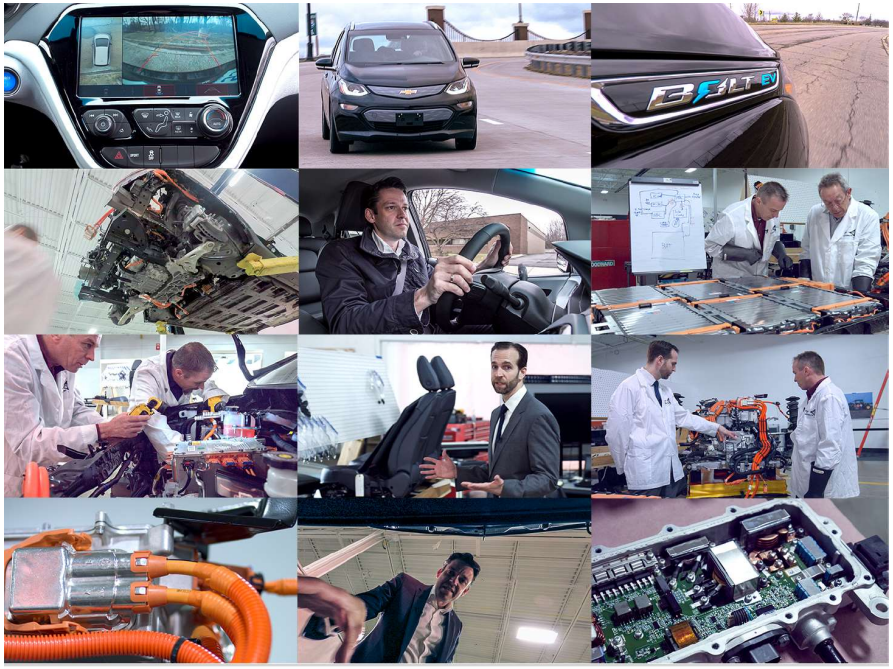
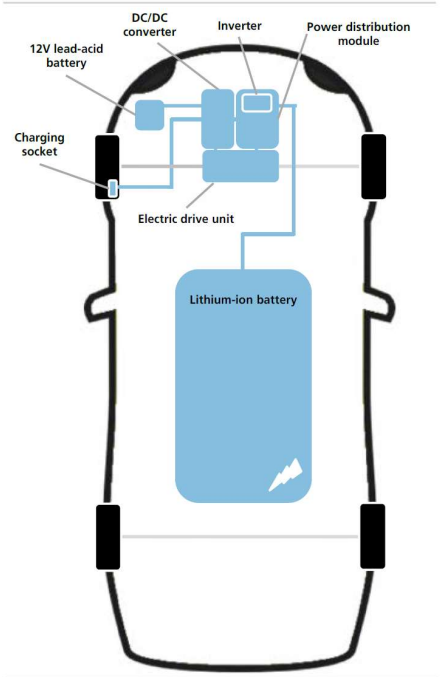
UBS Evidence Lab Electric Car Teardown – Disruption Ahead? (2017.05.18)

- Chevrolet Bolt: world's first *real* mass-segment electric vehicle (EV)
  - $37k price tag ($30k including US government subsidies) with an EPA-estimated range of 238 miles on a single charge



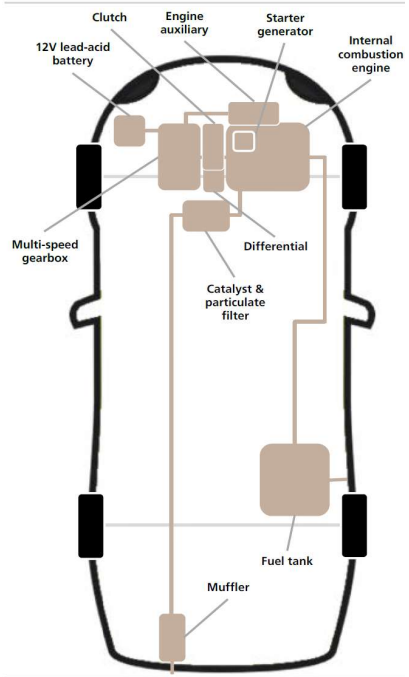
Source: UBS

Figure 40: Chevy Bolt powertrain



Source: UBS

Figure 41: VW Golf powertrain



Source: UBS

Source: GM

Source: Volkswagen

Figure 136: Key technical features Chevrolet Bolt vs. VW Golf

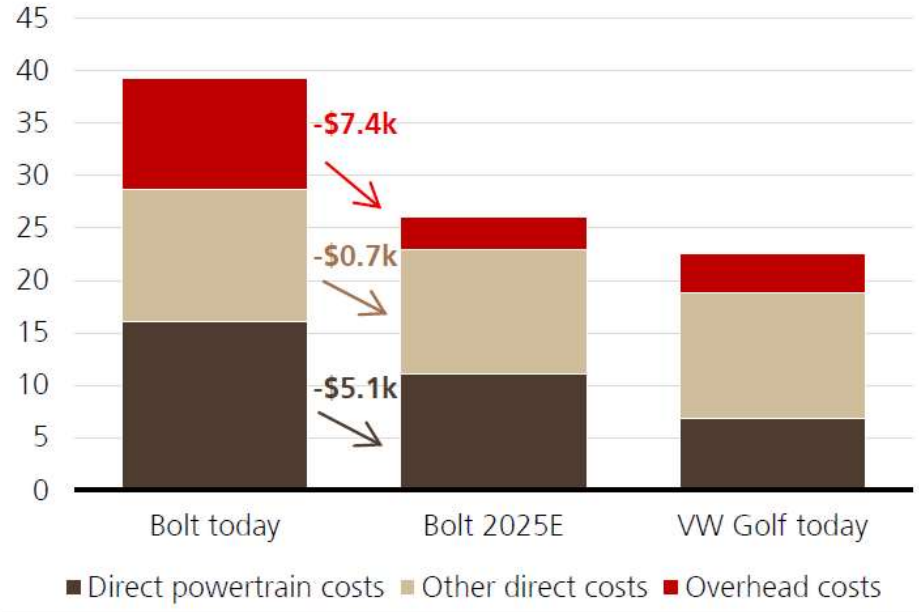
Chevrolet Bolt LT		VW Golf Wolfsburg 1.8 TSI
36,620	**Base price ($)**	23,515
	Dimensions – exterior	
1,616	Base curb weight (kg)	1,371
417	Length (cm)	425
160	Height (cm)	145
176	Width (cm)	180
260	Wheelbase (cm)	264
	Dimensions – interior	
2,673	Passenger volume (l)	2,648
1,178	Front legroom (l)	1,167
1,124	Front headroom (l)	1,087
1,034	Rear legroom (l)	1,008
1,073	Rear headroom (l)	1,079
	Performance specs	
Electric	Propulsion	Internal combustion
200	Horsepower	170
360	Torque (Nm)	270
145	Top speed (km/h)	200
6.5	0-100 km/h (sec)	7.3
	Fuel efficiency (EPA)	
128	MPG city	25
110	MPG highway	35
119	MPG combined	29
383	Range (km)	617
0	g CO_2 / km	192
	Powertrain description	
60kWh lithium ion battery	Fuel storage	50l fuel tank
Permanent magnetic drive motor	Engine	1.8l 4 cylinder turbocharged DI ICE
Single-speed integrated gearbox	Transmission	6-speed automatic transmission

Source: General Motors, Volkswagen, UBS

When will EVs reach consumer cost parity, and what will be the impact on EV sales?

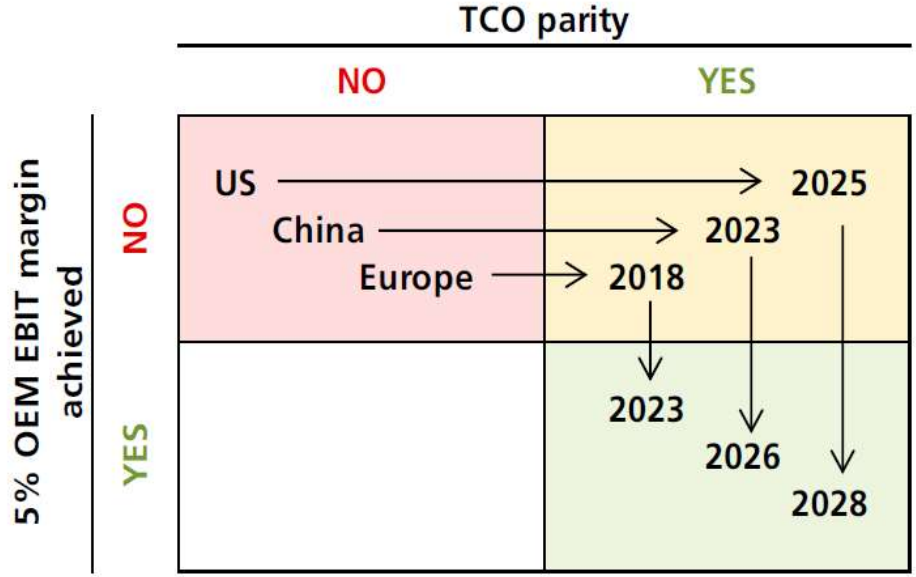
– In the Bolt's powertrain, costs are $3k lower for the battery and $2k lower for the other modules versus our previous expectations. This means TCO parity between EVs and ICE is reached 2-3 years earlier

Figure 3: Cost breakdown ($ per car) – Bolt versus Golf



Source: UBS estimates

Figure 4: TCO analysis

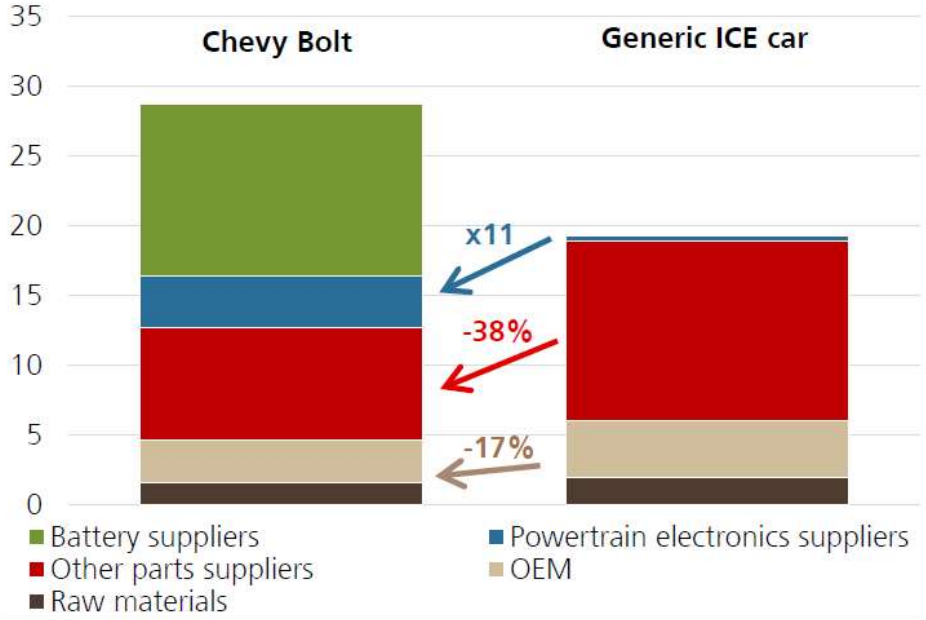


Source: UBS estimates

What is different in the Chevy Bolt, compared to an equivalent combustion engine car?

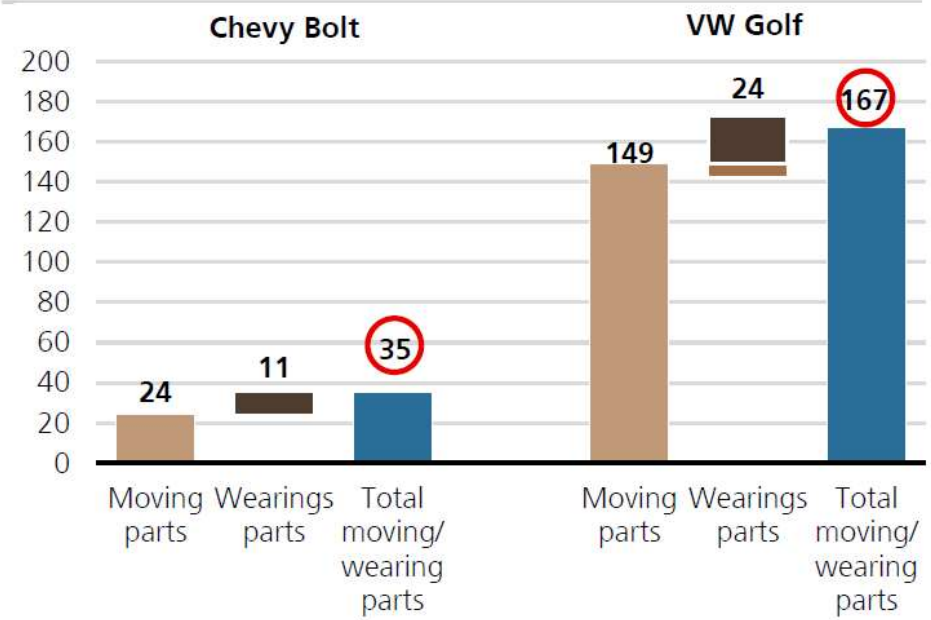
- Some 56%(14% excluding the battery) of the vehicle content comes from outside the traditional auto supply chain
- +$4k electronics

Figure 6: Vehicle content on tier-1 level by sub-sector ($k)



Source: UBS estimates

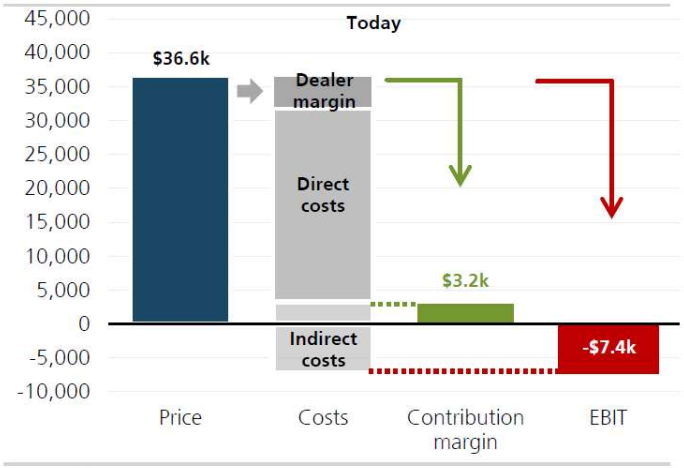
Figure 7: Number of parts in the powertrain



Source: UBS estimates

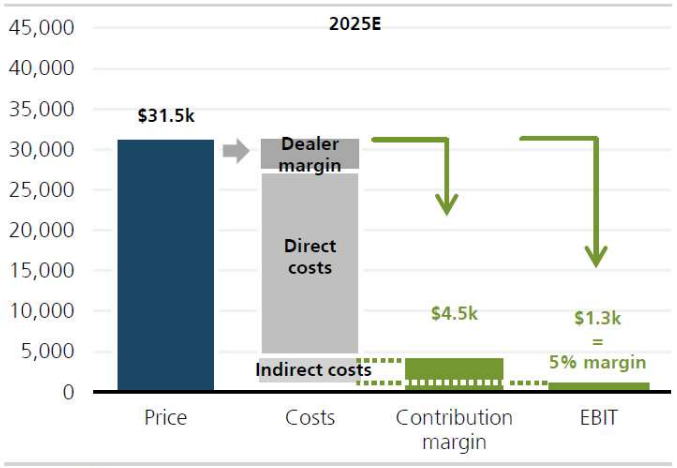
How profitable are EVs like the Bolt and the upcoming Tesla Model 3?

Figure 8: How much money does GM lose with a Bolt today (EBIT/contribution margin in $)...



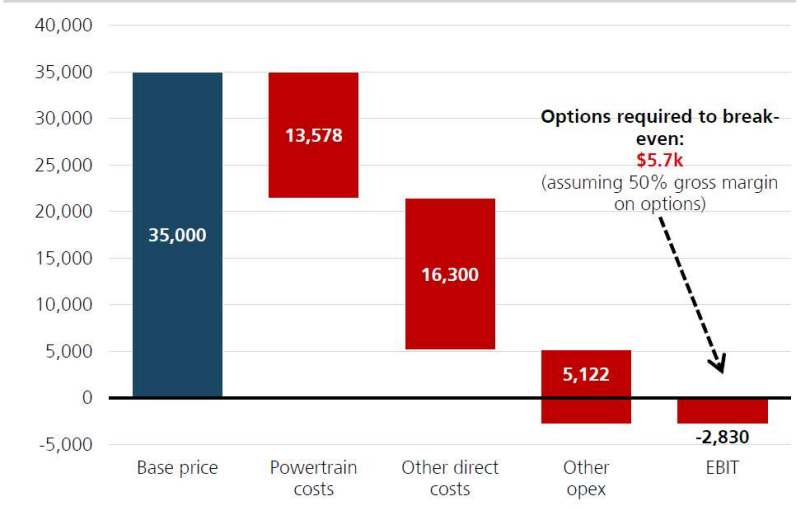
Source: UBS estimates

Figure 9: ...and how will it evolve until 2025E?



Source: UBS estimates

Figure 10: What will be the break-even selling price ($) for the Tesla Model 3?



Source: UBS estimates

Figure 76: Detailed Chevrolet Bolt profitability analysis ($)

	Today		2025E		Commentary
Battery cost ($, total)	**12,300**	**12,300**	**7,800**	**7,800**	
Battery cost ($ / kWh)	**205**	**205**	**130**	**130**	
Cell	145	145	90	90	Based on GM disclosure and UBS cost forecast
Pack*	60	60	40	40	Previous UBS estimate for 2016: ~$100/kWh
	w/ options	**Base**	**w/ options**	**Base**	
MSRP	**42,635**	**36,620**	**42,635**	**36,620**	Future Bolt MSRP likely lower; kept stable only for this exercise
Dealer/incentive (15%)	5,561	4,777	5,561	4,777	
Price charged by OEM	**37,074**	**31,843**	**37,074**	**31,843**	
Direct powertrain costs	**16,403**	**16,078**	**11,272**	**10,028**	$4.6k or 26% below our previous estimate
Battery cell	8,700	8,700	5,400	5,400	
Battery pack*	3,600	3,600	2,400	2,400	Pack cost based on teardown analysis
BMS	222	222	200	200	
Thermal management	250	250	225	225	
Inverter	697	697	523	523	
DC/DC Converter	179	179	134	134	
Power distribution module	328	328	295	295	Cost reduction of 10-25% per component on a 2025 view driven by scale, technology improvements and competition
High-voltage cables	335	335	302	302	
Electric drive module	1,200	1,200	1,080	1,080	
VCIM & EVCC**	144	144	130	130	
Onboard charger	598	273	449	205	
Charging cord	150	150	135	135	
Other direct costs	**15,608**	**12,600**	**14,908**	**11,900**	
Warranty provision	700	700	500	500	
Direct assembly staff cost	2,400	2,400	2,400	2,400	Based on average OEM factory assembly staff costs
Direct materials (assembly)	1,500	1,500	1,500	1,500	Primarily body and chassis
Supplier components	8,000	8,000	7,500	7,500	Includes interior, safety, ADAS & other electronics, etc.
Costs of optional features	3,008	0	3,008	0	Assume OEM generates 50% gross margin on options
Contribution margin	**5,063**	**3,165**	**11,895**	**8,916**	
% margin	14%	10%	29%	28%	
D&A	1,929	1,929	952	952	D&A cost degression driven by higher unit sales
R&D	7,143	7,143	714	714	R&D cost degression driven by higher unit sales
SG&A	1,512	1,512	1,512	1,512	Assume company-wide average SG&A / car for GM
D&A % of sales	5%	6%	3%	3%	
R&D % of sales	19%	22%	2%	2%	
SG&A % of sales	4%	5%	4%	5%	
EBIT	**-5,520**	**-7,418**	**7,716**	**5,737**	
EBIT margin	-15%	-23%	21%	18%	Assumed Bolt sticker price stays constant

Source: UBS
* ex BMS (Battery management system) ** VCIM = Vehicle interface control module; EVCC = Electric vehicle communication controller

Figure 75: Previous UBS EV powertrain cost estimate versus teardown findings

Powertrain	Previous UBS estimate	Teardown cost analysis
Battery cell	8,700	8,700
Battery pack (including BMS & thermal mgmt)	6,300	3,822
BMS	*500*	*222*
Thermal management	-	*100*
Other	*5,800*	*3,500*
Electric drive module	1,200	1,200
Inverter	850	697
DC/DC Converter	500	179
On-board charger (excl. fast-charge option)	700	273
Power distribution module		328
Thermal management		250
Vehicle interface control module (VCIM)		93
Electric Vehicle communication controller (EVCC)		51
High-voltage powertrain cabling		335
Charging cord		150
Other power electronics	2,400	
Total	**20,650**	**16,078**

Source: UBS

Figure 78: Detailed Model 3 profitability analysis ($) and comparison to Bolt (today)

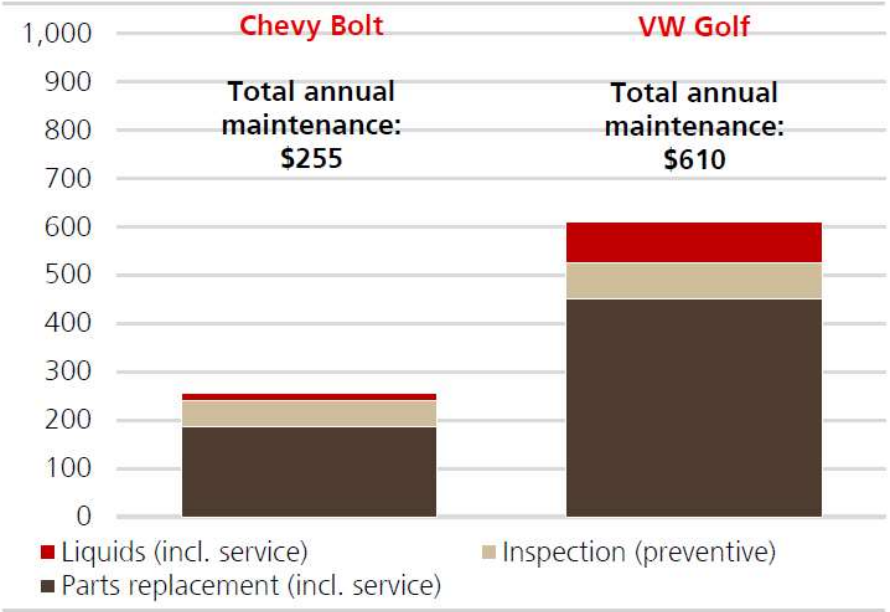
	Chevy Bolt		BMW 330i		Tesla Model 3		
	Base	w/ options	Base	w/ options	Base	w/ options	Comments
MSRP	**36,620**	**42,635**	**38,750**	**45,000**	**35,000**	**42,000**	*Model 3 assumed +20% of base*
Dealer/incentives (15%)	4,777	5,561	5,054	5,870	-	-	
Price charged by OEM	**31,843**	**37,074**	**33,696**	**39,130**	**35,000**	**42,000**	
Battery cost ($ / kWh)	**205**	**205**			**165**	**165**	*Assumes ~20% lower cost due to Gigafactory*
kWh	60	60			55	55	*TSLA guided to <60*
Battery cost ($, total)	**12,300**	**12,300**			**9,075**	**9,075**	
Powertrain cost	**3,778**	**4,103**	**8,500**	**8,500**	**4,503**	**4,503**	*$400 higher vs. Bolt (performance related)*
Warranty provision	700	700	674	783	1,700	1,700	*Half of Model S initial accrual*
Direct assembly staff cost	2,400	2,400	2,800	2,800	2,400	2,400	
Direct materials	1,500	1,500	1,800	1,800	2,200	2,200	*$700 higher vs. Bolt due to aluminium*
Supplier components	8,000	8,000	10,400	10,400	10,000	10,000	*Less luxury content but more ADAS tech than BMW 3-Series*
Optional features	0	3,008	0	3,125	0	3,500	*est. 50% contribution on options*
Contribution margin	**3,165**	**5,063**	**9,522**	**11,723**	**5,122**	**8,622**	
% margin	10%	14%	28%	30%	15%	21%	
D&A	1,929	1,929	1,685	1,685	3,000	3,000	*Higher due to Gigafactory*
D&A % of sales	6%	5%	5%	4%	9%	7%	
R&D	7,143	7,143	1,685	1,685	952	952	*Lower vs. Bolt given higher units*
R&D % of sales	22%	19%	5%	4%	3%	2%	
SG&A	1,512	1,512	2,965	2,965	4,000	4,000	*BMW's base; +$2k for dealer SG&A; -$1k for advertising*
SG&A % of sales	5%	4%	9%	8%	11%	10%	
EBIT	**-7,418**	**-5,520**	**3,187**	**5,388**	**-2,830**	**670**	
EBIT margin	-23%	-15%	9%	14%	-8%	2%	

Source: UBS

What is the impact on the auto industry?

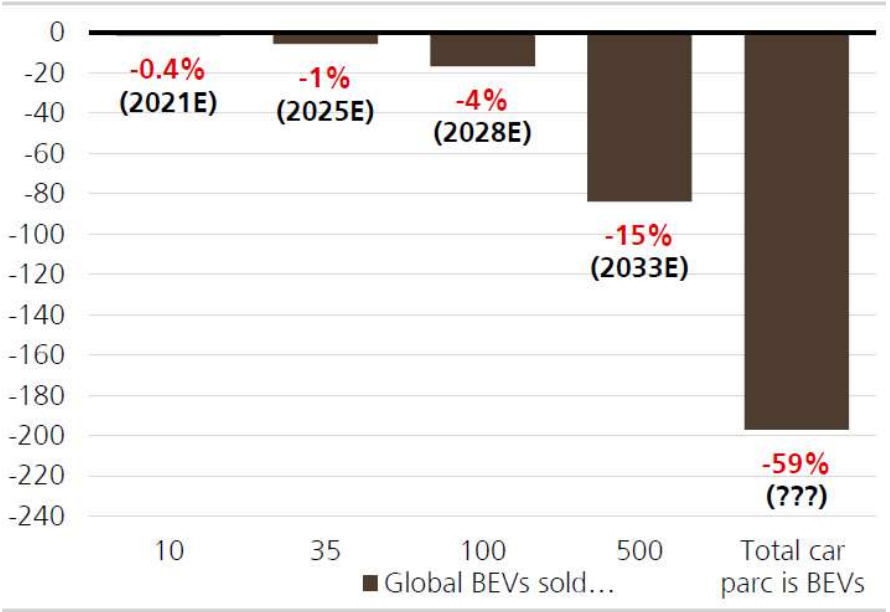
- OEMs: EV manufacturing costs are likely to be lower than previously expected
- "Traditional" tier-1 suppliers: potentially more risks
- Aftermarket: major challenge for dealerships

Figure 11: The Bolt has ~60% lower after-sales costs ($)



Source: UBS estimates

Figure 12: Aftermarket revenues ($bn) to drop by ~60%



Source: UBS estimates

Figure 92: Annual maintenance costs of the Bolt and Golf compared ($)

Chevrolet Bolt		VW Golf
790	**Retail value of wearing parts**	**3,950**
	Annual costs ($)	
	Common maintenance only (annualised)	
185	Parts replacement (incl. service)	450
55	Inspection (preventive)	75
15	Liquids (incl. service)	85
255	**Total maintenance**	**610**
	'Worst-case' maintenance (annualised)	
520	Battery/engine/transmission replacement	485

Source: JD Power, Edmunds, General Motors, Volkswagen, UBS

Figure 93: Comparing the Bolt's vs. the Golf's service and maintenance schedule

VW Golf

Miles	10k	20k	30k	40k	50k	60k	70k	80k	90k	100k	110k	120k
Tyre rotation	X	X	X	X	X	X	X	X	X	X	X	X
Oil change	X	X	X	X	X	X	X	X	X	X	X	X
Oil filter change	X	X	X	X	X	X	X	X	X	X	X	X
Cabin filter change		X		X		X		X		X		X
Transmission fluid change				X				X				X
Spark plug change						X						X
Engine air filter change						X						X
Brake fluid change	Every two years											

Chevy Bolt

Miles	7.5k	15k	22.5k	30k	37.5k	45k	52.5k	60k	67.5k	75k	82.5k	90k
Tyre rotation	X	X	X	X	X	X	X	X	X	X	X	X
Cabin filter change			X			X			X			X
Vehicle coolant change	Every five years											
Brake fluid change												

Source: General Motors, Volkswagen

How are global commodity markets influenced by the shift to EVs?

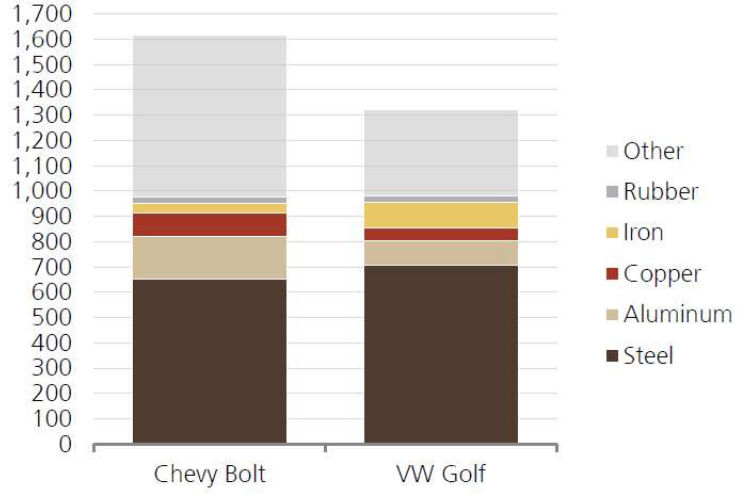
- body and chassis: conventional in terms of the commodities used
  - 70% higher aluminum content, no carbon fibre-reinforced polymers
  - Bolt's total weight is 22% higher than that of the VW Golf, mainly due to the battery
- $580 semiconductor content, or 6-10x more than an average equivalent ICE car, such as the VW Golf

Figure 103: Polymer content Bolt versus Golf (kg) – on major % of vehicle (engine, gears, battery, etc)

Materials		
Chevy Bolt	**Total (kg)**	**VW Golf**
652	Steel	707
169	Aluminum	97
91	Copper	50
40	Iron	102
24	Rubber	24
640	Other	342
9	**Polymer**	**24**

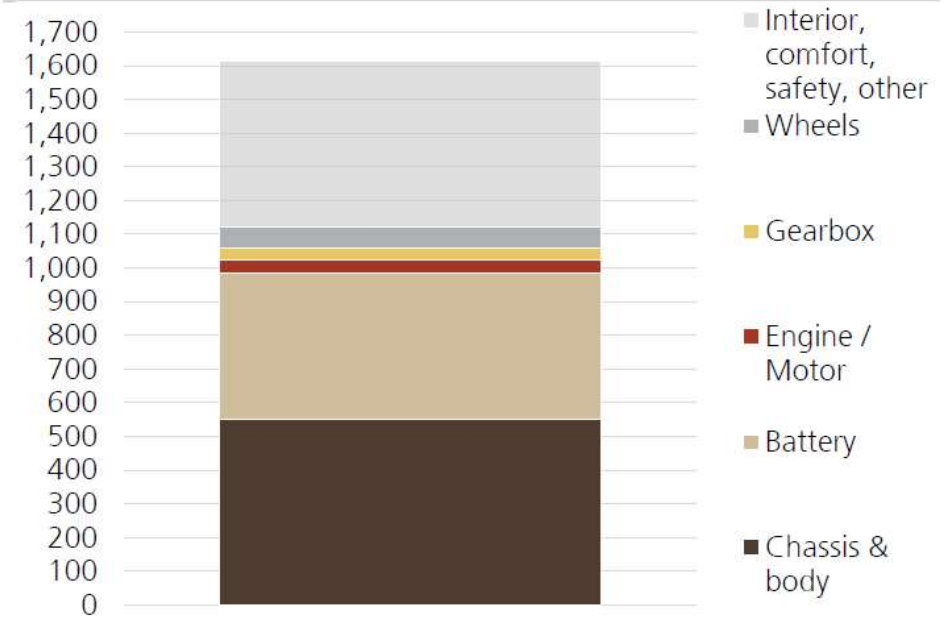
Source: UBS estimates

Figure 13: Weight of key commodities – Bolt versus Golf



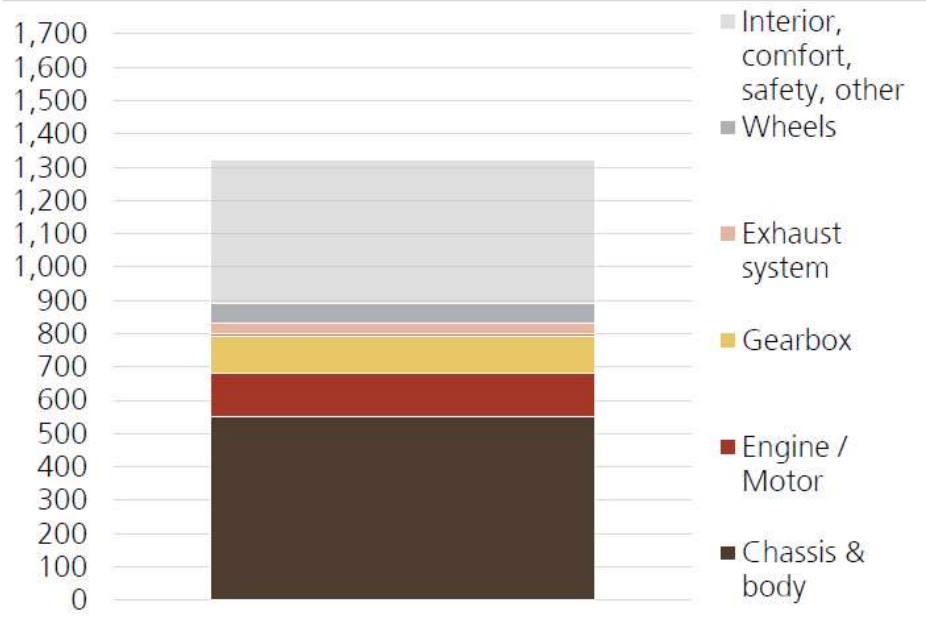
Source: UBS estimates

Figure 42: Chevy Bolt curb weight breakdown



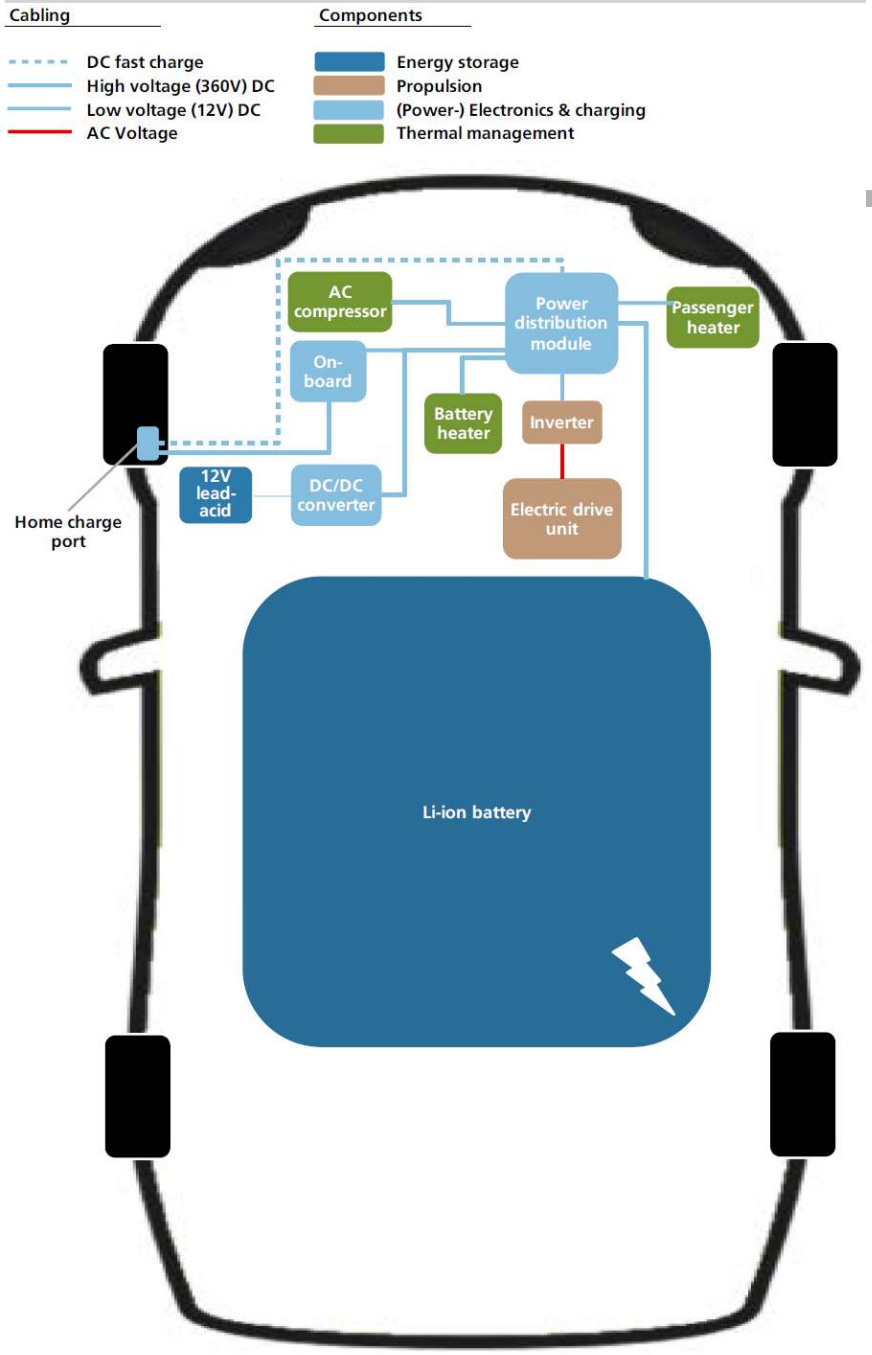
Source: General Motors, UBS estimates

Figure 43: VW Golf curb weight breakdown



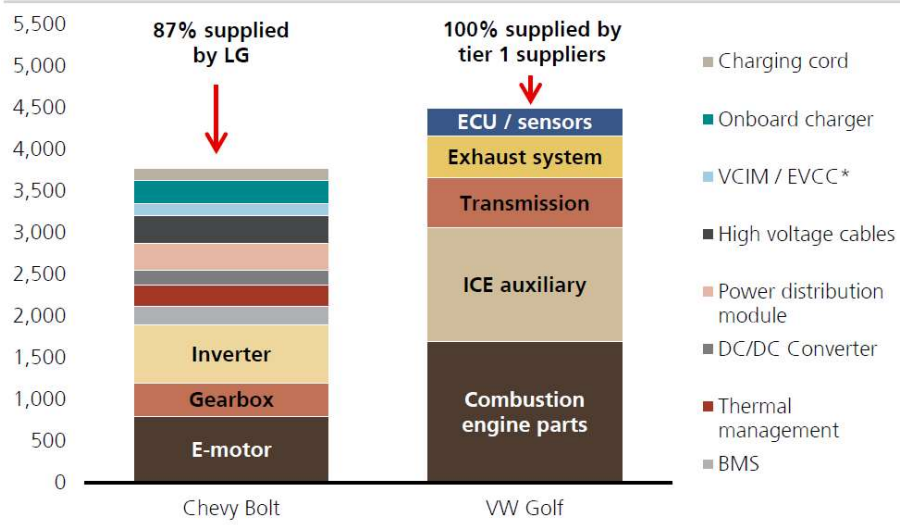
Source: Volkswagen, UBS estimates

Figure 49: Chevy Bolt Powertrain overview



Source: UBS

Figure 48: Powertrain components – Bolt vs. Golf ($)



Source: UBS estimates
* VCIM = Vehicle interface control module
** EVCC = Electric vehicle communication controller

Figure 50: Chevy Bolt powertrain modules

Component	Price today ($)	Price 2025E ($)	Change %	Function
Li-ion battery pack	**11,500-12,522**	**8,000**	**-30-36%**	**Entire battery pack including housing, thermal control, internal wiring, emergency switch and battery management system**
Li-ion battery cell	*8,700*	*5,400*	*-31%*	*Stores up to 60kWh of electric power, $145/kWh*
Battery management system (BMS)	*150-222*	*200*	*up to -10%*	*Monitors the voltage output of each cell group and temperature of the pack*
Battery thermal management	*100*	*90*	*-10%*	*Heats and cools battery in order to keep operating temperature within desired range; glycol/water based*
All other pack content	*2,550-3,500*	*2,310*	*-9-34%*	*Module frames, internal wiring, cooling plates, steel pack case, plastics cover, emergency switch, safety relays, pack assembly*
Thermal management	250	225	-10%	Controls temperature of electronics and cabin via liquid-based cooling/heating loops
Power distribution module (PDM)	250-328	295	*up to -10%*	Takes in DC from battery or charging system and distributes it to the inverter, DC/DC converter and electric heating system
Inverter / converter	697-700	523	-25%	Takes in DC from the PDM and converts it to 3-phase AC for the e-motor
Electric drive module	1,200-1,550	1,080	-10-30%	150kW permanent-magnet e-motor takes in AC from the inverter to turn a drive shaft via magnetic power; a single-speed gearbox is used to translate rotational speed down to final drive ratio
DC/DC converter	150-179	134	-11-25%	Takes in 360V DC from PDM and converts to 12V DC for low-power systems in the vehicle
Electric Vehicle Communication Controller (EVCC)	51	46	-10%	Supports communication between the vehicle and charger for fast charging
Vehicle Interface Control Module (VCIM)	93-100	84	-10%	Functions like a data storage and distribution centre, controlling and monitoring operations between inter-reporting modules; maintains diagnostic information related to the electric propulsion system
High voltage cables	335	302	-10%	Connects the various electronics modules, the e-motor and the battery
On-board charger	273-598	205	-25-66%	Charges the battery pack by converting AC from the charging cord to DC. High end of range represents fast charging (paid option in our Bolt vehicle)
Charging cord	150	135	-10%	Allows the customer to charge the car using a standard 120V AC outlet. Rated to withstand 10,000 mating cycles. With 1 mating cycle per day, the theoretical lifespan is approx. 27.4 years
Total	**14,949-16,763**	**10,416**	**-30-38%**	

Source: UBS estimates. Note: Estimates highlighted in blue are Munro estimates, which we use as basis for further modelling purposes in this report

Battery Pack

Figure 53: Chevrolet Bolt key battery specifications

Li-ion cell technology	Nickel-manganese-cobalt (NMC)
Cell format	Pouch
Capacity	60 kWh
EPA-rated range	238 miles
Number of cells	288 cells
Charge times	
Basic (Level 1) - standard 120V residential cord	~60 hours / home
Fast (Level 2) - 240V fast-charging cord	~9.5 hours / home + public
Super-fast (Level 3) - public DC fast-charging	~1.5 hours / public
Cost today	$209 / kWh = $12,522
… cell	$145 / kWh = $8,700
… pack	$64 / kWh = $3,822
Cost 2025 (UBSe)	$133 / kWh = $8,000
--> Cost digression	-36%
Pack weight	436 kg
… cell material	300 kg
… cell frame and cooling plate	54 kg
… protection case	71 kg
… other	10 kg

Source: General Motors, UBS

Figure 104: Battery cell materials (kg)

Weight distribution by material	
Aluminum	68
Graphite	63
Steel	57
Iron	40
Copper	33
Cobalt	24
Nickel	24
Manganese	22
Polyester	15
Lithium	10
Other	80
Total	**436**

Source: UBS estimates

Electric Motor (Drive Unit) (1)

Figure 60: Chevrolet Bolt key drive unit specifications

Type	Permanent magnet synchronous motor (PMSM)
Peak power	150 kW / 204 HP
Peak torque	360 Nm
Max rpm	8,810
Acceleration	0-60 mph in 6.9 seconds
Top speed (capped)	145 km/h
Cost today	$1,200
… E-motor	$800
… Gearbox, housing, rest	$400
Cost 2025 (UBSe)	$1,080
--> Cost digression	10%
Weight	76 kg
… E-motor	35 kg
… Gearbox, housing, rest	41 kg
Size / volume	~25 x 25 x 40 cm = 25,000 ccm
Gearbox final drive ratio	7.05:1

Source: General Motors, UBS

Figure 61: Chevy Bolt electric motor / gearbox unit

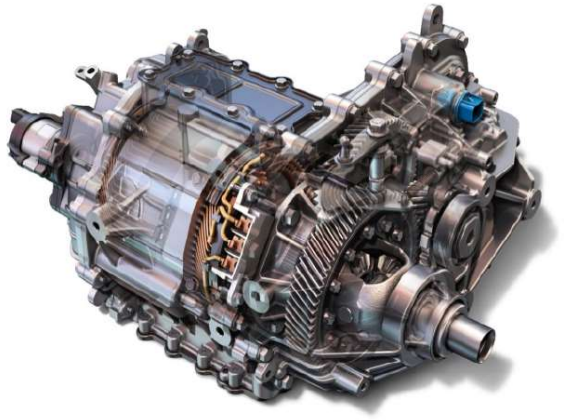
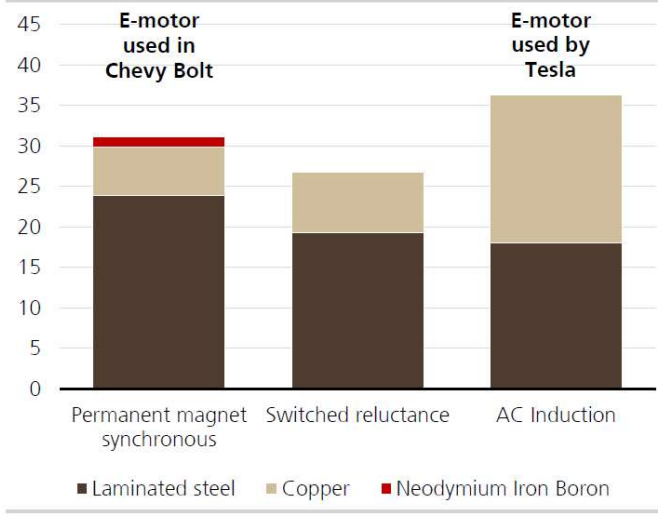


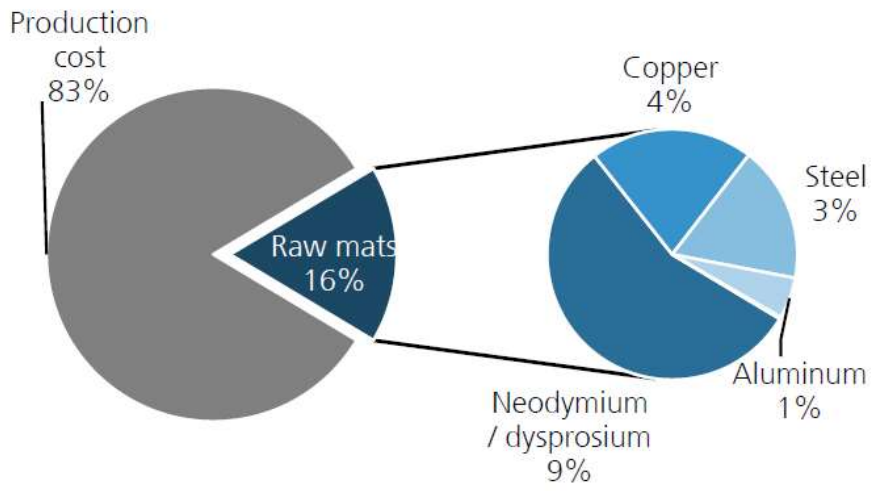
Figure 62: Electric motor commodity breakdown (kg)



Source: UBS

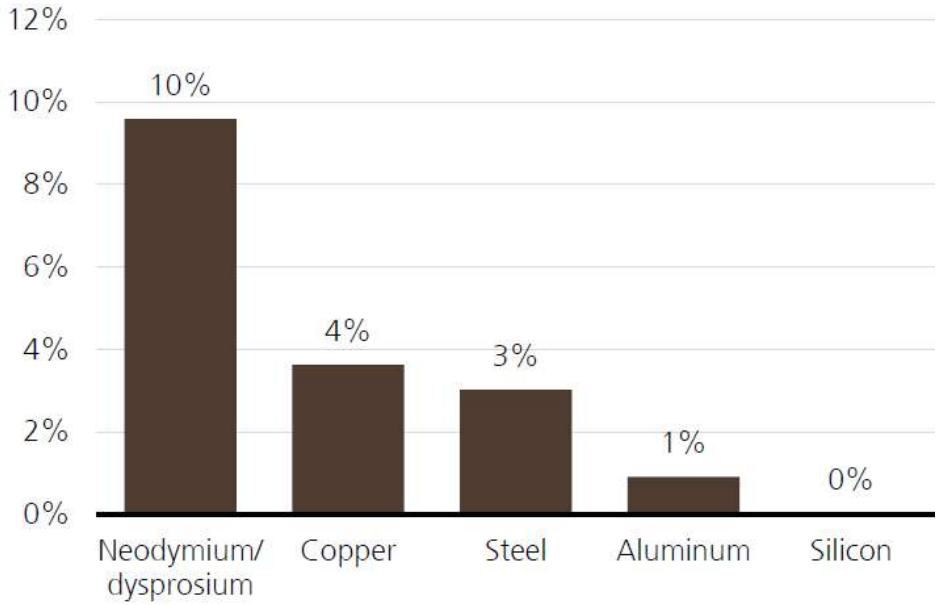
Electric Motor (Drive Unit) (2)

Figure 63: Bolt e-motor cost breakdown (total = $1,200-1,550)



Source: UBS estimates

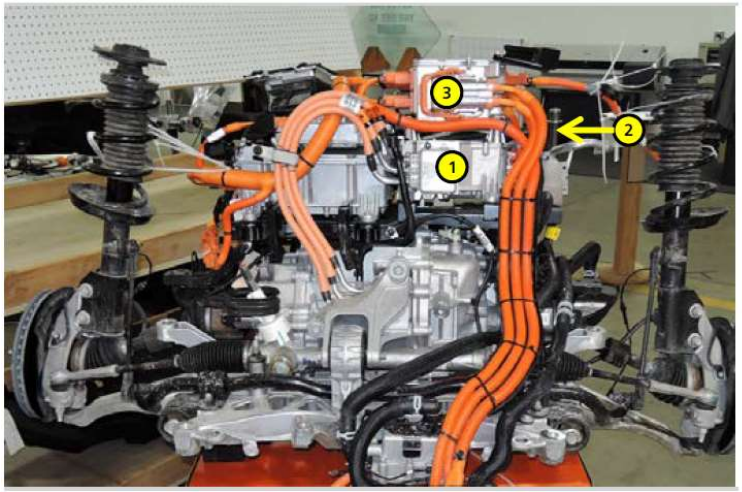
Figure 64: Stress test – impact of doubling commodity prices on total e-motor module costs



Source: UBS estimates

Power Electronics

Figure 66: Positions of the inverter (1), DC/DC converter (2) and power distribution module (3)

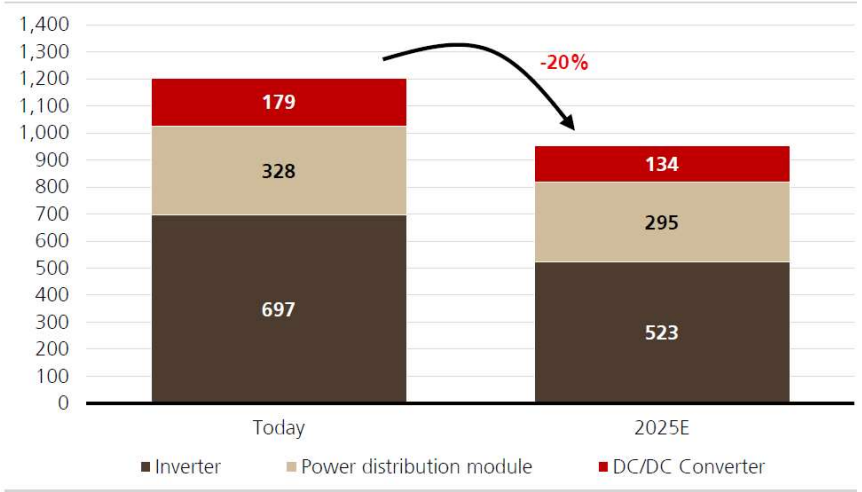


Source: UBS

Figure 67: Cutaway of a DC/DC converter (left) and inverter (right)

Source: UBS

Figure 68: Power electronics cost reduction potential of ~20% by 2025E



Source: UBS estimates

Thermal Management

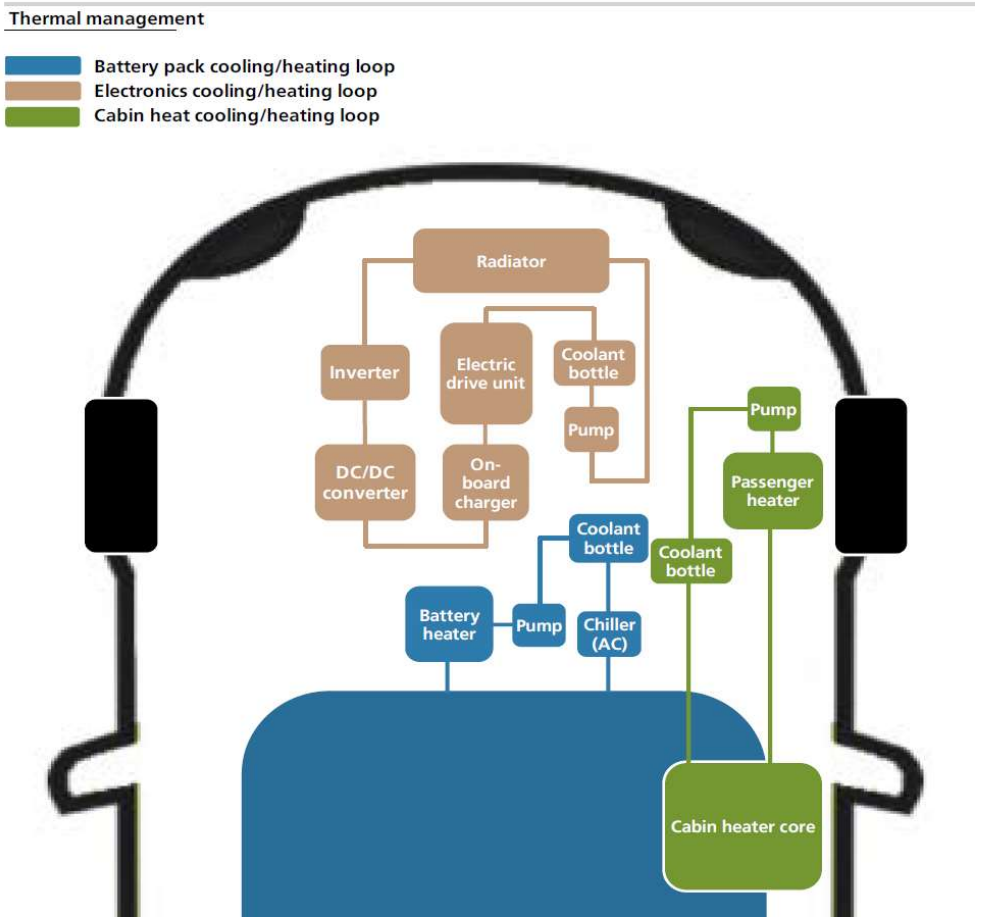
- battery (heating and cooling)
- e-motor/power electronics (cooling only)
- cabin (heating and cooling)

Figure 69: Thermal management supplier overview

Electric heater	Electric coolant pump
Beru	Bosch
BorgWarner	Buhler
Denso	**Continental**
Eberspächer	Nidec GPM
Valeo	**Valeo**
Infineon	**Pierburg (Rheinmetall)**
Mahle	**Schaeffler**

Source: UBS; UBS-covered companies in **bold**.

Figure 70: The Bolt has three thermal management circuits



Charger, charging cord and high-voltage cables

- charger module is responsible for charging the battery pack by converting AC to DC with high efficiency
- EV communication controller is a core device that supports communication between the vehicle and charger for fast charging

Figure 71: On-board charger

Source: UBS

Figure 72: Charging cord incl. electronics module

Source: UBS

Differences in Production Processes

Figure 73: BEV production process schematic

	Power Train Assembly	Stamping	Body Shop	Paint Shop	General Assembly	Quality Assurance
Summary	The EV powertrain production contains three main components (inverters, motors, battery). The electric motor is often manufactured in-house, e.g. at Tesla. The process is largely manual with some help of robots.	In the stamping plant, the metal for the frame is unrolled, cut, and stamped into panels by hydraulic presses.	Robots assemble the stamped metal panels, joining them through welding, riveting, or using adhesives. The final output is the "body-in-white", the unpainted metal shell of the car.	The body-in-white is primed and top coats are applied by robots in an environment that is carefully controlled to prevent contamination and defects in the paint. Baking and drying completes the process. Whilst the paint shop is highly automated, human input is required to inspect work and repair defects.	The shell is transformed into a fully functioning vehicle as the battery, pony pack, trim, and seats are attached. General assembly would typically be divided into three lines: trim, chassis, and final. The complexity of the process means that general assembly is labour intensive, with manual stations rather than robots.	The BEV is given alignment, and gets a water test, a drive test and a BSR (bumps, squeaks, rattles test).
Companies affected	SKF GKN Sandvik	Sandvik Andritz GKN	Atlas Copco Kuka	Dürr	Dürr Siemens ABB Kuka	
Number of robots, sample ICE plant (capacity > 350,000 p.a.)			700	150		
Number of robots, sample BEV plant (capacity c.120,000 p.a.)			350	70		

Source: UBS

- Powertrain assembly
  - 6-7 bearings in the drive module (e-motor and mini gearbox) vs. 40-50 bearings in ICE
  - largely manual, lower cost and less labour input
  - less machining: higher ratio of lighter materials (aluminum)
- Stamping
  - Aluminum: not possible to stamp out or extrude large panels → more panels → more robots, 5~10x more expensive
  - Steel frame: weight (range! from battery cell technology) vs. cost
- Body Shop
  - Aluminum: more panels → more robots, different end-effectors for joining, difficult to set up a flexible body shop
  - as many as 80% of a final assembly plant's robots

- Paint Shop
  - chemically different for a BEV manufactured from aluminium
- General Assembly
  - manufacturing line for both BEVs and ICE vehicles
  - BEVs tend to rely more heavily on software than mechanical processes: upload new software as updates
  - new risk management procedures once the battery is installed
- Quality Assurance
  - less lengthy testing process for a BEV because there is no need for emissions testing