Swiss Competence Center for Energy Research
Efficient Technologies and Systems for Mobility

In Zusammenarbeit mit der KTI
Energie
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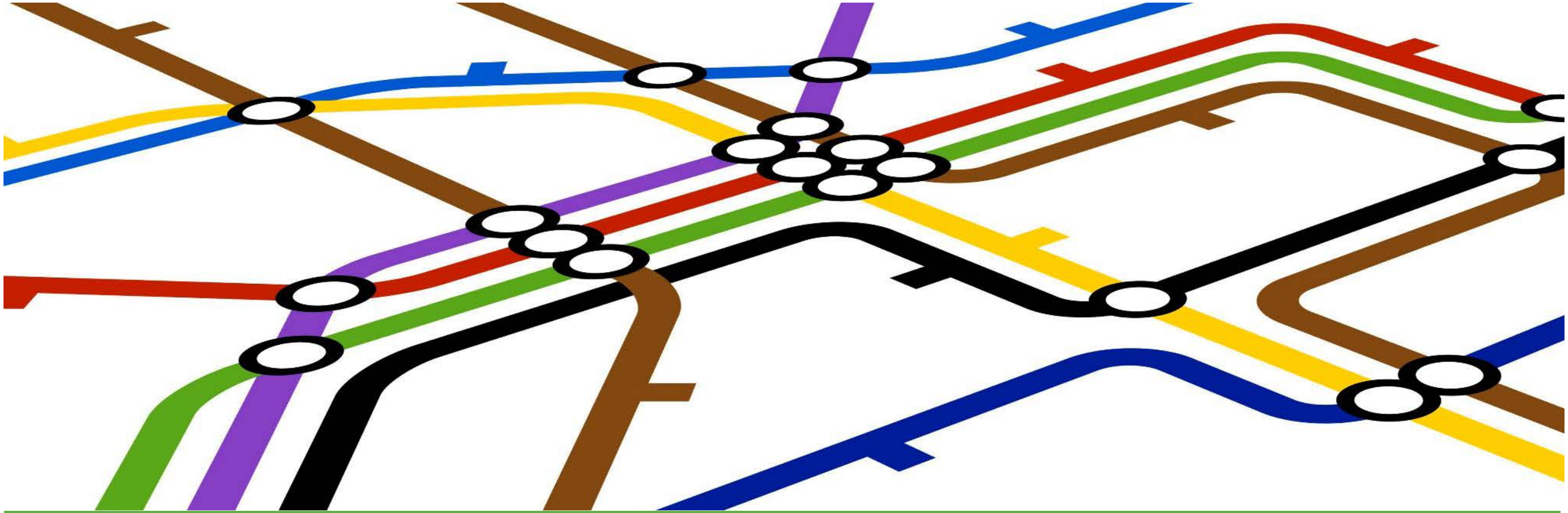

Opportunities and Challenges for E-Mobility and Batteries

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 ... ese earlier periods.

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

1832–39
Robert Anderson, of Scotland, builds the first prototype electric-powered carriage.

1834
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.

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

1

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

1897
The first commercial electric vehicles enter the New York City taxi fleet. The carmaker, Pope Manufacturing Co., becomes the first large-scale EV manufacturer in the United States.

1899
The "La Jamais Contente," built in France, becomes the first electric vehicle to travel over 100 km per hour.

1900
Electricity-powered cars become the top-selling road vehicle in the United States, capturing 28% of the market.

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

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

1909
William Taft becomes the first U.S. President to purchase an automobile, a Baker Electric.

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.

1912
GLOBAL EV STOCK REACHES HISTORICAL PEAK OF 30,000

2

1930s
By 1935, EVs become all-but-extinct due to the predominance of internal combustion engine (ICE) vehicles and availability of cheap petrol.

1947
Oil rationing in Japan leads carmaker Tama to release a 4.5hp electric car with a 40V lead acid battery.

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

1966
The U.S. Congress introduces legislation recommending electric vehicles as a means of reducing air pollution.

1973
... tions, ...

3

1996
To comply with California's Zero Emission Vehicle (ZEV) requirements of 1990, General Motors produces and begins leasing the EV1 electric car.

1997
In ... t ... 18, ...

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

2008
Oil prices reach more than USD 145 per barrel.

2010
The BEV Nissan LEAF is launched.

2011
The world's largest electric car sharing service, Autolib, is launched in Paris with a targeted stock of 3,000 EVs.

2011
GLOBAL EV STOCK REACHES NEW HISTORICAL PEAK OF 50,000

2011
French government fleet consortium commits to purchase 50,000 EVs over four years.

4

2011
Nissan LEAF wins European Car of the Year award

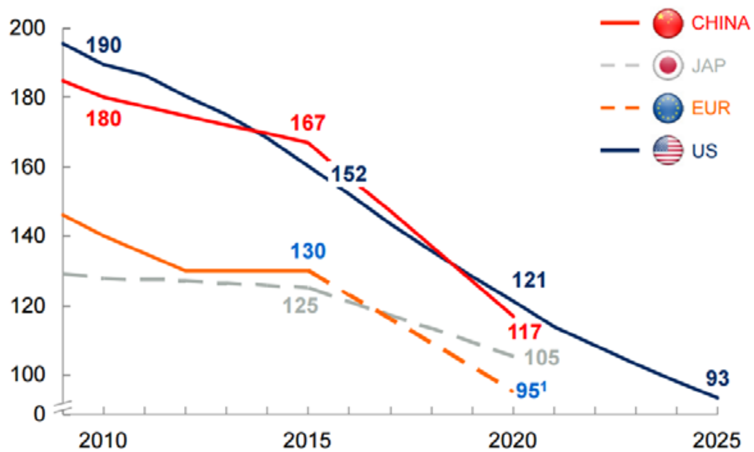
Sources: Curtis D. Anderson and Judy Anderson, *Electric and Hybrid Cars: A History*, McFarland and Company, 2012 ; burnanenergyjournal.com; pbs.org/now/shows/223/electric-car-timeline.


electric drive
Electric Drive

Governments around the world are setting ambitious targets for light vehicle CO_2 emissions

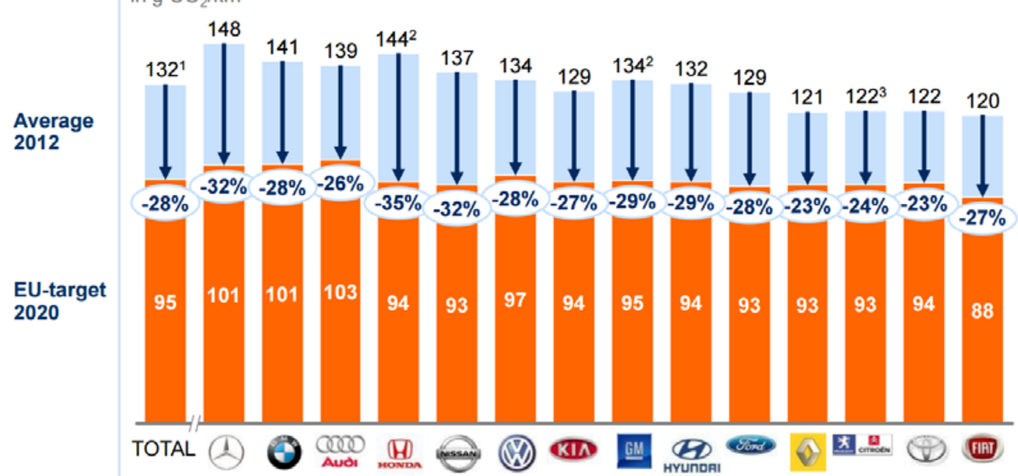
Planned emission standards in select regions

g CO_2/km normalized to New European Driving Cycle



CO_2 emissions of selected OEMs and brands 2012 in Europe (NEDC)

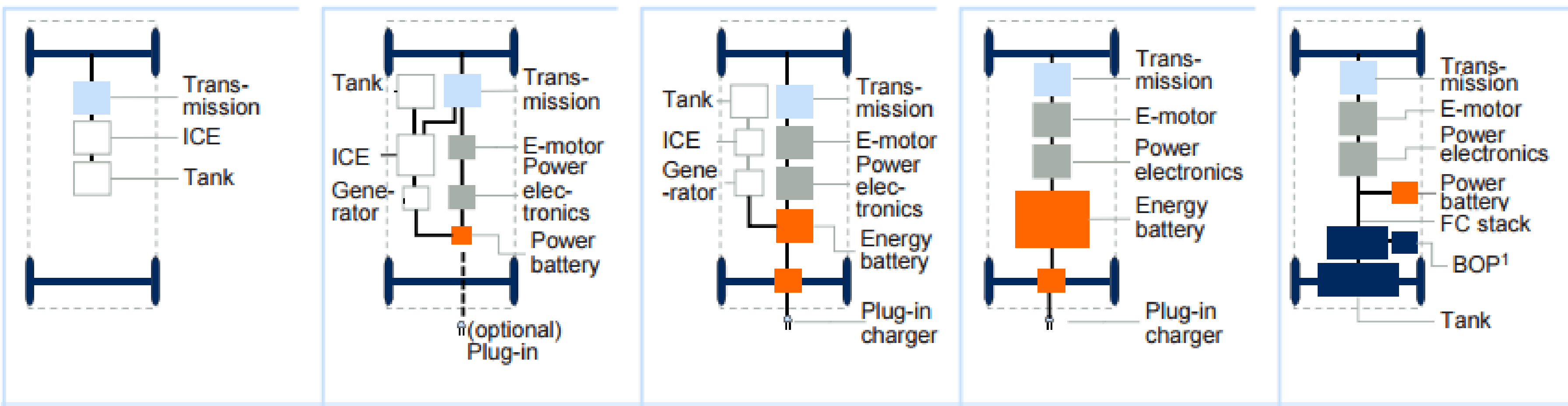
in g CO_2/km



- EU target of 130 g CO_2/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 CO_2/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 CO_2/km in 2025 from the 152 g CO_2/km threshold in 2016

ICE and the different types of EVs

Internal combustion engine, ICE	Hybrid electric vehicle (P) HEV	Range extended electric vehicle, REEV	Battery electric vehicle, BEV	Fuel cell electric vehicle FCEV



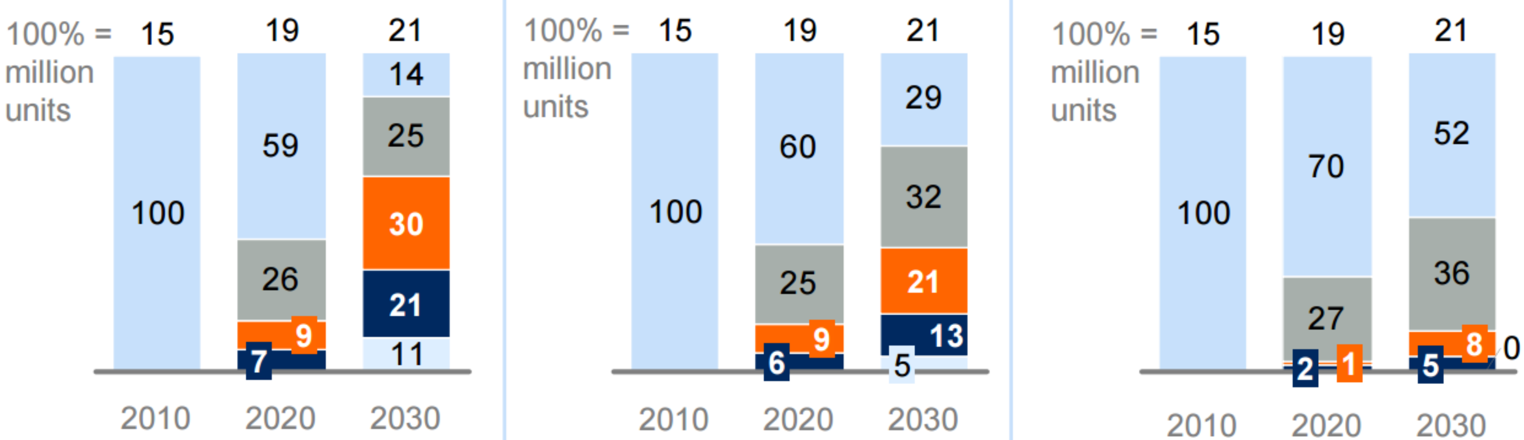
ICE primary source of propulsion

ELECTRIC MOTOR primary source of propulsion

In the long-term EV adoption remains uncertain, driven by regulation (Europe)

ICE HEV REEV BEV FCEV

Very strict regulation leads to BEV and FCEV world	2° climate goal leads to a 3 technology world	Little change in regulation leads to a world of hybrids and BEVs
BELOW 10	BELOW 40	BELOW 100



Very strict CO_2 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 industry[1]

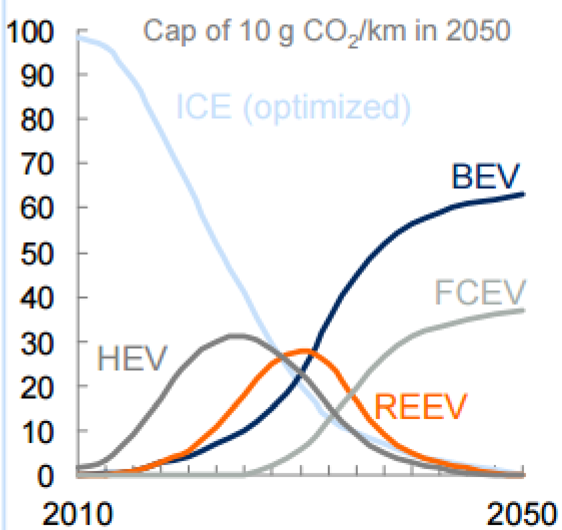
Strong CO_2 emission reduction to 40 g/km in 2050 – a scenario that foresees a continuation of increasingly restrictive emission standards[1]

Moderate CO_2 emission reduction to 95 g CO_2/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 standard[1]

1 For further details on scenarios, refer to Appendix 1
SOURCE: McKinsey – Boost! Powertrain KIP

Very strict regulation leads to BEV and FCEV world

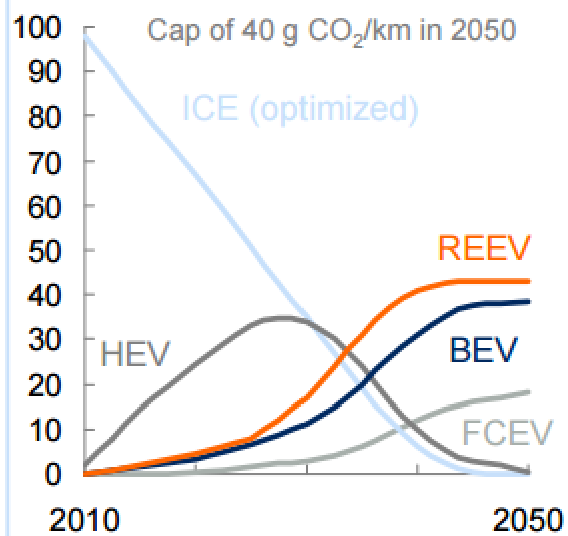
"Below : 10"



- 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

2° climate goal leads to a 3 technology world

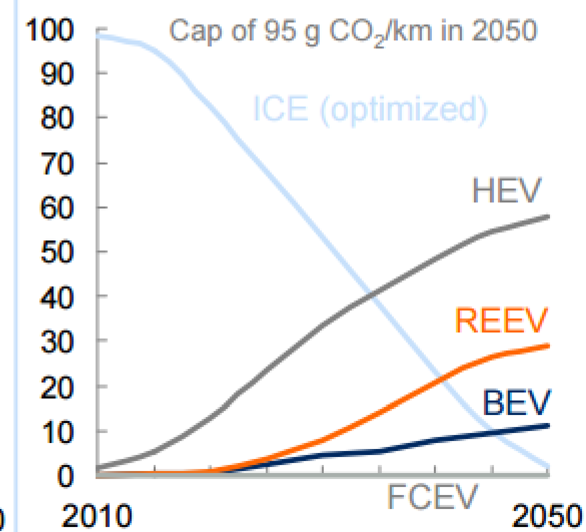
"Below : 40"



- 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

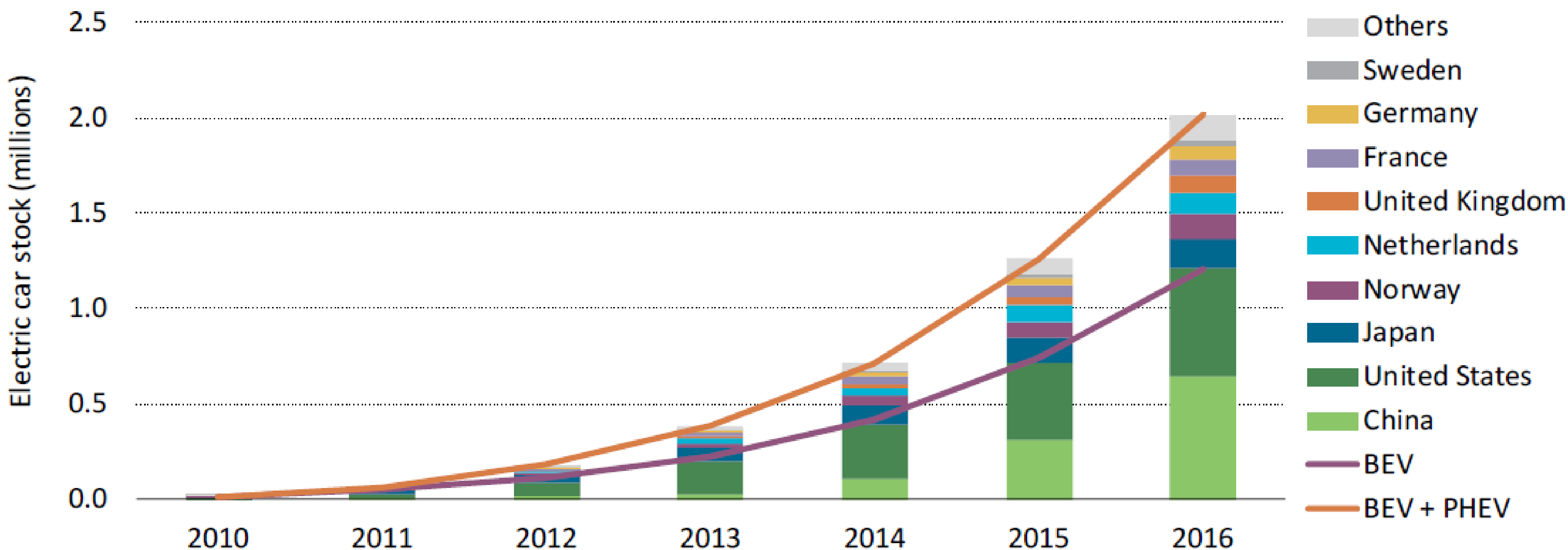
"Below : 100"



- 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

SOURCE: McKinsey – Boost! Powertrain KIP

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?

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)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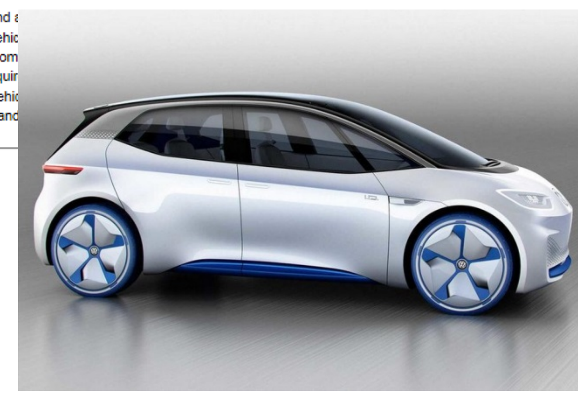
German minister snubs automakers backing China's quota for EVs
Bloomberg | 2016/11/8
Germany's environmental minister is throwing her support behind a aggressive Chinese plan to boost sales of electric and hybrid vehic putting her at odds with her country's automobile industry and som the German government. China is considering legislation to requir automakers to sell a specific quota of zero- and low-emission vehic 2018 and

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).

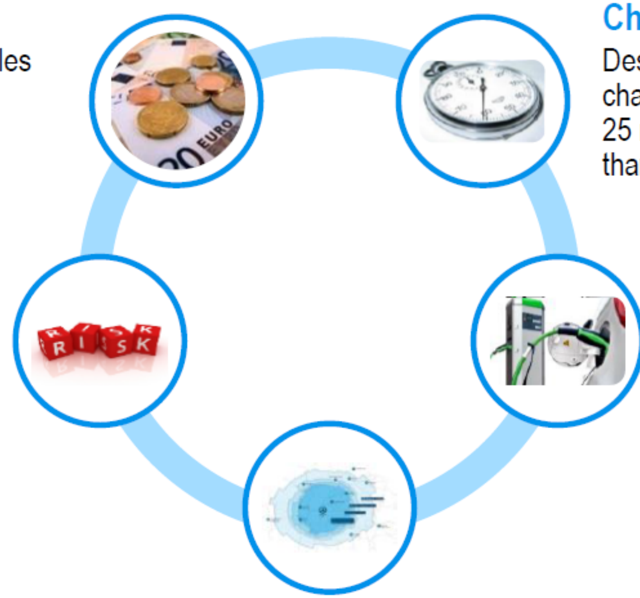
Volkswagen announced the planning to launch as many as 30 environmental friendly models and one million EV sales annually by 2025. **Volkswagen ID concept with 600 km driving range unveiled in Paris** (09/2017).



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 a electric vehicle is significantly lower compared to a vehicle with conventional powertrain

Source: Roland Berger

Main hurdles for e-mobility: All Battery related!

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

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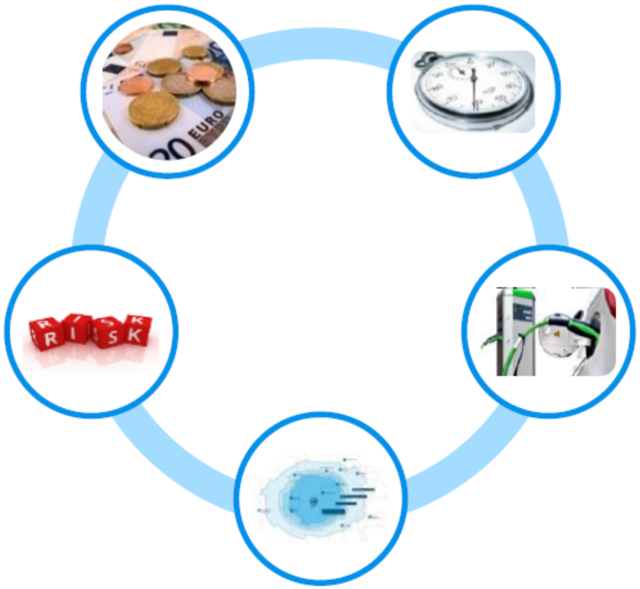
Recent accidents (e.g. burning battery of a Tesla Model S) lead to security concerns, e.g. regarding maturity of the technology



Source: Roland Berger

Main hurdles for e-mobility: All Battery related!

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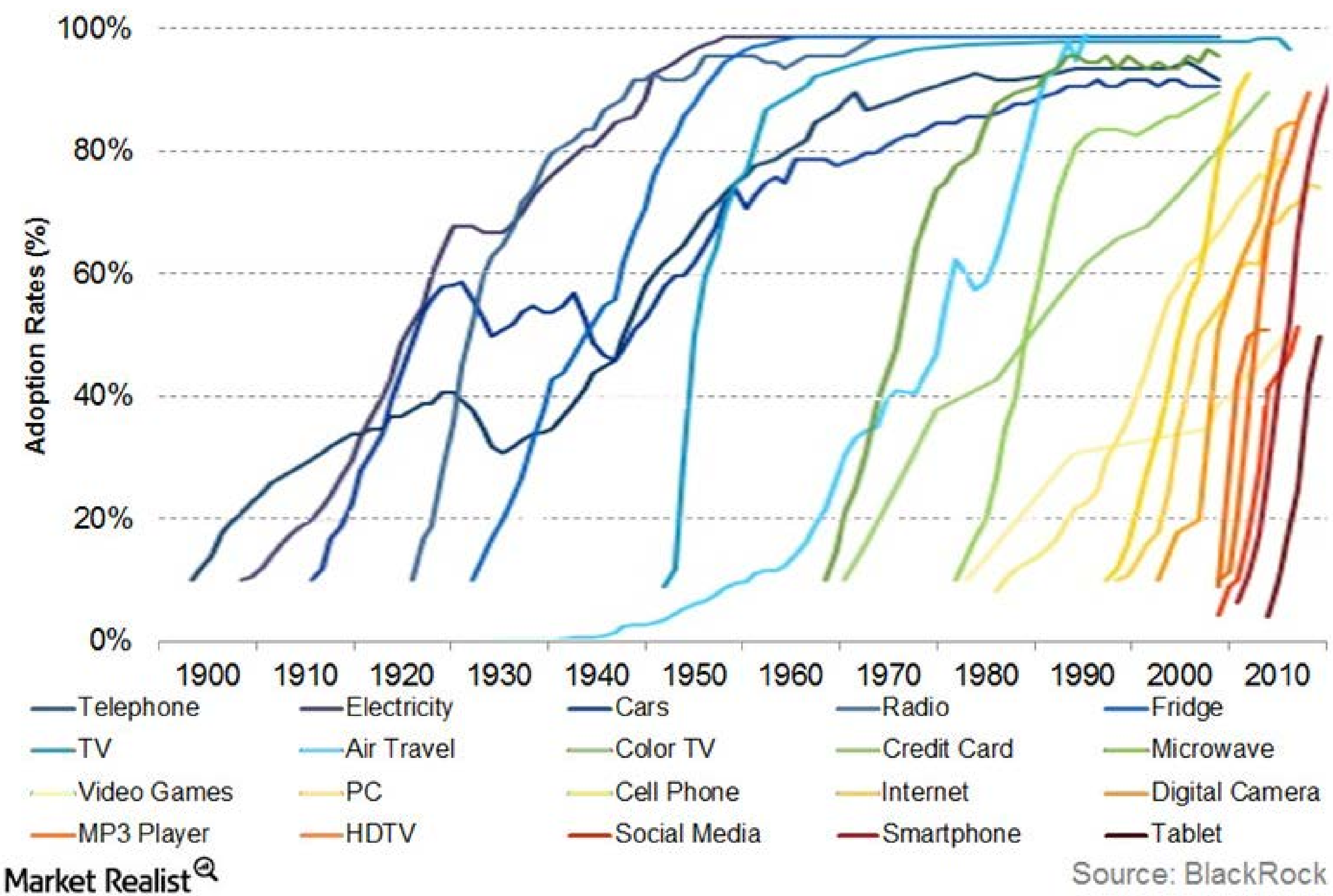
Source: Roland Berger

Game Changer

GM EV1 1997		2013 NISSAN LEAF	2017 TESLA MODEL 3
LEAD-ACID	BATTERY CHEMISTRY	LITHIUM-ION	ADVANCED LITHIUM-ION
1,310 POUNDS	BATTERY PACK WEIGHT	606 POUNDS	~700 POUNDS
18.7 KWH	BATTERY CAPACITY	24 KWH	50 – 75 kWh
55 TO 95 MILES	APPROXIMATE RANGE	75 MILES	~ 220 – 310 Miles
$49,350 INFLATION ADJUSTED	PRICE	$28,800 BEFORE SUBSIDIES	~ $35,000

- 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/, there are now (October 19th 2017) 554'502 reservations.

Adoption of technology in the US (1900 to present)



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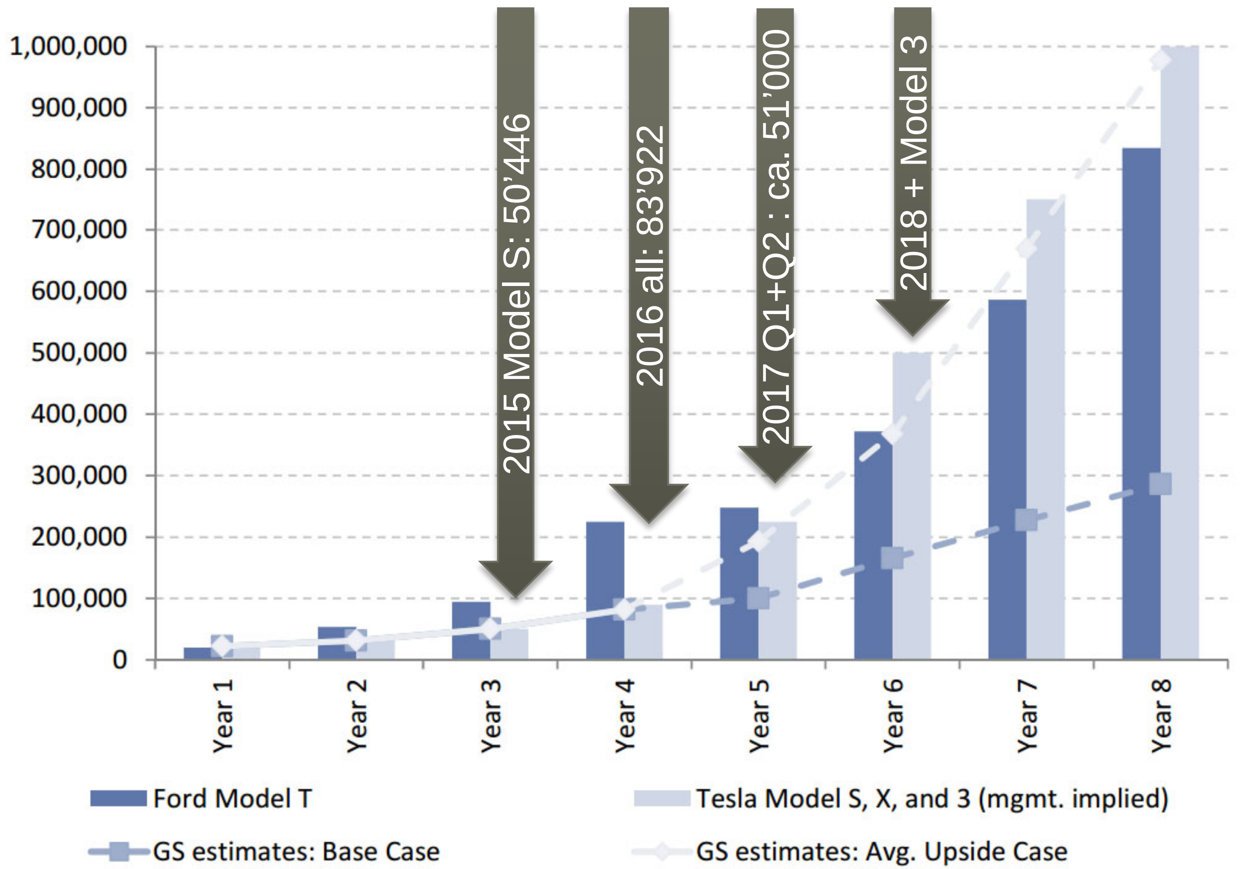
Game Changer:

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

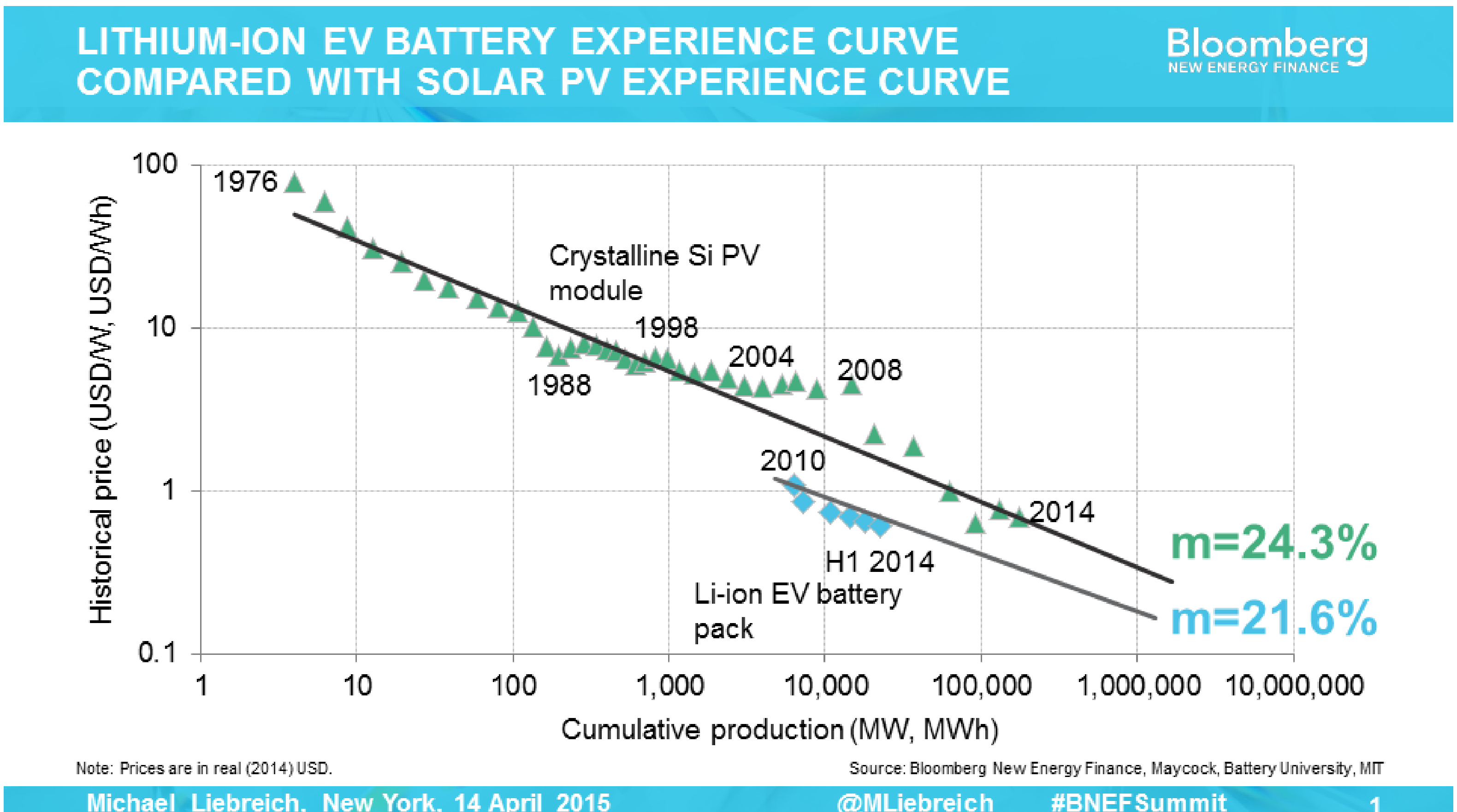


*Model T Year 1 is 1910; Tesla Year 1 is 2013.

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

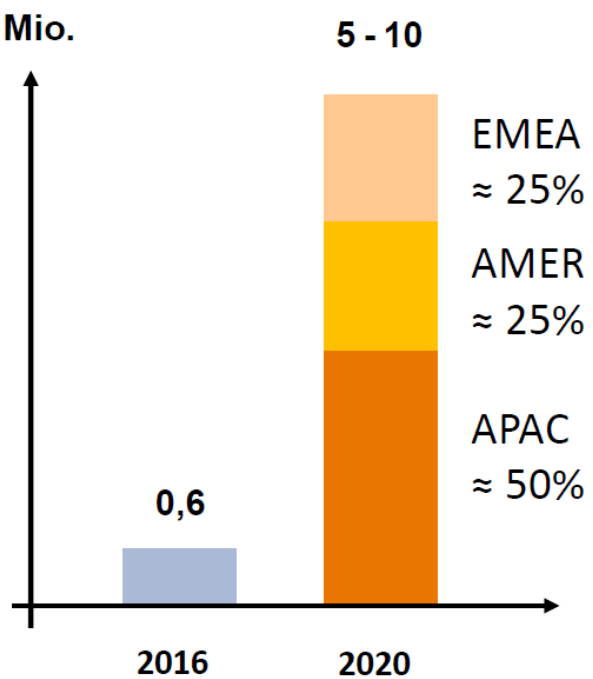


http://energypost.eu/cheap-can-energy-storage-get-pretty-darn-cheap/

E-Mobility Market – new Factories required

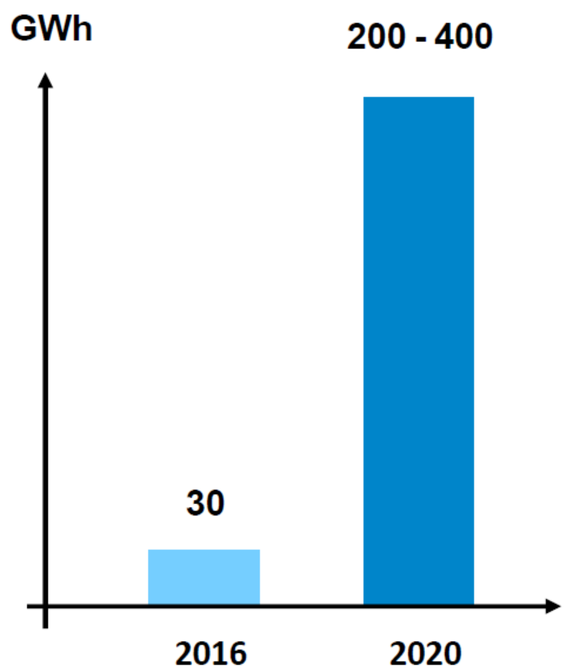
Scenario with sustainable Growth

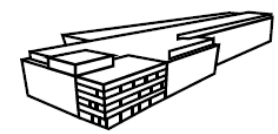
EV Sales



Sources: Bain, BCG, JRC, McKinsey

Battery Capacity Demand





25 - 50
FACTORIES*
REQUIRED
WORLD WIDE
UNTIL 2020

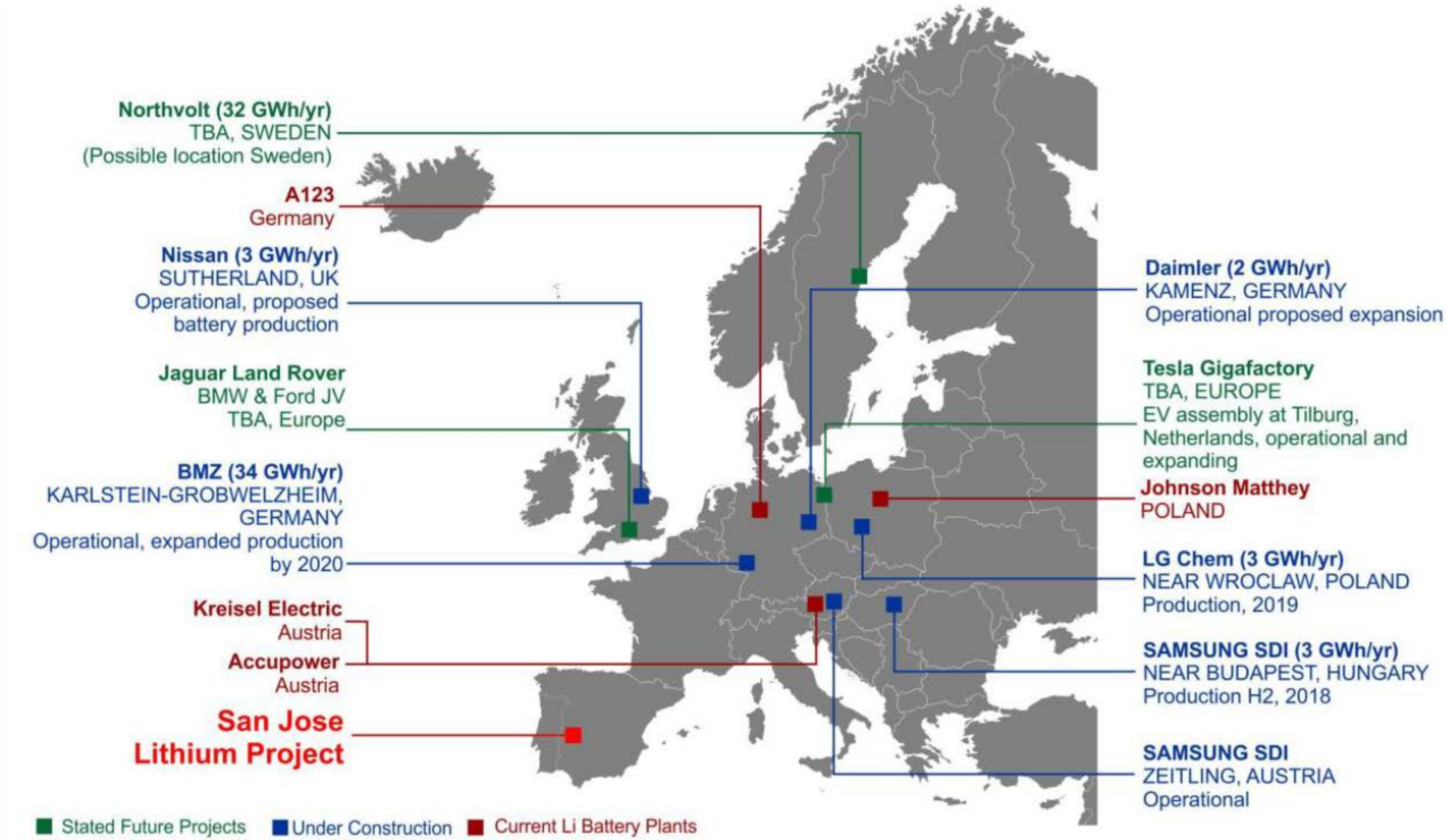
*One factory = 8 GWh/year = 200.000 EVs

TESLA's 150 GWh (?) Battery Factory (Gigafactory)

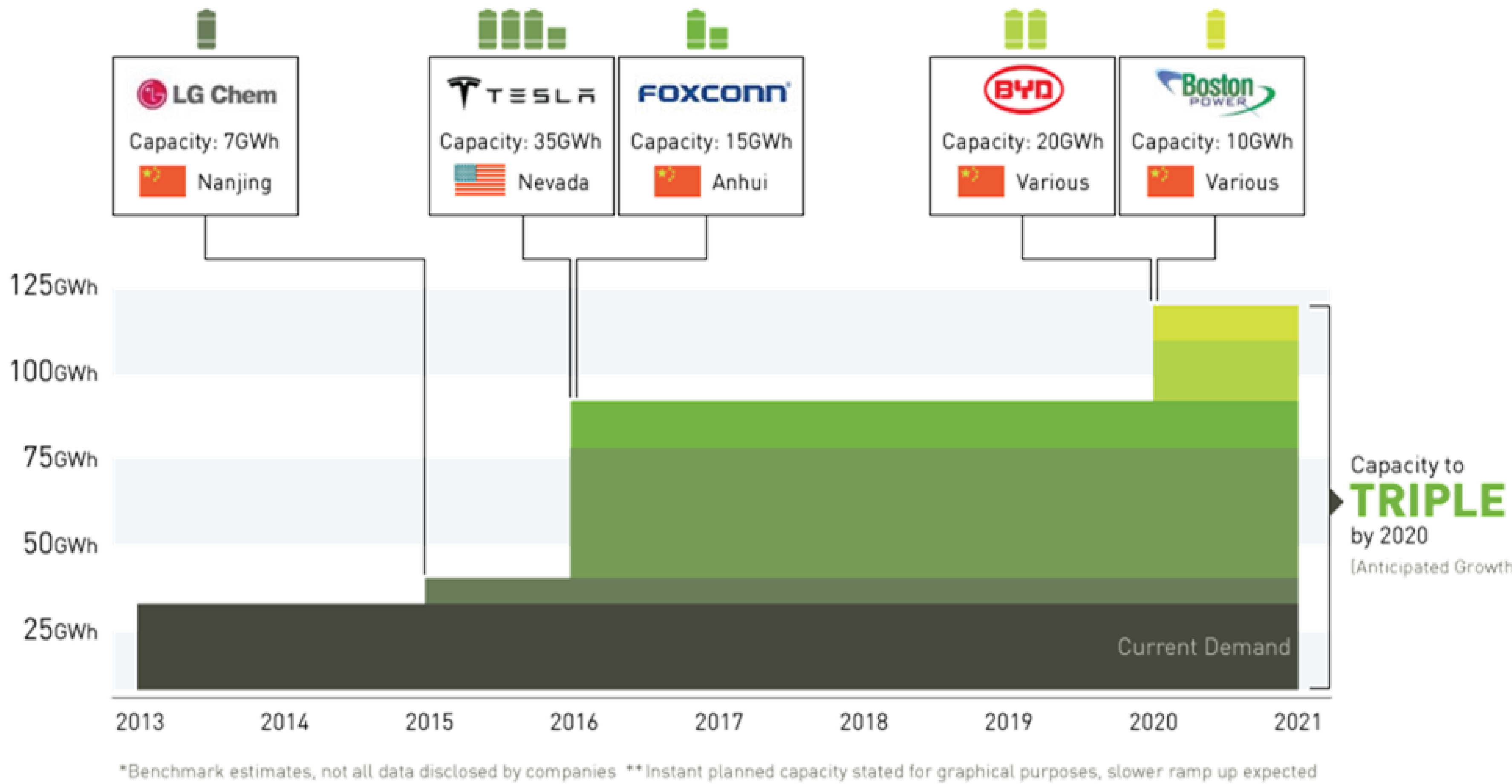
- Currently only approximately 20 percent of its 1-million-square-foot facility is already up and running.
- Its projected capacity for 2018 is 50 GWh/yr of battery packs and its final capacity upon completion of entire factory is 150 GWh/yr. This would enable Tesla to produce 1,500,000 cars per year (2020 ?)

Source: Tesla Motors JB Straubel – CTO, co-founder 2015 EIA Conference June 15, 2015 Washington, D.C.

Location of proposed Gigafactories in Europe



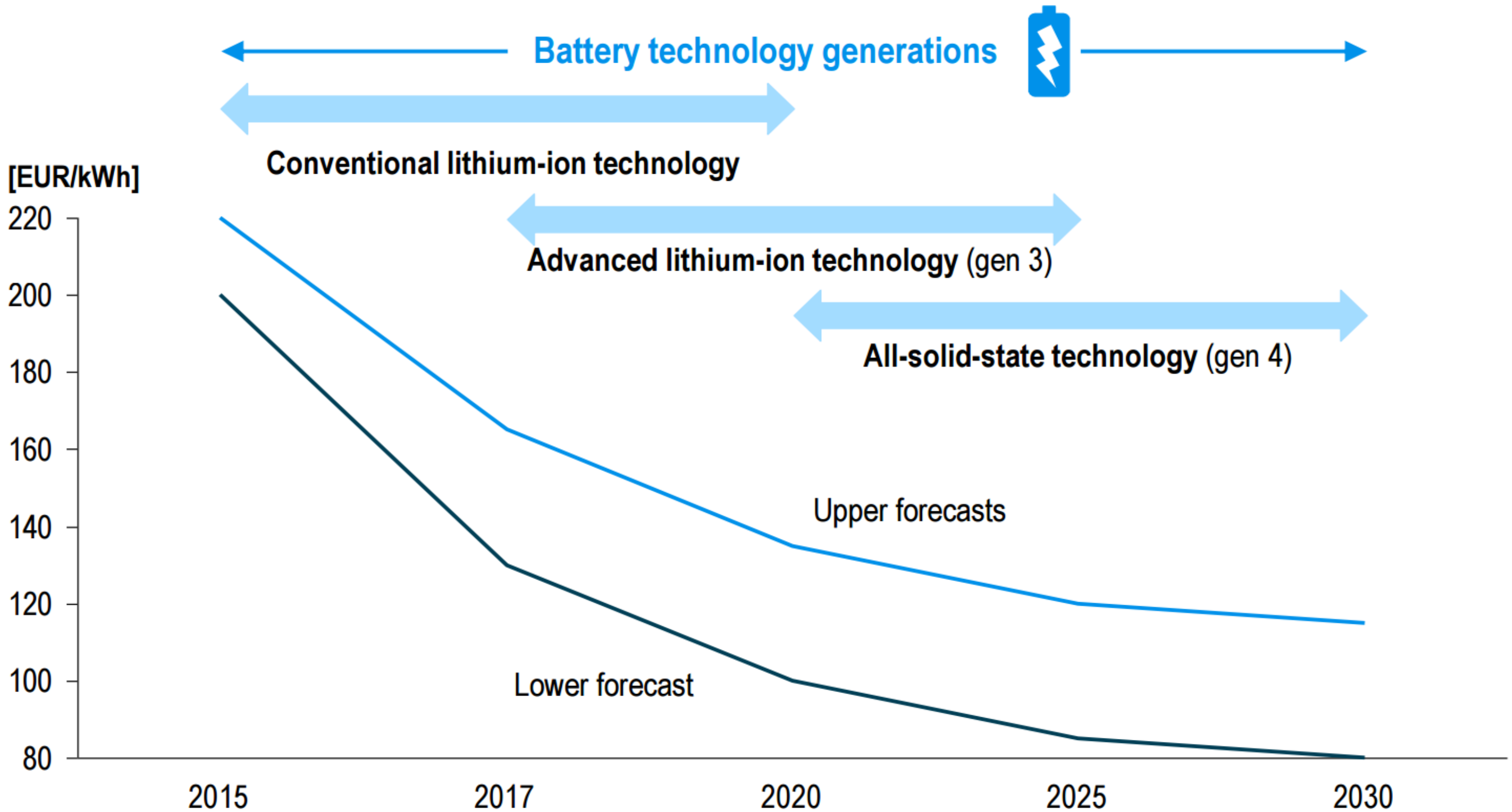
Lithium-Ion Battery Megafactories currently being build



Source: Roland Berger

Price development of battery cells [EUR/kWh]

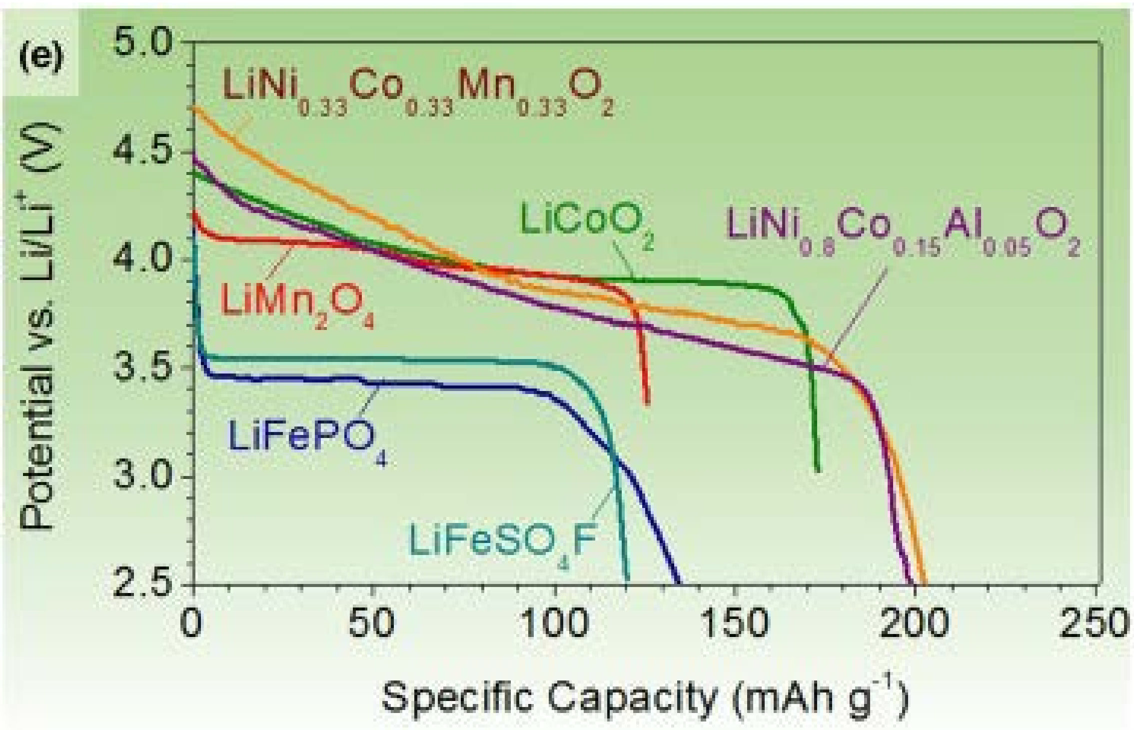
- Batteries make up a 1/3 to 1/2 of the production costs of an electric vehicle



Cost forecast for battery cells. Battery systems require also housing, cooling, battery management, …

Source: Roland Berger

Energy density depends largely on the chemistry of the electrode materials



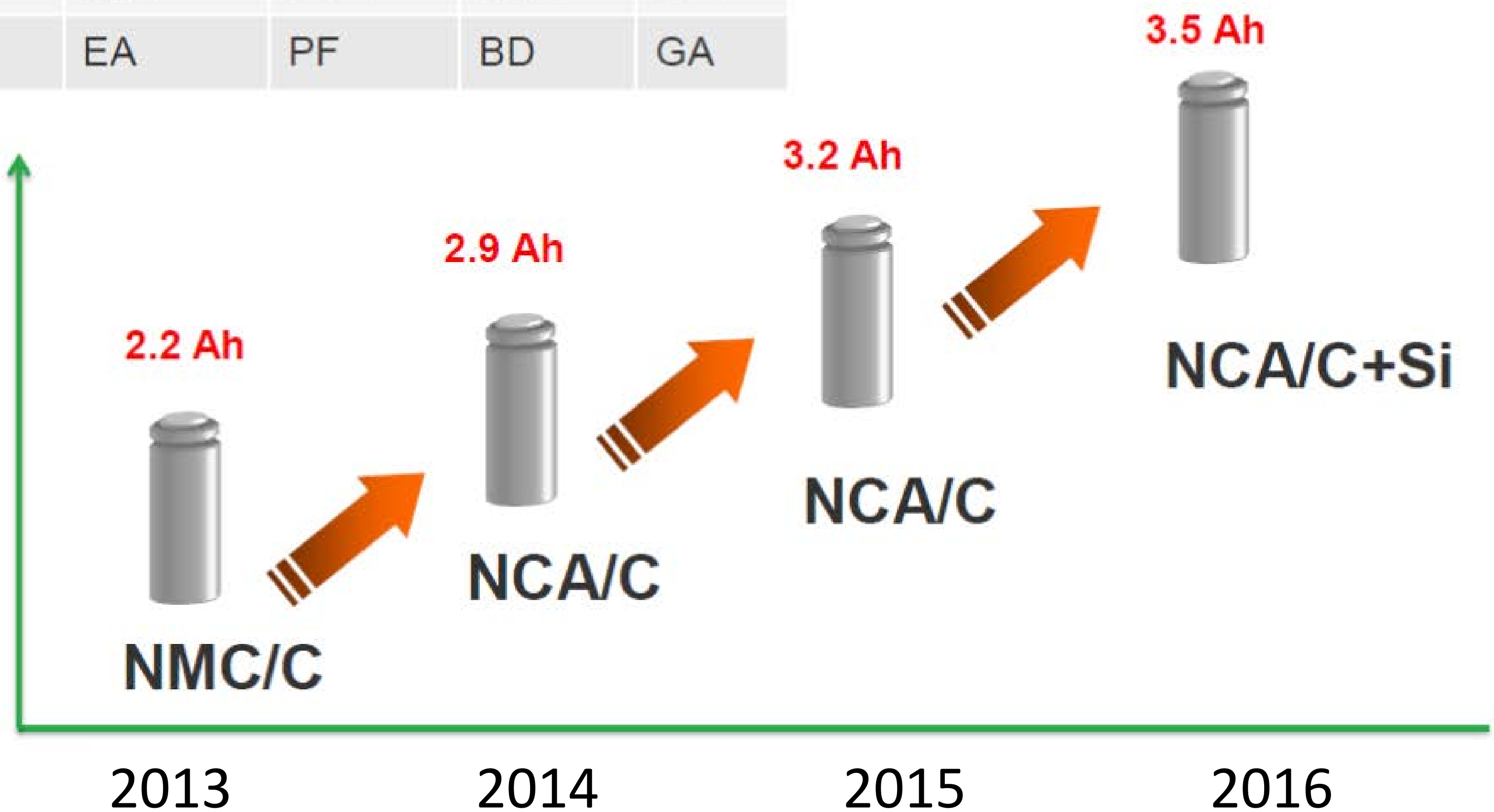
<u>Energy densities in the market:</u>

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

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

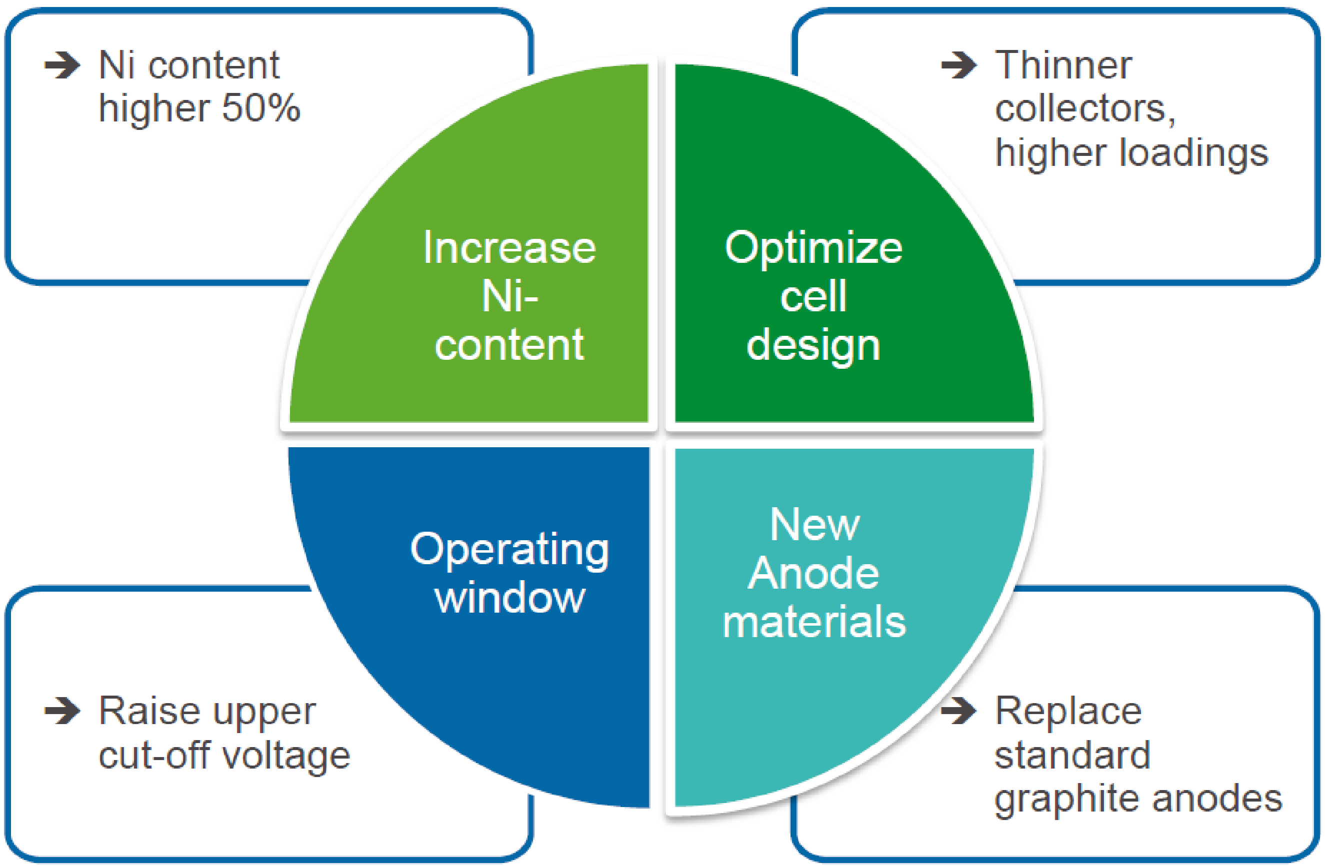
http://www.sciencedirect.com/science/article/pii/S1369702114004118

	2.2Ah	2.9Ah	3.2Ah	3.5Ah
Samsung SDI	22P	29E	32E	35E
LG Chem	MF1	MG1	MH1	MJ1
Panasonic	EA	PF	BD	GA



Source: Shmuel-de-Leon, 12/2016

Strategies to increase Energy Density



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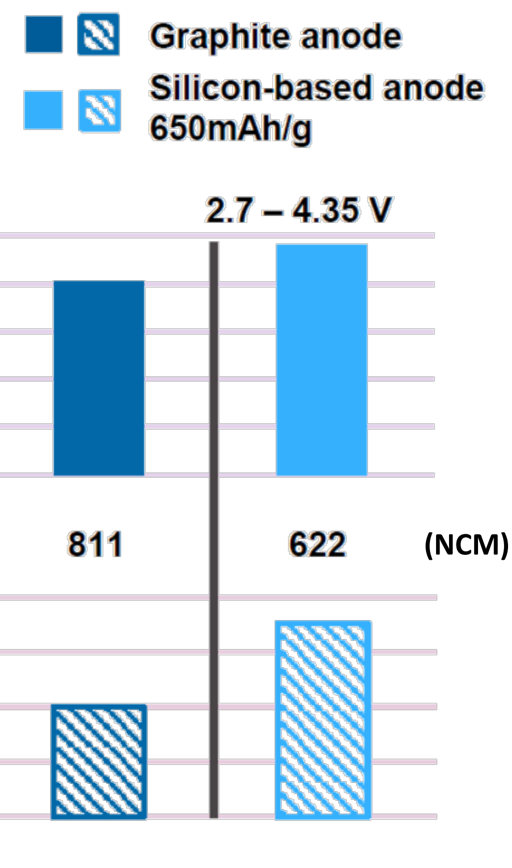
Both –high Nickel as well as high voltage appropriate measures to increase ED

- Resulting Energy Densities on cell level



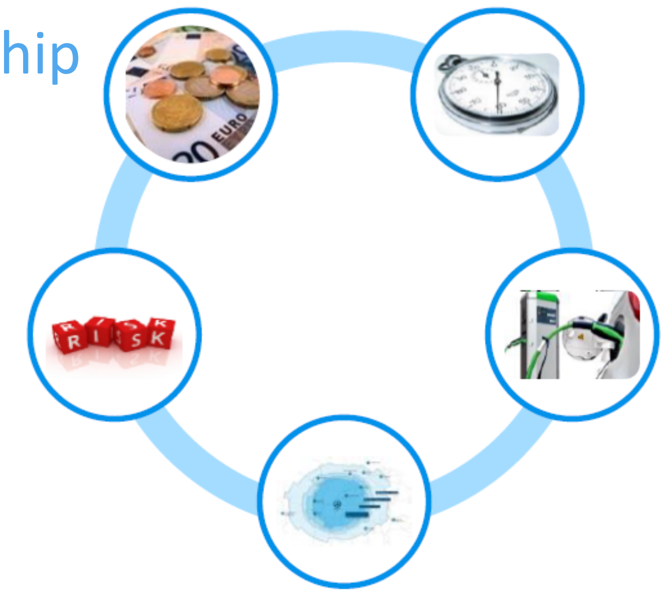
Simulation results: 120Ah prismatic hard case cell, low weight cell design, C/5 discharge rate

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

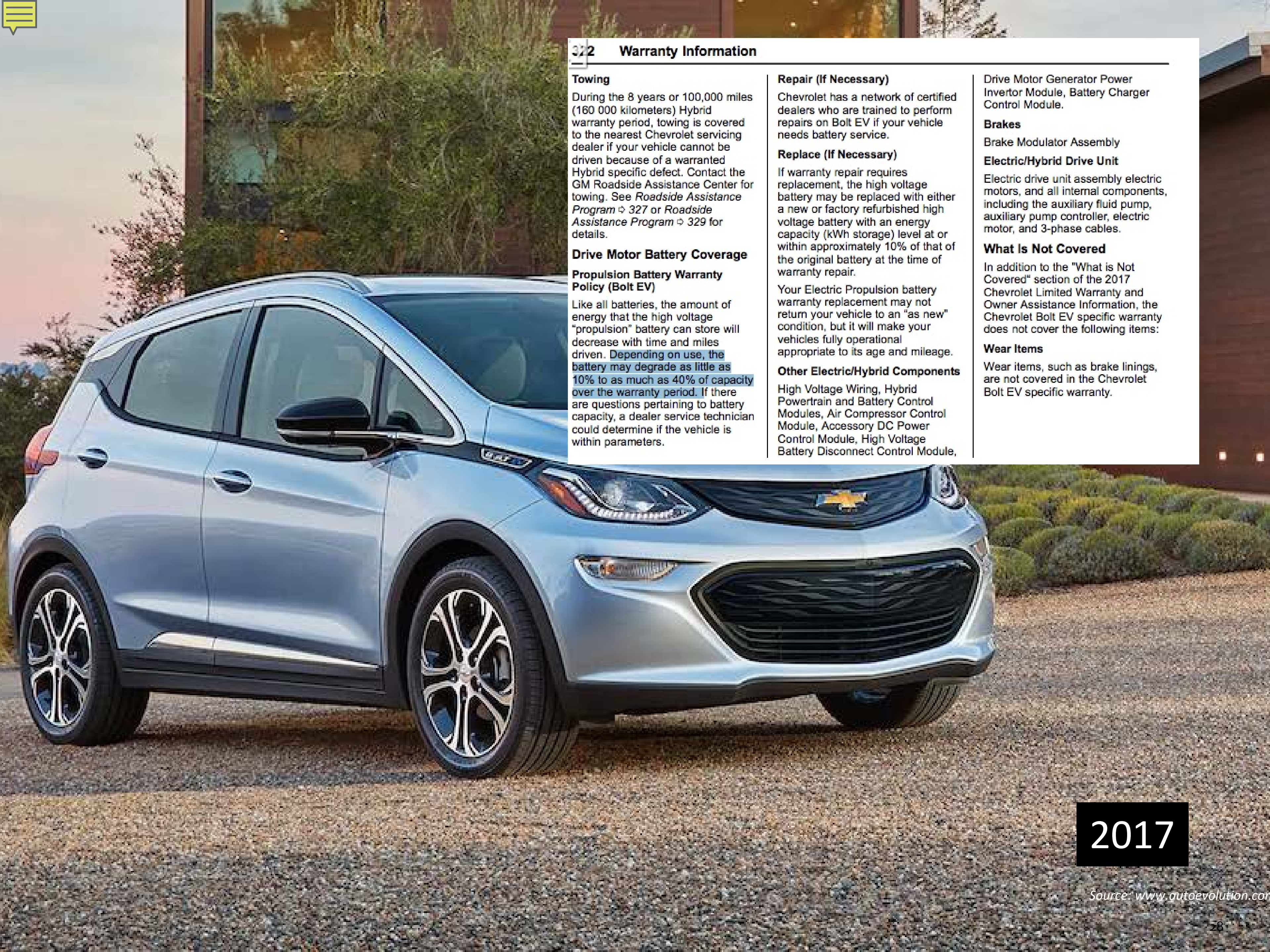
Ca. 25 % battery capacity loss within 1 -2 years of operation;

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

2012



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* ⇨ 327 or *Roadside Assistance Program* ⇨ 329 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 warranty 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 Invertor 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

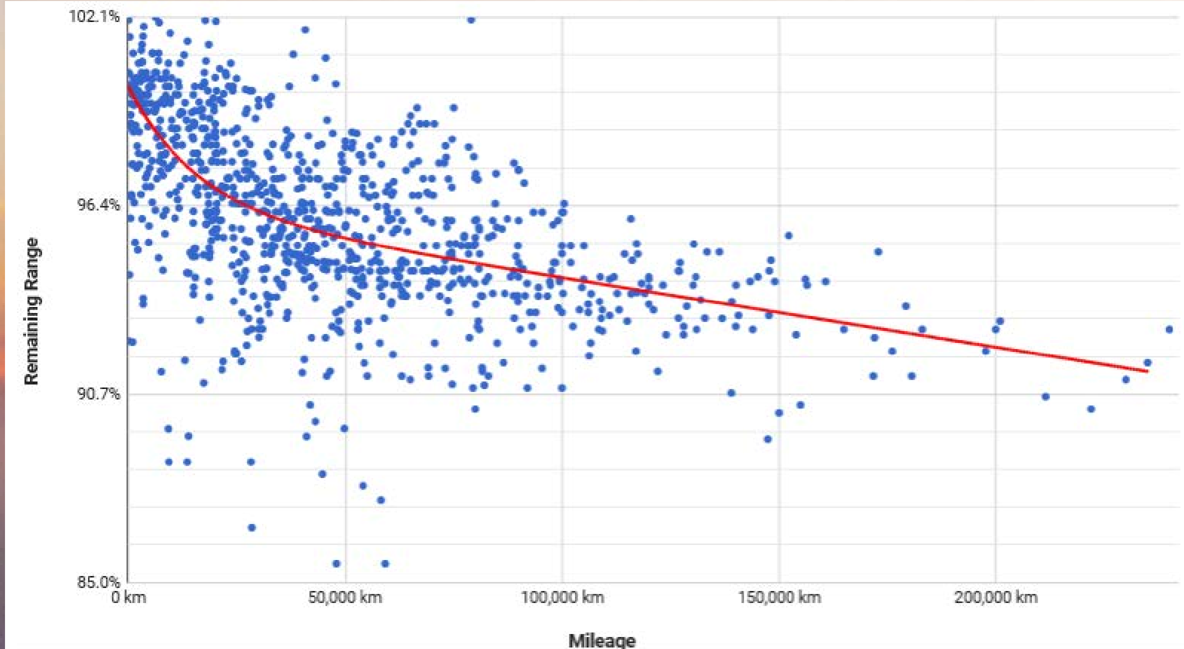
In addition to the "What is Not Covered" section of the 2017 Chevrolet Limited Warranty and Owner Assistance Information, the Chevrolet Bolt EV specific warranty does not cover the following items:

Wear Items

Wear items, such as brake linings, are not covered in the Chevrolet Bolt EV specific warranty.

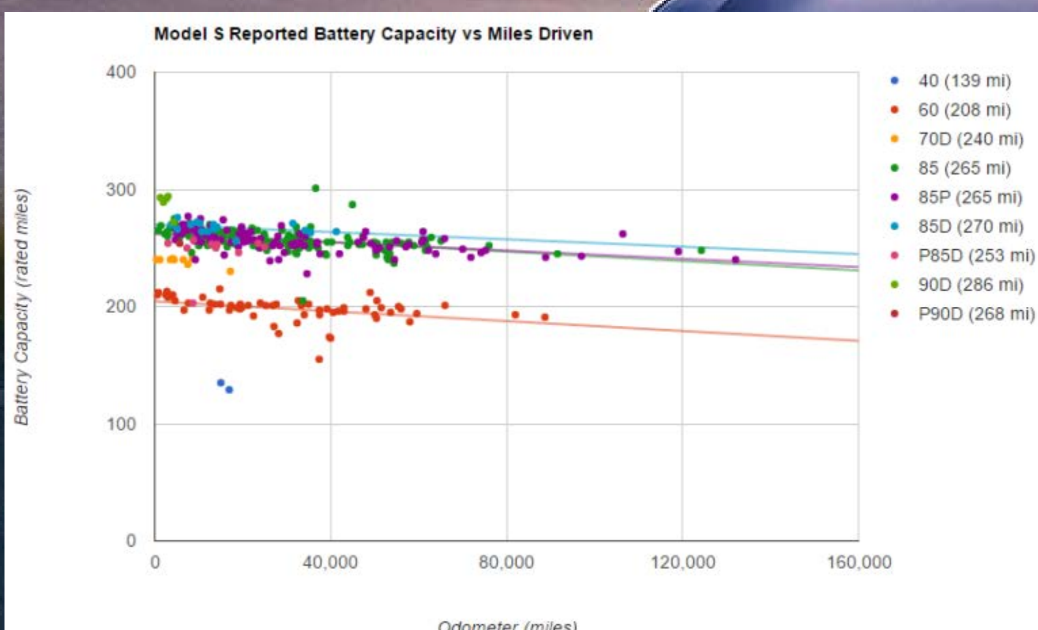
2017

Source: www.autoevolution.com



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.

Source: www.teslarati.com



2012 – 2017+

Main hurdles for e-mobility: All Battery related!

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

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

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

Source: Roland Berger

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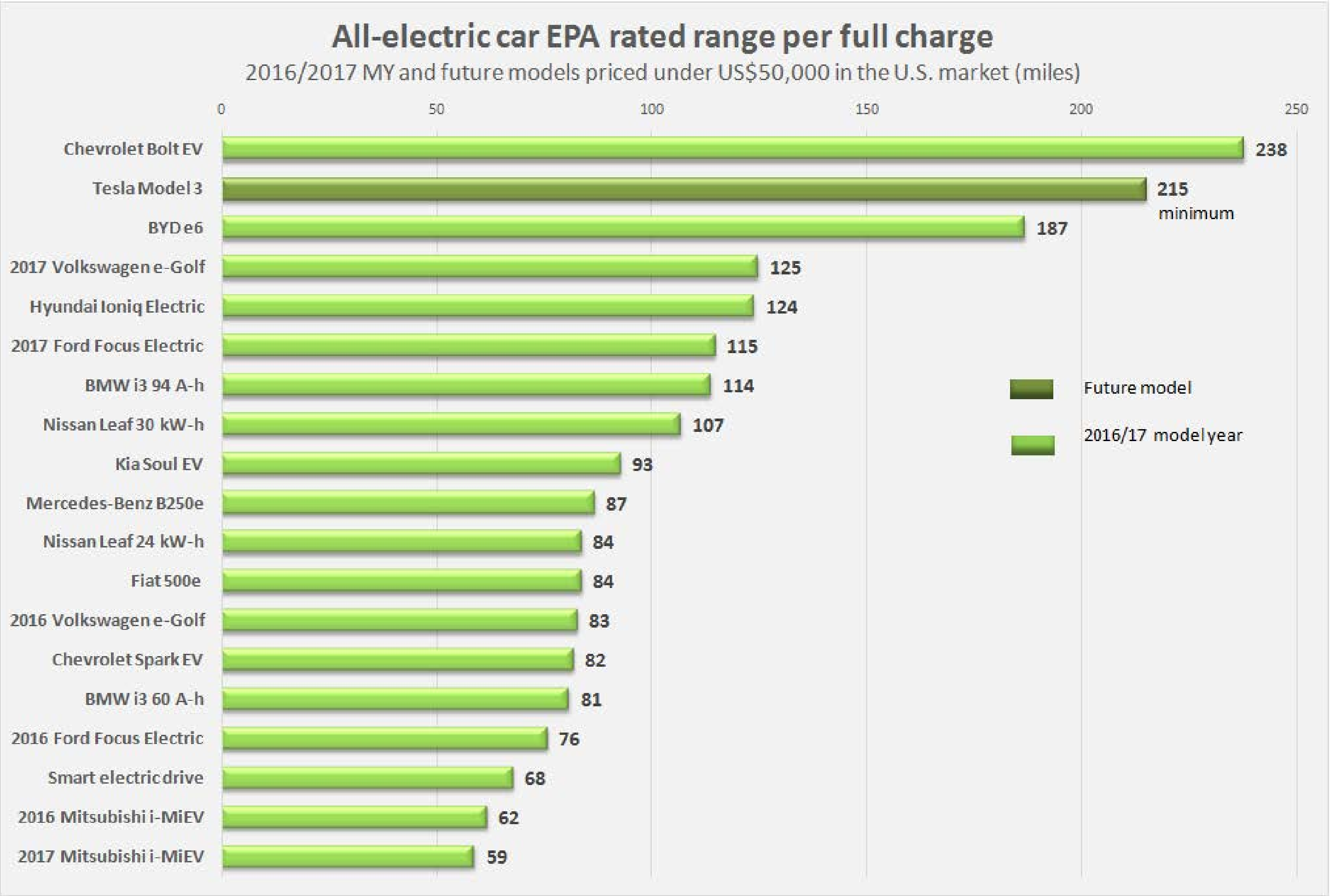
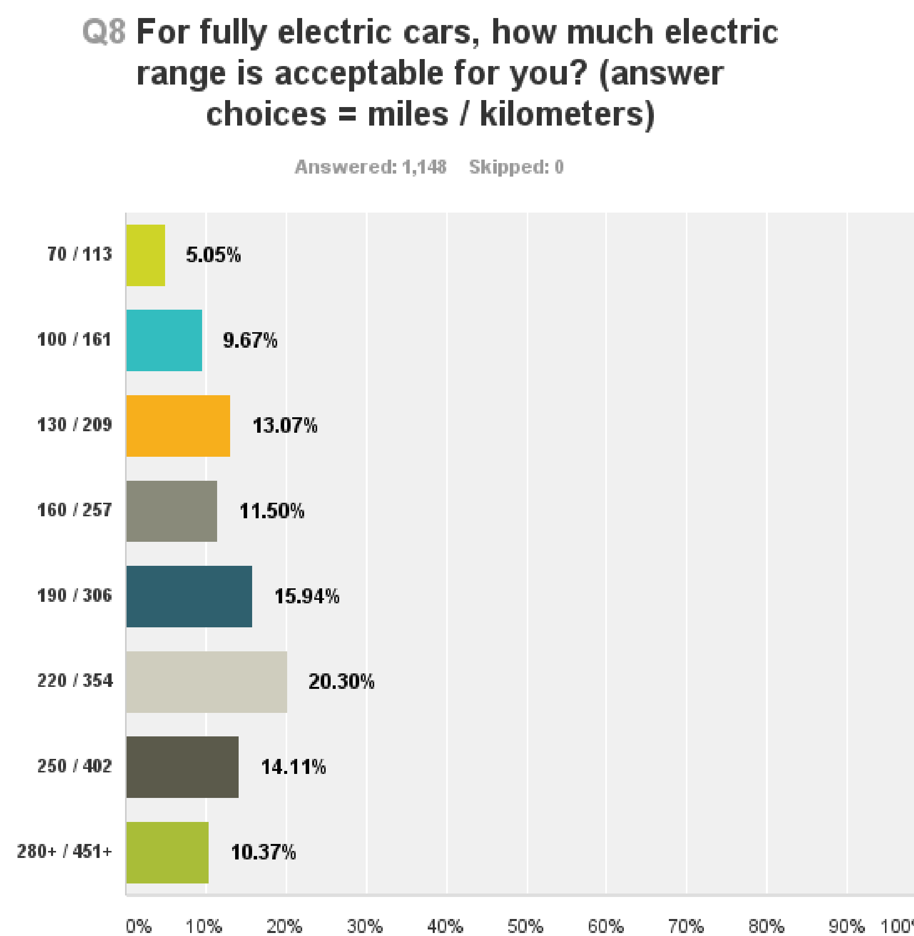
Range of E-Vehicles priced under USD 50'000



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

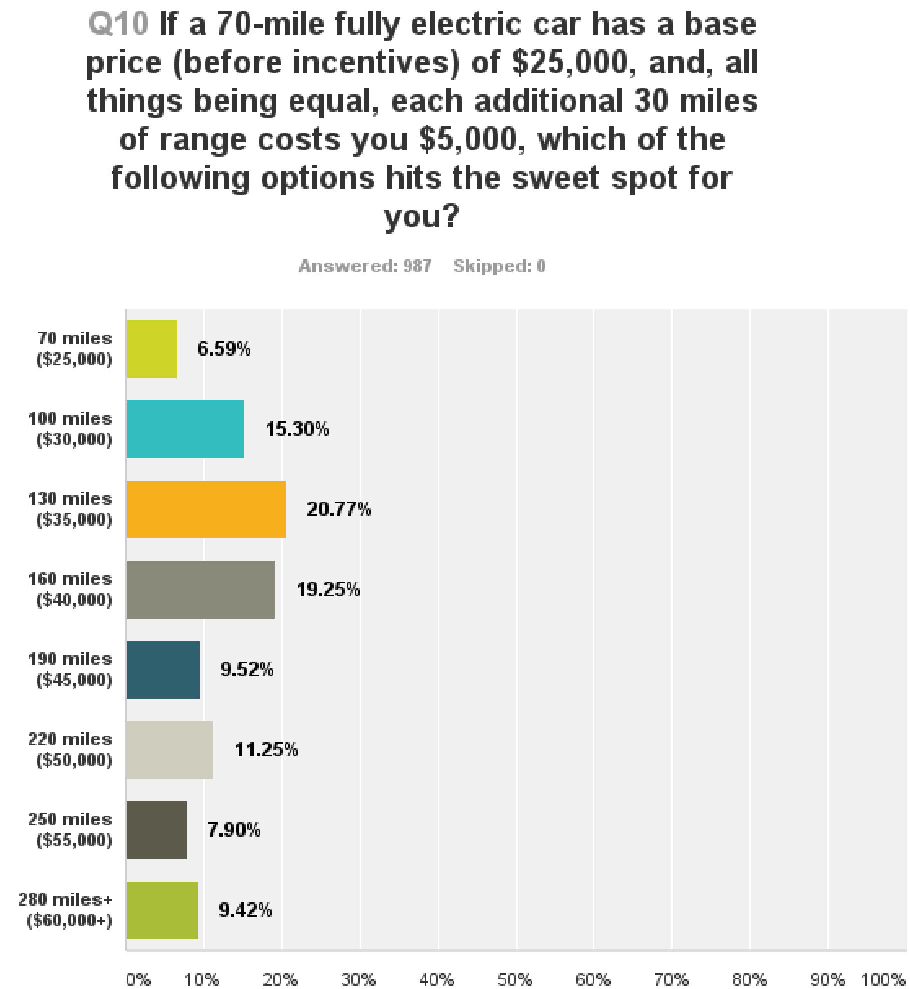
Among non-owners, 45% responded that they needed 354 or more km of range on a single charge.



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

Main hurdles for e-mobility: All Battery related!

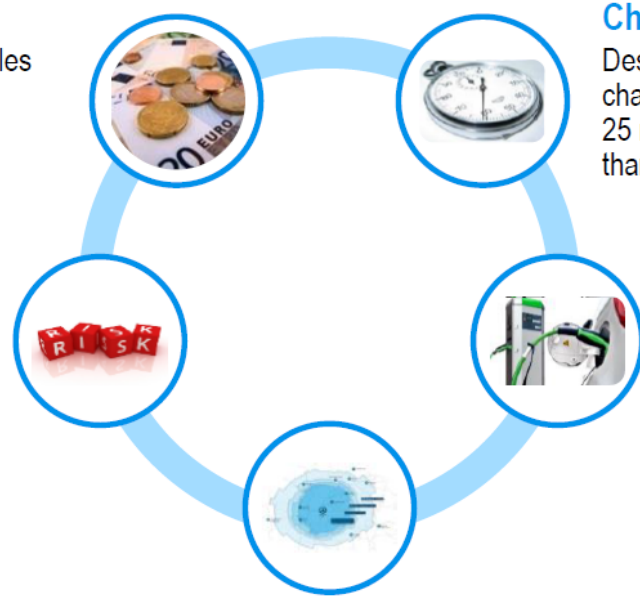
- Study: Integrated Fuels and Vehicles Roadmap to 2030 and beyond (2016)

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 a electric vehicle is significantly lower compared to a vehicle with conventional powertrain

Source: Roland Berger

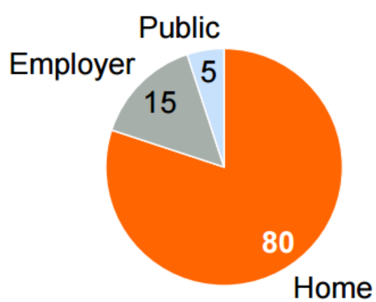
Implications for charging infrastructure

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

Early adopters

Distribution of charge-points for private

Home charging and semipublic dominates



Home and semipublic

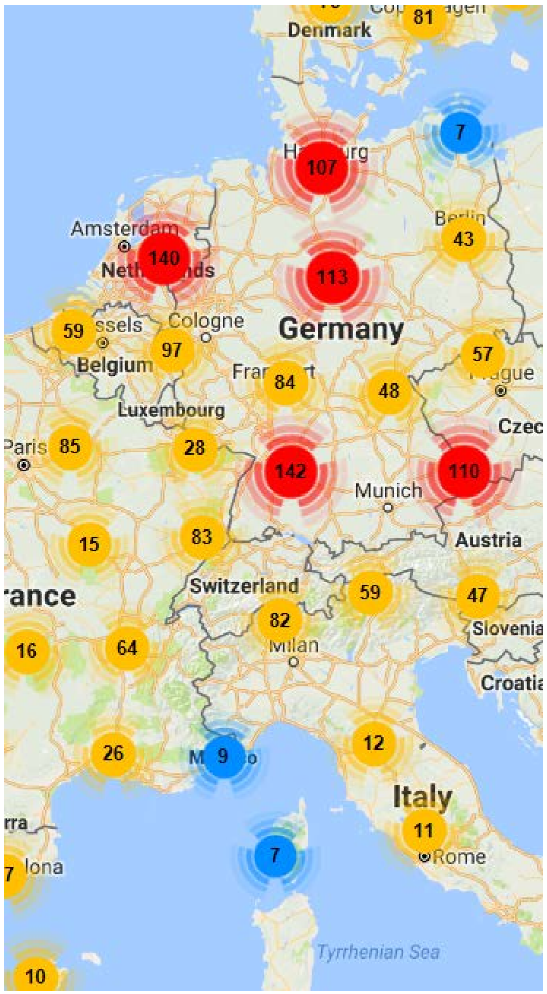
- Home and corporate charging dominate; cars are mostly **charged at home or at corporate locations**

Public

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

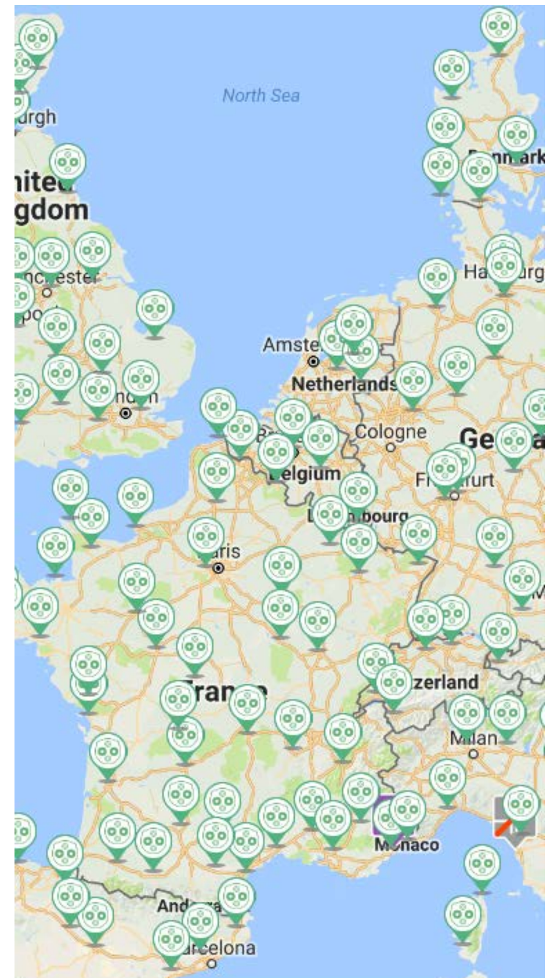
SOURCE: McKinsey

DC-charging stations: CCS, Tesla and CHAdeMO



https://ccs-map.eu/

https://www.tesla.com/supercharger



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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

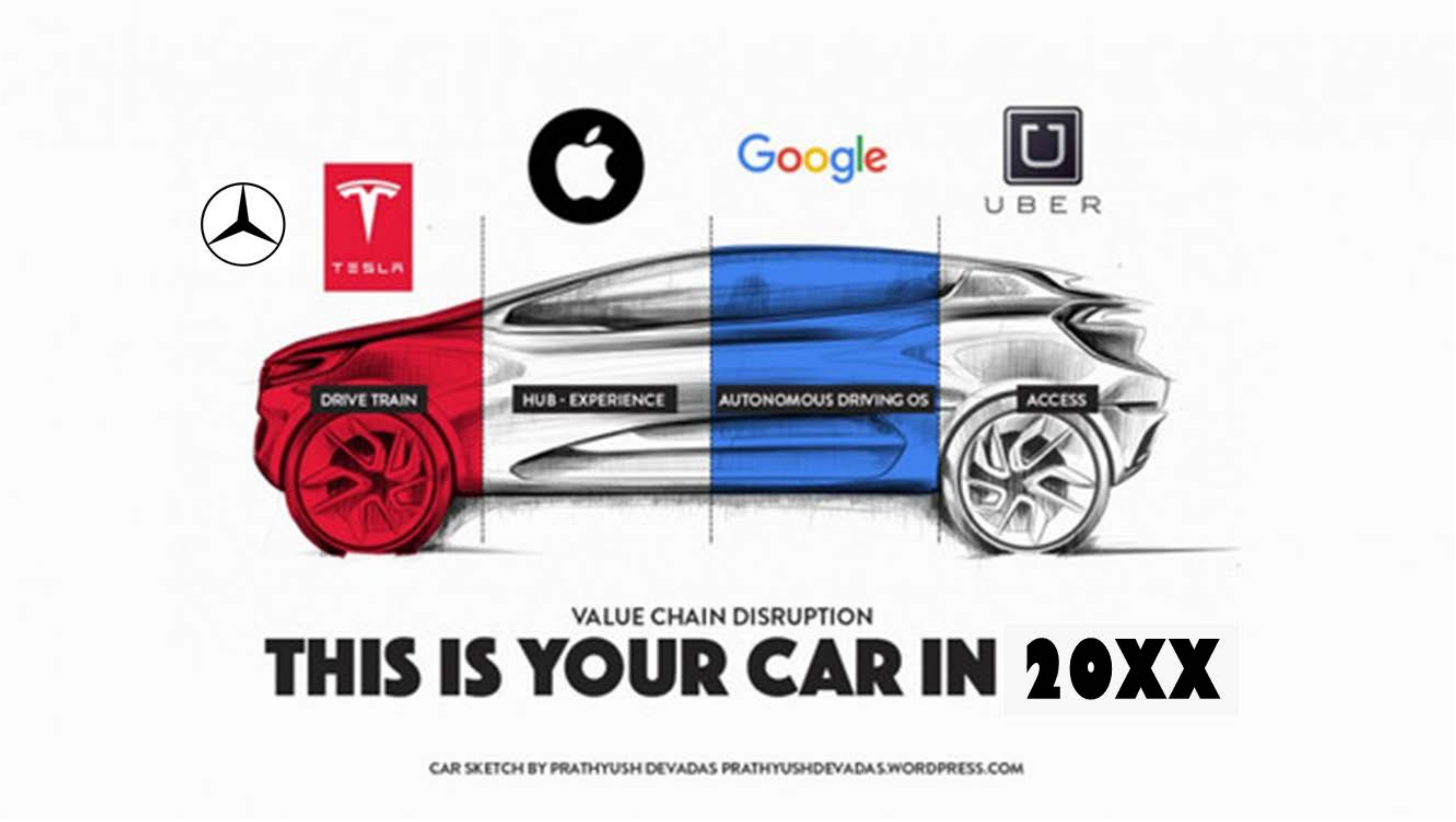
TYPE 2
Accelerated 22KW 380V AC-TRI 32A

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

From ownership to mobility as a service

- 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.

<u>Winners</u>

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

<u>Losers</u>

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

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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 CO_2 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

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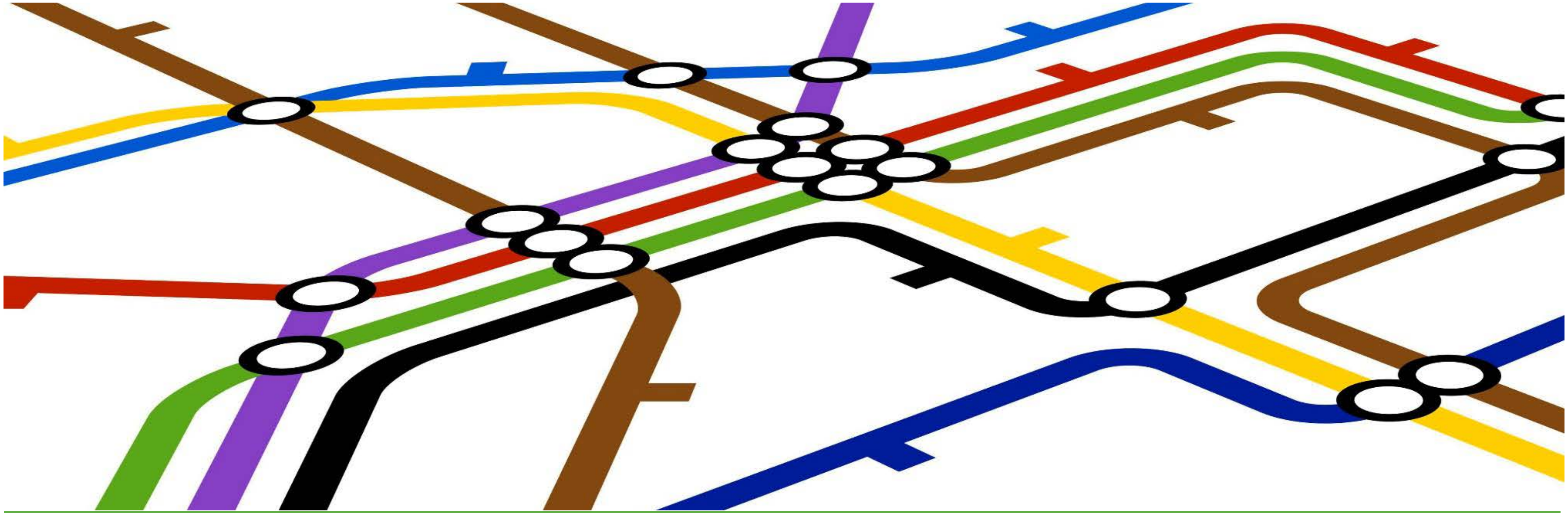

Q&A

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