system (?)
Conclusions

- Electric Vehicle sales and production numbers continue to increase aggressively over the next years but will reach 35% of all new sales only in 2040.
- The development in battery technology and the scaling up of production capacities make tomorrows EV’s cost competitive.
- All along the value chain of battery production material innovations and large investments will be required. Europe is lagging but there are some interesting initiatives.
- Range is for most users no longer an issue; it’s limitations will gradually be compensated by more and high power charging infrastructure. The question is not if? but when?
- An increasing renewable energy production makes EVs an ideal solution to reduce CO₂ emissions.
- Connected Autonomous Shared Electric (CASE) vehicles will reshape mobility behavior as well as the mobility industry
- Analysts have predicted that the autonomous car technology will be sufficiently reliable for mass-market use by the middle of the next decade. But before then a lot needs to change – particularly around regulation.
Partners

25 research groups at 10 institutes

ABB Turbosystems AG • Bcomp Ltd. • Bombardier • BRUSA Elektronik AG • Bucher-Schörling AG • Carrosserie HESS AG • CTI National Network Carbon Composites Schweiz • Designwerk GmbH • ESRI Schweiz AG • FPT Motorenforschung AG • FVV Forschungsvereinigung Verbrennungskraft-maschinen • Kistler Instrumente AG • Kummler & Matter AG • LEM SA • Liebherr Machines SA • myStromer AG • SBB AG • St. Gallisch-Appenzellische Kraftwerke AG • Swiss Center for Electronic and Microtechnic • Volkswagen AG • Verkehrsverbund Luzern VV • Kyburz Switzerland AG • Kummler & Matter AG • Dow Europe GmbH • Adaptricity AG

28 industry partners
Q&A

Dr. Alejandro Santis, Bern University of Applied Sciences, SCCER Mobility
SCCER School, Engelberg, Friday October 20th 2017

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